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From the Desk of Editor-in-Chief

It gives me immense pleasure to present this edition of our journal, which continues to serve as a platform for advancing knowledge, encouraging academic discourse, and fostering innovation in the field of Forensic Medicine and Toxicology. Each manuscript featured herein reflects the dedication, expertise, and curiosity of our contributors, addressing pressing issues and emerging trends that shape the practice and research of our discipline. As always, our commitment remains to ensure scientific rigor, ethical standards, and relevance to both academic and applied forensic settings.

In this issue, we bring together diverse articles that not only enhance our understanding of technical and investigative aspects but also highlight the social, legal, and public health implications of forensic science. It is my hope that these contributions will inspire further inquiry, collaboration, and practical application among our readers. I extend my sincere gratitude to our authors, reviewers, and editorial team for their invaluable efforts, and to our readership for their continued engagement and trust in our publication. My special thanks go to Joint Editor Dr. Harvinder Singh Chhabra and Assistant Editor Dr. Rattan Singh for their unwavering support and sincere efforts in the publication and release of this issue. Together, we move forward in our shared mission to expand the frontiers of forensic knowledge.

Thank you for being a part of this journey.

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EDITORIAL

Forensic Medicine in the Era of Synthetic Drugs: Are We Prepared for the Next Toxicological Crisis ?

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INTRODUCTION

The history of toxicology has always been a history of adaptation. As new poisons emerge, forensic medicine evolves in response—developing new analytical techniques, refining diagnostic criteria, and redefining the circumstances in which a substance may be considered causative of death. However, the current transformation of the illicit drug market may represent a challenge of an entirely different magnitude.

The rapid emergence of synthetic drugs and new psychoactive substances (NPS)[1-2] is creating a toxicological environment in which the substance responsible for poisoning may not even be known when the patient presents or when the autopsy is performed. These New psychoactive substances (NPS) are a complex and diverse group of substances often known as either designer or synthetic drugs, or by the more popular but misleading colloquial term of 'legal highs'.

They tend to be either analogues of existing controlled drugs and pharmaceutical products or newly synthesised chemicals, created to mimic the actions and psychoactive effects of licensed medicines and other controlled substances.[3-4] By their number, nature and composition, NPS pose significant challenges for drug consumers, clinicians – both in drug services and, more broadly, researchers, forensic toxicologists, healthcare systems and drug control policy globally – and have been described as a 'growing worldwide epidemic'.[3-4]

The question facing forensic medicine today is therefore not simply whether we can identify the drugs that are already known. It is whether our systems are capable of detecting, interpreting, and responding to substances that may not yet be part of our routine analytical repertoire.

The warning signals are increasingly difficult to ignore. According to the United Nations Office on Drugs and Crime (UNODC), more than 1,500 individual NPS had been reported worldwide by August 2026, with 1,525 substances reported by 155 countries and territories.[5]

During 2025–2026, 698 substances were reported, including 110 substances reported for the first time. Synthetic cannabinoids and stimulants accounted for a substantial proportion of reported substances, while synthetic opioids-particularly nitazenes and related compounds-continue to emerge across multiple continents.[6] This is not merely a problem of nomenclature. It is a problem of forensic visibility.

A drug market that is changing faster than our laboratories: Traditional forensic toxicology has historically operated around a relatively stable catalogue of drugs: opioids, benzodiazepines, barbiturates, cannabinoids, cocaine, amphetamines, organophosphorus compounds and other commonly encountered poisons. Laboratory methods, reference standards and screening panels have consequently evolved around substances with established epidemiological and toxicological importance.

Synthetic drugs challenge this model. NPS are frequently designed by modifying the molecular structure of existing psychoactive compounds.[7] A minor structural alteration can produce a new compound with different potency, metabolism, pharmacokinetics and analytical characteristics. By the time a laboratory acquires a reference standard, validates a method and incorporates the substance into a routine screening panel, another analogue may already have appeared. The result is an uncomfortable paradox: the more comprehensive our conventional toxicology panel becomes, the greater the possibility that the next important toxicant will still remain outside it.

The UNODC reported a record 688 unique NPS detected in drug samples during 2024, including 101 substances reported for the first time. Synthetic opioids constituted one of the prominent emerging groups, with nitazenes and brorphine analogues attracting particular concern.[6,8]

For forensic practitioners, this means that a negative routine toxicology report can no longer automatically be equated with the absence of a drug-related death.

Nitazenes: An Early Warning of What May Lie Ahead: The emergence of nitazenes illustrates the speed with which a relatively unfamiliar drug class can become a forensic concern. The first nitazene notified to the UNODC Early Warning Advisory was isotonitazene in 2019. By February 2026, 34 nitazene analogues had been reported to the UNODC, with these compounds detected in toxicology casework and seized drug samples across at least 37 countries.[6,8] The forensic implications of these findings are substantial. Many nitazenes are highly potent synthetic opioids, and some may have potency comparable to or exceeding that of fentanyl-related substances. UNODC data from 2019–2024 included 292 reported toxicology cases involving nitazenes, of which 82% were postmortem cases.[6-8] More concerning is the increasing appearance of synthetic opioids in unexpected products and matrices. Recent UNODC alerts have described synthetic opioids in vaping products and products misrepresented as other drugs. Such circumstances create an additional diagnostic hazard because the clinical syndrome may not immediately suggest opioid exposure.[9] A falsified medicine may appear to be a legitimate pharmaceutical preparation but contain a potent synthetic opioid. A powder sold as another drug may contain a nitazene. A vape cartridge may contain an unexpected psychoactive compound. In each scenario, the forensic question is no longer simply "What drug was taken?" but rather "What was actually present, and could we have recognized it?"

The Autopsy Problem: Synthetic drug deaths may present with relatively nonspecific findings. Respiratory depression, pulmonary edema, cerebral edema, aspiration, hyperthermia, seizures, cardiac arrhythmias and multiorgan dysfunction can occur with different classes of psychoactive substances. None of these findings, in isolation, identifies a particular NPS. This makes the circumstances of death increasingly important. Forensic pathologists should consider information from emergency medical records, scene investigation, witness statements, prescription history, suspected drug packaging, electronic communications where legally available, and information about other persons experiencing similar symptoms. In suspected clusters, apparently unrelated deaths may become diagnostically connected. The autopsy therefore needs to be viewed as one component of an integrated investigation rather than a standalone event. The traditional toxicological triad-scene, autopsy and laboratory-must increasingly become a larger network involving emergency physicians, intensivists, poison information centres, forensic laboratories, public-health agencies and law-enforcement authorities.

Is Routine Toxicology Sufficient?

This is perhaps the most uncomfortable question for forensic toxicologists. Routine immunoassay screening has considerable value, but it is inherently limited when confronted with structurally novel compounds. A newly emerging synthetic opioid may not cross-react with conventional opioid assays. Similarly, a novel benzodiazepine-type compound may not be reliably detected by a routine benzodiazepine screen. Consequently, **targeted testing alone is increasingly inadequate for unexplained toxicological deaths.** Modern forensic laboratories require access to high-resolution mass spectrometry, comprehensive spectral libraries, updated reference materials and validated strategies for non-targeted or suspect screening. High-resolution mass spectrometry and broad-spectrum liquid chromatography–mass spectrometry approaches can provide opportunities to identify unexpected compounds and metabolites that would otherwise escape conventional testing.

However, technology alone will not solve the problem. A laboratory cannot identify a compound for which there is no reference spectrum, inadequate metabolite information, insufficient validation or no mechanism for communicating the finding to other laboratories. The analytical challenge is therefore inseparable from the information-sharing challenge.

The Hidden Problem: Polysubstance Toxicity

Another important characteristic of the emerging synthetic-drug landscape is polysubstance exposure. Individuals may unknowingly consume mixtures in which a conventional drug is contaminated or replaced by an NPS. Even when several substances are identified after death, determining which substance caused or contributed to death may be difficult. The UNODC reported that 38% of postmortem cases in its 2024 NPS dataset involved two or

more NPS.[8-9] This creates a familiar but increasingly complicated forensic problem: **presence does not equal causation.** The interpretation of toxicological concentrations must therefore take into account postmortem redistribution, tolerance, metabolism, specimen type, sampling site, analytical uncertainty and the presence of other drugs. For many NPS, established therapeutic, toxic and fatal concentration ranges simply do not exist. The forensic toxicologist may consequently be required to provide an opinion based on incomplete pharmacological evidence. This uncertainty should not be hidden behind a numerical concentration. It should be explicitly communicated in the final forensic opinion.

The Developing-Country Challenge

The problem is particularly important for developing countries like India where forensic toxicology services remain unevenly distributed. Advanced mass spectrometry may be available in a limited number of central laboratories, while peripheral forensic centres may depend largely on conventional screening methods. This creates the possibility of geographical variation in the probability of detecting the same drug. A death investigated in a well-equipped metropolitan laboratory may be classified as a synthetic-drug poisoning, whereas an identical death elsewhere may remain "undetermined" or be attributed to another cause.

Preparedness must begin before the Crisis

Preparedness cannot begin after a cluster of unexplained deaths has occurred. An effective forensic early-warning system should incorporate at least five components.

First, **laboratory preparedness** is essential. Screening libraries and analytical methods must be continuously updated rather than revised only after a new substance has caused multiple fatalities.

Second, **rapid information exchange** is needed. A newly identified substance in one forensic laboratory should not remain isolated information. Its analytical characteristics, biological matrices, metabolites and associated clinical findings should be communicated through appropriate national and international networks.

Third, **clinical–forensic collaboration** must improve. Emergency departments and intensive-care units are often the first places where an emerging toxic syndrome becomes visible. If unusual presentations are communicated promptly to toxicology and forensic services, an early warning may be generated before deaths accumulate.

Fourth, **postmortem surveillance** should be strengthened. Unexpected deaths, particularly those involving young adults, unexplained respiratory depression, seizures, hyperthermia or sudden cardiovascular collapse, should prompt consideration of emerging substances when the circumstances support such suspicion.

Finally, **education must evolve.** Forensic medicine curricula should move beyond memorization of classical poisons and include principles of NPS, analytical limitations, interpretation of high-resolution mass spectrometry, polysubstance toxicity and forensic early-warning systems.

From Reactive Toxicology To Anticipatory Toxicology

Perhaps the most important conceptual change required is a transition from reactive to anticipatory toxicology. Traditional toxicology asks: What substance caused this death?

The Emerging model must also ask: What substances are appearing in our region?

Which compounds are escaping routine screening?

Are unexplained deaths occurring in clusters?

Are counterfeit medicines or recreational products being contaminated with novel compounds?

What analytical capability will we need One year from now?

This requires collaboration between forensic laboratories, medical colleges, poison centres, hospitals, regulatory agencies, law-enforcement agencies and public-health authorities. National forensic systems should develop comparable mechanisms appropriate to their own drug markets.

India and South Asia: An Opportunity to act Early

For India and the wider South Asian region, preparedness is particularly important because patterns of substance use, pharmaceutical availability, illicit drug trafficking and access to forensic infrastructure vary considerably across regions. A significant challenge is that absence of documented cases does not necessarily demonstrate absence of exposure. It may instead reflect limited surveillance, insufficient analytical capacity, lack of reference standards or failure to test for substances outside conventional panels. This distinction is crucial. **The absence of evidence should not be interpreted as**

evidence that emerging synthetic drugs are absent.

Regional forensic institutions could play a major role by establishing sentinel surveillance systems, periodically reviewing unexplained toxicology deaths, sharing emerging analytical findings and developing referral networks for difficult cases.

The Forensic Laboratory of Tomorrow

The forensic laboratory of the future cannot simply be a larger version of today's laboratory. It must be more connected, more flexible and more capable of detecting the unexpected. Broad-spectrum screening, high-resolution mass spectrometry, retrospective data analysis, metabolite identification, spectral-library sharing and automated data-mining approaches are likely to become increasingly important. Artificial intelligence and machine-learning tools may eventually assist in recognizing previously unidentified compounds from complex mass-spectral datasets. However, such technologies should supplement-not replace-analytical validation and expert interpretation.

Equally important is the need for quality assurance. A sophisticated instrument does not automatically produce a reliable forensic conclusion. Method validation, proficiency testing, chain of custody, appropriate specimen collection and interpretation by trained personnel remain fundamental.

Are we prepared? The honest answer is: **partially, but not sufficiently.** We possess better analytical technologies than ever before. We understand the limitations of conventional screening. We have access to increasingly sophisticated mass spectrometric platforms. Yet the pace of drug innovation may exceed the pace at which forensic systems adapt. The appearance of more than 1,500 reported NPS worldwide is not simply a statistic. It is a warning about the scale and speed of molecular innovation occurring outside conventional drug-control frameworks.[7] The next toxicological crisis may not arrive as a single recognizable poison. It may arrive as an adulterated tablet, a counterfeit medicine, a vaping product, an apparently familiar recreational drug containing an unexpected analogue, or a combination of several substances. The responsibility of forensic medicine is therefore evolving. We must continue to determine the cause and manner of death, but we must also become an early-warning system for society. The real question is whether our laboratories, autopsy services, clinicians, surveillance systems and public-health institutions can identify the next threat before it becomes a crisis. Preparedness should begin now—not with the next unexplained death, but with the recognition that the next unknown drug may already be here.

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ORIGINAL RESEARCH PAPER

Death Due to Hanging: A Retrospective Analysis of Hanging Cases in A Tertiary Care Hospital, Kashmir.

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ABSTRACT

Introduction: Hanging one of the foremost methods of suicide among Indian adults, attributing the top five methods of self-destruction, others being poisoning, drowning, burning, and falls. Every case of suicide is hanging is considered as suicide till proven otherwise. It is categorized into two types: complete (body suspended completely) and incomplete (feet or knees touching ground). Both types differ significantly in their biomechanical effects, and factors like point and manner of suspension, type of ligature, influencing internal as well as external patterns of injury. Understanding of these variables, along with socio-demographic elements, cultural and risk factors, along with other ideologies, plays a vital role for forensic interpretation along with guidance to public health interventions. Therefore, the present study aims. To study the sociodemographic profile of suicidal hanging in Kashmir.

Materials and Methods: The present research was carried out in the Department of Forensic Medicine and Toxicology, GMC Srinagar. All medico-legal autopsies of hanging performed in the department between September 2022 and September 2024 were reviewed. Post-mortem records were analyzed in accordance with standard autopsy protocols, with special emphasis on the type of hanging, age, sex, domicile, reasons for hanging, time and season of occurrence, and the ligature material used. The history provided by police and relatives, wherever available, was also incorporated into the analysis.

Results: Analysis of present research revealed that mainly hanging affects young adults, with males being predominant. Self-suspension was found in majority of the cases within home environment. Complete hanging was found in majority cases as compare to incomplete/partial. Psychological distress surfaced as major factor followed by family conflicts, social stress, and academic or occupation stress. Urban cases were more often linked to psychological and opportunity-related stress, whereas rural cases showed a greater association with domestic, relational, and cultural stressors. Seasonal variation was observed, with a higher incidence noted during summer months in urban areas and spring in the rural population, respectively

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Keywords: Hanging; Ligature; Suicide; Asphyxial Death.

INTRODUCTION

Asphyxia is a condition caused by interference with respiration, or by inadequate oxygen in inspired air, due to which organs and tissues are deprived of oxygen, combined with failure to eliminate CO2, and resulting in unconsciousness or death. The term asphyxia is a mode of dying, rather than a cause of death. Violent or Mechanical Asphyxia is a broad term in which respiration is prevented by any violent mechanical means applied externally to the neck, chest, or body, which is positioned in such a way that respiration is difficult and normal respiratory movements are impossible.[1] Hanging is a type of mechanical asphyxia in which the body is suspended with a ligature around the neck, and the gravitational pull of the body, or a part of it, causes constriction of the neck structures, leading to asphyxia and death.[2-3] Therefore, depending on which part of the body acts as the constricting force, hanging is complete or partial. Complete hanging signifies the body fully suspended from a high suspension and the feet clear the ground without any part touching the ground.[4] Partial hanging is when feet, knees, or any part of the victim's body touches the ground, the suspension point is low, or the

victim leans into the ligature.[5]

Earlier, preventing ventilation in respiratory asphyxia was considered the predominant mechanism causing death in hanging.[6] However, various authors have suggested other hypotheses which act alone or together, like pressure on the carotid sinus and reflex cardiac arrest; compression of the carotid arteries and cerebral ischemia; and jugular venous occlusion, leading to a fatal outcome.[7,25-26]

Material used for ligature in hanging is often substances readily available at hand and range from soft fabric such as saree, dhoti, head scarf, necktie to harder and more pliable materials like Electric cord, wires, leather belts. Basically, the material can be anything handy and available near the place of occurrence, as suicide is an impulse-mediated act.[8] In custodial settings, prisoners often use bed sheets tied to the lower rails of their cell railings or to the bedpost and hang themselves while kneeling or sitting down.[9]

The majority of hangings are self-suspension and are mostly suicidal in nature, while strangulation should be considered homicidal, unless proved otherwise.[10] It is not uncommon for perpetrators to conceal a crime by strangling the victim and then hanging the victim's body on a tree or a rafter to avoid doubt. Similar scenarios exist in which the cord breaks and the body of the victim is on the floor with the cord around his/her neck, which also necessitates an exhaustive assessment if the death is believed to be suspicious by police investigation. Identifying the subtle injuries that can exist in such cases plays a decisive role in ascertaining the manner and cause of death.[11-13]

Hanging is one of the preferred modes and the most common methods of suicide worldwide as well as in India, as it produces a painless and instantaneous death.[14-15,28] Due to population explosion in our country, increasing poverty, and psychosocial stress, we frequently come across cases of suicide. Both genders of our society are equally affected by these factors.

High suicidal incidents, especially from rural India among young adults, lay a great socio-economic burden on the Indian society.[16-17] To date, no focused research or dedicated study has been undertaken on fatal hangings in the Kashmir region that analyzes the contributory factors in a structured manner, as has been done in other parts of India. Furthermore, there appears to be no published research on this topic from a forensic medicine standpoint

The study aimed to assess the prevalence, patterns, and reasons of hanging cases presented to a tertiary care hospital in Kashmir. Any study that is carried out on methods, sociodemographic, risk factors, cultural aspects of suicide, and other well-known aetiologies in an area is helpful for forensic experts as well as to local governing bodies so that appropriate control measures would be taken, which is the main purpose of our study.

AIMS & OBJECTIVES

1. To study sociodemographic profile of suicidal hanging in Kashmir.
2. To determine the pattern and underlying factors of hanging.

MATERIALS AND METHODS

GMC Srinagar is a tertiary care hospital that covers the medico-legal post-mortem cases of unnatural deaths in Srinagar as well as the surrounding area. A retrospective study was conducted in the department of forensic medicine and toxicology at GMC Srinagar. After taking permission from the Institutional Review Committee (IRBGMC-SGR/FMT/876), post-mortem records from September 2022 to September 2024 were analyzed. The cases were studied in accordance with post-mortem findings with special reference to the type of hanging, age, sex, domicile, reasons of hanging, time of hanging, place of hanging, season of hanging for hanging. History obtained from the police and relatives was also taken into account. The result obtained was analysed, compared statistically, and tabulated.

Inclusion Criteria: Postmortem of all hanging cases done in the Department of Forensic Medicine, GMC Srinagar.

Exclusion Criteria: Hanging cases where bodies were in different stages of decomposition.

RESULTS

Demographic Profile

Table 1 presents the demographic and circumstantial profile of the 50 cases in the study. The majority of cases, n = 26 (52.0%), fell in the 20-30 years age group, followed by 13-20 years, n = 9 (18.0%), and 40-50 years, n =7 (14.0%). Males dominated at 70.0% (n = 35), with urban domicile slightly more common, n = 30 (60.0%). Islam was the predominant religion, n = 42, (84.0%). Most hangings occurred at home n = 39, (78.0%), in summer n = 18, (36.0%) or spring n = 17, (34.0%), during morning hours n = 18, (36.0%), as complete hanging n = 41, (82.0%), and were attributed to psychological reasons n =12, (24.0%), marital problems n = 11, (22.0%), or peer pressure n = 11,

Table 1: Shows the Demographic and Circumstantial Profile of the Study Population.

Variable	Category	F	Percent
Age-group	13-20 years	9	18.0
	20-30 years	26	52.0
	30-40 years	5	10.0
	40-50 years	7	14.0
	More than 50 years	3	6.0
	Total	50	100.0
Sex	Male	35	70.0
	Female	15	30.0
	Total	50	100.0
Domicile	Urban	30	60.0
	Rural	20	40.0
	Total	50	100.0
Religion	Islam	42	84.0
	Hinduism	6	12.0
	Sikhism	2	4.0
	Total	50	100.0
Site of Hanging	Home	39	78.0
	Others	8	16.0
	Undetermined	3	6.0
	Total	50	100.0
Time of Hanging	Morning	18	36.0
	Afternoon	12	24.0
	Evening	11	22.0
	Night	8	16.0
	Undetermined	1	2.0
	Total	50	100.0
Season of Hanging	Summer	18	36.0
	Spring	17	34.0
	Winter	11	22.0
	Autumn	4	8.0
	Total	50	100.0
Type of Hanging	Complete	41	82.0
	Incomplete	9	18.0
	Total	50	100.0
Reason for Hanging	Psychological	12	24.0
	Marital problems	11	22.0
	Peer pressure	11	22.0
	Love affair	8	16.0
	Undetermined	6	12.0
	Financial	2	4.0
	Total	50	100.0

(22.0%).

Table 2 illustrates that among females, 80.0% (n = 40) involved complete hanging compared to 20.0% (n = 10) incomplete, while males showed 82.9% (n = 29) complete and 17.1% (n =6) incomplete. The pattern of hanging was found similar across both sexes, revealing lack of gender differences in type of hanging. Further, results depict that males were more urban-oriented n = 23 (65.7%), than rural n = 12 (34.3%), whereas females showed a balanced split, n = 7 urban and 8 rural (46.7% urban, 53.3% rural), hinting at potential rural vulnerability among women.

Table 2: Shows the Association between Sex and Type of Hanging, Locale and Type of Hanging.

Variable	Group	Male		Female	
		F	(%)	F	(%)
Type of Hanging	Complete	29	(82.9)	12	(80.0)
	Incomplete	6	(17.1)	3	(20.0)
Locale	Urban	23	(65.7)	7	(46.7)
	Rural	12	(34.3)	8	(53.3)

Table 3 reveals marital issues were more frequent among rural cases, n = 6, (30.0%) followed by undetermined reasons n = 5 (25.0%), while cases belonging to urban areas reflected peer pressure n =11 (36.7%), and psychological problems, n = 9 (30.0%). The p-value of 0.0903 suggested no-significant association between these factors and hanging. Going deeper the analysis of Table 3 further revealed that mostly females reported marital problems n = 8, 66.7%), while peer pressure n = 9, (39.1%), psychological problems n = 11, (47.8%), and love affairs n = 6, (26.1%) were cited by males. Whereas, financial issues were limited to males, n = 4 (17.4%). The p-value (0.085) suggests no-statistical association between gender and reasons of hanging.

Table 4 shows the association between seasons and the reasons of hanging. Financial problems were the highest reason in the autumn, n = 3 (75.0%), while peer pressure was found to be highest during summer n = 8 (44.4%), in winter, psychological problems were dominant n = 4 (36.4%), marital issues were dominant in spring, n = 6 (35.3%) and also to autumn, n = 1 (25.0%). The p-value (0.0027) confirmed a strong association between seasonal variation and reasons.

Table 5 reveals males peaked in spring, n = 13 (37.1%), and summer n = 12 (34.3%), while females slightly led in summer, n = 6 (40.0%). Distributions were broadly comparable, with minor female elevation in autumn n = 2 (13.3%). **Table 5** further outlines domicile variations by season. Urban cases concentrated in summer n =12 (40.0%) and spring n = 9 (30.0%), while rural ones peaked in spring n = 8 (40.0%) and winter n = 5 (25.0%), reflecting possible urban seasonal peaks tied to activity patterns.

Table 3: Shows the Association between Domicile and Reason for Hanging, Sex and Reasons for Hanging.

Group	Domicile				Sex			
	Rural		Urban		Male		Female	
	F	(%)	F	(%)	F	(%)	F	(%)
Financial Problems	2	10.0	2	6.7	0	0.0	4	17.4
Love Affair	4	20.0	4	13.3	2	13.3	6	26.1
Marital Problems	6	30.0	5	16.7	8	66.7	3	13.0
Peer Pressure	0	0.0	11	36.7	2	13.3	9	39.1
Psychological Problems	3	15.0	9	30.0	1	6.7	11	47.8
Undetermined	5	25.0	3	10.0	2	13.3	4	17.4
Total	20	100.0	30	100.0	15	100.0	35	100.0
p-value: 0.0903								

Table 4: Shows The Association between the Season of Hanging and the Reason

Reason	Season of Hanging							
	Autumn		Spring		Summer		Winter	
	F	(%)	F	(%)	F	(%)	F	(%)
Financial problems	3	75.0	0	0.0	0	0.0	0	0.0
Love affair	0	0.0	3	17.6	5	27.8	0	0.0
Marital problems	1	25.0	6	35.3	2	11.1	2	18.2
Peer pressure	0	0.0	0	0.0	8	44.4	3	27.3
Psychological problems	0	0.0	6	35.3	2	11.1	4	36.4
Undetermined	0	0.0	2	11.8	1	5.6	2	18.2
Total	4	100.0	17	100.0	18	100.0	11	100.0
p-value: 0.0027								

Table 6 reveals the intersection of sex and site of hanging. Both sexes favored home as the site n = 28 males and 11 (males 80.0%, females 73.3%), with males more often at other sites n = 6 (17.1%) and females having higher undetermined.

Table 7 compares site of hanging with type. Home sites yielded 82.1% (n = 32) complete hangings, others 75.0%, (n = 6) and all undetermined were complete n = 3 (100.0%). Incomplete hangings were marginally higher at other sites n = 2 (25.0%).

Table 8 links the type of hanging to the reason. Complete hangings frequently involved marital problems n = 11 (26.8%) and psychological/peer pressure n = 2 (each 22.0%), while incomplete ones leaned toward psychological problems n = 3 (33.3%). No marital problems appeared in incomplete cases. This suggests that complete hangings are more commonly associated with definitive psychological and familial conflicts, while

Table 5: Shows the Association between Sex and Season of Hanging, Locale and Season of Hanging.

Variable	Category	Summer	(%)	Spring	(%)	Winter	(%)	Autumn	(%)
Gender	Male	12	(34.3)	13	(37.1)	8	(22.9)	2	(5.7)
	Female	6	(40.0)	4	(26.7)	3	(20.0)	2	(13.3)
Locale	Rural	8	(40.0)	6	(30.0)	4	(20.0)	3	(10.0)
	Urban	4	(30.8)	5	(38.5)	3	(23.1)	1	(7.7)

Table 6: Shows the Association between Sex and the Site of Hanging.

Sex	Home	(%)	Others	(%)	Undetermined	(%)
Male	28	(80.0)	6	(17.1)	1	(2.9)
Female	11	(73.3)	2	(13.3)	2	(13.3)

Table 7: Shows the Association between the Site of Hanging and the Type of Hanging

Site	Complete	(%)	Incomplete	(%)
Home	32	(82.1)	7	(17.9)
Others	6	(75.0)	2	(25.0)
Undetermined	3	(100.0)	0	(0.0)

Table 8: Shows the Association between the Type of Hanging and the Reason.

Reason	Type of Hanging			
	Complete		Incomplete	
	F	(%)	F	(%)
Financial Problems	3	7.3	1	11.1
Love Affair	6	14.6	2	22.2
Marital Problems	11	26.8	0	0.0
Peer Pressure	9	22.0	2	22.2
Psychological Problems	9	22.0	3	33.3
Undetermined	3	7.3	1	11.1
Total	41	100.0	9	100.0

incomplete hangings often occur under uncertain or situational influences.

DISCUSSION

The demographic profile reveals a young adult predominance, with over half the cases aged 20-30 years, underscoring the vulnerability of this group to suicidal hanging in the region. Males constituted the majority, aligning with global patterns where men exhibit higher suicide rates, possibly due to societal pressures and access to lethal means. Urban residents slightly outnumbered rural ones, yet both domiciles featured prominently, suggesting widespread risk factors. Home emerged as the primary site, reflecting private despair, while summer and spring peaks may link to environmental stressors like heat or academic pressures. Complete hanging dominated, with psychological distress, marital discord, and peer influence as leading triggers, consistent with youth mental health crises in Indian contexts. Similar patterns have been observed in South Asian studies that associate female suicides with domestic and marital stressors, while male suicides are linked with social and occupational burdens (Grover et al.,[22] The predominance of urban cases (60.6%) could reflect greater psychosocial challenges, higher rates of psychiatric morbidity, and changing societal expectations in urban settings, consistent with findings from Vijayakumar and John.[19]

Gender patterns in hanging type show minimal disparity, as both sexes overwhelmingly opted for complete suspension, implying similar intent severity regardless of gender. This uniformity challenges assumptions of method variation by sex and highlights universal lethality in chosen means, warranting targeted prevention across demographics. Domicile influences reasons subtly, with rural areas showing elevated marital and ambiguous triggers, potentially tied to familial isolation and limited support, while urban youth faced peer pressure and psychological burdens amid fast-paced lifestyles. The near-significant association (p=0.0903) signals environmental roles in motivation, urging context-specific interventions like rural counseling networks. Seasonal-reason interplay proves significant (p=0.0027), with financial woes clustering in autumn-perhaps harvest failures or post-festive debt-and peer-driven acts surging in summer, coinciding with vacations and social exposures. Psychological motivations spanned winter-spring, possibly exacerbated by isolation or academic stress, informing time-sensitive awareness campaigns. Sex-specific reasons expose stark contrasts: females disproportionately burdened by marital conflicts, reflecting patriarchal strains like early marriage or domestic violence in the region, whereas males grappled with psychological turmoil and peer dynamics, echoing masculinity norms suppressing emotional help-seeking. This divergence calls for gender-tailored mental health strategies. Domicile-sex overlaps indicate males' urban tilt, likely from employment or education migration, contrasted by females' rural equilibrium, hinting at gendered mobility barriers and heightened rural female risk, meriting focused outreach. Seasonal distributions by sex display overlap, with males slightly favoring spring-summer-potentially activity-linked-while females showed subtle autumn upticks, suggesting nuanced psychosocial timings that refine predictive models. Site preferences by sex reinforce home as normative, yet females' higher undetermined and other-site proportions may indicate concealment efforts amid stigma, with males' clarity pointing to overt acts; this underscores privacy's role in suicide facilitation. Domicile-season patterns highlight urban summer-spring concentrations, possibly from heat-amplified urban stress, versus rural spring-winter emphases tied to agrarian cycles, advocating seasonal, locale-adapted surveillance. Site-type associations affirm home's conduciveness to complete hanging, mirroring privacy-enabled determination, while non-home sites occasionally yielded incompleteness, perhaps due to

interruptions; undetermined sites' totality in complete cases stresses investigative gaps. Similar associations between seasonality and suicides have been noted by Christodoulou et al.,[23] Linking Spring and early summer to increased suicidality, possibly mediated through biological and psychosocial mechanisms. Home was the most frequent site (78.8%), emphasizing the private and accessible nature of the act, which matches previous forensic studies from India (Patel et al.,[24] Furthermore, the predominance of complete hanging (81.8%) underscores the determination and lethality of intent. The study's statistically significant association between reasons and seasons (p = 0.0027) highlights the role of contextual stressors and cultural timings in triggering suicide, consistent with literature on psychosocial rhythms and impulsivity (Ajdacic-Gross et al.,[14] Overall, the findings reaffirm that suicide by hanging in Kashmir reflects a mix of individual vulnerability, psychosocial stress, and cultural-environmental triggers. Effective prevention must include strengthening community-based psychiatric care, routine screening for depression and stress, and culturally tailored awareness programs addressing both men and women in vulnerable age groups.

CONCLUSION

The present retrospective study on deaths due to hanging in a tertiary care hospital in Kashmir highlights hanging as a critical public health and sociopsychological concern. The findings reveal that this mode of suicide transcends age, sex, domicile, and seasonal boundaries, yet certain patterns related to psychological distress, familial conflicts, social stressors, and accessibility of the home environment emerge as common determinants. Males were more affected overall, often due to psychological and peer-related pressures, while females were more vulnerable to domestic and marital stress. Urban populations faced distinct stressors linked to social and occupational demands, whereas rural populations were more influenced by traditional and relational conflicts.

The study underlines that hanging is not only a medical issue but also an outcome of complex psychological, social, cultural, and environmental factors. The predominance of the home as the site of occurrence suggests vulnerability linked to opportunity, isolation, and privacy. Seasonal variations further indicate that cultural, academic, and occupational stressors may play a role at different times of the year.

This research emphasizes the urgent need for targeted mental health interventions, awareness programs, family counseling, and community-based preventive measures. Strengthening emotional resilience, providing timely psychological support, and reducing social stigma around mental health could significantly reduce such preventable deaths. Additionally, policy-level initiatives are necessary to improve mental health infrastructure, involve community leaders, and integrate suicide prevention strategies into routine healthcare services.

RECOMMENDATIONS

- Mental health care should be made accessible to everyone across rural as well as urban areas. Health workers should be trained to identify people with suicidal tendencies.
- Counselling should be made easily available to families and married couples to help them cope with relationship problems and manage stress.
- Suicide prevention activities should be organized around times such as the examination and marriage seasons.
- Support building life skills like stress management and problem-solving so people can face challenges without harming themselves.

LIMITATIONS

- The present study was carried out on a single geographical region, covering cases registered in only one tertiary care hospital.
- The study was carried out on a small sample of 50 cases, so generalizability is not possible.
- Statistical procedure was confined to exploring associations/relationships only, not focusing on exploring the strong determinants of suicide.

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ORIGINAL RESEARCH PAPER

Human Foot and Footwear as the Stature Estimation and Sex Determinant Markers: A Forensic Investigatory Attempt

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ABSTRACT

Introduction: Foot impressions, whether barefoot or shoed, are among the most encountered forms of physical evidence at crime scenes.

Aims and Objectives: The present study aims to estimate human stature (vertex height) using foot anthropometry and footwear morphology, and to examine sexual dimorphism in foot-related parameters.

Materials and Methods: The present study included 100 youth (50 males; age 20.08±1.54 and 50 females; age 19.2±0.96) from North 24 Parganas, West Bengal, without disabilities. The inclusion criteria were designed to study only users of unisex footwear that are not new and have been used for at least three to four months and are not older than 18 months. Anthropometric variables, including stature, shoe size, foot length, and patterns of sectoral shoe sole erosion, were recorded using standard methods and instruments. Statistical analyses were performed using independent t-tests, paired t-tests, the Mann–Whitney U test, chi-square tests, and linear regression models to assess sexual differences and predictive relationships.

Results: The results suggested significant sexual dimorphism in foot and shoe length ($p < 0.05$), with males exhibiting greater bilateral foot and shoe length. The present study revealed that males wore tight-fitting shoes, whereas females wore oversized footwear ($p<0.05$). Furthermore, shoe sole erosion was assessed through physical observation, which confirmed that the deepest erosion was observed at the midfoot in the studied males ($p<0.05$) and at the heel in the females ($p<0.05$). Regression-based prediction equations for the bilateral side-based stature estimate were developed for the studied population.

Conclusion: The observed sexual dimorphism in foot dimensions and in footwear sole-erosion characteristics, along with the derived estimation formulae, underscores their forensic relevance and enhances the applicability of foot evidence for personal identification.

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INTRODUCTION

Stature estimation is a major component of personal identification, as it provides an indication of a person's size. Due to the allometric relationships among body parts, stature has been estimated from nearly all bones in the skeleton.[1-2] Globally, Forensic anthropologists have sought to estimate stature from various bones.[1-2] Stature is a feature of a person's physiognomy and a factor that can aid personal identification. When a body is found grossly mutilated, decomposed, or only in the skeletal state, the person's stature can be estimated from measurements of the skeleton and body parts.[3] Individualization is crucial for identifying physical remains found at the crime scene and linking them to the victim or suspect.[4] Globally, research has examined personal identification using various types of evidence. Sexual dimorphism is not

characterized solely by androgenic activity in males and oestrogenic activity in females, but also by critical sex- and time-dependent interactions among sex hormones, Insulin-like Growth Factor 1 (IGF1), growth rate, and mechanical loading, particularly during growth.[5]

The human foot is a complex musculoskeletal structure.[6] It comprises both physiological and morphological feature, and different characteristics of foot morphology are typically preceded by altering the feet pressure distribution and condition of the bones, muscles, tendons, and ligaments of the lower extremities, which in turn affect lower limbs bio-mechanical parameters and foot function and motor skill, knowledge of what shapes foot structure can be useful in explaining the basis of foot deformity and foot dysfunction and in creating more comfortable footwear as a factor, like age, sex, body mass index (BMI), and bilateral asymmetry, can influence foot structure to some extent.[7]

Footprints at the crime scene have become a vital part of the investigation, as they are highly individualized to each person, much like fingerprints.[8] One can intentionally destroy the fingerprints after the crime. However, a person may not leave prints while walking or standing, and sometimes a string of footprints is taken from the scene of the crime, indicating the criminal's movement and hence a clue to the modus operandi.[9] A bare footprint may also preserve information from the plantar surface of the foot, i.e., dermatoglyphic ridge detail and flexion crease marks.[8] In such instances, a fingerprint examiner would utilize this class of detail to establish individuality and prove or rule out links to the claimed owner of the footprint.[10]

The three-dimensional (3D) Footwear impressions are usually excavated from the crime scenes in environments such as mud, snow, or sand, and the impression of those to be obtained for intelligence or evidential purposes provides the Crime Scene Investigator a high number of potential recovery methods from two-dimensional (2D) photography to some form of 3D capture, i.e., a cast.[11] Quality photography under scrutiny and casting with dental stone provide two evidence recovery techniques that complement each other in the recovery of 3D imprinted evidence, while the success of both these collection strategies will differ based on the information that has been transferred into the impression and the duration, resources, and the crime scene technician.[11]

Therefore, the present study sought to assess stature from human foot and shoe lengths. Furthermore, attempts are made to observe sex-based patterns of shoe-sole erosion to distinguish between sexes and to identify sex differences in footwear as a behavioural trait.

MATERIAL AND METHODS

The present study was done on the Adamas University campus in Barasat, North 24 Parganas, West Bengal, India. This study examines differences in anthropometric variables between 50 males (age 20.08±1.54) and 50 females (age 19.2±0.96) from the youth population of North 24 Parganas, West Bengal. Participants with deformities, conditions, or injuries of the lower limb or foot that may compromise the accuracy of measurements are excluded.

Participants with recent foot or leg injuries are excluded to prevent bias in the results. Participants wearing new shoes were excluded because new shoes are rigid and may not cause erosion, whereas participants wearing old or regularly used shoes for more than 18 months were excluded. Furthermore, to achieve the purpose, only users of unisex footwear are incorporated as participants.

The present research included Stature **(Figure 1)**, Foot length **(Figure 2)**, Shoe length **(Figure 2)**, and the localization of shoe-sole erosion **(Figure 3)**, all assessed using anthropometric and observational techniques. All the foot and shoe measurements were taken from both feet (left and right). The standardization of shoe size to foot size was carried out in accordance with UK standards. Data sorting was initially performed in Excel 2013.

Figure 1: Pictorial Representation of Stature and Foot Length Measurement.

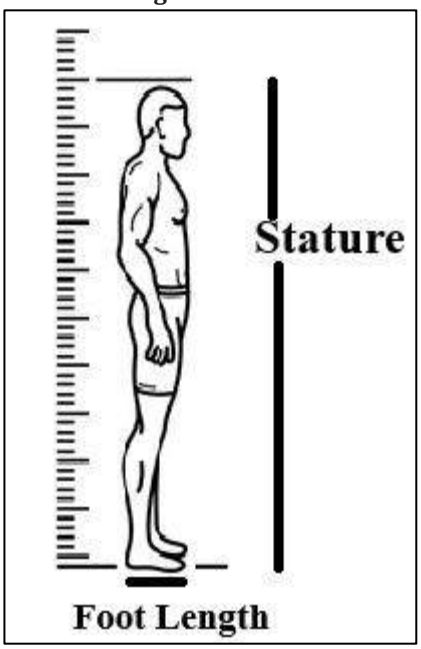


Figure 2: Pictorial Representation of Foot Length and Shoe Size Measurement.

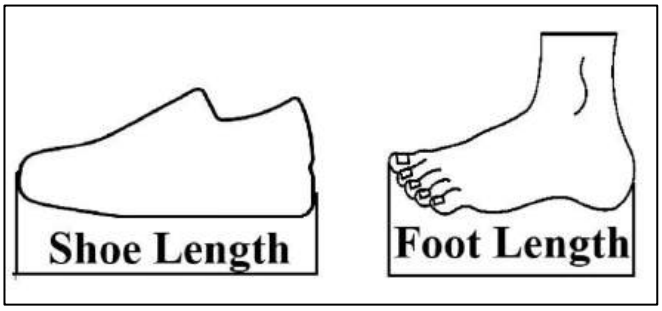
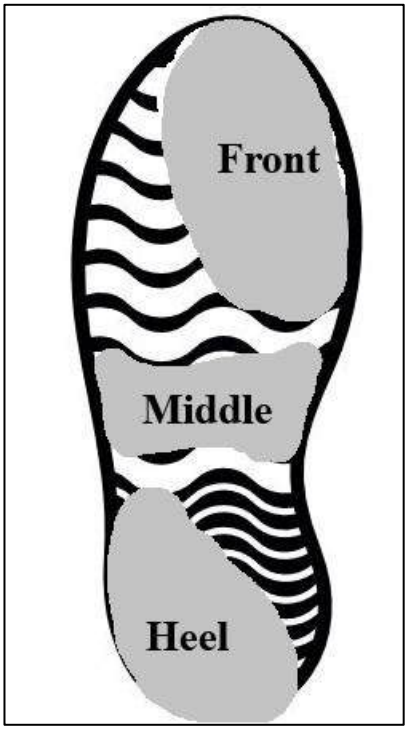


Figure 3: Pictorial Representation of the Erosion Zone in the Shoe Sole.



The parametric and non-parametric statistical analysis was conducted using SPSS (version 27.0), employing both parametric and non-parametric tests. Parametric tests, such as the paired t-test, were carried out for normally distributed data, while non-parametric tests, such as the Mann-Whitney U test, were carried out for non-normally distributed data. The cutoff level was set at 95% ($p \leq 0.05$) probability limits.

Verbal and written consent were obtained from all participants in this study, ensuring that their involvement was entirely voluntary and that their anonymity was strictly maintained. Prior verbal and written consent were obtained from the participants, and only willing individuals were included. Institutional ethical clearance was obtained from the research committee of the School of Basic and Applied Sciences at Adamas University.

RESULTS

The present study showed that males had significantly ($p < 0.05$) larger stature, foot length, and shoe size **(Table 1)**. This resulted in the shoe/footwear being unisex in design, but sizes above 24.07 cm (right foot) or foot lengths greater than 23.612 cm (right foot) and 23.546 cm (left foot) can be predicted as masculine traits **(Table 1)**. A marked discrepancy between actual foot length and shoe size was documented **(Table 2)**.

It was revealed that males wore quite tight-fitting (small-sized) shoes, whereas females wore slightly oversized shoes **(Table 2)**. The examination of shoe sole erosion indicated that male footwear showed significantly ($p<0.05$) higher erosion in the middle zone, whereas female footwear showed significantly ($p<0.05$) higher erosion in the front and heel regions of the sole **(Table 3)**. This reflects the behavioural gait trait of males and females. In a traditional forensic application, the present study proposed stature estimation formulas based on the actual lengths of the bilateral feet and shoes **(Table 4)**.

DISCUSSIONS

The present study demonstrates significant associations among foot anthropometric parameters, footwear morphology, and stature among youth in North 24 Parganas, West Bengal. Previous investigations across diverse populations have reported moderate-to-high correlations between foot length and height.[12-13] Similar high correlations have been documented among North Indian Gujjars[14] and Turkish adults,[15] reinforcing the viability of foot length as a predictor of stature in forensic contexts. The absence of significant bilateral differences in foot length ($p < 0.05$) aligns with earlier studies,[15-16] which observed negligible side differences, supporting the use of either foot for stature estimation. However, some populations have demonstrated asymmetry,[17-18] emphasizing the need for population-specific standards. The present study, like previous studies, revealed that males have significantly larger ($p < 0.05$) foot size **(Table 1)**, sole length **(Table 1)**, and stature **(Table 1)** than females. However, actual foot length and shoe size vary among individuals.[19] That selection has a gender-specific relationship[19] may act as a sex-determinant factor for unisex footwear users. The present study confirmed that all males studied wore footwear smaller than their actual foot length **(Table 2)**. However, the females were wearing little oversized footwear **(Table 2)**. The sole abrasion or erosion also resulted in marked sexual traits.[20] The

Table 1: Sexual Dimorphism of the Taken Anthropometric Measurements.

Variables	Group	N	Mean ± SD (cm)	SE	U-Statistic	p
Stature	Male	50	168.486±7.00*	0.99055	826	<0.00001
	Female	50	155.696±6.01	0.85134		
Right Foot Length	Male	50	26.046±1.22*	0.17307	840	<0.00001
	Female	50	23.612±1.19	0.16965		
Left Foot Lenght	Male	50	26.004±1.23*	0.17485	809	<0.00001
	Female	50	23.546±1.16	0.16426		
Shoe Size	Male	50	25.08±0.56*	0.08	748	0.00001
	Female	50	24.07±0.71	0.10103		

Table 2: Distribution of Variation of Foot Length and Shoe Size.

Side	Group	Paired T-Test			
		Variables	N	Mean±SD (cm)	Std. Error Mean
Left Foot	Male	Foot Length	50	26.004±1.236*	0.17485
		Shoe Size	50	25.080±0.566	0.08
	Female	Foot Length	50	23.546±1.161*	0.16426
		Shoe Size	50	24.070±0.714	0.10103
Right Foot	Male	Foot Length	50	26.046±1.223*	0.17307
		Shoe Size	50	25.080±0.565	0.08
	Female	Foot Length	50	23.612±1.199*	0.16965
		Shoe Size	50	24.070±0.714	0.10103

*p<0.05

Table 3: The Localization of Shoe Sole Erosion Among the Studied Groups.

Variables	Type of Erosion	Group	N	Front	Middle	Heel	χ^2 (df2)	p
Left Shoe	Major	Male	50	13	25	22	6.521*	0.03
		Female	50	21	12	15		
	Moderate	Male	50	14	21	17	10.667*	0.004
		Female	50	24	22	4		
	Mild	Male	50	38	7	5	6.397*#	0.04
		Female	50	47	2	1		
Right Shoe	Major	Male	50	14	24	12	6.262*	0.04
		Female	50	21	12	17		
	Moderate	Male	50	7	22	21	16.890*	0.0002
		Female	50	23	21	6		
	Mild	Male	50	36	8	6	8.902*#	0.011
		Female	50	47	1	2		

*p<0.05; #Yate's Correction

Table 4: The Stature Estimation Based on the Regression Equation.

Side	Variables	Group	Mean±SD (cm)	Regression Equations for Stature Reconstruction		
		Male	168.486±7.00*			
Stature		Female	155.696±6.01	R Square	p Value	Equation
Left Foot	Foot Length	Male	26.004±1.23*	0.395*	0.000	75.894+3.561(FL)
		Female	23.546±1.16	0.233*	0.000	96.824+2.500(FL)
	Shoe Size	Male	25.08±0.56*	0.281*	0.000	3.889+6.563(SZ)
		Female	24.07±0.71	0.252*	0.000	53.791+4.234(SZ)
Right Foot	Foot Length	Male	26.046±1.22*	0.347*	0.000	80.723+3.370(FL)
		Female	23.612±1.19	0.194*	0.001	103.557+2.208(FL)
	Shoe Size	Male	25.08±0.56*	0.281*	0.000	3.889+6.563*(SZ)
		Female	24.07±0.71	0.252*	0.000	53.791+4.234(SZ)

present study demonstrated that male footwear soles exhibit significant ($p<0.05$) maximum erosion in the middle zone. However, the maximum significant ($p<0.05$) mild to moderate erosion was in the front and heel zone of the soles **(Table 3)**. The progressive increase in mean stature with increasing foot length further substantiates a linear relationship, justifying the derivation of regression equations. The predictive models formulated in this study also support the previous documentation,[21] which reported strong correlations and minimal error using regression techniques. Multiple studies have highlighted regression analysis as the most reliable method for stature estimation from foot dimensions.[22-23] The present study also proposed Bengali-population-specific stature prediction formulas based on bilateral shoe size and foot length **(Table 4)**. Overall, the findings reaffirm that foot length is a stable and practical anthropometric trait for stature reconstruction. Given the minimal bilateral variation and high correlation coefficients, either right or left foot length may be used reliably for forensic identification when complete skeletal remains are unavailable.

CONCLUSION

The study confirms significant correlations between foot measurements, footwear morphology, and stature, with clear sexual dimorphism. The significant difference between foot length and shoe size enhances forensic applicability. Distinct sex-based patterns of shoe sole wear further support the utility of foot and footwear analysis for personal identification. Sexual variation in the localization of sole erosion can serve as a predictive marker of gender in unisex-designed footwear. Overall, the development of gender- and side-specific regression equations enhances the precision of stature estimation, particularly in cases involving unilateral footprints. The findings provide valuable population-specific forensic standards and strengthen the role of foot and footwear analysis in criminal investigations.

Limitations of the Study:

The present study was conducted only among the Bengali-speaking population of West Bengal. Therefore, the proposed regression equations may not be universally applicable to other ethnic populations of the state.

Conflict of Interest/Source of Funding: Nil

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ORIGINAL RESEARCH PAPER

"Application of Upper Extremity Measurements in Stature Reconstruction: A Study in Tamil Nadu"

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ABSTRACT

Introduction: Forensic Anthropologists aid by using crucial scientific knowledge in legal and Forensic investigations. Stature is an essential anthropometric measurement that refers to a person's height. It helps differentiate between individuals belonging to the same sex, age and ancestry by providing a circumstantial and conjectural identification of the individual. Variations in genetic makeup, nutritional quality and the level of physical activities are factors that can result in variations in the estimation of stature. The forearm and hand lengths are particularly useful for this purpose because they are relatively well-preserved in skeletal remains, even in cases where other body parts might have deteriorated or are missing.

Aim: The aim was to assess if the forearm and hand length measurements can be used to determine the stature of an individual using a regression model which is created for these parameters

Methods: A total of 218 participants were selected. The stature, forearm, and hand lengths were measured using vernier caliper.

Results: The regression equation has been postulated for all the measurements separately. Stature = Right hand length - 85.919 + 1.000(X) /Right forearm length - 85.919 + 2.069(X)/ Left hand length - 86.385 + 0.909(X)/ Left forearm length - 86.385 + 2.114(X). In this study that stature correlated with the forearm length in both males and females where the Pearson correlation coefficient was 0.617 for males and for females was 0.597. It was observed in this study that the hand length correlated well with the stature in both males and females where the Pearson correlation coefficient was 0.579 for males and for females was 0.534.

Conclusion: From the study it was observed that forearm length showed a significantly high correlation with stature when compared to length of the hand among females and males.

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INTRODUCTION

An important role in the criminal justice system is played by Forensic Science. Over the past few years there have been a rise in mass casualty events such as natural disasters, vehicular accidents, and terrorist attacks, often resulting in fragmented or skeletal remains. Establishing identity in such cases is vital, and Forensic Anthropology utilizes methods that scientifically scientific analyze remains of humans for legal investigations.

Forensic anthropologists contribute significantly by constructing biological profiles and assisting law enforcement with complex cases involving human remains. Anthropometry, the systematic measurement of the human skeletal and body, is a foundational tool in

biological anthropology for identification purposes. Key biological identifiers include age, sex, ancestry, and stature.[1] Anthropometry is a systemized technique used to quantitatively measure the human skeleton and body measurements. It is used for the purpose of identification and is considered to be a tool of biological anthropology. The "big fours" on the basis of which identification is established include -Age, Sex, Ancestry and Stature.

Stature, the vertical height of an individual, assists in differentiating persons of similar age, sex, and ancestry. It is the measurement from the vertex of the head till the soles of the feet. Estimation from skeletal remains can be done via two primary methods:

1. Anatomical method (Fully's method), which sums bone lengths and adds a soft tissue correction.
2. Mathematical method, employing regression formulas based on a single bone measurement, useful when only fragments are available.[2-3]

Stature estimation from either skeletal system or body parts is a comprehensive process that involves areas, such as the measurements of long bones, cranium, index finger, hand and foot, as well as head length, breadth. Each of these diverse measurements plays a crucial role in contributing to the accurate assessment of an individual's stature. By considering multiple body parts, experts can form a more holistic and precise understanding of a person's height, which can be valuable in various fields including such as Forensic Anthropological investigations.[4] Use of skeletal system in stature estimation is a time consuming and difficult process as the bones need to be first cleaned of the soft tissues. As a result of this the Forensic Anthropologists use percutaneous measurements of the bone.

Genetic diversity, nutrition, and physical activity cause variability in anthropometric measurements, emphasizing the need for population-specific studies. Research on assessment of stature from upper limb measurements in the Tamil Nadu population remains limited. Given that forearm and hand bones are often well-preserved in remains, this study attempts to understand the correlation of stature with these measurements.[5] Hence to current study aims to evaluate if the forearm and hand length measurements can be used to determine the height of an individual using a regression model which is created for these parameters. This technique can be crucial and can serve as corroborative evidence to establish identity in cases where bodies are mutilated, body parts missing or in cases of bodies that are unidentified.

MATERIALS AND METHODS

This study was conducted with 218 individuals as a cross-sectional study. The sample size was decided based on statistical calculations. Inclusion criteria were both physically fit males and females in the age group of 18-30 years, without any deformities, history of fracture of the forearm and hand bones and those who were Tamilians (mother tongue Tamil). After taking informed consent from the participants a stadiometer was used to measure the stature. The participants were asked to stand against a wall with their feet slightly apart but parallel to each other. The head was oriented in Frankfurt horizontal plane while the movable horizontal piece was adjusted to measure the subjects' height **(Figure 1)**. Height was recorded in centimeter.

Once the height measurement was completed, the subjects were allowed to relax in a comfortable position and both forearms and hands were extended for further measurements. Subsequently, hand length and forearm measurements were taken from each hand by using a sliding caliper.

Forearm lengths were measured for both right and left sides as the distance between the radial olecranon and styloid process, with flexed elbow at a 90-degree angle the forearm placed on a horizontal and firm surface with fingers adducted **(Figure 2)**.

Distance between the midpoint of distal crease of the wrist to the tip of the middle finger was taken to be the length of the hand. **(Figure 3)**.

Unit for the measurements was in centimeters for both males and females, contributing to the estimation of stature.

Statistical Analysis

The collected data was statistically analysed using SPSS software (Version 23).

RESULTS

This study was conducted among 109 males and 109 females in the age group of 18-30 years. The average height of the males was 173.001cms and that of the females was 159.239cms **(Table 1)**. The minimum and maximum height for the males and females studied along with the mean and standard deviation are also given in the **Table 1**.

The general formula for Linear regression equation is Y= a+bx, where

Figure 1: Stature Measurement Using Stadiometer.

Figure 2: Forearm Length Measurement using an Anthropometer.

Figure 3: Hand Length Measurement using Anthropometer.

Y= Dependent variable

a= Constant

b= Slope of line/multiplication factor

x= Explanatory variable (Length of the parameter studied)

The regression equations derived for the present study for both males and females has been stated above **(Table 5)**. Following the derivation of the regression equation the accuracy and reliability were tested for by taking 10 random individuals as per the inclusion criteria mentioned. Their forearm and hand lengths were measured and stature was calculated. It was then correlated with the actual stature measured. It was observed that the linear regression equations derived to estimate stature from the parameters revealed high accuracy and reliability.

DISCUSSION

Estimation of stature can help give clues as to the identity of the individual. This is especially important in cases of mutilated and skeletonized bodies. Forensic experts use regression models for stature estimation as a tool in crime investigations owing to the concept that stature differs from age, sex, race and regions.

The study population in this study belonged to on Tamil Nadu and it was observed that the mean stature of both males and females were around 173.00 +6.0497 and 159.239 + 6.8567. This was slightly more when compared to the Maharashtrian population studied by Samreen Panjakash et al where the mean height of males was 171.73+5.01and that of females was 154.34+5.49.[6]

However, when this is compared to the Iranian or Pakistani population the average height of the Tamil Nadu population is found to be lower as can be seen from the study done by Ali Fathi Jouzdani et al. The observed that the mean height of the Iranian males was 180.446 ±5.569 and that of females was 164.435 ±5.072. Pakistani's males had average height of 164.435 ±5.072 and females had average height 167.610 ± 7.580.[7]

Thus, it can be observed that from the average height of people from different geographical area can vary and hence it would be eminent to understand how anthropometric measurements vary in them for stature estimation. There have been studies earlier where stature estimation models were developed using head breadth and sternoclavicular measurements, findings of which have been published in the Journal of Punjab Academy of Forensic Medicine & Toxicology. These studies support the

Table 1: Mean and Standard Deviation for Overall Population.

Gender	Number	Minimum Height(cm)	Maximum Height (cm)	Mean	Standard Deviation (SD)
Male	109	151.40	185.00	173.001	6.0497
Female	109	145.70	178.00	159.239	6.8567

Table 2: Correlation of Stature with Forearm Length.
In this study that stature correlated with the forearm length in both males and females where the Pearson correlation coefficient was 0.617 for males and for females was 0.597.

Gender	Mimimum (cm)	Maximum (CM)	Mean	SD	R Value	p Value
Male	26.00	37.00	30.839	2.2524	0.617	0.000
Female	24.00	35.50	27.852	2.1540	0.597	0.000

Table 3: Correlation of Stature with Hand Length.
It was observed in this study that the hand length correlated well with the stature in both males and females where the Pearson correlation coefficient was 0.579 for males and for females was 0.534.

Gender	Mimimum (cm)	Maximum (CM)	Mean	SD	R Value	p Value
Male	17.00	24.50	20.437	1.4599	0.579	0.000
Female	15.00	24.00	18.532	1.6844	0.534	0.000

Table 4: Derivation of Constant and Multiplication Factors using the Parameters Studied.
From the table given the constant to be substituted in the regression formula for Right side measurements was found to be 85.919 and for left side was 86.385. The multiplication factor for each parameter was as given below in the table.

Parameter	RFA	LFA	RH	LH
Constant	85.919	86.385	85.919	86.385
Multiplication Factor	2.069	2.114	1.000	0.909

Table 5: Regression Equation Derived for Various Parameters in the Overall Population.
The general formula for Linear regression equation is
Y= a+bx, where
Y= Dependent variable
a= Constant
b= Slope of line/multiplication factor
x= Explanatory variable (Length of the parameter studied)
The regression equations derived for the present study for both males and females has been stated above (Table V). Following the derivation of the regression equation the accuracy and reliability were tested for by taking 10 random individuals as per the inclusion criteria mentioned. Their forearm and hand lengths were measured and stature was calculated. It was then correlated with the actual stature measured. It was observed that the linear regression equations derived to estimate stature from the parameters revealed high accuracy and reliability.

Right hand length	85.919 + 1.000(X)
Right forearm length	85.919 + 2.069(X)
Left hand length	86.385 + 0.909(X)
Left forearm length	86.385 + 2.114(X)

role of regional anthropometric databases in improving the accuracy of forensic identification.[8-9]

The present study was undertaken to understand how the upper limb measurements correlate with stature. Results of this study show that stature estimation can be done from forearm and hand length using appropriate regression formulas. In the current study, the results indicate strong positive correlation between stature and forearm length and a positive correlation with the stature and hand length in males and females. In the population studied in the current research it has been observed that the forearm length shows better correlation to stature than the hand length. Similar to this study it was observed that stature correlated forearm lengths (P = 0.000), with the exception of the hand length among the Iranian male and female students' with stature.[7]

Regression models were derived for determining stature and these equations reasonably suggested that living stature can be predicted from forearm and hand lengths. Similar to this while using forearm length and the stature as independent variables in the linear regression, the regression model was significant for the entire study population (P = 0.000) in the study by Ebrahimi B et al.[10]

Measurements of stature using ulna length was found to be equated to the forearm length in Marathwada region of Maharashtra by Dr,Anjali Prasad et al revealed mean height to be highly significant ($p<0.05$) with length of ulna. Hence,

there was a positive relation observed between stature and length of ulna and this study concluded that Simple linear regression equation so far derived is considered to be useful for estimation of height in Marathwada (Maharsashtra) region.[11] This was similar to our study where forearm length correlated with stature.

A study of estimation of stature from forearm length by Ashutosh B Potdar, et al, found that mean stature and forearm length of females was comparatively less than males, which seemed similar to other studies conducted to estimate stature. In regression analysis there was a positive correlation between forearm length and stature in both male and females which was similar to results of our findings.[12]

Use of percutaneous hand length among the students at a medical college by Alok Atreya and Anup Pandeya found that the length of the hand and correlation with stature was higher among males as compared to females.[13]

CONCLUSION

In this study of 218 Tamil Nadu adults, forearm length correlated more strongly with stature than hand length across both sexes. The simple linear regression equations developed reliably estimate stature from forearm and hand measurements. These findings support the use of upper limb anthropometry as a practical tool for stature estimation in forensic investigations.

Thus, this study can help in stature estimation from such variables.

Limitations of the Study

The following limitations of the present study have been identified. The study population of this study consisted of only young adults aged 18–30 years from Tamil Nadu, which may limit the generalizability of the regression equations to other age groups and populations. Another limitation is that the study population belonged to a single geographical region and hence may not be representative of the anthropometric diversity present across South India or the Indian population as a whole. Confounding factors such as socioeconomic background, occupational variations and nutritional status, were not taken into considerations, which may influence anthropometric dimensions. Therefore, it is suggested to conduct multicentric studies involving larger and more diverse populations that could help validate and refine the regression models developed in this study.

Conflict of Interest/Source of Funding: Nil

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ORIGINAL RESEARCH PAPER

Pattern of Homicidal Deaths: A Three Year Retrospective Autopsy-Based Study at A Tertiary Care Centre in Ballari, Karnataka

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ABSTRACT

Introduction: Homicide has become the major legal issue as well as public issue worldwide. This issue is more significant in developing countries like India where there is rapid population growth, unemployment, rapid urbanisation, economic discrepancy, interpersonal conflicts, drug abuse, illiteracy and lack of social education which as lead to high incidence of homicide death. Study of such homicidal deaths provide us the vital revelation into cohort, methods, association between victim and offender, behaviour after the crime and other inter connected factors. Comprehending such understanding helps to upgrade the investigation methods, formulating prevention approaches and reinforcing the existing safety regulation policies.

Materials and Methods: This was a retrospective descriptive autopsy-based study conducted in a tertiary care centre. The study included all cases of homicidal deaths that underwent medico-legal autopsy from January 2021 to December 2023.

Results: Incidences of homicidal deaths were more among males and most commonly involved age group was 31 to 40 years followed by 21 to 30 years, and Most victims belonged to lower middle class 51.31% and Poor class 40.78%, and Incidents were high during the daytime 59.21% and summer months, majority of cases occurred in rural areas 72.36%, and Most incidents occurred at Victim's House 34.21%, and the Reason behind Homicide was money/ property disputes 26.31% followed by enmity/ rivalry 23.68%, and the most common method of homicide was blunt force assault 48.67%, and Homicides were prevalent among intimate relationships 44.73%, and 31.08% of offenders were self-surrendered in front of law enforcement agency.

Conclusion: The findings highlight the need for stronger community-based conflict resolution methods, improved economic conditions, awareness of domestic violence and relationship-related issues.

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INTRODUCTION

Homicide is the act of one person killing another.[1] such act has become the most grave form of unnatural death and has posed substantial hurdle to community health, law enforcement system and to over all society. Medico-legal autopsies are crucial for determining the cause, manner, and mechanisms of death in homicide cases and provide valuable insights into homicide trends.[1-2] According to the World Health Organization, interpersonal violence causes hundreds of thousands of deaths each year, particularly affecting low and middle-income countries. Homicidal deaths reflect the various social, cultural, economic, and behavioural factors present in a community. They are often connected to issues such as poverty, unemployment, substance abuse, domestic disputes, political rivalry, and crime.[3] Research on homicide trends across countries has identified clear patterns and shown how structural factors, such as economic inequality, urbanization, and demographic composition, influence homicide trends.[4] A 2019 UNODC global study on homicide noted that the global homicide rate remains a critical public health and criminal justice issue, with about 464,000 homicide deaths reported worldwide in 2017. While the number of homicides has generally increased, the global rate fell from 7.2 per 100,000 people in 1992 to 6.1 per 100,000 in 2017.[5] A international data shows that homicide affects males and young adults, especially those aged 15-29, who are often both the main victims and offenders.[6] A multinational study of homicide trends in 126 countries shows that the global homicide rate has come down by

almost 20% since 1990, indicating a gradual decrease in lethal violence worldwide.[7] A 2023 UNODC global study on homicide observed the substantial gender, socio-criminal and regional differences in patterns of homicidal deaths, stressing the roles of interpersonal violence, intimate partner violence and organized crime.[8] A recent global study on homicidal deaths indicating that factors like demographic changes, aging populations, inequality, and organized crime continue to shape homicide patterns globally.[9] The National Crime Records Bureau (NCRB) note a slight decrease in the murder rate in India from 2.0 per lakh population in 2023 to 1.9 per lakh in 2024, indicating a small reduction in overall homicide rates.[10] Despite the number of crimes is at an alarming level, there is limited literature on the epidemiology and injury profiles of homicidal deaths in Ballari. This study aimed to analyze the patterns of homicidal deaths examined through medico-legal autopsy at a tertiary care centre in Ballari, Karnataka, over three years. It seeks to evaluate the demographic profiles of victims, reasons for the homicides, methods used, relationships between victims and offenders, and the surrender status of offenders after the crime in this region.

MATERIALS AND METHODS

This was a retrospective descriptive autopsy-based study conducted in the Department of Forensic Medicine and Toxicology at Ballari Medical College and Research Centre. The study included all cases of homicidal deaths that underwent medico-legal autopsy from January 2021 to December 2023.

Inclusion Criteria

- All medico-legal autopsy cases certified as homicidal deaths following complete investigations.
- Cases with complete autopsy records and relevant police documents.
- Victims of all ages and both genders were included in this study.

Exclusion Criteria

- Lawful homicide.
- Cases with undetermined or suspicious manner of death.
- Decomposed bodies with vague findings.
- Partial or mislaid medico-legal records were excluded from the study.

Retrospectively details were collected from post-mortem reports, police inquest reports, hospital treatment records, Forensic science laboratory results and histopathology reports where ever applicable.

Limitations: There is no scope for a psychological autopsy.

Ethical Considerations: Institutional ethical committee approval obtained.

RESULTS

This study reviewed a total of 76 cases of homicidal deaths, consisting of 52 males (68.42%) and 24 females (31.58%), which shows a clear male prevalence.

Age Distribution

Majority of the victims 32.9% (n=25) were in the age group of 31–40 years followed by those aged 21–30 years 26.3% (n= 20). Very few cases were reported in the extreme age ranges, particularly above 60 years 3.94% (n=03). Male victims were predominant across nearly all age groups, while a higher proportion of female victims appeared in the younger (<11 years) and middle age groups.

Socioeconomic Background

Most victims belonged to lower middle class 51.31% (n=39) and Poor class 40.78% (n=31).

No cases were reported from higher socio-economic groups.

Diurnal and Seasonal Distribution

Incidents were high during the daytime 59.21% (n=45) than night time 40.78% (n=31).

Incidents were high during the summer 3 months (March to May) 46.05% (n=35), followed by the Rainy 6 months (June to November) 32.9% (n=25).

Legal Sections under which the Cases were registered

Most cases were registered under Section 103 BNS 81.57% (n=62), while 18.42% (n=14) fell under Section 105 BNS, indicating that most cases involved intentional homicide.

Urban vs. Rural Distribution

A significant majority of cases occurred in rural areas 72.36% (n=55), compared to urban areas 27.63% (n=21).

Crime Scene Location

Incidents found to happen more at Victim's House 34.21% (n=26), followed by Remote place 27.63% (n=21) and Public places 22.36% (n=17). Female victims were more frequently assaulted in their residences.

Reason behind Homicide

The leading causes included money/property disputes

26.31% (n=20), enmity/rivalry 23.68% (n=18), suspicion of infidelity 21.04% (n=16), and arguments 13.15% (n=10).

Gender-specific Patterns Included

- Suspicion of infidelity was a significant factor contributing to homicides against females.
- Argument-related homicides were only observed among males.

Method Employed in Homicide

The most common method of homicide was blunt force assault 48.67% (n=37), followed by chopping 11.84% (n=9), and stabbing 10.52% (n=8).

Notably, strangulation 10.52% (n=8) occurred more often with females, cut-throat injuries 2.63% (n=2) were exclusive to females, and firearm-related deaths 1.31% (n=1) were rare.

Victim–Offender Relationship in Homicide

- Homicides were prevalent among intimate relationships 44.73% (n=34) followed by friends 28.94% (n=22). Female victims were mostly killed by intimate partners.

Post-Offence Surrender status of the Offender

Analysis was based on offender behaviour per incident rather than per victim (in 1 case, offender was 1 but victims were 3), among the 74 offenders, 66.2% (n=49) of offenders did not surrender, and 31.08% (n=23) self-surrendered, whereas 2.7% (n=2) committed suicide. Where as most of the offenders of homicide with the reason of the suspicion of infidelity were self-surrendered.

DISCUSSION

The predominance of young, males among homicidal deaths, may be attributed to increased social interaction, economic stress, interpersonal conflicts, substance abuse, and greater involvement in high-risk activities during the most active phase of life.

which aligns with the studies of Oberoi SS et al,[11] Rastogi AK et al,[13] Sonawane SS et al,[16] Sivakumar V et al,[18] Hariharan A et al,[19] Das NG[20] and Zanzrukiya K et al[21]

The majority of cases came from low socioeconomic backgrounds, indicating that economic pressures, personal conflicts, and limited support systems play a significant role. Similar findings were reflected in the studies by Oberoi SS et al,[11] Sweekriti S et al,[14] Gupta S et al,[15] Sonawane SS et al,[16] Sivakumar V et al,[18] Hariharan A et al,[19] Das NG,[20] And Zanzrukiya K et al[21]

Homicides were more during the day; it may reflect the increased social interactions and outdoor activities. And this finding is contrast with the findings of Mada P,[17] Sivakumar V et al,[18] Hariharan A et al[19]

Homicides were more during the summer 3 months; it may reflect the combined effects of elevated ambient temperatures, increased interpersonal exposure, and psychological irritability associated with heat stress and greater participation in outdoor and social activities. Similar finding is noted in study by Rastogi AK et al,[13] Zanzrukiya K et al,[21] but contrast with the findings of study by Gupta S et al,[15] observed that the homicides were more during the rainy season.

The higher percentage of homicidal deaths recorded among the rural population may be attributed to the fact that, this tertiary care centre caters service up to the radius of about 100 kms, and the rural population is significantly higher in this region, due to the fact that, large number of industries and vast irrigated agricultural land. This finding is similar with the findings of Oberoi SS et al[11] but contrast with the findings of Sweekriti S et al[14] and Zanzrukiya K et al,[21] conducted study in metropolitan cities.

The victim's residence constituted the most common crime scene, likely reflecting the predominance of domestic and acquaintance-related violence. Female victims were more frequently assaulted in their residences, whereas incidents occurring in public places may be associated with impulsive interpersonal conflicts and community disputes. This finding is similar with the findings of Sonawane SS et al,[16] Mada P[17] and Hariharan A et al[19] but contrast with the findings of Sivakumar V et al.[18]

Financial issues / Property Related, personal grudges, revenge, and rivalry were the main reasons behind male victim's deaths, this could be explained by; dissatisfaction, resentment, and animosity among members of the farmer families due to increased demand and Value for agricultural land due to industrial expansion and real estate activities in this region, and the suspicion of infidelity was a significant factor in the deaths of female victims, this point to the impact of conflicts in domestic and personal relationships. This finding is similar with the findings of Yadav N et al,[12] Sonawane SS et al,[16] Mada P,[17] Hariharan A et al[19] and Zanzrukiya K et al,[21] but contrast with the findings of Das NG[20] conducted study at Imphal,

Manipur the border state of India, a hot bed of militant activity.

The predominance of blunt force assault as the mode of homicide may reflect the spontaneous nature of many assaults, close victim–offender interaction, and offender lacked skill and did not use advanced methods in most cases. This finding is similar with the findings of Oberoi SS et al,[11] Rastogi AK et al,[13] Gupta S et al,[15] and Das NG[20]

Most homicides stem from existing social relationships rather than from strangers. Female victims were mostly killed by intimate partners. It may be attributed to emotional conflicts, domestic disputes, possessiveness, jealousy, substance abuse, and prolonged interpersonal interaction between the victim and offender. This finding is at par with the findings of Mada P[17] and Zanzrukiya K et al,[21] but contrast with the findings of Sonawane SS et al[16] where the Motive behind the homicide was argument.

A notable number of offenders's surrendering voluntarily; may be due to intense psychological distress after committing homicide or social and family pressure or fear of harsher punishment or religious or moral beliefs or safety concerns in cases involving revenge or gang-related killings or defense lawyers often advise surrender to strengthen arguments for leniency, bail, or reduced charges.

CONCLUSION

The findings highlight the need for stronger community-based conflict resolution methods, improved economic conditions, awareness of domestic violence and relationship-related issues, better law enforcement in vulnerable rural areas, increase in conviction rates, early identification of personal disputes and focused preventive measures may help reduce the number of homicides in society.

Conflict of Interest/Source of Funding: Nil

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Table 1: Age & Sex wise distribution of cases of Homicide.

Age Group	Male Homicides No (%)	Female Homicides No (%)	Total No (%)
<11	01 (1.31%)	04 (5.26%)	05(6.57%)
11 to 20	02 (2.63%)	01 (1.31%)	03 (3.94%)
21 to 30	14 (18.42%)	06 (7.9%)	20(26.3%)
31 to 40	17 (22.37%)	08 (10.52%)	25(32.9%)
41 to 50	08 (10.52%)	02 (2.63%)	10 (13.15%)
51 to 60	07 (9.2%)	03 (3.94%)	10 (13.15%)
61 to 70	02 (2.63%)	00 (%)	02 (2.63%)
>70	01 (1.31%)	00 (%)	01 (1.31%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 2: Socio-Economic Background of the Victim.

Category	Male victim No (%)	Female victim No (%)	Total No (%)
Destitute	02 (2.63%)	00 (%)	02 (2.63%)
Poor/ Low Class Family	18 (23.68%)	13 (17.1%)	31(40.78%)
Low Middle Class Family	29 (38.15%)	10 (13.15%)	39(51.31%)
Upper Middle Class Family	03 (3.94%)	01 (1.31%)	04(5.26%)
Rich/ High-class Family	00 (%)	00 (%)	00(%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 3: Diurnal Distribution of Cases.

Category	Male homicides No (%)	Female homicides No (%)	Total No (%)
Day time	29 (38.15%)	16 (21%)	45(59.21%)
Night time	23 (30.26%)	08 (10.52%)	31(40.78%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 4: Seasonal Distribution of Cases.

Category	Male victim No (%)	Female victim No (%)	Total No (%)
Summer	24 (31.58%)	11 (14.47%)	35(46.05%)
Rainy	18 (23.68%)	07 (9.2%)	25(32.9%)
Winter	10 (13.15%)	06 (7.9%)	16(21.05%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 5: Distribution of Cases Among the Urban and Rural Population.

Category	Male homicides No (%)	Female homicides No (%)	Total No (%)
Urban	15 (19.73%)	06 (7.9%)	21(27.63%)
Rural	37 (48.68%)	18 (23.68%)	55(72.36%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 6: Legal Sections Under Which the Cases were Registered.

Category	Male homicides No (%)	Female homicides No (%)	Total No (%)
Culpable homicide	39 (51.31%)	23 (30.26%)	62(81.57%)
amounting to Murder			
Culpable homicide not	13 (17.1%)	01 (1.31%)	14(18.42%)
amounting to Murder			
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 7: Distribution of cases According to Crime Scene Location.

Category	Male homicide No (%)	Female homicide No (%)	Total No (%)
Victim's House	11 (14.47%)	15 (19.73%)	26(34.21%)
Residential area	12 (15.78%)	00 (%)	12 (15.78%)
Public Place	16 (21%)	01 (1.31%)	17(22.36 %)
Remote Area	13 (17.1%)	08 (10.52%)	21(27.63%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 8: Distribution of cases According to Method Employed in Homicide.

Category	Male homicide No (%)	Female homicide No (%)	Total No (%)
Blunt Force Assault	31 (40.78%)	06 (7.88%)	37(48.67%)
Chopping	06 (7.9%)	03 (3.94%)	09(11.84%)
Stabbing	07 (9.2%)	01 (1.31%)	08(10.52%)
Cut Throat	00 ( )	02 (2.63%)	02 (2.63%)
By Immersion	02 (2.63%)	04 (5.26%)	06(7.9%)
Strangulation	02 (2.63%)	06 (7.9%)	08(10.52%)
Smothering	01 (1.31%)	01 (1.31%)	02(2.63%)
Mugging	01 (1.31%)	00 ( )	01 (1.31%)
Vehicular Run-over	01 (1.31%)	00 ( )	01 (1.31%)
Setting Fire	00 ( )	01 (1.31%)	01 (1.31%)
Gunned Down	01 (1.31%)	00 ( )	01 (1.31%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 9: Distribution of cases According to Reason behind the Homicide.

Category	Male homicide No (%)	Female homicide No (%)	Total No (%)
Financial issues / Property Related	18 (23.68%)	02 (2.63%)	20(26.31%)
Enmity/ Revenge/ Rivalry	17 (22.36%)	01 (1.31%)	18(23.68%)
Suspicion of Infidelity	00 (%)	16 (21%)	16 (21%)
Love Affairs	02 (2.63%)	02 (2.63%)	04(5.26%)
Heated Argument	10 (13.15%)	00 (%)	10 (13.15%)
Robbery	02 (2.63%)	00 (%)	02 (2.63%)
Suspicion of Adultery	02 (2.63%)	00 (%)	02 (2.63%)
Post sexual assault	00 (%)	02 (2.63%)	02 (2.63%)
Unwanted child	01 (1.31%)	00 (%)	01 (1.31%)
Illegitimate Child	00 (%)	01 (1.31%)	01 (1.31%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 10: Distribution of Cases According to Offender & Victim Relationship.

Category	Male homicide No (%)	Female homicide No (%)	Total No (%)
Intimate	14 (18.42%)	20 (26.31%)	34 (44.73%)
Friends	18 (23.68%)	04 (5.26%)	22 (28.94%)
Neighbors/ Known	10 (13.15%)	00 (%)	10 (13.15%)
Stranger	10 (13.15%)	00 (%)	10 (13.15%)
	52 (68.42%)	24 (31.58%)	76 (100%)

Table 11: Post-Offence Surrender Status of the Offender.

Category	Male homicide No (%)	Female homicide No (%)	Total No (%)
Self Surrendered	17 (22.97 %)	06 (8.1%)	23(31.08%)
Not Surrendered	35 (47.2%)	14 (18.9%)	49(66.2%)
Committed Suicide	00 (%)	02 (2.7%)	02 (2.7%)
	52 (70.27%)	22 (29.72%)	74 (100%)

Note: analysis was based on offender behavior per incident rather than per victim

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ORIGINAL RESEARCH PAPER

"Anthropometric Estimation of Height from Middle Finger Length in the Eastern Region of Gujarat."

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ABSTRACT

Introduction: Personal identification is crucial in both civil and criminal medico-legal investigations, especially when only partial human remains are available. Stature is one of the key biological indicators in forensic anthropology. Traditional stature estimation methods often rely on long bones; Phalanges have more chances of being missing than long bones. As an alternative, digital anthropometry—particularly middle finger length (MFL) has gained attention due to its length has a strong, consistent, and statistically reliable correlation with overall body height compared to other fingers.

Objective: This study aims to determine the correlation between MFL and stature among adults from eastern part of Gujarat and to derive sex-specific regression equations for stature estimation.

Materials and Methods: Cross-sectional research was performed on healthy 200 adults as per BMI (100 men and 100 females) from eastern region of Gujarat. Stature and MFL were assessed using conventional anthropometric methods. Predictive equations were derived using Pearson's correlation and linear regression analysis.

Results: There were significant positive relationships between MFL and stature (r = 0.61 for men, r = 0.67 for females). The regression equations obtained were: For Males Y = 169.77 + 14.21 (X-8.24) For Females Y = 159.53 + 16.53 (X-7.65)

Conclusion: MFL has a modest statistically significant association with stature and may be used as a viable proxy for estimating stature. The sex-specific regression models created in this research are geographically relevant and have practical relevance in forensic investigations with incomplete remains.

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INTRODUCTION

Personal identification is of great importance in medico-legal investigations in civil as well as criminal. In forensic anthropology, an important question is to identify a person by biological data, especially in cases when only parts of the corpse are accessible. Identification may be made in a number of ways. Physical characteristics such as age, sex, ancestry and size can be looked at. One of the basic biological profile parameters is stature, which is one of the first parameters utilized for restriction of identification in forensic investigations.[1]

Identification is essential for medico-legal purposes in civil (marriage disputes, inheritance, settlement of paternity, business litigation) and criminal (homicide, assault, sexual offences, mass mortality).[2] Estimation of stature is of particular importance in the identification of disaster victims (DVI) where whole bodies may not be available due to dismemberment, decomposition or burning as in mass disasters such as earthquakes, cyclones, floods, building collapses, bomb blasts and aviation accidents.[3] In such cases, the estimating techniques of skeletal or body pieces give an essential information for identification.

Stature has been shown to be closely correlated with several anthropometric parameters notably long bones like femur, tibia, humerus and ulna.[4] These bones, however, may not always be accessible or maintained. Thus, there are increased interests in examining the relationships between height and other available body measures, such as limb length, hand and foot dimensions,

and digital lengths notably fingers.[5] The middle finger length has been shown to be statistically correlated with height among individuals and provides a realistic, alternative anthropometric criterion for forensic investigations.[6]

There are several stature prediction studies worldwide employing long bones and foot measurements[7-8] but there is little region-specific data, especially in terms of finger length as a predictive feature. Regression equations developed in one ethnic or geographic group may not be relevant to other groups.[9] This is due to inter-population variances in body proportions that result from genetic, nutritional and environmental factors. Therefore, population-specific models are needed to improve the accuracy of stature estimates.

Given the wide ethnic and geographical diversities in India, it is important to establish customized anthropometric datasets. However, a large-scale investigation has not been completed in the eastern part of Gujarat to develop a valid regression model between middle finger length and stature. The disparity points to the necessity for concentrated study in this area. Hence, the current research is aimed to statistically assess the relationship between middle finger length and stature in the population of eastern Gujarat and to provide a population specific regression formula that can be used in forensic and medico-legal cases for stature estimate.

MATERIAL AND METHOD

Study Design and Duration

A Cross-Sectional Observational Study was undertaken for a period of three months i.e. from 1st April 2025 to 30th June 2025. The present research included of 200 healthy adult subjects (100 men and 100 females). The participants had to be born and brought up in the eastern area of Gujarat, India which includes the districts of Panchmahal, Dahod, Mahisagar, Chhota Udepur, Narmada, Arvalli and Godhra.

Inclusion Criteria

- The research comprised subjects aged 21 years and above (since full epiphyseal fusion of long bones is often attained at this age[10]).

Exclusion Criteria

- Individuals who were not native to the specified region or had a history of dwarfism, gigantism, spinal deformities, or long bone abnormalities.

Ethical Considerations

Prior to participation, informed written consent was obtained from all individuals. The study protocol was approved by the Institutional Ethics Committee.

Anthropometric Measurements

All anthropometric data were recorded by a single trained observer to eliminate inter-observer variability. Measurements were taken during daylight hours in a well-lit room to ensure accuracy and consistency.

Stature Measurement

Stature was measured using a standard anthropometer rod as the vertical distance from the vertex of the head to the floor. Subjects were instructed to stand barefoot on a flat surface with the heels, buttocks, and shoulder blades touching the wall, and the head positioned in the Frankfurt horizontal plane. The anthropometer's movable arm was brought into contact with the vertex along the mid-sagittal plane.

Middle Finger Length Measurement

Middle finger length was measured using a digital Vernier calliper with precision up to 0.01 mm. The subject was asked to place the hand on a flat table with the palm facing medially and fingers extended. The distance from the phalangion (proximal flexion crease at the base of the finger) to the dactylion (tip of the finger) was recorded.

Data Compilation and Statistical Analysis

All collected data were compiled in a master chart and processed using Microsoft Excel. Descriptive statistics including mean and standard deviation (SD) were computed for stature and middle finger length for both sexes.

The Pearson correlation coefficient (r) was calculated to evaluate the relationship between stature and middle finger length. A simple linear regression analysis was conducted separately for males and females to formulate a population-specific predictive equation for stature estimation.

$Y = \bar{Y} + (Sy/Sx)(X - \bar{X})$

The formula used was:

Where:

Y = standing height (stature)

$\bar{Y}$ = mean of standing height

X = middle finger length

$\bar{X}$ = mean of middle finger

Sy =standard deviation of standing height

Sx =standard deviation of middle finger length

All statistical analyses were carried out using OpenEpi software, and results were interpreted at a 95% confidence level ($p < 0.05$ considered statistically significant).

RESULT

Standing height of the males varied from 185 cm to 150 cm with standard deviation (S.D) of 7.39 and mean value of 169.77 cm. For females it varied from 176 cm to 143 cm with standard deviation of 8.10 and mean value of 159.53 cm. **(Table 1)**

Table 1: Stature of Study Group.

Height	Male	Female
Maximum	185 cm	176 cm
Minimum	150 cm	143 cm
SD	7.39	8.10
Mean	169.77	159.53

Middle Finger Length

The length of middle finger varied from 9.5 cm to 7 cm with mean value of 8.244 cm, standard deviation 0.522 and correlation co efficient with standing height 0.61. The length of middle finger for females varied from 9 cm to 6.5 cm with mean value of 7.659 cm, standard deviation 0.49 and correlation co efficient with standing height 0.67. **(Table 2)**

Table 2: Middle Finger Length for Males and Females.

Middle Finger Length	Male	Female
Maximum	9.5 cm	9 cm
Minimum	7 cm	6.5 cm
SD	0.52	0.49
Mean	8.24	7.65
Correlation Coefficient	0.61	0.67

Regression equation was derived from middle finger length for estimation of stature separately for male and female using this formula $Y = \bar{Y} + (Sy/Sx)(X - \bar{X})$

Middle Finger

For Male: $Y=169.77 + (7.39/0.52)(X-8.24)$

$Y= 169.77 + (14.21)(X-8.24)$

For Female: $Y= 159.53 + (8.10/0.49)(X-7.65)$

$Y = 159.53 + (16.53)(X -7.65)$

For males, regression equation for stature from middle finger length is 169.77 + (14.21) (X-8.24) and for females 159.53 + (16.53) (X -7.65). Here X is middle finger length. By putting X value, the stature can be calculated and it can be compared with corresponding real standing height.

DISCUSSION

The present study aimed to derive sex-specific regression equations for stature estimation using middle finger length (MFL) in a sample of healthy adults from eastern Gujarat. The results revealed a statistically significant, moderately strong correlation between stature and middle finger length, with Pearson's correlation coefficient(r) of 0.61 for males and 0.67 for females. These observations are in agreement with the earlier anthropometric studies undertaken in different areas of India and other countries. Length of the middle finger is a good proxy to estimate the stature in the absence of complete skeletal remains or complete body measurements.

Our results are in good accord with the work of Rastogi et al. on the Indian population who observed a substantial positive association between MFL and stature and presented sex-specific regression equations for forensic application.[11] Similarly, Koulapur et al. in Karnataka also reported the correlation to be greater in females (r = 0.68) compared to men (r = 0.63) and this is similar to our findings of slightly higher correlation in females.[12] Gupta et al.[13] also found significant connection between finger lengths and stature in which regression models showed good predictability especially when sex-specific equations were utilized.

Correlation coefficients are similar with foreign research. Osaat et al.[14] reported correlation coefficient between MFL and stature of 0.56 and 0.68 for men and females respectively among Nigerian adults. Similarly, Diab and Tawfik in Egypt observed a Spearman correlation of

Table 3: Regression Equations and Variations in Calculated Stature.

	Regression Equation	Length of Middle Finger	Standing Height	Calculated Stature	Variations in cm
Male	Y= 169.77 + (14.21) (X-8.24)	Max 9.5 cm	185 cm	187.67 cm	2.67
		Min. 7 cm	150 cm	152.14 cm	2.14
Female	Y = 159.53 + (16.53) (X -7.65)	Max. 9 cm	176 cm	181.84 cm	5.84
		Max. 6.5 cm	143 cm	140.52 cm	-2.48

around 0.60 to 0.72 between MFL and height supporting the idea that MFL is a reasonably good predictor of stature in ethnically varied groups.[15] While these correlations are generally consistent, the intensity of the link may vary based on ethnic, genetic, environmental and dietary variables, as well as the techniques employed for data collecting and statistical analysis.

The regression equations used in this research, Y = 169.77 + 14.21 (X - 8.24) for men and Y = 159.53 + 16.53 (X - 7.65) for females, provided fairly accurate predictions of height with only small discrepancies. For instance, the highest departure from the actual stature was ± 5.84 cm in females and ±2.67cm in men. These estimates are within acceptable forensic margins of error, particularly when considering that standalone anthropometric predictors usually account for around 40–50% of height variance. Similar predictive powers were also discovered for similar research. Osaat et al. (2010) suggested formulae such as Height = 6.398 × MFL + 125.07 for Nigerian men and Height = 5.839 × MFL + 125.99 for females, with estimate errors of ±4 to ±6 cm.[14] However, the Egyptian model of Diab and Tawfik calculated male stature as Height = 12.885 × MFL + 67.713 , showing regional variance in the slope and the intercept.[15]

These differences highlight the significance of establishing population-specific equations. Regression equations are not transferable and have to be developed for a unique genetic and anthropometric background, as pointed out by Diab and Rastogi in many investigations.[11,15] Probably these disparities are driven by variation in limb proportions which in turn depends on such variables as race, geographic region and diet in early life. For example, individuals living in colder climates tend to have somewhat shorter limbs compared to their stature (Allen's rule) and this may affect the strength of association between limb segment lengths and overall height.

Our results further support the idea of sexual dimorphism of anthropometric characteristics, with men presenting higher absolute values of MFL and stature, while females exhibited somewhat stronger linear correlations. This may be related to more homogenous development patterns in females or less diversity in the skeletal dimensions following complete epiphyseal fusion. These trends have also been seen in other Indian research conducted previously by Koulapur et al. and Gupta et al. which highlight the need of sex specific equations for accurate forensic identification.[12-13]

Stature estimate from fragmentary remains, especially distal portions of limbs, is a useful method in forensic anthropology and legal medicine when conventional methods are not available. MFL has a number of advantages: it is easily measurable, resistant to postmortem alterations and typically maintained even in decayed or fragmented remains. Many scholars such as Osaat and Diab have said that the finger-based models may be very important for the first identification in mass disasters, criminal investigations and historical skeleton assessments.[14-15] But it is worth noting that the standard error of the single-variable regression models should be used with caution. MFL combined with additional anatomical measurements (e.g. foot length, arm spread, or metacarpal length) in multivariate model would probably lead to a better prediction accuracy when feasible.

Based on the findings reported in your uploaded manuscript, the present study demonstrated a statistically significant positive correlation between middle finger length and stature in both sexes, with a slightly stronger correlation observed among females (r = 0.67) than males (r = 0.61). The derived sex-specific regression equations indicate that middle finger length is a reliable anthropometric parameter for stature estimation in the eastern Gujarat population. These findings are in agreement with the study by Singh et al., who reported that finger length, particularly the middle finger, exhibited a significant association with stature in Punjabi adults, and emphasized the usefulness of regression equations for forensic identification from fragmented human remains.[16] Furthermore, the present study also corroborates the observations of Garg et al., who demonstrated a strong positive correlation between hand dimensions and stature among young adults in Kota and concluded that hand anthropometric measurements are dependable predictors of body height for forensic applications.[17]

The findings of the present study are also consistent with those reported by Bashir et al., who observed a statistically significant correlation between finger length and stature in the native Haryana population, with females showing a stronger Pearson correlation than males, similar to the present investigation.[18] Although the magnitude of correlation coefficients varies across studies, these differences are likely attributable to variations in ethnicity, geographic location, nutritional status, sample characteristics, age distribution, and measurement techniques. Nevertheless, all studies consistently support

the concept that finger dimensions, particularly middle finger length, are valuable anthropometric indicators for estimating stature when complete skeletal remains are unavailable. Therefore, the sex-specific regression equations generated in the present study provide a population-specific and practical tool for medico-legal and forensic identification in the eastern region of Gujarat.

Limitation

The present study was conducted on a relatively small sample of participants from eastern part of Gujarat. Therefore, the results and regression equations may not be applicable to other populations of different ethnic or geographical characteristics. Moreover, the only anthropometric parameter used for estimation of stature was the middle finger length. An amalgamation of several body measurements might lead to better predictive accuracy. Larger and more diverse populations in further multicentric studies are warranted to validate and refine the regression models.

CONCLUSION

The current research shows a statistically significant link between middle finger length and stature in both men and females, with a somewhat better prediction accuracy shown in females. Sex-specific regression equations obtained may be used as a good non-invasive technique for estimating stature, particularly in cases of forensic and anthropological interest when complete body measurements are not available. The length of the middle finger is easily measured and less variable, and may be a good anthropometric criterion. However, future research with bigger and more heterogeneous populations are necessary to confirm and improve the prediction accuracy of these equations in other ethnic and geographic groupings.

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ORIGINAL RESEARCH PAPER

"Autopsy based Retrospective Study of Death due to Hanging in Eastern Gujarat: A Three Year Retrospective Study"

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ABSTRACT

Introduction: We analyzed 60 cases of death due to hanging in this autopsy-based retrospective study, conducted at Zydus Medical College and Hospital, Dahod, eastern Gujarat, from January 2022 to December 2024. Hanging accounted for 7.3% of all autopsies performed during the study period. A marked female predominance was observed (75%), and the majority of cases (55%) were from the 21–30 years age group. Most incidents (78.3%) took place in closed environments. Soft materials such as odhani (45%) and saree (26.7%) were most commonly used as ligature. Incomplete encirclement of the ligature mark was noted in 90% of cases, with peri-ligature abrasions observed in (16.7%). These results highlight the significant role of cultural and social factors in the pattern of hanging deaths in this region and emphasize the need for targeted suicide prevention measures to improve mental health support for young adults.

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INTRODUCTION

Hanging is the most frequent method of suicidal death worldwide and remains a major public health concern, particularly in developing countries such as India.[1] It is a form of asphyxial death that results from the suspension of the body by a ligature encircling the neck, where the constricting force is derived from the weight of the body itself.[2]

In India, hanging accounts for a substantial proportion of suicides reported annually. According to the National Crime Records Bureau (NCRB), hanging contributed to more than 50% of all recorded suicides in recent years.[3-4] Despite its prevalence, regional studies analysing the demographic and autopsy findings in such cases are limited. The eastern region of Gujarat, particularly Dahod and its surrounding areas, presents a unique sociocultural and demographic profile, which may influence the pattern and prevalence of suicide by hanging. Despite the high burden of suicide in India, region-specific forensic data remain very less. This study was conducted to address this gap, offering localized insights into autopsy findings, common ligature materials, and demographic trends associated with hanging deaths.

A retrospective autopsy-based study of deaths due to hanging enables systematic evaluation of patterns such as age and sex distribution, usage of ligature material, characteristics of external and internal injuries, and other associated factors. The main purpose of this study is to evaluate the incidence, pattern, and forensic characteristics of deaths due to hanging in the eastern region of Gujarat through autopsy-based retrospective analysis

MATERIAL AND METHOD

This retrospective study was conducted from January 2022 to December 2024 which includes 60 cases of deaths due to hanging. All the autopsies were conducted at the mortuary of Zydus Medical College and Hospital, Dahod, Gujarat, India. The data was collected from the police papers and postmortem examination reports. Information regarding the crime scene was obtained from the inquest reports. The collected data were analyzed with respect to age, sex distribution, postmortem findings, and characteristics of ligature marks and the ligature material used. All information was compiled into a master chart and was analyzed using Microsoft Excel version 2507.

RESULTS

During the study period, a total number of 821 postmortem examinations were conducted. Among these, 60 cases were determined to be deaths due to hanging (7.3%)

Out of the total 60 cases of hanging, 15 (25%) cases were males and 45 (75%) were females, indicating that the majority of the victims were female. The highest number of cases 33 (55.0%) occurred in the 21–30 years age group, followed by 14 (23.3%) victims in the 16–20 years group and 09 (15.0%) victims in the 31–40 years group. The minimum incidence was noted in the 41–50 and 51–60 age groups, accounting for 03 (5%) and 01 (1.7%) case respectively. **(Table 1)**

Table 1: Distribution of Cases of Hanging based on Age and Gender.

Age (in years)	Male	Female	Total No. of Cases	(%)
11-20	03	11	14	23.3%
21-30	06	27	33	55.0%
31-40	06	03	09	15.0%
41-50	00	03	03	5.0%
51-60	00	00	01	1.7%
>60	00	01	00	00
Total	**15**	**45**	**60**	**100%**

The majority 47(78.3%) cases were reported in closed environments. Of these, 44 (73.3%) incidents occurred inside a room, 1(1.7%) case was documented within a bathroom, and 2(3.3%) cases took place in police custody. Conversely, 13 (21.7%) cases were observed in open settings, comprising 11(18.3%) instances where the victims were found suspended from a tree and 2(3.3%) cases involving an electric pole. **(Table 2)**

Table 2: Distribution of Hanging Cases Based on Ligature Material.

Place of Crime		Cases	(%)
Inside	Room	44	73.33%
	Bathroom	01	1.67%
	Lockup	02	3.33%
Outside	Tree	11	18.33%
	Pole	02	3.33%

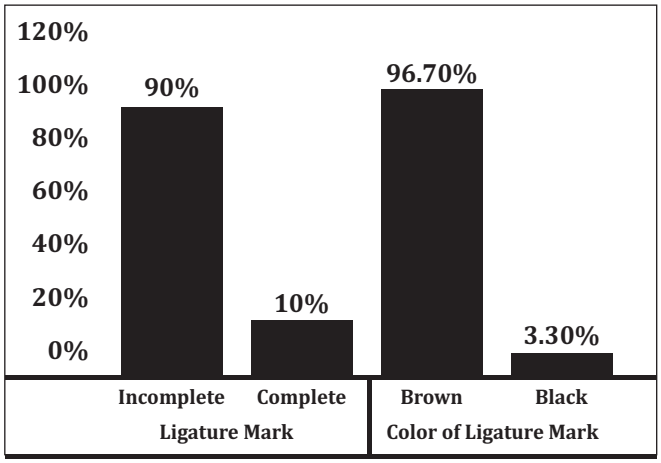
The most common ligature material was the Odhani (Scarf), which was used in 27 (45.0%) cases. This was followed by the saree, observed in 16 (26.7%) cases, and the Dordu (Rope), which was identified in 11 (18.3%) cases. **(Table 3)**

Table 3: Distribution of Hanging Cases Based on Ligature Material.

Ligature Material	Cases	(%)
Chadar (Bedsheet/Shawl)	3	5%
Dordu (Rope)	11	18.3%
Nylon Dori (Nylon Rope)	1	1.7%
Odhani (Scarf)	27	45.0%
Saree	16	26.7%
T-Shirt	1	1.7%
Electric Wire	1	1.7%
Total	**60**	**100%**

An incomplete encirclement of the neck by the ligature mark was observed in 54 (90%) cases of hanging, whereas complete encirclement was noted in 6 (10%) cases. The ligature mark exhibited a brownish coloration like parchment in 58 (96.7%) cases. In 2 (3.3%) cases, the mark appeared black, which was attributable to decomposition of the body. In our study, peri-ligature abrasions were observed around the ligature mark in 10 (16.7%) cases. **(Figure 1)**

Figure 1: Characteristics of Ligature Mark.



DISCUSSION

In the present study, hanging accounted for 7.3% of all autopsies. This proportion aligns with findings by Ankita[5] et al., who reported hanging comprising 5% of postmortem examinations in a tertiary care centre in India, and Reddy[2] et al., who observed that hanging is among the most frequent modes of suicidal deaths in the country, often ranging between 6–10% depending on the region.

Regarding age distribution, the highest incidence was in the 21–30 years age group (55.0%), followed by the 16–20 years group (23.3%). Similar trends have been documented by Amandeep[14] et al., who reported that 59.2% in victims were below 30 years, and Ankita[5] et al.,

observed it to be 42.5% in the age group of 21-30 years, attributing this predominance to psychosocial stressors, relationship issues, and academic pressures prevalent among young adults. The current study found a female preponderance (75%), which contrasts with earlier studies indicating a male predominance. For example, Akshay[6] et al., documented 52% male victims, while Salam[9] et al., observed 53.01% male cases. However, Verma[10] et al., have noted female suicides in certain regions of India, potentially reflecting increased domestic violence, dowry-related stress, and changing social dynamics.

In relation to the place of occurrence, 78.3% of the cases took place in closed environments (primarily in rooms). This is consistent with the observations of Patel AP[7] et al., who reported 96.25% of incidents occurring indoors, as victims often seek privacy, reducing risk of discovery at the time of attempting suicide. The occurrence of two cases in police custody emphasizes the importance of vigilance and proper medicolegal documentation in custodial settings, as highlighted by DiMaio[11] et al.,

The ligature material most frequently used was the odhani (45%), followed by the saree (26.7%) and the dordu (18.3%). This correlates with findings by Reddy[2] et al., and Akshay[6] et al., who described that in India, soft ligatures such as dupattas, odhanis, and sarees are commonly used, especially by female victims. The ligature mark was incompletely encircling around the neck in 54 (90%) cases of hanging, in the current study. Similar were the observations made by Rohit Raj[13] et al., (93.3%). The type of knot and the type of suspension determine the ligature mark and its continuity over the neck. In the present study, peri-ligature abrasions were observed around the ligature mark in 10 cases (16.7%). The presence of such abrasions has been described as a frequent finding in antemortem hanging due to friction and movement of the ligature during suspension or struggling. Jitender[12] et al., reported peri-ligature abrasions in 17.5% of cases, indicating a slightly higher prevalence than observed in the current study. This difference may be attributed to factors such as the nature of the ligature material, the tightness of application, the duration of suspension, and the body weight of the victim.

Similarly, Reddy[2] et al., and Knight and Saukko[3] et al., have emphasized that soft, broad ligatures (e.g., odhani, saree) may produce less prominent or absent peri-ligature abrasions compared to thin, hard ligatures (e.g., rope, electrical wire). In this study, the predominance of soft cloth materials such as odhani and saree could explain the relatively lower incidence of peri-ligature abrasions compared to reports from regions where harder ligatures are commonly used. Among external findings, cyanosis (81.6%), face congestion (33.3%), dribbling of saliva (11.6%), and bleeding from orifices were frequently observed. These findings are recognized features of antemortem hanging, consistent with descriptions in Knight and Saukko[3] (2016) and Reddy[2] et al. The absence of hyoid bone fractures in all cases in the present study is also in agreement with DiMaio[11] et al., who stated that such fractures are more commonly associated with judicial hangings or older individuals with ossified bones. The only limitation of the present study is the retrospective nature of the study with limited sample size.

CONCLUSION

This autopsy-based retrospective study of 60 hanging cases in eastern region of Gujarat reveals a predominance among young females, with most incidents occurring indoors using soft ligatures materials such as odhanis and sarees were most commonly employed, aligning with regional cultural practices. Common forensic signs included cyanosis and incomplete ligature marks. The findings highlight regional suicide trends and emphasize the need for improved mental health case & Community awareness and preventive measures.

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ORIGINAL RESEARCH PAPER

Comprehensive Analysis of Traumatic Brain Injury vis a vis Glasgow Coma Scale, Head Computed Tomography (CT) Findings along with Rotterdam CT score and Post-Mortem Examination Data: A Cross-Sectional Study

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ABSTRACT

Introduction: Traumatic brain injury (TBI) is one of the major causes of mortality globally, with road traffic accidents (RTA) being the primary cause. This makes it imperative to figure out ways of elucidating the severity and prognostic possibility in TBI patients. Head computed tomography (CT) is also taken into consideration by forensic pathologist during the post-mortem examination (PME) to better comprehend the injuries to arrive at the final opinion. This study aims to analyze the correlation between Glasgow Coma Scale (GCS), head CT findings along with Rotterdam CT score and PME findings in patients with fatal head injuries by evaluating the disparity along with assessing the agreement and disagreement among them.

Materials and Methods: This is a prospective cross-sectional study comprising of all traumatic brain injury patients following RTA, fall from height, railway accidents and assault, who were admitted in the hospital, died during treatment and underwent autopsy, as per our inclusion & exclusion criteria.

Results: 50 patients with TBI were studied and significant correlation was found between lesions in ante-mortem CT findings and PME findings. Agreement and disagreement between different traumatic head lesions were calculated. Significant correlation was found between clinical assessment of TBI patients done through GCS and Rotterdam CT scoring system (p value-0.012*, chi square-12.911). Total agreement between CT and autopsy findings was 81.78%, the rest showing disagreement.

Conclusion: We found differences between ante-mortem head CT scans and PME, in terms of undetected lesions, false positive and false negative lesions. We found correlation of GCS with Rotterdam score for prognostication, factors that lead to discrepancies between the results of CT and PME in victims of head trauma.

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INTRODUCTION

Traumatic brain injury (TBI) is a serious public health and socio-economic problem worldwide, resulting in morbidity and mortality. It is characterized by alteration in the level of consciousness, accompanied with signs of brain pathology induced by trauma. Globally, road traffic accidents (RTA) are the primary cause of head trauma.[1] Modalities of treatment vary extensively, based on its severity and clinical condition of the patient guided by radiological imaging. For initial evaluation along with diagnosis of TBI in emergency situations, head computed tomography (CT) is a rapid, easily accessible and non-invasive method.[2] The immediate consequences of head trauma are fractures of the skull, hemorrhages like epidural hemorrhage (EDH), subdural hemorrhage (SDH), subarachnoid hemorrhage (SAH), intra-cerebral hemorrhage and contusions, whereas the subsequent effects are brain edema, necrosis leading to raised intracranial pressure (ICP) and midline shift (MLS). The prognosis of such patients depends on several variables

such as age, Glasgow Coma Score (GCS) at the time of admission, pupillary reaction and other traumatic injuries. GCS is widely used to evaluate the level of consciousness in traumatic head injury patients, categorizing them into mild, moderate and severe head injuries.[3] CT is used for evaluating and diagnosing various traumatic head lesions in TBI patients, thereby further aiding in management and treatment of neuro-trauma patients. The Marshall System (1991) and the Rotterdam CT (2005) can be used to predict the outcomes in TBI patients based on CT imaging.[4] According to one of the studies, Rotterdam CT score has a better predictive value as compared to the Marshall score in traumatic head injury (HI) patients. A completely normal looking scan has Rotterdam score of 1 and worst possible score is 6.[5]

When there are fatal cranio-cerebral lesions, post mortem examination (PME) is performed for medico-legal purposes, including ascertaining the cause of death.[6] The ante-mortem head CT scans are also taken into consideration by forensic doctors and comparing them with the PME can help to better comprehend the injuries. With the advancement in radiological technology and their combination with emerging artificial intelligence, the field of virtual autopsy could be seen as an emerging domain of research for interdisciplinary teams of forensic experts and radiologists in future for medico-legal PME. Moreover, virtual autopsy could serve as an alternative where conventional PME is restricted due to religious, cultural or social customs.[7] Literature also highlights the superiority of this technique in comprehensive analysis of complex anatomical structures with enhanced visualization, which may not be thoroughly examined by conventional autopsy techniques.[8]

The aim of this study was to analyze the correlation between GCS rating, head CT findings along with Rotterdam CT score and post-mortem findings in patients with fatal HI by evaluating the disparity along with assessing the agreement and disagreement among them.

MATERIALS AND METHODS

This is a prospective cross-sectional study conducted from March 2023 to September 2024 in a North Indian Tertiary Care Hospital, after approval from the Institutional Research & Ethics Committee vide reference number GMCH/IEC/2023/914R and written informed consents were obtained. Inclusion criteria included all medico-legal cases with fatal HI after RTA, fall from height, railway accidents or assault, who underwent treatment in the hospital and were then subjected to PME after their death; along with availability of their head CT scans. Exclusion criteria consisted of brought in dead cases, where history of incident or radiological investigations were unavailable and those where head injury was not the exclusive cause of death and cases with Diffuse axonal injury (DAI).

Information was gathered using a systematic pro-forma. Case files were perused for noting down the neurological status at the time of admission. Head CT findings were reported by the radiologist and PME observations were noted by the forensic doctors. Rotterdam CT score was calculated as per the following classification[5]: 1) Basal cisterns [0: normal, 1: compressed, 2: absent] 2) Midline shift [0: no shift or <=5 mm, 1: Shift present >5 mm] 3) Epidural mass lesion [0: Present, 1: absent] 4) IVH or traumatic SAH [0: Absent, 1: Present] and then, 1 point was added to the total score. Additional demographic information about the patient such as age, gender, place along with time of incident, any alcohol intoxication, types of vehicles involved in accident, etiology of head trauma, along with hospital stay were also collected. All findings were compared and analyzed. Agreement and disagreement between head CT findings and autopsy findings were calculated. Statistical analysis was done with SPSS software version 20.0.

RESULTS

A total of 50 cases that met our inclusion criteria were analyzed. Of these, 10 cases (20%) were admitted directly to the hospital, 40 cases (80%) were referred from adjoining northern states. Majority of the incidents leading to traumatic brain injury occurred in rural area (54%). Eighty two percent victims were male. The most common age group involved was between 21 to 30 years (28%), followed by 41 to 50 years (22%) [Mean 41.33 and standard deviation (SD) 19.78]. Most cases admitted to the hospital suffered trauma due to RTA (76%), followed by fall from height (16%), railway accidents (4%), and assault (4%). Eighteen percent had consumed alcohol at the time of the incident. In 50% cases of RTA (n=19), the offending vehicle involved was a four-wheeler and in 18% (n=7), it was a two wheeler. The rest 32% cases had miscellaneous reasons such as bursting of tyre, hitting the tree, stray animal, or skidding of the two wheeler. Majority of these patients (68%) were two-wheeler riders/ pillion riders; 21% were pedestrians and 11% were driving four-wheelers **[Table 1]**. This implies that the chances of injury and mortality are high in two wheeler riders and it is

equally high when the offending vehicle was a four wheeler. Majority of incidents (30 %, n=15) occurred late evenings between 6 pm to 9 pm.

Most (64%, n=32) of the patients had severe HI with GCS < 8 on arrival, 32% (n=16) had moderate head injury with GCS 9-12, while 4% (n=2) had mild traumatic brain injury. Fourteen patients died within 24 hours of trauma, of which 12 had severe HI and 2 had moderate head injury. The Rotterdam CT score was also calculated, as summarized in **Table 2**. Two patients with mild HI, 6 patients with moderate HI (GCS 9 -12) and 4 patients with severe HI (GCS < 8) had Rotterdam CT score 3. Nine patients with moderate HI and 17 patients with severe HI were given Rotterdam score 4. One patient with moderate HI and 11 patients with severe HI had Rotterdam score 5. Mean GCS of TBI patients was 7.02 (SD-3.40). Mean Rotterdam CT score was 4.06 (SD-0.74).

The total agreement between CT and PME findings was found to be 81.78%, whereas the disagreement was 18.22%. Moreover, the individual agreement and disagreement between head CT findings and PME observations were analyzed along with Kappa and p-value was calculated, as summarized in **Table 3**.

DISCUSSION

It is said that even a small external trauma to the head can lead to gross internal injury to the brain, and on contrary, a patient may easily recover from a gross external head trauma.[9] According to the World health organization (WHO) report, it is estimated that every year, 1.35 million people die because of RTA.[10] Another report by WHO predicted that TBI affects 69 million people annually, worldwide, with the burden of TBI being three times higher in low and middle income nations than in high income nations.[11-12]

In one of the study published in the literature, it was seen that the most common cause of TBI were RTAs and was more prevalent in males aged between 15 to 35 years.[13] In our study, it was seen that RTAs were the most common reason for TBI with preponderance in male population, and the most common age group being 21 to 30 years; with mean survival period of 3.4 days (SD - 3.44). TBI patients with moderate and severe head injury, with poor GCS at the time of admission, diminished pupillary reactivity, systolic hypotension and head CT findings indicating hemorrhage, are some of the factors that predict poor outcome. Acute pupillary dilatation (aniscoria) in severe head trauma is a neuro-surgical emergency. It is hypothesized that pupillary dilatation is due to the uncal herniation resulting in brainstem compression along with compressing of the occulomotor nerve.[14] Our study found significant correlation between clinical assessment of TBI patients done through GCS and Rotterdam CT scoring system (p value-0.012* - **Table 2**) and that the chances of mortality increases with increase in the Rotterdam score indicating poor prognosis. This agrees with the findings and is affirmed by other studies published in the literature done by Huang, et al and Fujimoto, et al, who found that Rotterdam score is a good predictor of outcome and can be used as a prognostic indicator.[15-16]

Radiological imaging is essential for both the diagnosis and treatment of TBI. Non-contrast CT (NCCT) can rapidly and accurately identify traumatic head lesions. PME in a deceased person can further aid in accurately identifying the head injuries and ascertaining the cause of death.[17] During our study, both agreement and disagreement were observed between head CT and PME findings, as summarized in **Table 3**. The agreement and disagreement in fractures of vault of skull were found to be 92% and 8%, respectively, whereas, the concordance and discordance in fractures of base of skull were found to be 80% and 20%, respectively. In vault fractures of skull CT reported 2 (4%) false positives. We observed that the base of skull fractures were missed more frequently than vault fractures. PME found base of skull fractures in 27 cases but CT found them in 17 cases.

The results of our study were compared with other similar studies published in the literature. Anand, et al, found that of the 76 cases, CT scan detected vault fractures in 29 cases and base of skull fractures in 11 cases, while PME revealed vault fractures in 39 cases and base of skull fractures in 31 cases.[18] Alexis, et al, found that from a total of 303 cases, PME found skull fractures in 205 cases while CT detected them in 99 cases and missed them in 106 cases with base of skull fractures were frequently missed than cranial vault fractures.[19] The possible reason hypothesized by authors could be difficulty in detecting non-displaced fractures, particularly in cases where the fracture is very thin or subtle and the bones don't move from their normal position. Sometimes, CT scan's resolution might not be high enough to detect very fine fractures. Moreover, areas of skull such as the base of skull, which is uneven, may be difficult to visualize adequately on a standard CT, leading to fractures being overlooked.[6]

In two cases, CT reported false positive detection of

fractures of skull and the possible reason for this could be motion artifacts, changes in bone density such as areas of calvarial thinning in cases of metabolic disorders for example, hyperparathyroidism or other inflammatory diseases, any previous surgery or trauma could cause the bone to appear irregular on CT leading to misdiagnosis of a fracture.[6,20-21] The diagnosis of isolated, undisplaced fracture of skull is not significant in clinical settings as long as there are no consequences or clinical symptoms. But their diagnosis is crucial in medico-legal cases in order to determine the nature, mechanism and manner of injury, as per Section 116 Bharatiya Nyaya Sanhita (BNS),[22] because presence or absence of a fracture determines whether the injury was simple or grievous in nature.[6]

In our study, EDH was the least commonly observed hemorrhage, while SAH and SDH were the most common. EDH was found, both on CT and PME, in 6 cases (12%), but in 4 cases (8%) it was evident during PME and not on CT. Hanganu, et al, also found that in 27 cases in which EDH was observed during PME, only 13 were found to have it on CT, with matching rate of 48.14%.[17] Alexis, et al, also observed that EDH was the least common finding on autopsy and it was found in 26 cases (8.6%) during PME, while 21 cases were found to have EDH during CT evaluation.[19] Again, in our study, SDH was seen both in CT and PME in 37 cases (74%) but in 11 cases (22 %), only in PME. Pathak, et al, found that out of 60 patients, CT detected SDH in 5, however PME showed the presence of SDH in 15,[23] while Alexis, et al, observed that of the total 303 cases, CT found to show SDH in 130 cases while PME revealed SDH in 228 cases.[19] Further, in our study, SAH was found both on CT and PME in 41 cases (82%), but in 5 cases (10%), it was seen in PME and not observed on CT. Alexis, et al, observed that of the total 303 cases, CT detected SAH in 94 cases, while PME observed it in 247 cases.[19] Pathak, et al, found that out of 60 patients, CT detected traumatic SAH in 10, while PME did so in 33 cases.[23] A significant CT-autopsy discrepancy in cerebral contusion was observed in our study in 23 cases (46%), it was seen on both CT and PME. But in 10 cases (20%) it was evident only on PME and not on CT. In 7 cases (14%), CT scan reported a false positive diagnosis as cerebral contusions were not present during PME.

Further, Hanganu, et al, found that of the 114 cases, 96 had brain contusions, but only 47 cases had both CT and PME confirmation, with 10 cases having false positive and 39 cases having false negative lesions.[17]

The possible reasons for discordance between CT and PME findings in traumatic EDH, SDH, SAH and cerebral contusions hypothesized by authors are that subtle, early stage or developing traumatic EDH, SDH, SAH and cerebral contusions may not be large enough or apparent on the CT, particularly if bleeding is minimal and CT is done early in the injury timeline. So, in order to detect a slow developing hematoma, further scans might be necessary.[24-26] Beam hardening streak artefacts may resemble similar to thin subdural haemorrhage or vice-versa, a real hematoma can be rejected as beam hardening artefact.[21] Presence of other overlapping injuries in TBI, such as skull fractures or contusions can sometimes obscure the presence of traumatic SDH or SAH. Moreover, in case of SDH, in sub-acute (3 to 7 days after injury) or chronic phases (>14 days after injury), blood can appear hypodense (less dense) or isodense (similar in density to the brain tissue on CT). So, in these phases, blood may not be easily distinguished from the surrounding brain tissue, which makes it harder to detect.[25] Traumatic hemorrhage located near the base of skull could be overlooked as anatomical complexity due to intricate structures can obscure such hemorrhagic lesions during CT imaging.[27] In case of cerebral contusions, low accuracy could be due to the streak artifacts from adjacent bone and co-exiting SAH. Fractures of skull, particularly involving the inner table, can create areas of high density on CT which could be mistaken for contusions.[21] Small contusions which resolve over time may not be apparent at the time of autopsy examination. Motion artifacts from uncooperative and restless patients can also distort CT images, causing partial loss of clarity and thereby obscuring the findings and can lead to misinterpretation leading to false positive diagnosis on CT.[6] Moreover, CT windowing and slice thickness are equally important as they can impact the visibility. Insufficient scan resolution, contrast settings or sub-optimal imaging quality can reduce the ability to detect the findings in TBI patients.[28]

Another significant CT-autopsy discordance in our study was observed in midline shift (MLS), as in 18 cases (36%), it was found both in CT and PME, but in 13 cases (26%), it was evident on CT and not on PME, leading to false negative autopsy findings. CT is a sensitive investigation for midline shift. Cerebral edema and hematoma can cause midline shift.[29] However, during our study it was seen that subtle midline shift might not be apparent on PME. Moreover, the brain undergoes autolysis after death, which can make it more difficult to detect midline shift.[30] So, all these reasons could result in false negative findings of midline shift on

autopsy.

In our study, sulcal effacement was observed on both CT and PME in 24 cases (48%), but in 18 cases (36%) it was observed on only on PME. Duration of sulcal effacement following head trauma varies according to nature and severity of the injury, along with involvement of underlying mechanisms as sulcal effacement, is the critical indicator of mass effect and raised ICP.[31] So sometimes, on initial CT scans there is not much cerebral edema and it was not evident on initial CT scans but later on with due course of time, there might have been increase in cerebral edema and after death by the time autopsy was performed, it was observed on it.

CONCLUSION

TBI includes a diverse range of intracranial injuries comprising injury at the time of impact and the secondary cascade of events. In our study, positive correlation was found with the degree of traumatic head injury as assessed by GCS and head CT in TBI patients. Rotterdam CT scores and GCS can be useful tools for predicting the mortality. In our study, most of the ante-mortem CT findings were in concordance with the PME observations, and only in few cases was discordance between them. Moreover, the review and analysis through the interdisciplinary approach of the cases of head trauma gives us an insight in weighing the limitations of virtual autopsy in fatal head injury patients which is an emerging technique in order to supplement conventional post-mortem examination, as for medico-legal purposes accurate description of injuries helps in reliable determination of the conclusive diagnosis which must be established with certainty. Thus, analyzing the head CT and PME findings in fatal head trauma can give us insight whether to step further from conventional autopsy to virtual autopsy.

Through this research study we evaluated the diagnostic accuracy of virtual autopsy and also underline the advantages along with limitation of imaging modality which serve as a backbone of this technique. Moreover, the resources, cost of equipment, along with specially trained personnel, are some of the issues which need to be taken care of while conducting the autopsy through this technique. However, our study has a limitation - due to lack of resources we were not able to do the head CT scans before the post-mortem examination. So, the lacunae in our study need to addressed in further studies regarding adoption of virtual autopsy as a standard for post-mortem examination in fatal head trauma cases.

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ORIGINAL RESEARCH PAPER

Microbial Succession and Functional Profiling of the Human Remains During Early Decomposition

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ABSTRACT

Introduction: Microbial communities are important in postmortem decomposition and have been identified as potential PM interval indicators. Studies on the microbiological changes in human remains during decomposition, however, are limited, especially in India.

Objectives: The purpose of this research was to study stage-associated shifts in gut microbial communities during early stages of decomposition, identify taxonomic diversity across decomposition stages, and identified functional microbial metabolic pathways associated with postmortem microbial activity.

Materials and Method: The present study was an exploratory study in which six different human cadaver specimens representing fresh, bloated and decay stages of terrestrial decomposition were used. Gut swab samples were taken during medico-legal autopsy and sequenced with the Illumina MiSeq in a high throughput bacterial amplicon sequencing workflow. The microbial diversity, functional metabolic pathways and taxonomic composition were studied by using QIIME, MicrobiomeAnalyst, and KEGG annotation.

Results: 382,257 high quality sequence reads obtained. The alpha diversity revealed no significant difference between the decomposition stages while the beta diversity revealed significant stage-wise variation in microbial community composition. Bacillota and Bacteroidota were predominant at the fresh stage and Clostridia-associated taxa were predominant at the bloated stage. Increased abundance of Actinomycetota and Coriobacteriia-associated taxa were obtained in the decay stage. Segatella, Faecalibacterium, and Bifidobacterium were the predominant genera in the fresh stage, while Clostridium was dominant during the bloating stage. Pathways involved in glycolysis, propanoate metabolism, lysine degradation and pyruvate metabolism were identified through functional profiling.

Conclusion: The results showed that there are distinct microbial and metabolic changes during the early stages of postmortem, which can potentially be utilised in PMI estimation and in forensic investigations.

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INTRODUCTION

Biochemical degradation of tissues following death is the main process controlling the decomposition of human remains, and the process is dominated by microbial activity.[1] Endogenous microbial communities quickly multiply and infiltrate surrounding tissues following the loss of circulation, respiration, and immune function, starting autolysis and putrefaction. The dense and metabolically active microbial population of the gastrointestinal tract makes it a large source of microorganisms involved in decomposition post mortem.[2,3] They assist in the recycling of nutrients,

decomposition gasses production and soft tissues decomposition.

In the last few years, the use of forensic microbiology and high throughput technologies has been shown to prove that microbial communities have relatively predictable successional patterns during decomposition.[2,4-5] The consistent microbial changes have led to the idea of a "postmortem microbial clock" that could provide a means of determining the postmortem interval (PMI).[6-7] Based on the patterns of microbial abundance and diversity, various PMI estimation models have been developed to predict PMI with greater accuracy and based on machine learning approaches to predict PMI.[8-11]

Most of the current research, however, has been done in a controlled laboratory setting or in an animal study and there are relatively few studies that include human decomposition in a natural terrestrial environment. The five stages of decomposition of human remains are fresh, bloat, active decomposition, advanced decomposition, and dry/remains stage in a terrestrial environment.[12]

The fresh stage is one in which there are few visible changes of decomposition after death, and the bloat stage is one in which gas production in the abdomen occurs and the abdomen becomes distended. Rapid tissue disintegration and fluid release during the active stage of decay, and advanced decay with significant soft tissue deterioration. Lastly, skeleton exposure and little soft tissue left are characteristics of the dry/remains stage.

In India, studies involving human decomposition remain limited due to ethical and legal constraints for forensic research. Consequently, most of the available decomposition research has relied on animal proxies, which may not fully replicate human postmortem microbial dynamics. In the present study, six human cadavers representing Fresh, Bloat and Decay stages of terrestrial decomposition were examined to investigate postmortem microbial composition within the gut region.

The primary objective of this research is to investigate gut microbial succession during terrestrial decomposition and to study microbial composition and predicted metabolic pathways associated with decomposing human remains and determine their potential application in PMI estimation. Being one of the first studies of its kind in India, the findings of this research may provide baseline data for human decomposition studies under Indian environmental conditions.

MATERIAL AND METHODS

Gut Microbiome Sampling Protocol

Guru Gobind Singh Medical College and Hospital in Faridkot, Punjab, India (30.678°N, 74.740°E) was the site of this study. Cadavers were received for medico-legal autopsy from the semi-arid south-western districts of Punjab. All samples were collected between April to August 2023. Cases involving individuals below 18 years of age were excluded due to differences in body surface area-to-mass ratio compared to adults.

Additionally, submerged, burned, or buried bodies were excluded because these conditions significantly alter decomposition patterns. Relevant metadata were obtained from police and autopsy records. A total of six human cadavers, comprising two cases each representing the fresh, bloated, and decay stages of terrestrial decomposition, were included in this exploratory study. The sample size was determined based on the availability of eligible medicolegal autopsy cases that met the inclusion criteria during the study period.

During routine medicolegal autopsy, the caecum was exposed and a small incision was made using a sterile scalpel. A sterile swab was then inserted into the caecum to collect gut contents. The swabs were transported on ice and stored at −20 °C. Details of the cases included in the study are presented in **Table 1**.

Table 1: Summary of cases, decomposition stage, sample type, and tissue source.

DNA Extraction, PCR Amplification and 16S rRNA Sequencing

Genomic DNA was extracted using the Xploregen DNA Isolation Kit (Xploregen, India) according to the manufacturer's instructions. The V3–V4 region of the bacterial 16S rRNA gene was amplified using universal primers 16sF (5′-AGAGTTTGATGMTGGCTCAG-3′) and 16sR (5′-TTACCGCGGCMGCSGGCAC-3′). PCR amplification was performed in 25 µL reaction mixtures containing high-fidelity DNA polymerase, primers, dNTPs, $MgCl_2$, and reaction buffer. The amplified products were purified using AMPure beads, followed by library preparation and quantification using the Qubit dsDNA High Sensitivity Assay. Sequencing was performed on the Illumina MiSeq platform.

Statistical Analysis

The raw BCL files generated by the Illumina MiSeq sequencer were demultiplexed to produce FASTQ files.

Table 1: Case Description with Assigned Stage of Decomposition, Name of Collected Sample and type of Tissue Collected.

S. No	Age	Sex	Date of Body Recovery	Date of Sample Collection	Stage of Decomp-osition	Actual PMI /PMSI (in days)	Assigned Stage Code	Type of Sample	Cause of Death	Enviro-nment / System Type	Region
1	18	M	03/05/2024	03/05/2024	Fresh Stage	2	FS1	Gut	Hanging	Terrestrial (Indoor)	Faridkot
2	20	M	14/05/2023	14/05/2023	Fresh Stage	2	FS2	Gut	Head Injury	Terrestrial (Indoor)	Faridkot
3	47	M	04/05/2024	04/05/2024	Bloat Stage	3	BS1	Gut	Hanging	Terrestrial	Mansa
4	29	M	15/06/2023	15/06/2023	Bloat Stage	4	BS2	Gut	Head Injury	Terrestrial (Indoor)	Moga
5	50	M	18/05/2023	18/05/2023	Decay Stage	7	DS1	Gut	Head Injury	Terrestrial (Indoor)	Faridkot
6	40	M	05/06/2023	06/06/2023	Decay Stage	7	DS2	Gut	Hanging	Terrestrial (Indoor)	Faridkot

** Cause of death could not be determined due to advanced decomposition.*

After evaluating the quality of the de-multiplexed data using FastQC (v0.11.9) and MultiQC (v1.10.1), TRIMGALORE trimmed adapters and low-quality reads. High-quality reads were processed using the Biokart 16S metagenomic pipeline using QIIME. Taxonomic assignment was done using NCBI databases. The Microbiome Analyst (https://www.microbiomeanalyst.ca/) was used with default parameters for statistical analysis. The Chao1, Shannon, and Simpson indices were used to calculate the alpha diversity. Principal Coordinates Analysis (PCoA) based on the Bray–Curtis dissimilarity index was used to evaluate beta diversity among sample groups. Metagenomic sequences from gut samples were functionally annotated using the KEGG database. Predicted genes were assigned KEGG Orthology (KO) identifiers, which were subsequently mapped to metabolic pathways using the KEGG pathway hierarchy. One-way ANOVA was used to assess differences in pathway abundance between the decomposition stages ($p < 0.05$). Log_2 fold changes and Cohen's d were calculated to assess the magnitude of differences between stages.

RESULT

A total of 382,257 high-quality merged sequence reads were acquired, with a median (IQR) of 38,288 (32,901–71,389) reads per sample.

Alpha and Beta Diversities

Alpha diversity analysis showed no statistically significant differences in richness across decomposition stages (Chao1: $p = 0.6699$; $F = 0.459$) **(Figure 1a)**. Additionally, there was no statistically significant variation in Shannon diversity between stages ($p = 0.0683$; $F = 7.4766$) **(Figure 1b)**. In contrast, beta diversity analysis demonstrated stage-wise variation in microbial community composition, with PERMANOVA results showing an F-value of 4.5562 and an R^2 of 0.7523 **(Figure 2)**.

Figure 1: Alpha Diversity of Gut Microbial Communities Across Decomposition Stages Assessed using (a) Chao1 Richness, (b) Shannon Diversity.

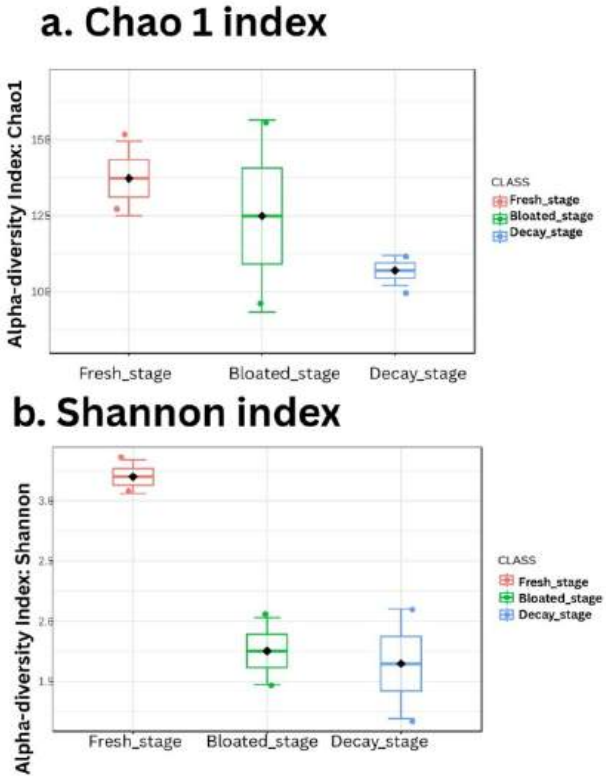


Figure 1. Alpha diversity across decomposition stages assessed using (a) Chao1 richness, (b) Shannon diversity

Figure 2. The Bray Curtis dissimilarity index is used to construct beta diversity at the genus level.

Taxonomic Diversity

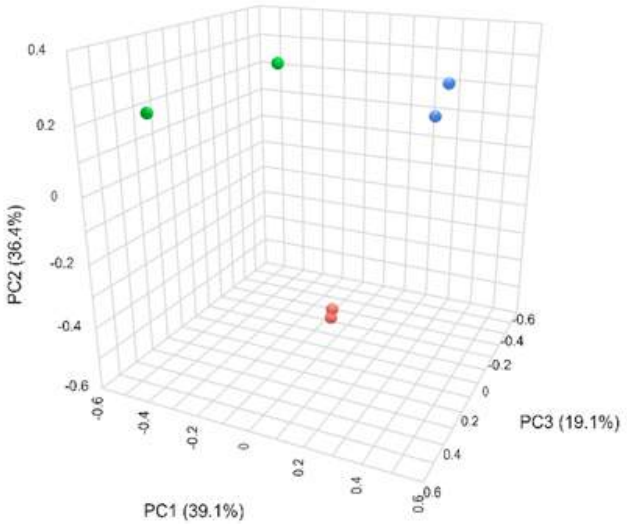
A total of 36 phyla, 82 classes, 188 orders, 411 families, and 1261 genera were allocated taxonomically.

Figure 3. Relative abundance of dominant microbial taxa across decomposition stages from phylum to genus level (A-E).

Bacillota, Bacteroidota, and Actinomycetota dominated the fresh stage at the phylum level **(Figure 3A)**. In the bloated stage, Bacillota remained overwhelmingly dominant, with Pseudomonadota and Bacteroidota present at comparatively lower levels. In the decay stage, Actinomycetota emerged as the predominant phylum, followed by Bacillota and Pseudomonadota. Other phyla, including Cyanobacteriota, Deinococcota, Fusobacteriota, Thermodesulfobacteriota, and Verrucomicrobiota, were consistently detected at low abundance across all stages.

In the class level, the most predominant groups in the fresh stage were Bacteroidia and Clostridia, with significant presence of Negativicutes and Actinomycetes **(Figure 3B)**. Bloating was mainly colonised by Clostridia, with minor presence of Gammaproteobacteria and Bacilli. During decay stage, the growth of Coriobacteriia and At the order level, Bacteroidales and Eubacteriales predominated in the fresh stage, along with Bifidobacteriales, Veillonellales and Lactobacillales. **(Figure 3C)**. In the bloated stage, Eubacteriales was the most common order, then Pseudomonadales and Enterobacteriales. In the decay stage, the predominant bacteria were Coriobacteriales and Bifidobacteriales, with Eubacteriales and Bacteroidales found at lower levels. Prevotellaceae and Lachnospiraceae dominated the fresh stage at the family level, with contributions from Oscillospiraceae, Bifidobacteriaceae, and Veillonellaceae **(Figure 3D)**. The bloated stage was primarily characterized by Clostridiaceae, along with Peptostreptococcaceae and Pseudomonadaceae. In the decay stage, Atopobiaceae and Bifidobacteriaceae emerged as the dominant families, while Clostridiaceae and Prevotellaceae were present at lower levels. Segatella, Roseburia, Prevotellamassilia, Faecalibacterium, and Bifidobacterium were the genera that best described the fresh stage. The most common genus during the swollen stage was Clostridium, which was followed by Paeniclostridium, Peptostreptococcus, and Pseudomonas. **(Figure 3E)**. In the decay stage, Parafannyhessea and Bifidobacterium were the most prominent genera, while Clostridium persisted at lower levels.

Figure 2: Beta Diversity Constructed at the Genus Level using the Bray Curtis Dissimilarity Index.



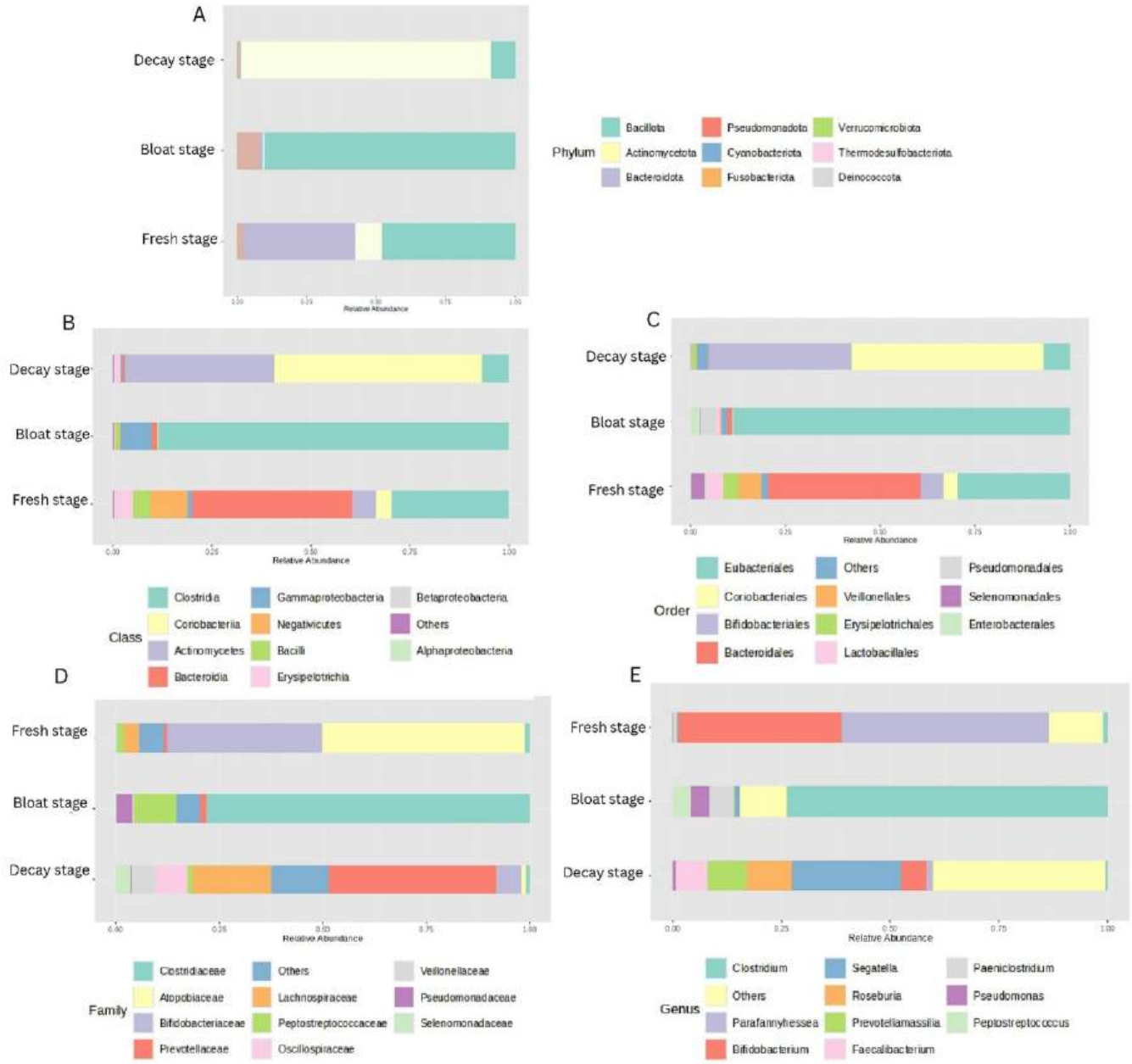
Function Profiling

Functional annotation of the metagenomic dataset yielded 6,460 KEGG gene entries, of which 685 genes were associated with key metabolic pathways relevant to postmortem microbial activity. The KEGG annotation revealed that the identified genes were associated with nine major metabolic pathways. These pathways included central carbon metabolism processes such as Glycolysis / Gluconeogenesis, the Citrate cycle (TCA cycle), and Pyruvate metabolism, which play key roles in microbial energy production. Furthermore, a number of genes were linked to fermentation and short-chain fatty acid pathways, such as butanoate and propanoate metabolism. Other functional pathways detected were Methane metabolism and Sulfur metabolism, indicating microbial involvement in anaerobic respiration and elemental cycling. Furthermore, genes related to amino acid metabolism were identified, including Lysine degradation and Arginine and proline metabolism. Heatmap based on top 5 significant pathway is given in **Figure 4**.

Figure 4: Heat Map of top 5 Significant Pathways.

ANOVA) did not detect significant differences among decomposition stages for any of the identified metabolic pathways ($p > 0.05$). However, variations in pathway abundance were observed between stages. The largest changes were recorded between the bloated and decay

Figure 3: Taxonomic Composition Based on Relative Abundance of Dominant Microbial Taxa Across Decomposition Stages from Phylum to Genus Level (A-E).



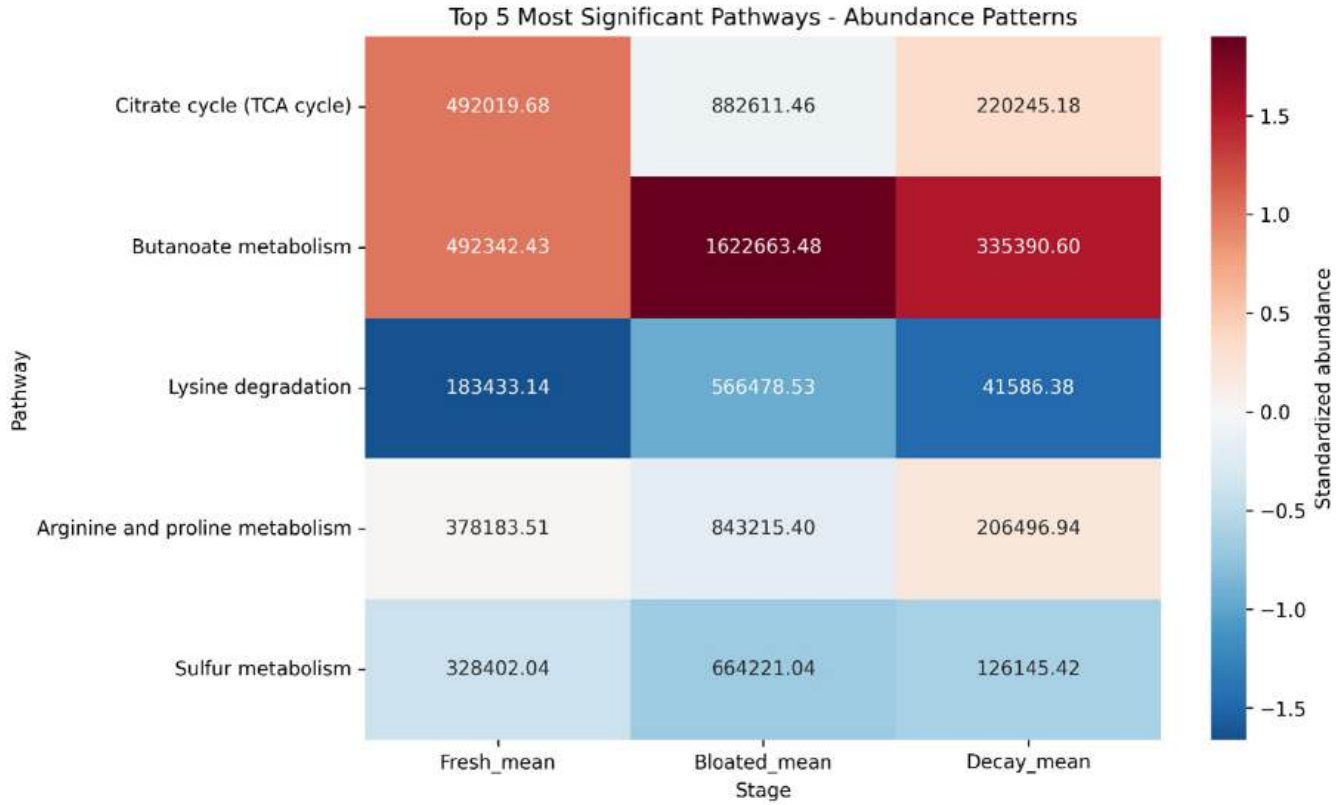
stages.

Among the pathways, Lysine degradation exhibited a 3.76 $\log_2$ fold change between the bloated and decay stages. Similarly, Propanoate metabolism showed a 2.36 $\log_2$ fold change, while Pyruvate metabolism displayed a 2.08 $\log_2$ fold change between the same stages.

DISCUSSION

The traditional method for estimating the PMI in decomposing bodies is based on forensic entomology, which is based on the developmental stages and succession of necrophagous insects, such as Diptera and Coleoptera.[13-14] But conventional methods, such as post-mortem entomology, are influenced by environmental factors that impact insect activity, colonization and larval development, including humidity, temperature, rainfall, and seasonality.[14-15] For example, insect colonization might

Figure 4: Heat Map of Top 5 Significant Pathways.



be delayed or prevented with low temperatures, whereas high temperatures could shorten the insect life cycle and stimulate larval activity. Burial, submergence, clothing and physical barriers can also limit access of insects to the remains and thus affect the normal successional pattern in the same way.[17] The species composition of insects is also variable from one geographic area to another and by habitat type is also very important. These factors can cause PMI estimates to be variable based on entomological evidence, especially in the early stages when insects are not easily accessible.[18] Recently, the use of microbial communities has been the focus of extensive research in forensic science, as they undergo characteristic changes during different stages of decomposition, and can therefore be used for estimating the PMI.[4-5,19-20] The microorganisms play a key role in the decomposition of tissue after death, and the microbial community that decomposes the tissue will undergo a structure and time-dependent change, creating what is known as a "microbial clock".[6,21] Some of these patterns have been studied across the world and they have been identified as having potential for PMI estimation. But with the lack of ethical guidelines and proper facilities for studying human decomposition, such research is yet limited in India. In the present study, microbial composition changes were detected at both the phylum and genus level, with distinct differences observed between the stage. The present study also showed similar trends in microbial changes during decomposition as previously published studies. The predominance of Bacillota (Firmicutes) and Bacteroidota in the fresh stage at the phylum level indicates the gut-derived microbiota's persistence just after death, which has been repeatedly documented in investigations including humans and animals.[22-23] Bacillota is significantly different from control at bloated stage, and was dominated by anaerobic Bacillota, which agrees with the results of previous studies that reported anaerobic Firmicutes dominance during decomposition under oxygen-depleted conditions.[2,23] The microbial community, however, in the decay stage of the present study was characterized by a substantial shift towards Actinomycetota, indicative of a restructuring of the microbial community. The same shift to more resilient and environment adapted taxa (Actinomycetota) has been observed at the later phase of decomposition after a significant decay of tissues and an exposure to the external environment.[24-25] In terms of genera, the dominating ones were typical gut genera, including Segatella, Faecalibacterium and Bifidobacterium, as expected and consistent

with previous observations of the initial postmortem gut microbiome closely reflecting the antemortem gut microbiome.[3,26-27] The predominance of Clostridium was observed in the bloated stage, which is common in all the decomposition studies, as this bacterium is responsible for anaerobic putrefaction and tissue breakdown.[2,23] The most significant change was seen in the decay stage where genera like Parafannyhessea and Bifidobacterium were predominant while there was a significant reduction in Clostridium. These findings have been similar to previous work reporting similar microbial shifts in the later stages of decomposition.[6,28] In general, phylum- and genus-level succession observed during the decomposition process also supports the notion that decomposition of microbial communities is predictable, lending credence to their prospect as potential tool for PMI estimation. The functional profiling results show clear biological relevance to post mortem decomposition, with active microbial involvement shown in energy production, anaerobic metabolism and protein degradation. Pathways identified include glycolysis, pyruvate metabolism and short-chain fatty acid metabolism, indicating the metabolic shift of the post mortem environment and microbial community. Interestingly, the metabolism of amino acids and propanoate was more abundant during the bloated to decay stage compared to the normal stage, indicating a greater rate of amino metabolism and fermentation in this critical transition period. These results have been previously reported.[24,29] The metabolic activity of the decomposers, such as carbon utilization and energy metabolism has been found to be different at different stages of decomposition and depends on environmental conditions and insect activity.[24] Enhanced breakdown of lipids and proteins during decomposition have also been reported when lipolytic and proteolytic activities were increased during active decay.[29] The results combined seem to indicate that there are stage specific microbial communities that could be used for the estimation of PMI.

LIMITATIONS

The present study is exploratory in nature and has limitations, such as a small number of samples, a limited temporal sampling, and the lack of predictive models of estimation of the postmortem interval. More extensive data sets, full environmental parameters, and sophisticated methods like predictive regression and machine learning would be beneficial for future analyses and the creation of accurate microbial biomarkers for PMI estimation.

CONCLUSION

This research, to our best knowledge, is one of the first to study the stage-related changes in the gut microbiome of the human body during the decomposition process in India using 16S rRNA gene sequencing. The results show preliminary evidence of microbial and metabolic changes that occur in a staged manner. The major differences in microbial community were found at the phylum level and the genus level during the fresh, bloated and decay stages. Functional profiling also identified stage-dependent differences in metabolic pathways related to energy production, fermentation and degradation of amino acids, indicative of metabolic changes of the microbial communities during decomposition. Although it is exploratory in nature, and has small sample size, this work provides some initial data regarding the postmortem microbiome of human cadavers in an Indian environment. The findings will add to the expanding area of forensic microbiology and provide the groundwork for future studies.

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ETHICAL PERMISSION: This study has been approved by the ethical committee of GGSMCH, Faridkot under approval no. GGS/IEC/79. The families of the dead were asked to sign informed consent before the autopsy started.

Conflict of Interest/Source of Funding: Nil

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ORIGINAL RESEARCH PAPER

To Collect Demographic Specific Data for Age Estimation using Nolla's Method in Mandibular and Maxillary Second and Third Molar with Orthopantogram.

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ABSTRACT

Introduction: Dental age estimation is a process of assessing one's factual age and is a key research area in medical forensics. It is highly important to know the chronological age of a living/ dead person. A person's age can also be influenced by several factors, including their background, lifestyle choices, exposure to the outside world, and smoking history. In 1960, Nolla devised a method of age estimation by evaluating the calcification of the permanent dentition. This was a cross sectional, retrospective study conducted on patients coming to dental OPD for regular oral checkups along with the department of Oral Medicine and Radiology, Dr Harvansh Singh Judge Institute of Dental Sciences and Hospital, Sector-25, Panjab University, Chandigarh. With the help of Nolla's staging using OPG only for second and third mandibular and maxillary molars scoring of various stages was done.

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INTRODUCTION

Dental age estimation is a process of assessing one's factual age and is a key research area in medical forensics. It has been used for clinical and medical investigation and forensic science. Forensic age estimation is usually requested by courts for legal purposes, to enforce policies or offer age sensitive services.[1] It is highly important to know the chronological age of a living/ dead person1. Previous studies have shown that there is a solid relationship between dental age and physiological age, meaning that dental age can be used as a better estimate of physiological age than skeletal estimation as they are a good biomarker because they remain intact long after death and it's easier to calculate the age in because it's based on the developmental stages of teeth. Age estimation using dentition could be done by two methods such as 1) atlas method, where development (mineralization) of dentition is compared with published standards. 2) Scoring method, where the development of dentition is divided into various stages and are assigned scores and evaluated through statistical analysis. Dental age estimation methods are based on changes throughout lives that comprise of growth and development and post – formation change and rely on evaluation of developmental changes on conventional radiograph, CT Scan and MRI. There are various methods available which are used collectively to accurately predict the age. Therefore, having a demographic specific data will further enhance the accuracy with which the age can be predicted and increase the practical application of dental age estimation.[2]

Recent studies continue to validate Nolla's method for age estimation, particularly with second and third molars, in various populations worldwide. While Nolla's stages are generally applicable, researchers stress the importance of calibrating the method to specific populations due to genetic and environmental factors that influence tooth development. These studies highlight that Nolla's method remains a valuable tool in forensic science and anthropology, especially for younger individuals, and further studies are necessary to refine it for diverse demographic groups.

A person's age can also be influenced by several factors, including their background, lifestyle choices, exposure to

the outside world, and smoking history. Forensic perspectives state that the Taner et al. method for determining age based on the maturity of the arm and wrist is somewhat prone to inaccuracy because environmental damages can alter bone development. Because dental growth is genetically controlled and less changeable, it is less impacted by disease and dietary deficiencies. The order in which teeth develop can be used to determine an individual's age in a variety of contexts, including consent, criminal responsibility, and reaching a certain level of maturity.[3]

Panoramic X-ray orthopantomogram (OPG)is the first and foremost method of estimating age from development of teeth used by forensic physicians. As a non-invasive method, dental radiography provides a valuable toolkit for clinicians in determining dental age, and performing such techniques on living objects has its own benefits such as low cost, simplicity and reliability. According to the recommendations proposed by the Study Group on Forensic Age Diagnosis (AGFAD) founded in Germany in the year 2000, to increase the accuracy in the estimation of age and to improve diagnoses, three tests need to be combined and conducted independently, viz., a physical examination, an X-ray examination of the left hand, and an examination of the dental development.[4]

Dental age (DA) can be estimated based on an individual's dental development. Chronological age (CA) is based on birth date. DA can be helpful in determining age when a birth certificate is not available or when it is evident that the age of the patient does not match their dental development.

The reasons for considering permanent mandibular and maxillary second and third molar for this study were:

a) The third molars are in their developing age till the age of 28 years thus making them the most evident tooth in the human dentition, also making them reliable for age assessment,

b) Active growth of most children extends up to the age of 16 to 17 years which coincides with the apex closure of the chosen tooth (second molar) while the apex of maxillary and mandibular canines ordinarily close by 13 years of age.[5]

In 1960, Nolla devised a method of age estimation by evaluating the calcification of the permanent dentition. The calcification of permanent dentition was divided into 10 stages Nolla's method measures calcification progression in a tooth by quantifying it objectively. A population specific assessment for Nolla's method for North Indian population may help forensic odontologists, age estimation boards, and healthcare professionals, therefore forming the rationale of this study.

MATERIAL AND METHODS

This was a cross sectional, retrospective study conducted on patients coming to dental OPD for regular oral checkups along with the department of Oral Medicine and Radiology, Dr Harvansh Singh Judge Institute of Dental Sciences and Hospital, Sector-25, Panjab University, Chandigarh. Study was done after taking due permission from institutional ethical committee

Inclusion Criteria:

- Patients who require routine OPGs for both diagnostic and therapeutic purposes in the age group (12-30 years)
- Patients giving valid age proof (Driving License, Birth certificate, 10th certificate, or Passport).

Exclusion Criteria:

- Patients with a history of dental caries, tooth extraction, previous dental repair, missing molar, or ectodermal dysplasia

SAMPLE SIZE of 500 cases.

(Minimum Sample size was calculated on the basis of anticipated 50 percent accuracy of dental age estimation using Nolla'smethod with OPG. On the basis of confidence coefficient and 10 percent absolute precision sample size comes out to be 96.) keeping in the view, unclear OPGs and impacted teeth etc, a 10% extra sample size will be considered. It will be a retrospective cross-sectional study. Written informed consent from the legal heirs of the patient or the guardian will be taken.[6]

MATERIALS AND METHOD

With the help of Nolla's staging using OPG only for second and third mandibular and maxillary molars scoring of various stages was done. As the developmental stage of the tooth falls between any of the two consecutive stages, 0.5 years will be added to the estimated age. If the radiograph showed a reading that that was slightly greater than the illustrated grade but not as much as half way between the stage and the next, the value 0.2 was added. If the development is slightly less than the grade indicated the value 0.7 was added. The total score was calculated by adding the stages for second and third mandibular and

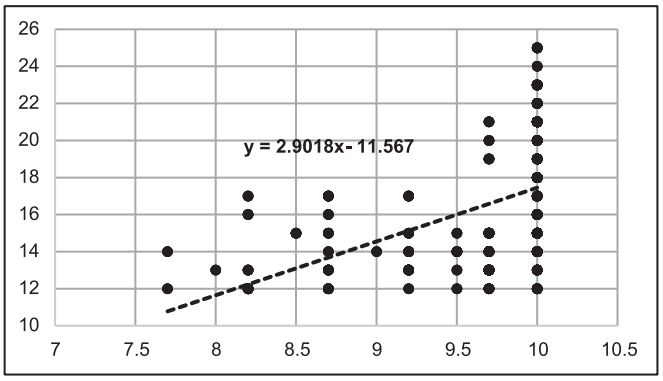
maxillary molars and the regression curves for each was created from which, a regression formula was derived by plotting the total score on x axis and chronological age on y axis. Then the estimated dental age was calculated by putting the corresponding values in the regression formula. Followed by the deviation of mean standard deviation of each molar.

RESULTS

In our study, male to female ratio was 1:1. The results of the study are as follows: (the chronological age is plotted on the y axis and score on the x axis)

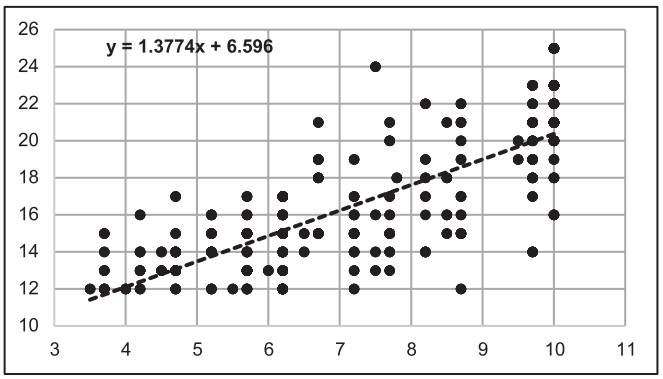
Mean score of second mandibular Molar (37) was 9.65 with mean chronological and calculated age 16.5 years and mean standard deviation of +/- 4.8 **(Graph 1)**

Graph 1: Age With Score of Second Mandibular Molar (37).



Mean score of third mandibular Molar (38) was 6.9 with mean chronological and calculated age 16.26 years and mean standard deviation of +/- 6.56 **(Graph 2)**

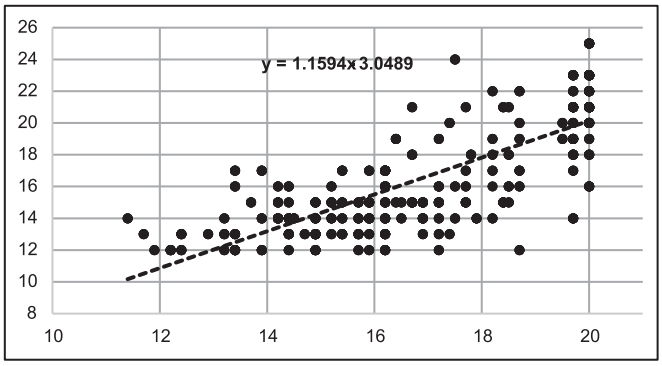
Graph 2: Age With Score of Third Mandibular Molar (38).



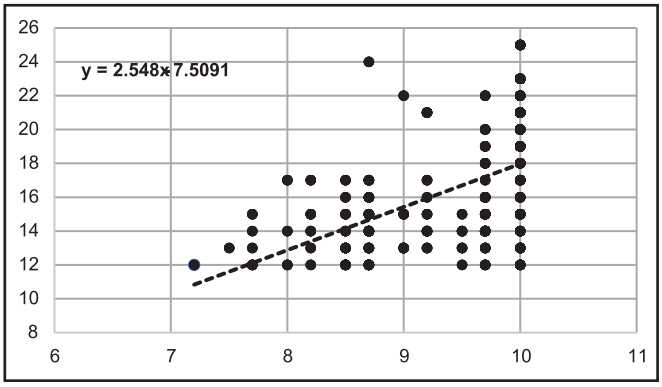
Mean score of second and third mandibular Molar (37 & 38) was 16.69 with mean chronological and calculated age 16.26 years and mean standard deviation of +/- 0.221 **(Graph 3)**

Mean score of second maxillary Molar (27) was 9.39 with mean chronological and calculated age 16.39 years and mean standard deviation of +/- 4.93 **(Graph 4)**

Graph 3: Age With Score of Second and Third Mandibular Molar (37 & 38).

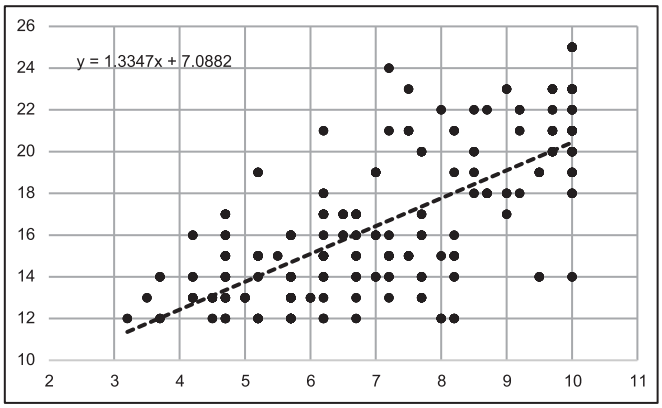


Graph 4: Age With Score of Second Maxillary Molar (27).



Mean score of third maxillary Molar (28) was 6.78 with mean chronological and calculated age 16.30 years and mean standard deviation of +/- 6.66 **(Graph 5)**

Graph 5: Age With Score of Third Maxillary Molar (28).



Mean score of second and third maxillary Molar (27 & 28) was 16.29 with mean chronological and calculated age 16.29 years and mean standard deviation of +/- 0.055 **(Graph 6)**

DISCUSSION

In our study, demographic specific data was collected to estimate the age using Nolla's method by evaluation second and third maxillary and mandibular molars. The

Graph 6: Age With Score of Second and Third Maxillary Molar (27 & 28).

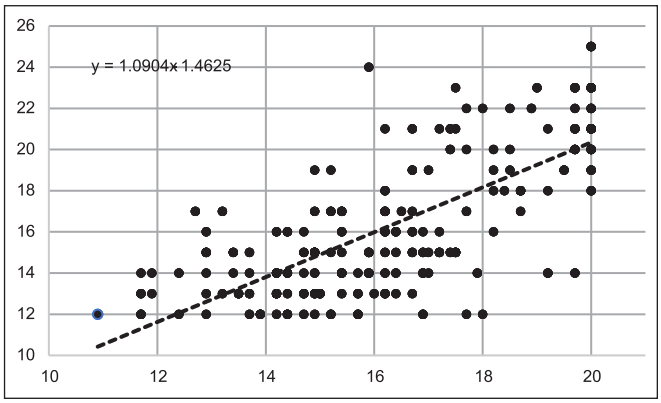


Table 8: Shows the Association between the Type of Hanging and the Reason.

Tooth	Mean Score	Mean Calculated Age	Mean Standard Deviation
2nd Mandibular	9.65	16.50	4.80
3rd Mandibular	6.90	16.26	6.56
2nd Maxillary	9.39	16.39	4.93
3rd Maxillary	6.78	16.30	6.66
Both Maxillary	16.69	16.26	0.22
Both Mandibular	16.29	16.29	0.05

male to female ratio was balanced at 1:1, minimizing potential sex based bias which ensures the representativeness of our findings.

For the second mandibular Molar (37) was mean score was 9.65 with mean chronological and calculated age 16.5 years and mean standard deviation of +/- 4.8. which was consistent with findings from Singh et al.[1] They had estimated dental age in north Indian children using Nolla's method and found comparable results. The second mandibular molar is one of the first permanent molars to emerge and its development has been well documented in the context of age estimation.

For the third mandibular Molar (38) mean score was 6.9 with mean chronological and calculated age 16.26 years and mean standard deviation of +/- 6.56 similar to result from Paz Cortes et al[2] and Demirgian et al.[3] More variation is noted in third molar as compared to second likely due to genetic factors and nutritional differences (Farhadian et al)[4]

For the second maxillary Molar (27) mean score was 9.39 with mean chronological and calculated age 16.39 years and mean standard deviation of +/- 4.93. As noted by Challiot et al,[5] maxillary molars exhibit a slightly delayed eruption compared to mandibular counterparts. Furthermore, for third maxillary Molar (28) mean score was 6.78 with mean chronological and calculated age 16.30 years and mean standard deviation of +/- 6.66 was noted in line with results of Paz Cortes[2] and Nandial et al.[7]

When considering total scores of both mandibular and maxillary molars, it was noted that total mandibular score was 16.69 and maxillary 27 and 28 showed a combined score of 16.29 with mean calculated age 16.26 and 16.29 respectively with standard deviation of 0.221 in mandibular and 0.055 in maxillary molars which is consistent with earlier research of Demirjian et al. This pattern is significant as it highlights reliable use of molar using Nolla's method. The slight variations observed in the result align with the findings of Yassin et al[8] who reported similar variations across different populations which signifies the difference in the dental age maturity with chronological age due to factors like ethnicity, genetics and environment.[9]

Our study therefore supports the established understanding that age estimation by evaluating second and third molars using Nolla's method serves as a reliable method, however individual variations are seen which emphasises on the importance of demographic specific data to recalibrate the method and make it more accurate. As noted by Maret et al[10] and Mualla et al[11] advancements in imaging techniques like cone beam computed tomography (CBCT) can further enhance the efficiency of the method. These findings underscore the critical role of dental age estimation in forensic odontology, highlighting the need for continued refinement of these methods to accommodate the diverse factors influencing dental maturation.

CONCLUSION

In our study, we applied a regression formula derived from molars to estimate chronological age. Our study revealed that the estimated chronological age predominantly fell within 17- and 23-year age group which exhibited lowest standard deviation. Deviation increased with increasing age. The analysis primarily considered second and third molars from left side of the jaw (second quadrant and third quadrant) the focus was shifted to right side in case of missing or congenitally affected left side.

Overall, our study and results highlight the accuracy of Nolla's method for age estimation while emphasising on the importance of demographic specific data which would minimise variability in the findings.

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ORIGINAL RESEARCH PAPER

A Shikakai – Ash Small Particle Reagent for Latent Fingerprint Development on Non-Porous Surfaces

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ABSTRACT

Introduction: Latent fingerprints serve as a reliable means of personal identification and routinely developed from crime scene surfaces for criminal investigations. Although, the conventional methods are quite effective in latent fingerprint development, they often involve chemicals that poses health hazards.[1-2] The present study proposes a novel organic Small Particle Reagent (SPR) formulated using Shikakai and ash extract for the latent fingerprint development. A total of 90 latent impressions from 30 individuals using thumb prints were deposited across non-porous surfaces including glass surface, plastic material and metal surface. The recovered latent fingerprints were assessed based on ridge clarity and graded from very good to poor visibility. The results demonstrate that proposed organic formulation provides a good fingerprint quality with clear ridge details on all non-porous surfaces. The formulation offers a non-toxic, cost-effective and highly efficient approach in the visualization of latent fingerprints from non-porous surfaces.

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INTRODUCTION

Fingerprints are widely recognized as one of the most accepted form of forensic evidence due to their uniqueness, immutability and permanence. The pattern of the epidermal ridges on our fingers, palms and soles is referred to as fingerprint. It is characterized by the parallel ridges present on the outermost layer of the skin.[1-3] The pattern of ridges is mainly categorized into Arch, Loop, Whorl and Composites. The ridges exhibit small structures known as Minutiae (bifurcation, ridge ending, short ridge) which act as the major factor in the identification of individuals.[4] Fingerprints have wide applications such as personal identification through biometric system,[5-6] criminal investigations,[7] donor profiling,[8] disease diagnosis,[9] age estimation of prints.[10] In criminal investigations, fingerprints can be found on variety of porous surface such as paper, cardboard, fabric, leather; non-porous surface including glass, metal and plastic; semi-porous surface includes varnished wood, waxed paper. The fingerprints can be found as latent (invisible), patent (visible) and plastic (3D) prints. The latent prints required development for further identification.[11]

A fingerprint is composed of sweat secreted from pores located on friction ridge skin of fingers, palms and soles **(Table 1)**. When hands touch any surface, the sweat residue can be deposited onto a surface, producing an impression of the ridge pattern called as fingerprint. The fingerprint residue also includes secretions from sebaceous glands, apocrine glands and external contaminants.[12] Latent prints can be developed using various optical (alternate light source, oblique lighting), physical (powder dusting, cyanoacrylate fuming) and chemical methods (ninhydrin, silver nitrate). The development methods can be applied depending on the type of the surface, that is, porous, non-porous, semi-porous, wet or sticky surface.[13-14]

Small Particle Reagent (SPR) is a technique used for developing latent fingerprint on wet, non-porous surfaces such as plastic, glass and metal. SPR consists of Molybdenum disulfide (MoS_2) particles dispersed in a surfactant solution. The technique works by the adhesion of fine particles of treating solution with the water insoluble sebaceous components present in latent fingerprint residues. The effectiveness, contrast and quality of developed fingerprint depend on the composition of the reagent and the way of preparation. The treatment solution should be free of clumps of suspension material in the treating solution.[15-16] The reagent may be

Table 1: Composition of Fingerprint Residue.[10]

Source	Location	Constituents
Eccrine sweat (60%-70%)	Eccrine sweat glands are found all over the body and are particularly abundant on the palms and fingertips.	Water, urea, uric acid, creatinine, amino acids, ammonia, choline, glucose, lactic acid, lactate, sodium, chloride, and potassium.
Sebum (15%-25%)	Sebaceous glands on the face, head, and other locations are associated with hair follicles.	Free fatty acids, cholesterol esters, mono-, di- and triacylglycerols, wax esters, cholesterol, squalene.
Apocrine sweat (1%-5%)	Apocrine sweat glands are found in the axillary regions of the body, namely the armpits and genital area.	Ammonia, androgenic steroids, cholesterol, glycogen, iron, proteins, and water.
External contaminants (5%-10%)	They were picked up as a consequence of touching other objects and surfaces.	Illicit drugs, nicotine, cosmetics, explosives, foodstuffs, dust, and grease.

Table 2: Organic Formulation of SPR:[22,32]

Sr. No.	SPR Formulation	Types of Surfaces	Key Findings (Grade 0-5)	Advantages
1	Commercial Shikakai Powder	Non-Porous Surface	Clear Ridge Detail Through Natural Adherence.	Eco- friendly, cost-effective
2	Ashwagandha Powder	Porous & Non-Porous Surface	Visible Prints On Most Surfaces	Eco-Friendly Natural Alternative
3	Activated Charcoal SPR	Submerged Non-Porous	Glass: 11 Days (Pond Best)	Long Shelf Life (52 Days)

Table 3: Distribution of Samples Based on Visibility of Fingerprint Development.

Visibility Category	No. of Samples	Percentage
Very Good Visibility	29	32.22%
Good Visibility	25	27.78%
Poor Visibility	21	23.33%
Bad Visibility	12	13.33%
Blur/ No Print	3	3.33%

applied to the surface by spraying, pouring or dipping method depending on the size and shape of the object. Prior treatment of the substrate with volatile bases can be done prior to the development of latent fingerprint.[17] There are some other factors which can affect the efficiency of SPR reagent. For instance, the change in pH of SPR may affect the efficiency of fingerprint development under unfavorable condition (acidic nature).[18] The average shelf life of fingerprint immersed in water is 45 days, later fingerprint may not be developed.[19]

The existing literature has explored SPR reagents from different perspectives. There are various formulations proposed by different studies. Formulation of iron oxide – based SPR reagent that exhibited enhanced sensitivity, contrast, clarity compared to molybdenum disulfide suspension and was effective on dry, wet and smooth surfaces.[20] Multiple SPR composition and identified zinc carbonate – based suspension on dark surfaces immersed in saline condition.[21] Similarly, modified the Small Particle Reagent by including dyes and fluorescent components, enhancing the visualization of fingerprints exposed to conditions such as arson, burial and prolonged immersion (upto 45 days).[22-23] The formulation of Zinc oxide and Silicon dioxide nano powders enhanced ridge detail and visibility compared to conventional powders.[24] The growing importance of fluorescent nano materials for achieving higher sensitivity, improved clarity and less-toxicity.[25] Various studies by introduced novel Small Particle Reagent formulation including activated charcoal, fluorescent dyes and Phloxine B, resulting in improved performance and extended shelf life and shows effectiveness on non-porous surfaces.[26-28] Nano bio-based reagents that exhibit improved performance on aged fingerprints.[29] Comparative studies conducted between different SPR variants,[30] the composition of the formulation provides higher fingerprint clarity (White SPR) on aluminium substrate[31] and also there are studies including silver-based reagents emphasizing the efficacy

of SPR based techniques.[32]

The effectiveness of SPR reagent has been studied on different substrates and it has been found that SPR has better performance than conventional methods Early findings provided information on the SPR method for obtaining quality latent impressions on wet firearms and compared it with conventional methods such as powder dusting method and cyanoacrylate fuming.[33] Following these findings, studies demonstrated its ability to develop latent fingerprints especially on non-porous surfaces after prolonged water exposure through surfactant-assisted adhesion.[34-35] The efficiency of black powder and cyanoacrylate fuming in aquatic environments.[36]

There has been increased used of organic method for latent fingerprint visualization. The studies have explored plant-based powders such as Gambir, Ashwagandha and shikakai to produce clear ridge characteristics on non-porous surfaces.[37-39]

This study proposes a novel organic SPR formulation prepared using Shikakai and ash for developing latent fingerprints on non-porous surfaces. The shikakai-ash formulation is an eco-friendly advancement in SPR technique for developing latent fingerprint. The proposed formulation is low cost, easily available and low-toxicity in nature and make it a potential green alternative for existing SPR formulation. Prior studies on organic SPR variants evaluated raw plant materials, such as Gambir and Ashwagandha powders. These studies have not explored ash-processed formulations and their efficacy in latent fingerprint development. The present study has assessed the quality of developed fingerprints using proposed formulation. The result demonstrated sufficient ridge detail in latent fingerprint developed using Shikakai-ash formulation indicating its potential as a sustainable alternative for forensic applications. This study aims to formulate a novel eco-friendly SPR reagent for the development of latent fingerprint across non-porous surfaces. The objectives of the study includes to understand the efficacy of the organic small particle reagent for latent fingerprint development, evaluate the ridge clarity and to study the durability of the organic SPR for future studies.

MATERIALS AND METHODS

Study Design

Place of Study: The study was carried out at the Forensic Science Department, Chandigarh University, Mohali, Punjab, India. Collaborations with other departments of institutions were not involved.

Time Period: The study was conducted between August 1st, 2025 to March 31st, 2026.

Ethical Aspects: Informed written consent was collected from 30 individuals prior to fingerprint collection. They were briefly described about the study, purpose and nature of my research.

Inclusion and Exclusion Criteria:

Inclusion Criteria: Deposited latent fingerprints voluntarily by individuals with informed consent, study conducted on non-porous surface, showed clear ridge deposition

Exclusion Criteria: Fingerprints deposited on porous or semi-porous surface.

Sample Size

A total of 90 latent fingerprint samples were obtained from 30 individuals (3 prints from thumb at 0, 30and 60 min intervals).

Statistical Methods

The Mean Visibility Score of the recovered fingerprint is calculated:[40]

$$\left(\text{Mean visibility score} = \frac{\sum(f.x)}{\sum f}\right)$$

Where f = frequency (number of samples) and x= score

Preparation of Organic SPR: An organic Small Particle Reagent (SPR) was prepared using Acacia concinna (shikakai) extract and finely ground ash (cattle product). Shikakai extract was prepared by boiling 250gm of raw shikakai pods in 100ml of distilled water for 10 minutes, it was cooled and filtered to obtain a solution that is rich in saponin. Its saponin content facilitates adhesion to fingerprint residues producing high-contrast ridge and minutiae on non-porous surfaces.

The cow dung ash (25 g), was finely ground and sieved. The ash was dispersed in 100ml distilled water with continuous stirring to obtain a uniform suspension. The shikakai extract (30ml) was mixed with a portion of the ash solution (15ml), and SPR reagent was formulated and stored in a glass bottle.

Sample Collection and Surface Preparation: The latent groomed fingerprints were collected from 30 individuals - 15-male; 15-female with an age group of 19 to 30 years. Written informed consent was obtained from all

individuals before the sample collection. The fingerprint samples were collected from thumb of each individual resulting in 90 prints (3 per individuals at 0, 30 and 60-min intervals). 'Groomed' or 'loaded' fingerprints are collected whereby donors carried out a specific pre-treatment.[41]

Prior to deposition of fingermarks, the participants' hands were washed with soap and water and further dried to eliminate external contaminants. The individuals were instructed to rub their forehead, face and folder neck regions to accumulate sebaceous material. The fingertips were pressed firmly onto the cleaned substrates: mobile covers, jewellery box, glass, flask and plastic surfaces. Fingerprints were allowed to dry for about 1 hour. The substrates were submerged in distilled water for 10 minutes and were taken out for treatment with proposed Organic SPR formulation.

Fingerprint Development: The Organic SPR formulation was applied by pouring method for fingerprint development.[42] The reagent was poured over the substrate using the sterile spoon, until the print is visible. Further, the print was rinsed with clean water with light pressure to removes excess reagent. Photographic documentation of the developed fingermarks was carried out using a Digital Single-Lens Reflex (DSLR) camera under consistent lighting conditions.

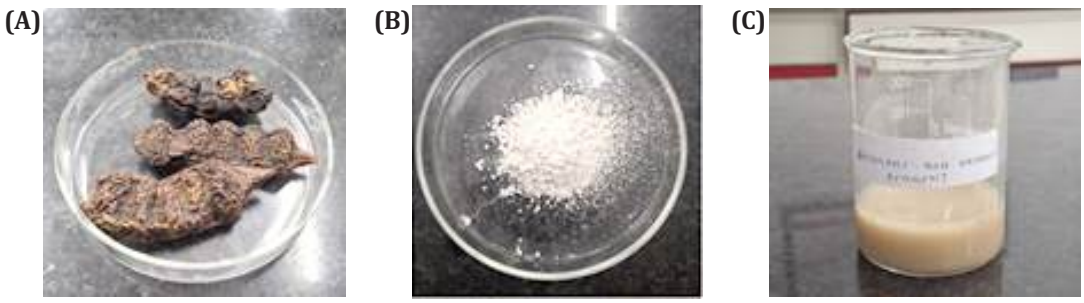
Fingerprint Quality Assessment

The quality of the developed latent print was evaluated using the fingerprint quality assessment scale where fingerprints were scored from 1 to 5 based on clarity of ridges. Score 5 – high-quality ridge detail, the ridge details are well defined which is used for individualization, including distinct, countable minutiae. Score 4 – good ridge visibility, the fingerprint ridges are clear but for pattern recognition and for approximate partial comparison.

Score 3 – poor ridge clarity, the ridge details are only visible on some area of print. The fingerprint may exhibit smudging. The print cannot be identified into one of the three basic fingerprint patterns. Score 2 – bad visibility, ridge characteristics are poorly defined. The fingerprint is almost completely smudged and cannot be identified into one of the three fingerprint patterns. Score 1 – blurred/no visible print, only the outline of the print is visible, with no observable ridge characteristics.

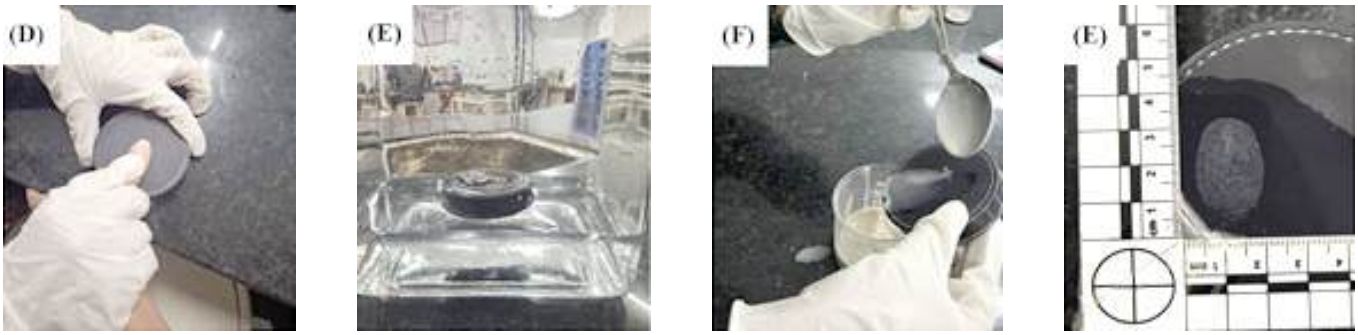
Figure 1. Stepwise Procedure used for Latent Fingerprint Development with the Proposed SPR Formulation.

I. Preparation of Shikakai-Ash based SPR



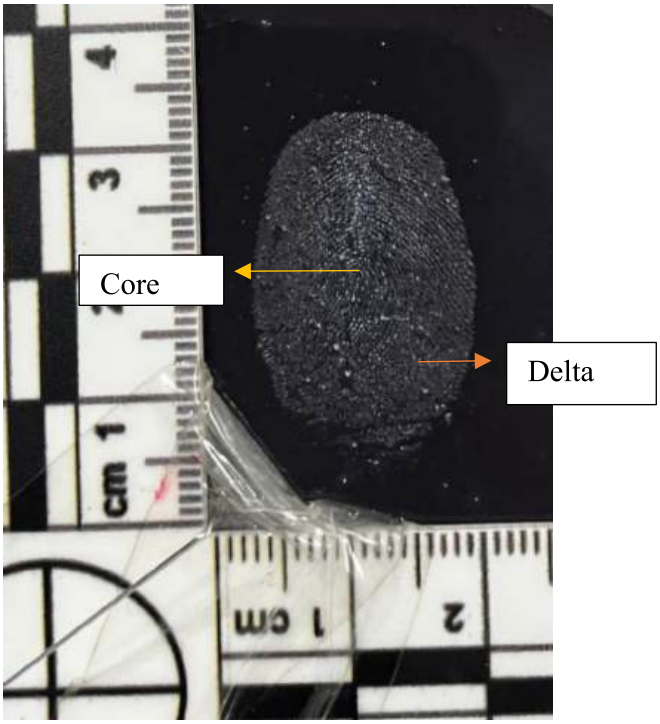
Dried Pods of Acacia Concinna **Burned Ash of Cattle Product** **Shikakai - Ash Formulation**

II. Application of Shikakai - Ash Based SPR for Latent Fingerprint Development

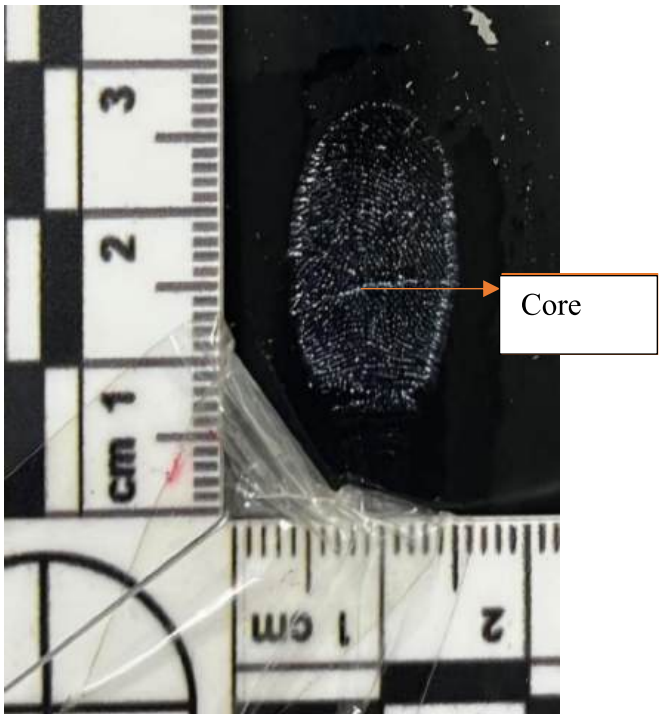


Fingerprint Deposition on the Substrate **Substrate Immersed in Water** **Application of the Reagent** **Developed Latest Fingerprint**

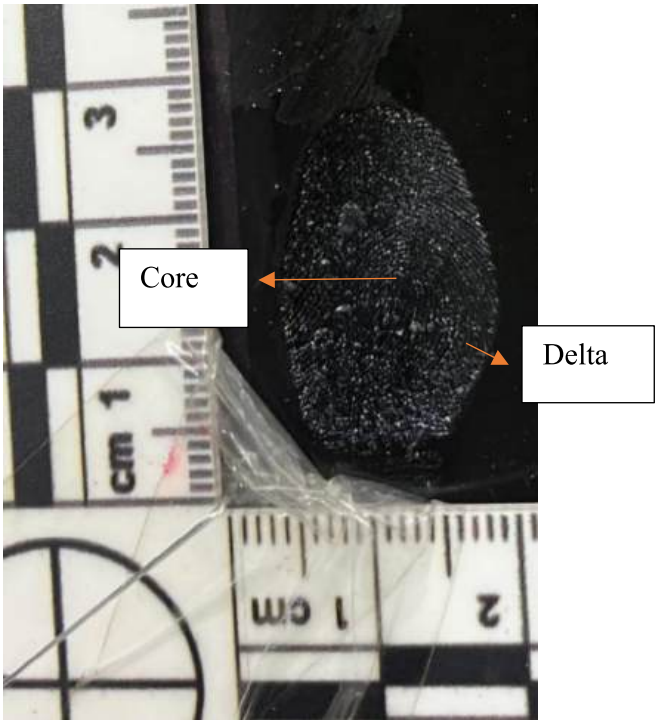
Figure 2. Development of Latent Fingerprint using Shikakai-Ash Extract Reagent (a) Jewellery Box (b) Glass (c) Flask (d) Mobile cover (e) Plastic.



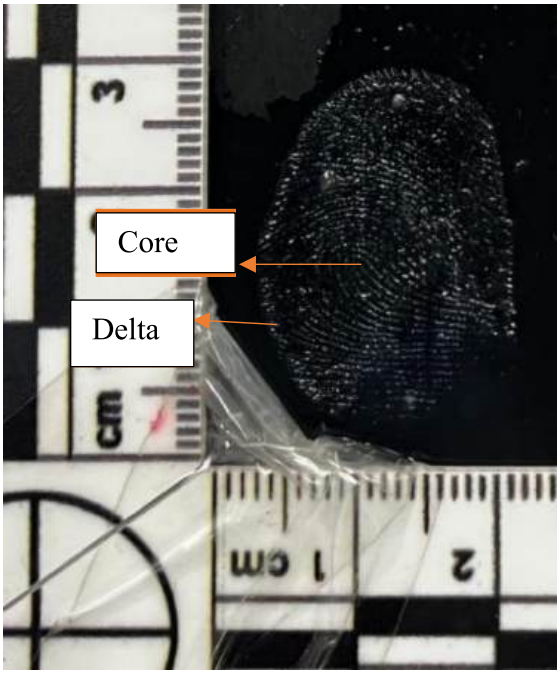
(a) Fingerprint Developed on Jewellery Box and Scored as 5



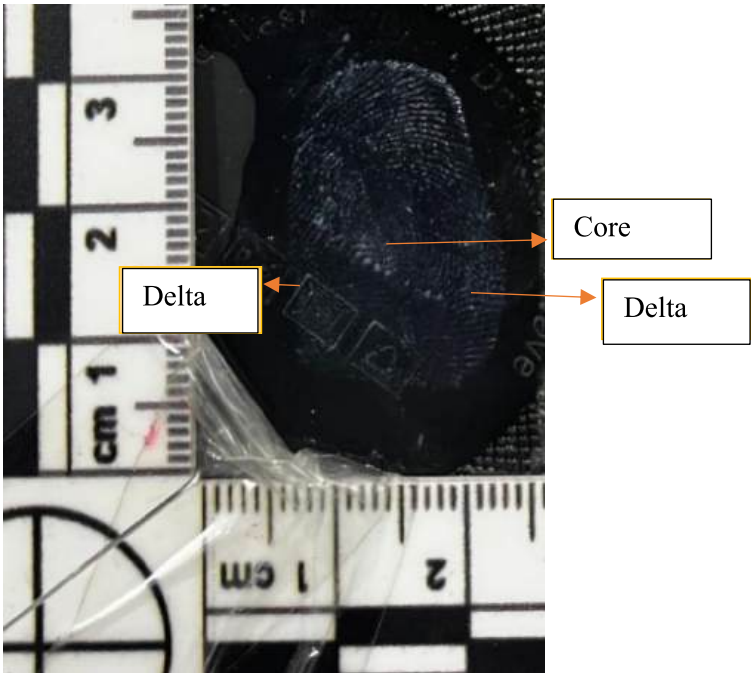
(c) Fingerprint Developed on Flask and Scored as 3



(b) Fingerprint Developed on Glass and Scored as 4



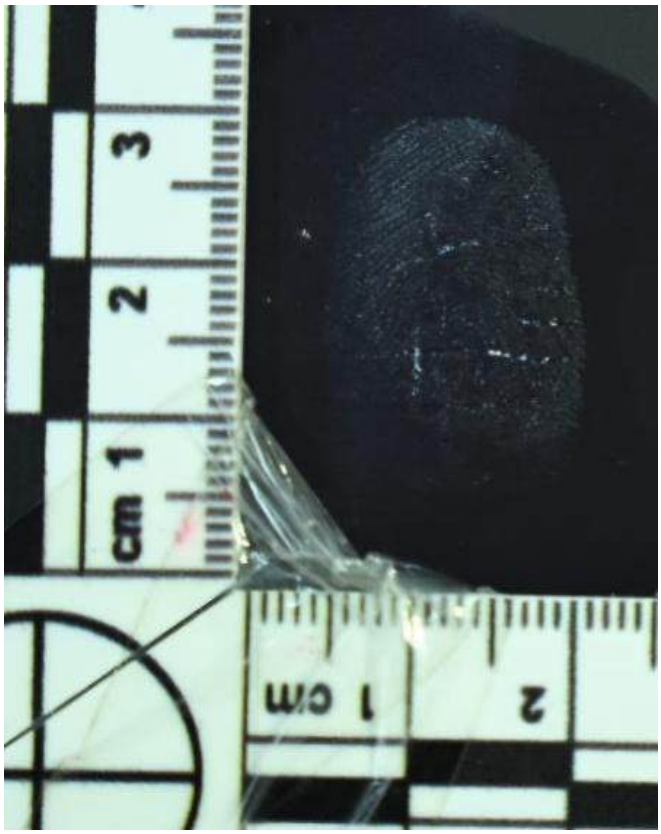
(d) Fingerprint Developed on Mobile Cover and Scored as 2



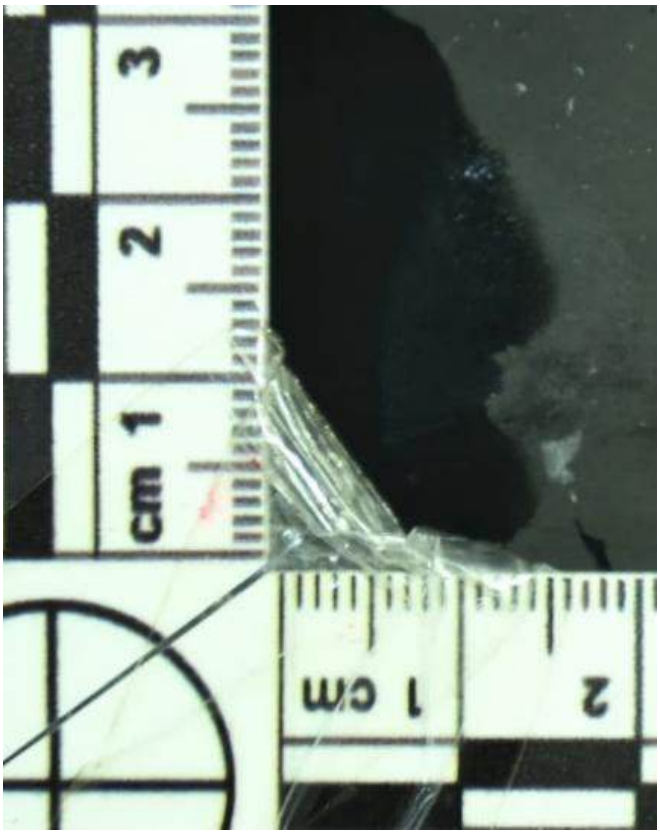
(e) Fingerprint Developed on Plastic and Scored as 1

Figure 3: Development of Latent Fingerprints – (a) Clear and Complete Fingerprint, (b) Partial Fingerprint, (c) Smudged Fingerprint.

(a) Complete Fingerprint Developed on Jewellery Box and Scored as 5



(a) Complete Fingerprint Developed on Flask and Scored as 3



(c) Smudged Fingerprint Developed on Mobile Cover and Scored as 1

RESULTS

The organic Small Particle Reagent based on of shikakai-ash formulation effectively developed latent fingermarks at high ridge clarity, revealing distinct ridge characteristics on mobile cover, flask, plastic, Jewellery box, glass.

Very good visibility to good visibility was shown by 69% of the developed latent fingerprints. Only 3.33% showed blur or no print. One case of Adermatoglyphia resulted in non-classifiable prints. The Mean Visibility Score of the recovered fingerprint was approximate 3.72, indicating the effective enhancement by the Shikakai-ash formulation. The effectiveness of the reagent demonstrates its potential as an eco-friendly alternative method for development of fingerprint on non-porous, water-challenged substrates. **(Figure 1)**

DISCUSSION

The present study evaluated the efficacy of proposed SPR formulation for developing latent fingerprints on mobile cover, flask, Jewellery box, plastic and glass. The overall mean visibility score (3.72) and the highest percentage of samples exhibiting between very good and good visibility indicating that the organic reagent performs effectively on non-porous surfaces. Shikakai (Acacia concinna) contains natural saponins, which act as surface-active agents. The findings are comparable with earlier green and eco-friendly SPR formulations, such as turmeric-based, charcoal based and plant derived particle reagents which have demonstrated satisfactory fingerprint development on non-porous surfaces. The prepared reagent can serve as viable alternative to conventional Small Particle Reagent formulations containing toxic exposure.

The shikakai-ash reagent offers low toxicity, affordability and environmental sustainability. Non-porous surfaces such as glass and Jewellery boxes produced higher visibility scores. In contrast, plastic surfaces produce lower visibility scores due to irregular surface. Unclear or failed fingerprint development may result from insufficient fingerprint residues, pressure difference and inherent biological conditions like Adermatoglyphia. In such cases, even if the reagent is applied the print will be in blurred manner. These observations show the reagent efficacy which is not only the created formulations but also on the basis of the variability in the donors and surface conditions.

CONCLUSION

The present study shows that proposed organic SPR formulation provides appropriate result in developing and visualizing latent fingerprint on different non-porous surfaces. However, the reagent may not completely replace with conventional method of fingerprint development or standard Small Particle Reagent formulation but it may serve as a green alternative. The quality of developed fingerprint can be affected by donor and nature of the substrate. It is particularly suitable for resource-limited settings which is low cost, easy preparation, environment friendly and non-toxic in nature. Further studies with larger sample size and comparative evaluations are recommended to establish its forensic applicability. Limitations: The study had focussed only limited donors, not every surface develops the print and it has not been developed by using the reagent as it is stated as one of the limitations in this study. Therefore, the results obtained might not completely reflect the performance of the Organic Small Particle Reagent on natural latent fingerprints observed under real crime scene scenarios.

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ORIGINAL RESEARCH PAPER

Stature Estimation Using Foot Length: A Forensic Approach to Identification

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ABSTRACT

Introduction: Identification is one of the important objectives of medico-legal autopsy besides the determination of cause, mode and manner of death. Race, age, sex and stature are considered the big four in identification; hence, estimation of stature helps identify the individual, especially when the dead body is decomposed, mutilated, fragmentary or skeletonised. Identification by estimating stature, hence, plays a crucial role in identifying the dead to cremate them as per their religious practices.

Objectives: The present study is intended to derive linear regression formulae for estimating stature by foot length and to correlate them with the known stature.

Materials and Method: The cross-sectional study was conducted on participants aged 20 to 23 years, whose two generations were the natives of the Raebareli district of Uttar Pradesh. Pearson's correlation test was applied to assess whether or not there was a relationship between foot length and stature. Gender-specific linear regression models for estimating stature were established. The paired t-test was performed to compare the known and estimated stature.

Results: Pearson's correlation in the combined gender group showed a good correlation between foot length and stature. The paired t-test between known and estimated stature was statistically not significant with a p-value of > 0.05.

Conclusion: The present study has established a correlation between stature and foot length. The stature can be estimated from foot length in situations where only the foot or lower torso is available for post-mortem examination and subsequent identification.

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INTRODUCTION

Identification is the determination of the individuality of a human being, whether living or dead, and is mainly classified as partial (incomplete) and absolute (complete) identification. Among the objectives of medico-legal autopsy, the cause of death, manner, and mode of death, identification is also an important objective to provide the religious autonomy of the dead individual for cremation as per their religious practices.[1-4] Further, it is not uncommon to receive unknown or unclaimed dead bodies, decomposed bodies, mutilated or fragments of body parts or even skeletons for medico-legal post-mortem examination, where the forensic expert has to identify the body based on anthropometric measurements, a study known as anthropology.[5-8] Recently, many incidents have occurred where the perpetrators have mutilated the dead body or cemented the dead body inside a drum; in these cases, the identification of the dead is a more challenging task. Race, age, sex and stature are considered the big four in identification; hence, stature estimation is one of the most crucial components in the identification of an individual.[9-11] Various body parts can be used for stature estimation. Several studies have already been conducted in different regions of the country and worldwide to estimate stature from various body parts; however, the study done on one particular set of population cannot always be applied to another set of population because of the vast variation in lifestyle, genetic makeup, and environmental

factors.[12-14] There are several inter-racial & inter-geographical differences in the measurements & their correlation with the stature. As India caters to the numerous ethnic and indigenous groups of the population, and because of its ethnic and genetic diversity, it is important to study different ethnic or indigenous populations.[1,5] The present study was performed to estimate the stature from foot length measurement in the population of Raebareli district, Uttar Pradesh, India, and to determine whether a significant correlation exists between stature and foot length dimensions. Further, it was also intended to derive linear regression formulae for the stature estimation from foot length and to determine the correlation between the known stature and the estimated stature derived from the linear regression equation using foot length.

MATERIALS AND METHODS

The present cross-sectional study was conducted at the Department of Forensic Medicine & Toxicology in our institute, a tertiary care centre of Uttar Pradesh. Institutional Ethical Committee approval was obtained before initiation of the study (F. 3/BIOETHICS/AIIMS-RBL/APPRO/IM/2021/2023- 5/12, Dated 29.10.2023). The study was conducted following the ethical principles given in the Declaration of Helsinki. Participation of students was voluntary, and informed consent was taken and affirmed to keep their identity anonymous. The study was conducted on 200 students (100 male and 100 female) aged between 20 and 23 years studying in a degree college of Raebareli district, Uttar Pradesh, whose two generations were atleast the part of Raebareli district. The sample size was determined using online software G-power, with an initial calculation of 30 participants based on an r-value of 0.5 (Chawla H1); however, to enhance the precision and the external validity of the regression equations, a larger sample of 200 participants was selected. A two-stage sampling method was performed: in the first stage, simple random sampling was used to select one degree college from the list provided by the Education Department, and then convenience sampling was used in that particular selected college to recruit willing/ voluntary participants based on selection criteria.

Selection Criteria

Inclusion Criteria

1. Adult students (aged 20 to 23 years).
2. With no stature, hand and foot-related anomaly.
3. Willing to participate in the study and give informed consent.

Exclusion Criteria:

1. With any traumatic anomaly of stature and hand.
2. With any congenital or genetic anomaly of stature and hand.
3. With any infectious disease-causing anomaly of stature and hand.

PROCEDURE

Stature: After making sure that the participant was not wearing any kind of footwear or headwear, the stature was measured on a stadiometer. They were instructed to stand upright on the stadiometer with their heads in the Frankfurt Horizontal Plane, hands hanging at their sides, and feet parallel or slightly divergent. The stadiometer's movable horizontal headpiece was gently placed on the scalp, and height was recorded in centimetres.[1,15]

Foot Length: Distance from the most prominent part of the heel backwards to the most distal part of the longest toe (whichever is longest in the particular participant). A digital sliding vernier calliper was used to measure the length of the foot. The calliper was horizontally placed along the inner border of the foot, taken care of that no participants could be injured.[2-5]

Measurements were taken in centimetres up to two decimals and were taken each day at a fixed time between 14:00 and 15:00 by the same observer every day to avoid intra-observer error, to eliminate the incongruities due to diurnal variation. The instruments were always pre-checked regularly for accurate readings. Before proceeding with the data collection, a pilot study was also carried out to get a measure of the precision and reliability.

Statistical Analysis: The data were statistically analysed using IBM SPSS Statistics Version 20.0 for Windows (Armonk, NY: IBM Corp). A p-value of <0.05 was considered statistically significant. Correlations between the length of the foot and stature were determined by using Pearson's correlation test. Gender specific linear regression equations for the estimation of stature were developed using the foot length. The correlation coefficient (R), coefficient of determination (R^2), and standard error of estimate (SEE) were also calculated. The comparison between known and estimated statures was done by using a paired t-test.

RESULTS

A total of 200 students participated in the study, comprising 100 males and 100 females. The mean age for males and females was 21.27 and 20.91, respectively. The descriptive statistics for age, stature, and measurement of both foot lengths for males, females and a combined group consisting of both males and females are depicted in **Table 1**. Pearson's correlation between foot length and stature in males, females and a group consisting of both genders is depicted in **Table 2**. Pearson's correlation in the combined group showed the strongest association between foot length and stature, with left foot length (LFL) exhibiting the highest correlation (r=0.740). Among males and females, females showed a stronger correlation, and LFL in both sexes had a slightly better correlation with stature. A summary of linear regressions in males, females and a group consisting of both genders is depicted in **Table 3**. By employing the linear regression equation, the stature can be approximated by using the regression: y (stature) = b (constant) + a (regression coefficient of the independent parameter) x LFL/ RFL. The standard error of estimation (SEE) was lowest in females as compared to males and the combined group. The lowest standard error of estimation among females was lowest in LFL as compared to RFL **(Table 3)**. The descriptive statistics between known stature and estimated stature derived from regression formulas are depicted in **Table 4**. There was no statistically significant difference between known stature and estimated stature by using a paired T-test **(Table 5)**

DISCUSSION

Stature estimation has a definitive value in identification, especially in cases where the dead bodies are decomposed, unknown, unclaimed, mutilated, fragmentary, or skeleton remains as received for medico-legal autopsy, especially in cases of mass disaster, natural calamities, train or bus accident, or human terror attacks. The findings from one set of population may not necessarily be applied to another set of population because of vast variations in racial, ethnic, cultural, genetic and environmental factors, which affect the stature of the individual to a greater extent. The present study was conducted on residents of a particular area, whose at least two generations have neither immigrated nor emigrated. The present study revealed the positive correlation between length of the foot and stature which was highest when both gender groups were taken into consideration (r=0.740, p-value 0.0001) as highlighted in the another study done by Chawla H et al[1,5] (r=0.655), Sen J et al[9] (r=0.813) Xu et al[15] (r=0.863 for males and 0.619 for females) Moshkdanian et al[16] (0.89) Ozden H et al[17] (r=0.579) Sen J et al[9] (r=0.759 for males and 0.512 for females). The majority of studies have taken the left foot measurement only. The regression equation derived from both foot lengths in the present study showed the lowest standard error of estimation (SEE) from Left foot length in Females (SEE 4.769), followed by males. Hence, the measurement of the left foot can be considered a better parameter than the right foot while determining the stature; however, the difference in SEE was not significant in the present study. There was no significant difference in the mean among the statures derived from the linear regression equation and the known stature; however, the minimum and maximum values of estimated stature were 4 cm above or below the actual known stature. The paired t-test between the known stature and estimation stature revealed p-values of 0.995, 0.982 and 0.979 for females, males and combined gender group respectively, indicating no statistically significant difference, this is also consistent with studies done by Chawla et al,[1,5] thus, the equations derived for stature estimation from right and left foot can be used for determination of stature in that particular region of the country. The comparative data derived from various studies done on the same topic have been tabulated in **Table 6**.

Study Limitation: Boundaries between the different racial groups have been extremely influenced by migration, relocation, and intermarriage, which ultimately leads to a genetic mix-up. The present study has taken into consideration such factors as migration and relocation;

Table 1: Descriptive Statistics of Age, Stature, Right Foot Length (RFL) And Left Foot Length (LFL).

Parameter	Gender	(Mean ± SD)	Min	Max
Age	Female (100)	20.91 ± 1.03	20	23
	Male (100)	21.27 ± 1.07	20	23
	Combined (200)	21.09 ± 1.06	20	23
Stature	Female	154.03 ± 6.22	125.40	166.50
	Male	165.58 ± 6.45	151.30	191.20
	Combined	159.80 ± 8.57	125.40	191.20
RFL	Female	22.88 ± 0.99	20.50	25.70
	Male	24.80 ± 1.28	16.70	27.30
	Combined	23.84 ± 1.49	16.70	27.30
LFL	Female	22.90 ± 0.99	20.50	25.70
	Male	24.80 ± 1.26	17.00	27.30
	Combined	23.85 ± 1.48	17.00	27.30

Note: RFL – Right Foot Length, LFL – Left Foot Length

Table 2: Pearson's Correlation Analysis Between Foot Length and Stature.

Parameter	Females		Male		Combined	
	R	p-value	R	p-value	R	p-value
RFL	0.639**	0.0001	0.464**	0.000	0.737**	0.0001
LFL	0.646**	0.0001	0.465**	0.000	0.740	0.0001

** Correlation is significant at the level 0.01 (2-tailed)

Table 3: Linear Regression Equations for Stature (cm) Estimation in Males, Females & Combined Gender.

	Parameter	Equation	R	R	Adjusted R^2	SEE
Females	RFL	62.504 + 4.0 RFL	0.639	0.408	0.402	4.809
	LFL	60.870 + 4.068 LFL	0.646	0.418	0.412	4.769
Males	RFL	107.619 + 2.338 RFL	0.464	0.215	0.207	5.748
	LFL	106.525 + 2.382 LFL	0.465	0.216	0.208	5.745
Combined Gender	RFL	58.933 + 4.231 RFL	0.737	0.543	0.541	5.811
	LFL	57.370 + 4.295 LFL	0.740	0.547	0.545	5.783

Table 4: Descriptive Statistics of Mean Values of Known Stature and Estimated Stature in Males and Females.

Parameter	Gender	Min	Max	Mean	SD
Known Stature	Female	125.40	166.50	154.03	6.21765
	Male	151.30	191.20	165.58	6.45499
	Combined Gender	125.40	191.20	159.80	8.57235
Estimated Stature	Female	144.51	165.31	154.03	3.97
	Male	146.66	171.43	165.58	2.99
	Combined Gender	129.60	174.45	159.81	6.32

Table 5: Paired T-test between known & Estimated Height.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Females	.00300	4.78453	.47845	-.94636	.95236	.006	99	.995
Males	-.01290	5.71918	.57192	-1.14771	1.12191	-.023	99	.982
Combined Gender	.01060	5.79647	.40987	-.79765	.81885	.026	199	.979

however, the history of intermarriage has not been taken into consideration. Further, it is recommended to conduct the study on the same set of population, considering all factors influencing the genetic make-up and stature of the population to improve the accuracy of the derived equation, so that the result can be validated and more reliable.

CONCLUSION

The linear regression equation derived from the present study has confirmed the usefulness of foot length for the estimation of stature in our region. The left foot measurement has shown a strong correlation with stature, in accordance with the literature. Stature estimation from foot length is a useful parameter for identification because it is easy to perform, convenient, relatively simple and economical. Anthropologists, forensic experts and even the investigating officers may use this method of stature estimation from foot length. Therefore, the present study can provide a population-specific regression model for stature estimation from foot length in individuals.

Conflict of Interest/Source of Funding: Nil

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Table 6: Comparison of Data Derived from the Present Study with the Studies done by Different Authors on the Same Topic.

Study	Gender	Left Foot			Right Foot		
		R value	Regression Equation	SEE	R value	Regression Equation	SEE
Present Study	Male	0.465	106.525 + 2.382 LFL	5.745	0.464	107.619 + 2.338 RFL	5.748
	Female	0.646	60.870 + 4.068 LFL	4.769	0.639	62.504 + 4.0 RFL	4.809
	Combined Gender	0.74	57.370 + 4.295 LFL	5.783	0.737	58.933 + 4.231 RFL	5.811
Sagar S et al (18)	Male						
	Female						
	Combined Gender	0.869	46.418 + 4.752	3.43	0.865	45.498 + 4.779	3.514
			x LFL +3.430			x RFL +3.514	
Karmalkar AS et al (19)	Male						
	Female						
	Combined Gender	0.6736			0.6745		
Siripurapu B et al (20)	Male			3.05547			
	Female		76.105+3.505	4.1156		76.262+3.498	
			FLLT4.34513			FLRT4.26964	
	Combined Gender	0.754	156.498+0.423		0.773	154.107+0.518	
			FLLT3.01653			FLRT3.00200	
Oghenemavwe LE et al (21)	Male	0.68	3.1687(FL) + 909.54				
	Female	0.54	2.2926(FL) + 1093				
	Combined Gender	0.23	3.21189FL) + 883.13				
Hussain SS et al (22)	Male		53.618 + 4.7762 X2			53.050 + 4.802 X1	
	Female		78.724 + 3.601 X2			78.538 + 3.597 X1	
	Combined Gender						

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ORIGINAL RESEARCH PAPER

A Retrospective Study of Rape Cases in West Bengal Between 2019 - 2023: Trends & Contributing Factors

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ABSTRACT

Introduction: Sexual violence remains a critical challenge to public health and the criminal justice system in India. This study examines the trends, demographic characteristics, and geographic distribution of reported rape cases in West Bengal between 2019 and 2023, while evaluating the systemic and cultural factors impacting case reporting and legal outcomes.

Materials and Method: A descriptive, retrospective research design was utilized, extracting quantitative data from the National Crime Records Bureau (NCRB) and West Bengal State Police records. To determine the factors driving the rising incidence and the sociocultural barriers to reporting, a secondary thematic and structural analysis was applied to regional infrastructural metrics, national crime data patterns, and comparative sociological literature.

Results: The data revealed a 33% increase in reported rape cases over the five-year study period, peaking at 1,675 reported cases in 2023. Women aged 18–25 years represented the most vulnerable demographic (48%), and a significant portion of victims (67%) belonged to low socio-economic backgrounds. Urban centres (Kolkata and Howrah) accounted for 65% of reported cases, highlighting major under-reporting in rural areas driven by community stigma. Furthermore, systemic bottlenecks were evident, with forensic evidence processing averaging 3 to 6 months and the state conviction rate tracking at 24%.

Conclusion: The upward trend in reported cases underscores both an escalating incidence and a marginal improvement in public reporting awareness. Addressing the low conviction rates and high rural under-reporting requires urgent multi-faceted interventions, including upgrading forensic infrastructure and expanding localized community education campaigns to dismantle socio-cultural barriers.

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INTRODUCTION

Sexual violence, particularly rape, is a heinous crime that causes grave physical, psychological, and emotional harm to its victims. In India, despite a stringent legal framework and repeated legislative amendments, the incidence of rape remains high. West Bengal, known for its rich culture and social heritage, has seen a disturbing rise in rape cases in recent years. This study explores the trends, demographic profiles, and geographic distribution of these cases in West Bengal from 2019 to 2023.

As culture varies, the definition of rape also varies. The flexibility of this phenomenon can be traced through the definition provided by the World Health Organization (WHO), which states that "rape is a type of sexual assault usually involving a forced unwanted sexual intercourse or other form of sexual penetration carried out against a person without consent of the person".[1]

Sociologists emphasize rape as "a story of a moment by which men can easily impair the dignity of female slaves". Greenfield defined rape as a "way to express male dominance over feminine self and groups of women". Legally, Section 63 of the Bharatiya Nyaya Sanhita (BNS)

defines rape as penetration of the vagina, urethra, mouth, or anus of a woman against her will and without her consent.

After independence, national crime rates were systematically studied in 1953 and compared with metrics from 1951. The Indian Penal Code (IPC) offenses were broadly categorized into three major divisions: violent crimes (such as kidnapping, murder, and rape), property crimes (burglaries, theft), and economic crimes (cheating, counterfeiting). In 1953, the total national incidence of violent crimes was recorded at 49,578. A remarkable rise was subsequently noted in 1961 (55,726), 1971 (124,338), and 1990 (234,338), with a particularly sharp rise in violent crimes observed between 1971 and 1980.[2]

Socio-economic challenges among different populations, gender inequalities, and periodic political unrest in the state create an environment where sexual violence can thrive. Data from the National Crime Records Bureau (NCRB) suggest a significant rise in reported cases in West

Bengal, driven both by an increase in the actual incidence of crime and an increased rate of reporting.[3] Simultaneously, the data point to significant deficiencies in the state's criminal justice system, represented by low conviction rates and prolonged judicial timelines.

The study holds distinct academic and practical significance. First, it aims to clarify the specific factors responsible for the rapid rise in the incidence of reported cases in recent years. Secondly, it endeavours to uncover the primary social and cultural barriers that prevent victims from reporting these offenses to the authorities. Thirdly, it evaluates and compares the state's conviction rates against national averages to highlight systemic judicial gaps. Although retrospective, this study provides findings that are highly representative and relevant to current forensic practice. The resulting data may serve as a baseline for future comparative research, assist in policy formulation, and meaningfully contribute to the regional medico-legal literature.

AIMS & OBJECTIVES OF RESEARCH

The objectives of this research are structured to address critical empirical gaps in regional forensic and criminological literature. Specifically, the study aims to:

1. Identify and evaluate the specific legal, social, and administrative factors responsible for the rapid rise in the incidence of reported rape cases during the years 2019–2023.

2. Identify and analyse the primary social and cultural barriers that deter or prevent victimsfrom reporting sexual violence to law enforcement, particularly in rural jurisdictions.

3. Analyse and compare the judicial conviction rates of West Bengal against the national Indian average to measure the performance and challenges of the regional criminal justice apparatus.

EXPECTED OUTCOMES

The study is expected to provide a comprehensive overview of the patterns, demographic profiles, and geographic distribution trends of rape cases reported during the period 2019–2023.

By converting these retrospective records into clear analytical frameworks, the findings offer insights directly applicable to modern forensic and legal medical practices. Ultimately, these results are expected to serve as an active baseline for legislative comparison, guide healthcare and law enforcement resource allocations, and contribute robust data to the medico-legal literature of this region.

MATERIALS AND METHODS

Study Design and Setting

A retrospective, descriptive research design was conducted from March 2025 to July 2025. The institutional framework for data compilation and analysis was based at the Jhargram Government Medical College and Hospital and the ESI-PGIMSR & ESIC Medical College, Joka.

Inclusion and Exclusion Criteria

• ***Inclusion Criteria:*** The study included all official data, registries, and institutional files concerning reported cases of rape within the geographic boundaries of West Bengal between January 1, 2019, and December 31, 2023, which contained complete demographic, geographic, and judicial outcome profiles.

• ***Exclusion Criteria:*** Legal records or crime registry entries originating outside the designated 2019–2023 timeline were excluded. Cases involving incomplete data arrays regarding the victim's age, district of occurrence, or missing structural information regarding forensic status were omitted from the final statistical analysis.

Data Collection and Operationalization of Aims

To ensure scientific rigor beyond basic demographic reporting, the three primary research objectives were achieved and cross-verified through specific data tracking streams:

1. Tracking Factors Behind Rising Incidence (Objective 1): The 2019–2023 statutory spike was evaluated by auditing changes in reporting mechanisms, assessing the enactment and public implementation of the Bharatiya Nyaya Sanhita (BNS) frameworks, and evaluating annual variations in institutional legal aid access across districts. This data was cross-referenced with national trends to isolate whether the rise represented a true increase in crimes or an increased administrative efficiency in recording cases.

2. Evaluating Social and Cultural Barriers (Objective 2): Cultural barriers and underreporting trends were evaluated via a comparative proxy analysis. By tracking the statistical variance between high-reporting urban districts (with higher access to media and support groups) and low-reporting rural districts and correlating these gaps with documented regional delays in initial case filing, the study mapped out the operational impact of community stigma, family pressure, and fear of social retaliation.

3. Conviction Rate and Judicial Analysis (Objective 3): To evaluate judicial trends, the study extracted finalized disposition metrics from NCRB and State Police records. The state's yearly conviction percentages were calculated against total trials completed and weighed directly against the national average benchmark. Systemic delays were quantified by tracking the average duration between the initial incident, the collection and dispatch of forensic samples to state laboratories, and the final issuance of chemical examiner reports.

4. Forensic and Judicial Challenges : An assessment of structural workflow timelines revealed severe backlogs, with professional forensic sample testing taking an average of 3 to 6 months per case. This lag is primarily driven by institutional staff shortages and limited regional laboratory infrastructure. Reflecting these systemic delays, the final conviction rate for rape cases in West Bengal remained low, hovering at an average of 24% during the study window.[8]

DISCUSSION

The findings of this retrospective study highlight clear temporal trends, demographic patterns, and deep systemic challenges within the criminal justice and forensic framework of West Bengal. The steady rise in reported rape cases from 2019 to 2023 reflects a positive shift in public reporting habits, likely stimulated by enhanced media tracking, robust public awareness initiatives, and localized anti-rape advocacy campaigns.[4-5] However, this trajectory also underscores the ongoing vulnerability of younger women from economically marginalized backgrounds.

Demographic tracking confirms that women aged 18–25 years from low socio-economic backgrounds face disproportionate vulnerabilities. This pattern aligns directly with broader domestic data frameworks; for instance, a landmark study by Tamuli et al. analysing a cohort of sexual assault victims underscored that young adult demographics constitute the most vulnerable layer of society, requiring rigorous, uniform socio-demographic tracking to understand regional crime patterns.[10] Studies conducted in Rajasthan and Bihar reveal similar trends, indicating that restricted educational and economic opportunities directly heighten exploitation risks while limiting access to essential legal and psychological support networks.[6-7]

Geographically, the sharp divide between urban and rural reporting rates underscores the presence of severe systemic barriers. Urban centres show higher reporting rates due to concentrated access to police stations, immediate media exposure, and active civil society organizations. Conversely, rural under-reporting is heavily sustained by community-enforced social stigma, deep-seated mistrust of local law enforcement, and localized political pressures.[5] This urban-rural variance is a well-documented phenomenon across India, matching structural disparities previously identified in Bihar and Madhya Pradesh.[7]

A critical finding of this study is the prolonged processing time for forensic evidence, which directly undermines judicial efficiency, extends trial durations, and depresses conviction rates. With a 3-to-6-month forensic backlog and an average conviction rate of 24% in West Bengal, the state's legal apparatus mirrors broader national challenges.[8] The evolution of gender-based violent crimes in India, as documented by Kaur et al., highlights that delays in comprehensive medical and forensic collection inevitably create critical structural loopholes that defence counsels exploit, leading to depressed conviction rates.[11] For comparison, forensic processing timelines in Uttar Pradesh and Madhya Pradesh average between 5 to 8 months, contributing to a national backlog of over 18,000 cases across state forensic science laboratories.[8] In contrast, countries with modernized forensic infrastructure, such as Canada, maintain average sample

processing timelines of just 1 to 2 months, resulting in shorter trial durations and significantly higher conviction rates. This stark difference emphasizes the urgent need to overhaul India's public forensic infrastructure.

Finally, socio-cultural barriers such as shame, victim-blaming, and fear of social ostracization remain deeply entrenched obstacles to justice, particularly within rural West Bengal. Sociological assessments from rural Punjab reflect identical dynamics, where intense family pressures and fear of community backlash frequently force survivors to suppress reports.[5] While these cultural barriers remain pervasive across South Asia and parts of South Africa, they show a significantly lower operational prevalence in Western nations, showing how cultural frameworks directly shape legal outcomes.[9]

CONCLUSION

This retrospective study provides an empirical evaluation of rape case trends, demographic vulnerabilities, and institutional challenges in West Bengal from 2019 to 2023. The data reveals an upward trend in overall reporting, with young women from low socio-economic backgrounds bearing the brunt of these crimes. A profound urban-rural reporting disparity persists, driven by a combination of rural social stigma and uneven resource distribution.

Furthermore, systemic vulnerabilities within the forensic and judicial sectors-particularly delayed evidence processing and prolonged trial periods-continue to result in low conviction rates. A broader comparison with adjacent Indian states and international frameworks reveals shared structural vulnerabilities: significant under-reporting tied to community stigma, deficient laboratory infrastructure, and persistent socio-cultural barriers.[9]

Challenges Identified

The primary systemic and structural bottlenecks identified by this study include:

- Severe under-reporting of cases in rural jurisdictions driven by social stigma, fear of community retaliation, and family isolation.
- Deficient forensic and judicial infrastructure, marked by prolonged sample processing backlogs and delayed scientific medical testimonies.
- Pervasive socio-cultural barriers that delay initial case registration and limit survivor access to formal legal aid.

RECOMMENDATIONS

Addressing the rising incidence of sexual violence and improving legal outcomes in West Bengal requires a coordinated, multi-faceted strategy. The following actions are urgently recommended:

1. Modernization of Forensic Infrastructure: Expand regional forensic science laboratories and hire specialized personnel to reduce case backlogs, aiming to bring sample processing times down from 6 months to under 30 days.

2. Expansion of Fast-Track Courts: Allocate dedicated judicial resources to fast-track courts specializing in sexual offenses to accelerate trials, minimize survivor trauma, and improve conviction rates.

3. Strengthening Victim Support Systems: Establish accessible, institutionalized medical, psychological, and legal counselling centres within rural hospitals to bypass local socio-political interference.

4. Targeted Community Campaigns: Launch grass-roots educational initiatives focused on breaking down the cultural stigma surrounding sexual violence, with a particular focus on rural panchayats and community leaders.

Limitations of the Present Study

- The primary quantitative data analysed in this paper is restricted to the years 2019 through 2023. More recent administrative records could not be integrated due to technical delays in publication and upload schedules by the NCRB and State Police agencies.
- Despite this temporal boundary, these records provide critical baseline insights into regional medico-legal trends and remain highly relevant for guiding modern forensic practice and public policy.

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Table 1:

Year	No. of Reported Cases	% Increase From Previous Year
2019	1250	-
2020	1375	10%
2021	1440	5%
2022	1610	12%
2023	1675	4%

Table 2: (Percentage of Victim According to Age).

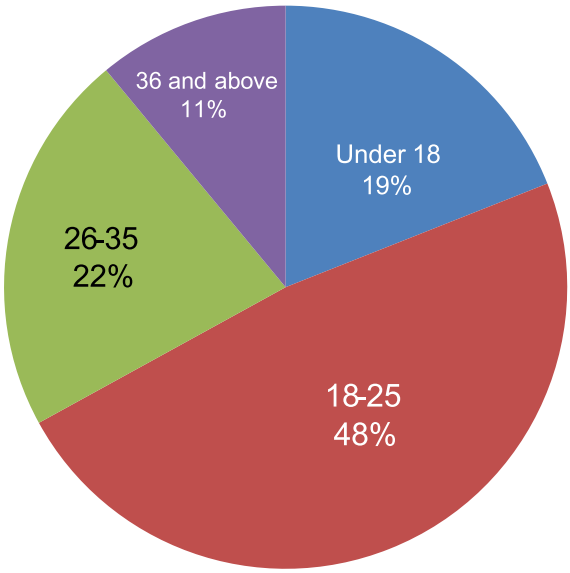

Table 3:

Socio-Economic Status	Percentage of Victim
Lower-Income	67%
Middle- Income	28%
Upper-Income	5%

Table 4: (Percentage of Cases Location-wise)

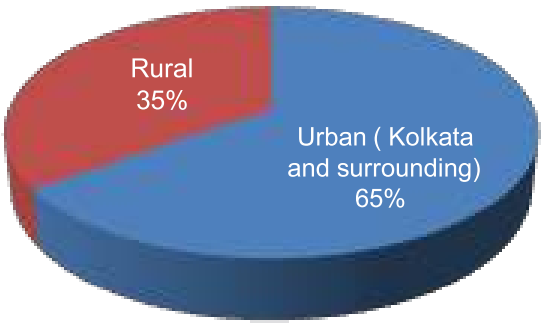

Table 5:

District	No. of Reported Cases (2023)
Kolkata	320
N-24 Paraganas	270
South-24 Paraganas	240
Howrah	200
Purulia	35
Birbhum	30

Table 6:

Year	Average Forensic Processing Time (months)	Conviction Rate	Average Trial Duration (months)
2019	5.0	22%	20
2020	5.5	21%	22
2021	6.0	23%	23
2022	6.2	25%	25
2023	6.5	24%	27

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ORIGINAL RESEARCH PAPER

A Novel, Fluorescent Small Particle Reagent for Detection of latent Fingerprints: A Preliminary Study on Submerged Glass and Metal Surfaces

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ABSTRACT

Introduction: This study reports the development of a novel fluorescent small particle reagent (SPR) for the detection of latent fingerprints on glass and metal surfaces that have been submerged in water for different periods of time.

Materials and Method: Each formulation consists of basic zinc carbonate as the particulate base, a chromophoric dyes (basic yellow 40, trypan blue, crystal violet or rose Bengal) and a commercial liquid detergent serving as the surfactant. The ingredients were mixed in fixed proportion, thoroughly agitated and used as a developing reagent.

Results: Each reagent demonstrates high sensitivity, producing well-defined ridge detail on glass and metal substrates exposed to water for up to110 h duration. At 168 h, the results fade out glass surface. However, compositions based on trypan blue and basic yellow 40 gave moderate quality prints on metal surface. Its fluorescent characteristics enhance the visualization of weak and fragmented impressions, often encountered in forensic casework.

Conclusion: Each formulation is cost-effective, non-toxic, and operationally suitable for routine forensic applications involving submerged items.

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INTRODUCTION

Fingerprint examination is considered one of the most vital procedures in casework investigations. Since latent fingerprints are present in most crime scenes, these serve as the most infallible means of identification of criminals. At any typical crime scene, there are a host of porous and non-porous substrates on which the suspect may leave the finger impressions. The detection techniques should be chosen according to the type of surface, the background color of the surface and the texture of the surface[1]

Small particle reagent is one of the rare techniques that can develop latent impressions on non-porous submerged articles.[2] In conventional small particle reagent technique, a suspension of molybdenum disulfide, in concert with a commercial liquid detergent is used as the developing reagent.[3] However, there are several problems associated with molybdenum disulfide. Firstly, it is a toxic and costly chemical. Secondly, it is dark gray in color and hence it is difficult to develop fingerprints on dark colored items due to lack of contrast. Thirdly, it is non-fluorescent in nature and therefore cannot visualize weak and faint prints.[4] In order to overcome these problems, we have used a modified version of small particle reagent wherein white colored basic zinc carbonate, suspended in a detergent solution, acts as the base material.[5] The contrast problem, on both light and dark surfaces, has been resolved by adding a fluorescent dye to the base material. A host of stains have been used separately in each composition and a comparative assessment has been made with respect to their efficacy in detecting latent impressions. A plausible mechanism for the development process has been proposed. This follows our interest in using luminescent dyes for visualizing latent fingerprints.[6-7]

MATERIALS AND METHOD

A total of forty five latent fingerprint impressions from different donors were impinged on glass surface and an equal number on metallic (aluminium foil) surface. Both the items were submerged separately in water for varying

periods of time: 24 h, 48 h, 72 h, 110 h and 168 h. For each time interval, and for each surface, nine slides were used.

Four different small particle reagent compositions were formulated. Each composition contained 5 g of basic zinc carbonate, 2-3 drops of a commercial liquid detergent and 25 mg of either of the following fluorescent dye: Trypan blue (TB), rose Bengal (RB), basic yellow 40 (BY) or crystal violet (CV). The ingredients were suspended in 75 mL of water and shaken thoroughly.

The surface bearing the latent fingerprint, which was earlier submerged under water, was sprayed with/dipped in the suspension for two minutes. It was thereafter washed under a gentle stream of water and allowed to dry naturally or with the aid of a hair dryer. Clear and sharp fingerprints developed which were photographed using a SLR camera (Model: D3100 Nikon) and stored in JPEG format.

The prints were illuminated under UV light to gauge their fluorescence characteristics. In order to avoid interference by background surface fluorescence character, the illuminated prints were observed through red goggles.

RESULTS

The quality of the developed fingerprints, on both the glass and metallic foil, was assessed on the basis of a scale from 0 to 5[8], as depicted in **Table 1**.

Based on this scale, the assessment of the quality of fingerprints developed on glass and metal surfaces are presented in **Table 2** and **Table 3**, respectively.

The assessment results are displayed in form of graphical representation in **Figure 1**.

Representative fingerprints developed using different small particle reagent composition with respect to varied immersion times in water are shown in **Figure 2**.

On glass, the best results were obtained by basic yellow 40 composition after a lapse of 24 h immersion, followed by crystal violet composition after 48 h immersion. When assessed at 72 h submersion, all the compositions developed the latent impressions to a reasonable extent, paving the way for identification. At 110 h, only basic yellow 40 and crystal violet compositions could develop moderate level impressions. Beyond this threshold, the results were unsatisfactory.

Table 1: Fingerprint Quality Scale.

Grade	Description
0	No visible prints
1	Poor quality, very few visible ridges
2	Moderate quality, a few ridge details visible
3	Reasonable quality, sufficient ridge characteristic identifiable
4	Good quality prints and fingerprint visible
5	Excellent quality, clear prints

Table 2: Quality of Fingerprints Developed on Glass Surface at Various Time Intervals.

Formulation	Immersion Time for Glass Surface				
	24h	48h	72h	110h	168h
TB	4	2	3	1	1
RB	2	2	3	1	1
BY	5	3	3	2	1
CV	3	4	2	2	0

Table 3: Quality of Fingerprints Developed on Metal Surface at Various Time Intervals.

Formulation	Immersion Time for Metal Surface				
	24h	48h	72h	110h	168h
TB	2	2	3	3	2
RB	2	2	3	3	0
BY	3	4	3	3	2
CV	2	3	2	3	1

On metal, basic yellow 40 develops good quality finger impressions after 48 h immersion. The remaining compositions detect reasonable quality prints up to 110 h submersion. Beyond this time interval, the quality rapidly deteriorates.

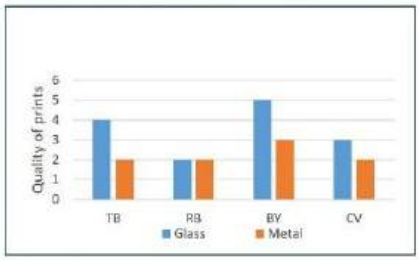
It was observed that better quality fingerprints were obtained longer duration of immersion (72 h) than shorter ones. For example, trypan blue-based formulation developed better quality prints after 72 h submersion than after 24 or 48 h immersion. This anomalous behaviour may be attributed to the bulky organic function in the colorant. This, in turn, delayed the hydrophobic interactions with the detergent and therefore the quality of prints increased with lapse of time.

The proposed method is simple and cost-effective.[9] It does not pose occupational hazard to the user. In fact, the main ingredient, basic zinc carbonate is an astringent and topical antiseptic.

Small particle reagent tags the water immiscible components of sweat, mainly fatty acids and lipids, for developing latent fingerprints. The covalent end of the detergent undergoes hydrophobic interactions with the covalent lipids or fatty acids in sweat. The ionic end of the

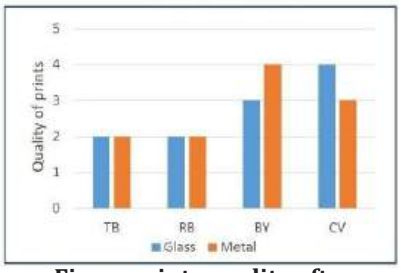
Figure 1: Graphical Representation of the Quality of Developed Fingerprints.

Immersion Time: 24h



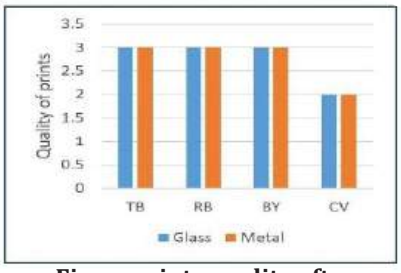
Fingerprints quality after 24h immersion

Immersion Time: 48h



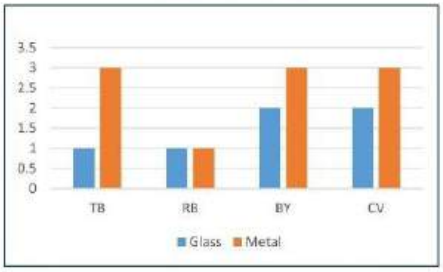
Fingerprints quality after 48h immersion

Immersion Time: 72h



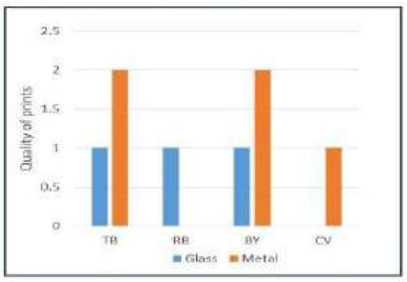
Fingerprints quality after 72h immersion

Immersion Time: 110h



Fingerprints quality after 110h immersion

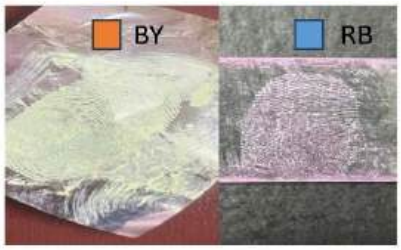
Immersion Time: 168h



Fingerprints quality after 168h immersion

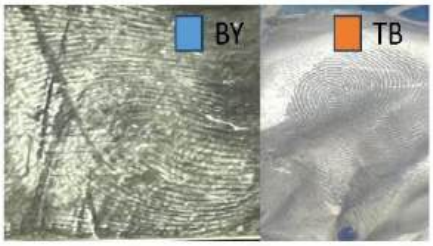
Figure 2: Representative Fingerprints Developed By Different Small Particle Reagents.

Immersion Time: 24h



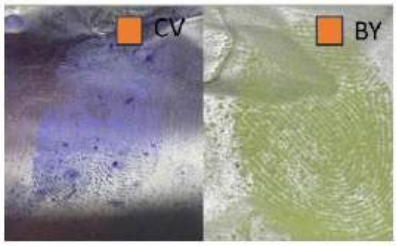
Fingerprints developed after 24h immersion

Immersion Time: 48h



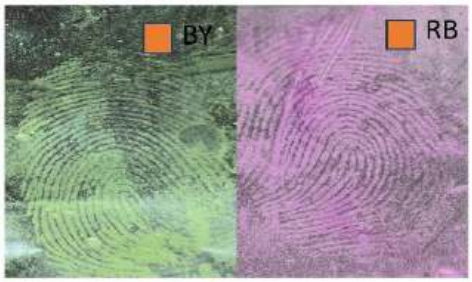
Fingerprints developed after 48h immersion

Immersion Time: 72h



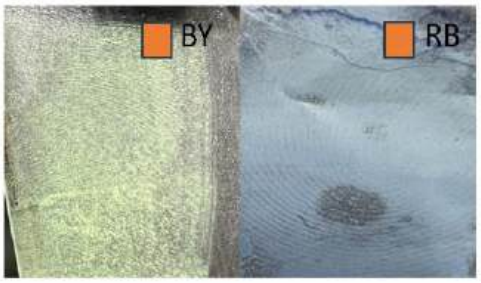
Fingerprints developed after 72h immersion

Immersion Time: 110h



Fingerprints developed after 110h immersion

Immersion Time: 168h



Fingerprints developed after 168h immersion

Glass **Metal**

detergent enters into hydrophilic interactions with basic zinc carbonate. The hydrophobic-hydrophilic complex gets deposited on the ridges, while the stain gets adsorbed on the complex, rendering visibility to the latent impressions.

A limitation of this research is that poor quality finger impressions are obtained if the surface in question is buried under wet soil for different periods of time.

CONCLUSION

At times, an investigator may come across crime evidence which has been deliberately or accidentally soaked in water. Such evidence is difficult to process for fingerprint development by conventional techniques. However, under such circumstances the small particle reagent method may be instituted to detect fingerprints on non-porous items. We have tested this method using a few fluorescent small particle reagents and found that it is possible to procure reasonable to good quality fingerprints on glass and metallic surfaces even after 72-110 h submersion. The formulations are cost effective and non-hazardous. For this reason, we propose that these may be used in actual casework investigations.

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ORIGINAL RESEARCH PAPER

The Sociodemographic Landscape of Suicide: 1 Year Study of Suicide Cases in a Tertiary Care Center in the state of Uttarakhand

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ABSTRACT

Introduction: This retrospective observational study examines the sociodemographic landscape and etiological drivers of suicide in Dehradun, Uttarakhand, covering a one-year period from January 1st to December 31st, 2023. Analyzing 282 fatal suicide cases from medicolegal autopsies, the research identifies a significant male predominance (68.1%) with a male-to-female ratio of 2.1:1. The young adult cohort (15–30 years) emerged as the most vulnerable demographic, accounting for 61.0% of cases. Notably, the study found a high incidence among formally educated individuals, with undergraduates representing 39.7% of the sample. While married individuals constituted the largest marital group (57.4%), the majority of victims belonged to nuclear families (43.3%) and urban domiciles (87.9%). Hanging (60.3%) and self-poisoning (29.8%) were the primary mechanisms of death. The leading precipitating factors were identified as financial loss or debt (23.4%) and family disputes (22.7%), suggesting that the pressures of modern urban life and interpersonal conflict are critical drivers in the region.

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INTRODUCTION

The WHO defines suicide as "the act of deliberately killing oneself".[1] Suicide remains a critical global public health challenge, with > 720,000 people dying by suicide every year, ranking as the third leading cause of death among 15–29-year-olds globally as of 2021. Beyond the completed acts, for every person who dies by suicide, many more make attempts, which serves as a major risk factor for future self-harm.[1]

Based on the latest 2023 NCRB data, India recorded a total of 171,418 suicides, reflecting a marginal increase of 0.29% from the previous year, though the overall suicide rate dipped slightly. The lowest income group accounted for 66% as economic and social vulnerabilities continue to be the key causes. The situation is most severe among young adults between the ages of 18 and 45, who account for two-thirds of suicide. Family problems and chronic or mental disorders continued to be the most reported reasons of such catastrophes, with Maharashtra, Madhya Pradesh, and Tamil Nadu reporting the largest numbers geographically.[2]

The number of suicides in Uttarakhand increased from 946 in 2022 to 1,027 in 2023, making the state's suicide rate 8.9 per 100,000 people. This is still less than the 12.3 national average. Family conflicts, chronic or mental disease and marital problems are the state's main drivers, which are similar to national trends, with daily wage earners and independent contractors being identified as high-risk.[2]

Suicide rates increased during the COVID-19 pandemic as financial crises, loneliness, social boycott, pressure to be placed under quarantine, inability to return home due to lockdown, lack of alcohol, etc. have all been connected to suicide.[3]

Aims and objectives- The research was initiated with the primary aim to establish an understanding of local suicidal behavior to determine the incidence of suicide and identify the precipitating factors contributing to them. The study evaluates the specific method of suicide, the type of poisoning involved (if applicable) and the underlying

precipitating factors.

MATERIALS AND METHOD

This retrospective observational study was conducted in the Department of Forensic Medicine and Toxicology at Government Doon Medical College and Hospital, Dehradun, with data collection done at Pandit Deen Dayal Upadhyaya (Coronation) Hospital. During the one-year study period from January 1st, 2023, to December 31st, 2023, a total of 1,297 medicolegal autopsies were performed at Coronation Hospital among which 282 fatal suicide cases across all age groups were identified and included for analysis.

The inclusion criteria comprised all confirmed fatal suicides while the exclusion criteria included decomposed bodies and unidentified remains cases with obscure/undetermined cause of death. Data were then gathered from primary medicolegal documents, including autopsy reports and police inquest papers (Panchnama) to analyze parameters such as age, gender, education, occupation, marital status, type of family, domicile, socio-economic status (SES), manner of death and location of death.

The study was approved by the Institutional Ethics Committee. The resulting data were tabulated in Microsoft Excel and analyzed using descriptive statistics and chi-square tests to determine the statistical significance of associations between gender, manner of death and psychological triggers.

RESULTS

Gender- On analysis of the study population (N=282) reveals a significant gender disparity and a distinct concentration within specific age cohorts. Males constituted the majority of the sample, accounting for 68.09% of cases, while females represented 31.91% resulting in a male-to-female ratio of 2.1:1.

Age- Males comprised 68.09% of the sample, generating a male-to-female ratio of 2.1:1 **(Figure 1)**. The young adult age (15–30 years) was the most vulnerable group (61.0%), with individuals under 45 years representing 87.2% of all fatal cases **(Table 1)**. The age of the subjects in the study population (N = 282) ranged from 10 to 75 years with a mean age of 30.93 ±10.48 years.

Education- Most individuals were educated, with 72.69% completing at least senior secondary schooling. Undergraduates formed the largest single cohort i.e 39.96%. Individuals with lower educational status were less represented.Those with primary or upper primary education made up 14.89% of the sample, while illiteracy was rare at only 1.77%. Only a small portion of the total sample had postgraduate qualifications or higher.

Occupation: Occupational analysis reveals a heavy concentration in private and commercial sectors **(Figure 1)**. Self-employed individuals predominated (31.91%), followed by private service employees (24.82%) and students (21.28%). Agricultural laborers and unemployed individuals accounted for minimal percentages (<5% each). Housewives constituted 11.70% while government

Figure 1: Distribution of Suicide Victims Based on Occupation (N=282) in %

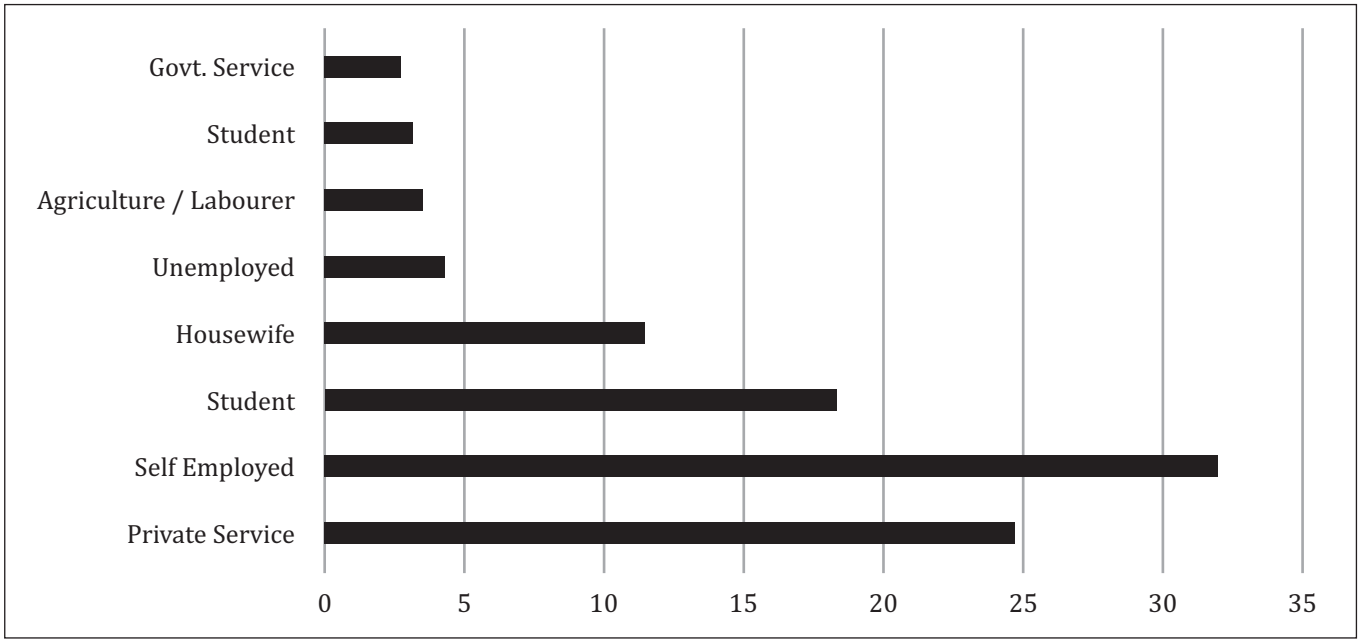
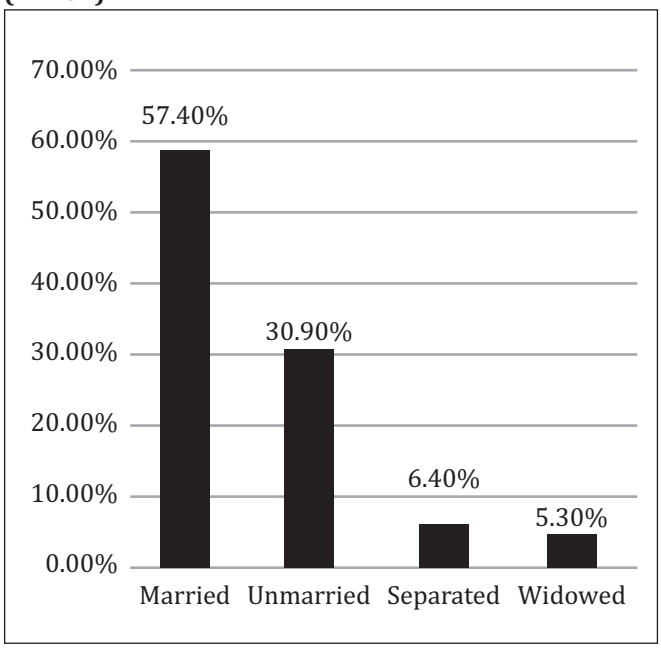


Table 1: Age Distribution of Suicide Victims (n=282)

Age (Years)	Total (n=282)	Percentage (%)
<15	11	3.9
15-30	172	61
31-45	74	26.2
46-60	20	7.1
>60	5	1.8
Total	**282**	**282**

Figure 2: Marital Status Among the Suicidal Victims (N=282)



service was the least represented group (2.48%).

Marital Status: Figure 2 shows the analysis of marital status across the study population (N=282) identified married individuals as the largest group, representing 54.96% while unmarried individuals constituted the second largest group. Also, the study records the presence of victims who were separated (8.87%) or widowed (5.32%), which represented smaller segments of the study population.

Family Type: Nuclear family predominated among victims (43.26%), followed by single-member households (24.82%; **Figure 3**). Joint families represented the least frequent cohort (7.09%).

Domicile: Here the distribution of the suicide victims (N=282) were more focused in metropolitan areas with 87.94% of the population originating from urban domicile. In contrast, victims from rural backgrounds consisted 12.06% of total sample.

Socioeconomic Status (SES): Socioeconomically, the lower income status prevailed, with upper-lower (46.10%) and lower classes (21.99%) collectively accounting for over two-thirds of the total sample (68.09%; **Figure 4**).

Manner of Death: Table 2 shows that hanging is the most prevalent method accounting for 60.28% of all recorded cases. Self-poisoning (copper sulphate, aluminum phosphide and organophosphate) was utilized in 29.79% of the incidents. High lethal methods were recorded in smaller frequencies, including self-immolation (n=16,

Figure 3: Distribution of Suicide Victims Based on Family Type (N=282) in %

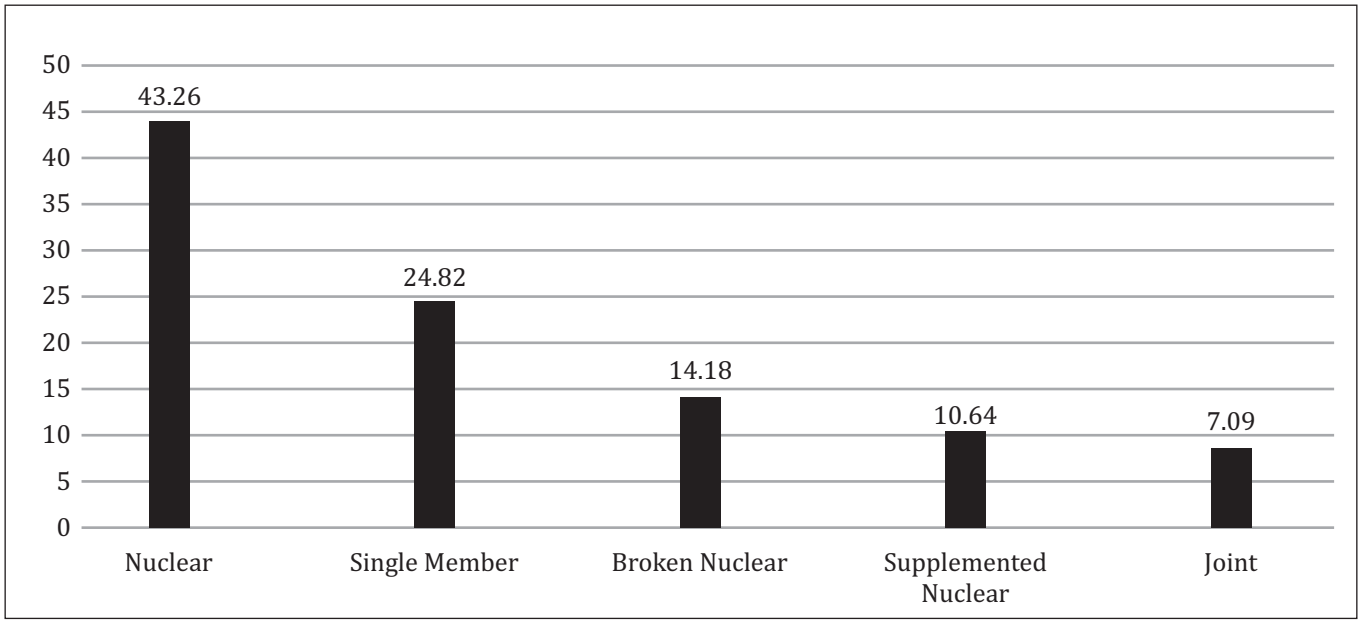


Figure 4: Distribution of Suicide Cases by Socioeconomic Status in % (N=282)

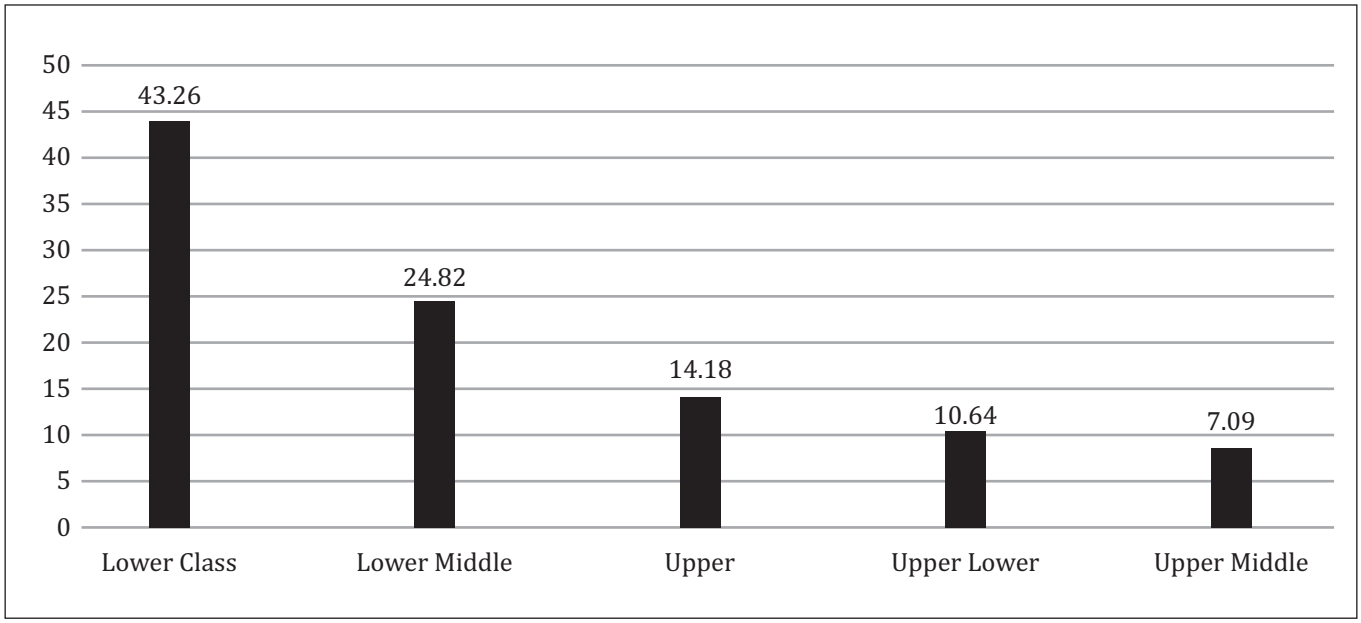


Table 2: Distribution of Suicide Cases by Manner of Suicide (N=282)

Manner of Suicide	Male (n=192)	Male (%)	Female (n=90)	Female (%)	Total	(%)
Hanging	137	48.58	33	11.70	170	60.28%
Self-Poisoning	27	9.57	57	20.21	84	29.79%
Self-Immolation	16	5.67	0	0	16	5.67%
Railway Suicide	8	2.82	0	0	8	2.84%
Fall from Height	4	1.41	0	0	4	1.42%
Total	**192**	**68.09**	**90**	**31.91**	**282**	**100.00%**

Table 3: Distribution of Suicide Cases by Precipitating Factors (N=282)

Precipitating Factor	Male (n=192)	Male (%)	Female (n=90)	Female (%)	Total (n)	(%)
Financial Loss/Unemployment	73	38.0%	0	0.0%	73	25.89%
Family/Property Dispute	40	20.8%	28	31.1%	68	24.11%
Marriage Related	29	15.1%	17	18.9%	46	16.31%
Chronic/Mental Illness	20	10.4%	12	13.3%	32	11.34%
Romantic Entanglements	13	6.8%	16	17.8%	29	10.28%
Academic Failure	6	3.1%	15	16.7%	21	7.45%
Substance Abuse	11	5.7%	2	2.2%	13	4.61%
Total	**192**	**68.09**	**90**	**31.91**	**282**	**100.00%**

5.67%), railway suicide (n=8, 2.84%), and fall from height (n=4, 1.42%).

To determine if strong association between sex and manner of death exists, a Chi-Square test was performed:

- Chi-Square Statistic (x^2): 75.295
- Degrees of Freedom (df): 4
- p-value: < 0.001 (Specifically 1.72 x 10-15)

The result is highly statistically significant ($p < 0.05$).

Precipitating Factors: Table 3 shows us the analysis of precipitating factors reveals a diverse landscape of stressors, primarily led by financial loss/ unemployment and family/property disputes. Marriage-related issues and chronic/mental illness also emerged as reasons behind suicidal behavior. The data highlights the impact of romantic entanglements and career-related stress

respectively, contributing to the overall mortality.

To evaluate if the precipitating factors are significantly associated with gender:

- Chi-Square Statistic (x^2): 61.844
- Degrees of Freedom (df): 6
- p-value: < 0.001 (Specifically 1.89 x 10-11)

The results demonstrate a highly significant relationship between sex and precipitating factors.

DISCUSSION

Age: Our observation revealed that the young adult cohort (15–30 years) was the most vulnerable group of the total cases, followed by the 31 to 45 age group. These findings coincide with the NCRB 2023 data.[5] Our findings correlate with Rawat et al and Verma et al who found suicide to be more prevalent among 18-30 years age group.[6-7] Badrinarayana et al found in his study that individuals in the age group of 10 to 30 years were more prone to suicidal attempts and Halliburton observed that suicide rates above 45 are significantly higher than the national average. The main reasons were recognized as Mental illness and interpersonal relationships.[8-9]

Sex-In this study a sex disparity was observed, with males constituting the majority of the sample. Male victims accounted more than females resulting in a distinct male-to-female ratio of 2.1:1. This male predominance is consistent with Kanchan T et al. (2.8:1) and Soman et al., reflecting global patterns of completed suicide.[10-11] However, it contrasts with studies by Shukla et al,[12] and Banerjee et al,[13] where women were more susceptible to suicide due to socio-cultural dynamics in parts of India.

Education: A majority of the subjects in this study were either undergraduates or had completed senior secondary schooling. This correlates with the findings of Latha et al.,[14] concluding that academic awareness does not always serve as a protective factor against suicidal behavior in Indian context.[14] However recent NCRB suggests that highest number of suicide victims possesses educational status of matriculation or below.[2] This disproportion of undergraduates in our cohort compared to the national average may be due to stressors such as high academic competition, career uncertainty and the overly ambition in the Dehradun district. While Lorant et al. linked low educational attainment to male suicide in Europe, Hem et al. revealed that high academic achievements (e.g., physicians and graduates) faced higher risk due to professional pressures.[15-16]

Occupation: Our study observed that most suicide victims were self-employed followed by private sector and students correlating with research by Sunil Srivastava et al.[17] The private sector seems to be quite vulnerable as there is no assurance of job security. While the NCRB 2023 reports daily wage earners and farmers primarily at risk,[2] our data shows a shift toward students and service professionals. This suggests that in Dehradun, urban and academic stressors may outweigh that of agricultural distress seen in other parts of the country. Among women in this study, housewives represented a major percentage of suicides similar to findings by Dandona et al.[18] with marital conflicts and dowry-related stress being the main reasons.

Marital Status: The analysis of marital status across the study population identifies married individuals as the largest demographic while unmarried individuals constitute the second largest. The findings align with the 2018 Lancet Global Burden of Disease study, highlighting that marriage in India does not offer "protective effect" seen in Western.[19] The 2023 Lancet report found that currently married women represent over 63% of female suicide deaths.[20] For men, the findings align with NCRB data,[2] adding to the "breadwinner burden," where failure to meet economic expectations in high pressure environment leads to higher fatality, hence aligning with research by Sheikh et al.[21] Social isolation after the collapse of marriage is a critical risk factor seen among separated, divorced and widowed in this study.

In Dehradun, this risk is amplified by emotional strain and reduced concept of joint family, suggesting that family life is no longer a safe haven from the outside stress in the modern environments and why counselling and interventions are necessary to help survive.

Family Type: This study uses the classification system proposed by Niranjan et al.[22] Nuclear families represented the largest category. These findings prove similar to M.K. Srivastava's research, reflecting transitioning from joint and extended family structures to nuclear family. This shift raises questions about changing social connectivity and support system.[23] The absence of an extended support system during crises can leave people in nuclear setups more vulnerable to stress-induced vulnerability. Single-member households representing the second largest category strongly supports Durkheim's theory of "Egoistic Suicide," i.e individuals with low social connectivity and absence of "significant others" increases risk of suicidal

behavior.[24] The fact that only 7.09% of victims came from joint families suggests that this traditional concept may act as a protective factor. The shared responsibility and presence of multiple relatives can provide a safety net that prevents isolation.[25] This contrasts with the results found by Sahu et al, where majority of suicide victims were said to be from joint families.[26]

Domicile: Findings reveals majority victims originating from urban domicile aligning with NCRB data and Chavan Singh, et al,[2,27] but contradicted studies who reported higher rural prevalence due to agricultural stress and displaced migrants.[28-29] Urban predominance may be attributed to the erosion of community support systems, social isolation and high cost of living. Findings also align with Reddy's observation linking them to higher prevalence of mental health disorders in urban populations.[30]

Socio-Economic Status (SES): We have used Modified Kuppuswamy classification to determine the SES of each victim.[31] Our study observed that lower strata prevailed, with upper lower and lower classes comprising majority of sample, aligning with previous studies.[32-33] Southern states report higher suicide rates compared to northern states attributing to factors like higher socioeconomic status and higher literacy.[34]

Manner of Suicide: Our study identifies hanging as the most prevalent method followed by self-poisoning aligning with NCRB 2023 data,[2] as well as previous studies.[32,35] However Ambade et al, observed poisoning as the leading method of suicide.[36] A significant direct correlation between sex and manner of death as suggested by chi square analysis ($p < 0.001$) seen.

Hanging remained the dominant choice for both genders in this study; poisoning showed a slightly higher relative frequency among female, similar to findings by D Souza et al.[37] Other lethal methods were only seen in men concluding that men allow a lesser window of survival compared to females. Victims of hanging often interpret it as rapid and painless method that preserves body's integrity and minimizes trauma for survivors, also driven by easily accessible materials and minimal skill.[38]

Precipitating factors –Our study proves a direct correlation between sex and precipitating factors as suggested by chi square analysis ($p < 0.001$). These findings suggest that while family-related issues affect both sexes, financial pressure appear to be a male-dominated while academic and romantic stressors are higher in females.

For men, financial loss / unemployment represents the largest trigger due to societal expectation of the male as primary provider, aligning with Lorant et al.'s observations.[39] Marriage related and family disputes are main drivers in females, accounting for 60% of all female suicides aligning Rakhi Dandona's study.[22]

Other triggers like academic failure, romantic entanglements and substance abuse creates sense of hopelessness and impulsivity reducing rational thinking. Alessi et al identified a potential suicide risk specific to men characterized by dispositional antagonism and a profound experience of defeat highlighting complex psychological dynamics behind suicide attempts.[40]

CONCLUSION

This study concludes with presence of gender paradox in the community. Men's reluctance to express emotional unlike women who maintain strong connections within their communities hence seek help, share emotional burdens with peers and utilize support systems. Men tend to choose more violent methods while women frequently opt methods that have a higher window for medical intervention. The findings emphasize the need for :–

- Strengthening mental health infrastructure at primary healthcare level.
- Promoting mental health education and destigmatization campaigns.
- Implementing support systems for high-risk groups including youth, unemployed individuals and homemakers.
- Encouraging family counseling and psychological support in schools and colleges.

Conflict of Interest/Source of Funding: Nil

Limitations: The sample is drawn only from tertiary autopsy center within the Dehradun region hence the socio-demographic trends and patterns identified may not fully represent the wider rural or remote populations of Uttarakhand.

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ORIGINAL RESEARCH PAPER

Exploring Sexual Dimorphism in the Sternal End of Fourth Rib Through Discriminant Function Analysis

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ABSTRACT

Introduction: Establishing the biological profile of an unidentified person requires determining sex from the human skeleton. When human remains are found following large-scale tragedies like armed conflicts, terrorist attacks, plane crashes, or war-related crimes, they are frequently badly deteriorated, broken, or damaged, leaving only a few bones or pieces of bone. Identifying biological traits, particularly the person's sex, becomes crucial in such circumstances. The pelvic girdle, long bones, and skull have been the main focus of sex determination based on sexually dimorphic features. Experts must extract as much information as they can from the few and diverse resources available when dealing with partial skeletal remains. As a result, in forensic anthropology, even a single bone, like the sternal end of the fourth rib, is highly valuable. The current study employs statistical analysis of morphometric characteristics such superior inferior height and anterior posterior breadth to examine the sexual dimorphism of the sternal end of the fourth rib.

Material and Methods: As a result, in forensic anthropology, even a single bone, like the sternal end of the fourth rib, is highly valuable. The current study employs statistical analysis of morphometric characteristics such superior inferior height and anterior posterior breadth to examine the sexual dimorphism of the sternal end of the fourth rib. Ninety-nine medico-legal autopsy cases were analyzed. A sliding vernier caliper was used to measure the maximum anterior-posterior breadth and maximum superior-inferior height to the nearest tenth of a millimeter after the sternal end of the right fourth rib was carefully removed. Statistical analysis was used to assess the accuracy of sex estimation from obtained data. F-statistics were used to identify gender differences, followed by discriminant analysis with the Standard Canonical Discriminant Function coefficient. The sensitivity and specificity were used for the differentiation of gender by Receiver Operating Curve [RoC] with AUC and cut-off value. In all of the statistical techniques, the probability value of 0.05 was regarded as the significant level.

Results: For the young age group, the old age group, and the total groups, the stepwise discriminant function analysis was determined. To determine discriminant scores, the conical discriminant function coefficients were utilised. Significant sexual dimorphism was revealed by the morphometric analysis, with males showing larger measurements than females. Statistical analysis confirmed that MSIH and MAPB were reliable parameters for distinguishing between sexes, with high accuracy rates. Mean difference of the maximum superior inferior height of the sternal end of right 4th rib was higher in males as compared to females in all three groups. Superior inferior height (SIH) of sternal end of 4th rib is the best discriminant of sexing of the rib as it is showing up to 91.7% accuracy compared to anterior posterior breadth (APB) with 81.3% accuracy.

Conclusion: The superior-inferior height (SIH) of the sternal end of the fourth rib proved to be the best discriminant for sex determination, demonstrating an accuracy of up to 91.7%, compared to the anterior-posterior breadth (APB), which showed an accuracy of 81.3%. In conclusion, the sternal end of the fourth rib proves to be a valuable skeletal indicator for sex determination, especially in cases where no other bones are available. Future studies could incorporate other factors, such as the pit depth of the fourth rib, and extend the research to include other ribs.

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INTRODUCTION

In forensic anthropology, identification of unknown persons is established by the use of anatomical, biological, and osteological information, mostly through the examination of human skeletal remains. The necessity of addressing matters pertaining to missing persons, unidentified dead bodies, and crime investigations has highlighted the significance of forensic anthropology in mass disasters and other cases.[1-2]

In order to identify human remains, sex determination is an essential component of forensic anthropology. Forensic examinations frequently need to determine the deceased's sex in circumstances involving unidentified or mutilated bodies.[3] One of the most important aspects of determining the biological profile of an unidentified person is determining sex from the human skeleton. When human remains are found following large-scale tragedies like armed conflicts, terrorist attacks, plane crashes, or war-related crimes, they are frequently severely damaged, decaying, or fractured, leaving only a few bones or pieces of bone.

In such situations, identifying biological characteristics, especially the individual's sex, becomes essential.[4] The pelvic girdle, long bones, and skull have been the main focus of sex determination based on sexually dimorphic features. Complete sex estimation is attainable utilizing the entire skeleton, 95% when only the pelvis is available, 98% with skull and pelvis, 92% with long bones, and 98% with long bones and pelvis.[5] In addition to the skull, pelvis, and long bones, several investigations have demonstrated that axial skeleton components such the vertebrae,[6-7] sternum,[8–10] and metacarpal[11] also yield accurate results for sex determination.

Experts must extract as much information as they can from the few and diverse resources available when dealing with partial skeletal remains. As a result, in forensic anthropology, even a single bone-like the sternal end of the fourth rib-has substantial significance.[12]

Sexual dimorphism has been investigated in the sternal end of the fourth rib. It displays population-specific morphometric traits, just like other skeletal remains.[13] It is crucial to remember that, similar to other forensic anthropology techniques, sex determination from the fourth rib is only an estimate with individual variation. Genetics, nutrition, and overall health all have an impact on the accuracy of these estimations.

Forensic anthropologists frequently develop age and sex estimation methodologies based on reference standards derived from big population studies. However, some methods are more accurate for specific populations and may have limitations. Furthermore, the reliability of sex determination methodologies varies by demographic and ethnic group.

The current study aims to analyze the sexual dimorphism of the sternal end of the fourth rib using statistical analysis of morphometric variables such as superior inferior height and anterior posterior breadth. The majority of forensic anthropological studies have been conducted on preserved and dried bone samples, but the data or results obtained from these studies are rarely useful for practical purposes because most dismembered, mutilated, or unknown fragmentary remains arriving for autopsy have some soft tissue attachment. Since the sternal end of the fourth rib may be readily removed and dissected from a relatively fresh or decomposing cadaver, we tried to bridge this gap in our study by taking measurements from fresh bones.

MATERIALS AND METHODS

A cross-sectional observational study was undertaken in a tertiary care center in southern Haryana, India. All medico-legal autopsy cases over one year were included using purposive sampling, following ethical approval (SHKM/IEC/2022/82, dated 21/10/2022). 99 medico-legal autopsy cases in all were examined. The study examined cases with a known sex and age more than 18. Excluded were cases where the sternal ends of the fourth rib were morphologically abnormal, broken, or malformed. After obtaining consent from the deceased's legal guardian, the sternal end of the right fourth rib was removed during the autopsy.

Age was taken from the official records. Using a rib cutter, the rib was sliced at two locations-three centimetres inside and five centimetres outside the costochondral junction-cleaned, dried at room temperature, and measured without being preserved after the autopsy. A sliding Vernier calliper was used to record two key measurements, maximum anterior-posterior breadth (MAPB) and maximum superior-inferior height (MSIH), to the closest tenth of a millimetre. The greatest distance between the most superior and inferior locations at the end of the rib was used to calculate the maximum superior-inferior

height. The distance between the most anterior and posterior sites at the end of the rib was used to calculate the maximum anterior-posterior breadth. Each measurement was recorded thrice by the same observer, and the average was used. To account for age effects on sexual dimorphism, samples were analyzed in different age groups.

IBM SPSS Statistics for Windows, Version 29.0 (Armonk, NY: IBM Corp.) was used to evaluate the data after it was entered into Microsoft Excel 2016. For categorical variables, frequency analysis and percentage analysis were employed to explain the data descriptive statistics; for continuous variables, the mean and standard deviation were utilised. The Independent sample t-test was used to determine whether there was a significant difference between the bivariate samples in Independent groups.

F-statistics was used to determine the significance between males and females, and then the Standard Canonical Discriminant Function Coefficient was used for discriminant analysis. The accuracy of the classification was determined using the structural matrix. The Receiver Operating Curve [RoC] with AUC and cut-off value was utilised to differentiate gender based on sensitivity and specificity. The probability value of 0.05 is regarded as the significant level in all of the aforementioned statistical tools.

RESULTS

In the present study, 99 subjects were included in the study with fulfillment of inclusion and exclusion criteria. Slight male predominance was observed in the study subjects as 51 subjects (51.51%) were males and 48 subjects (48.48 %) were females. The age of the subjects varied from 18 years to 70 years, with a mean of 32.2 ± 13.75 years. Males averaged 35.2 ± 14.2 years, while females averaged 31.2 ± 13.3 years. The study's participants were divided into three groups in order to manage the impact of age on sexual dimorphism, i.e. young age group (18-30 years), old age group (31-70 years) and total (18-70 years).

The categorization of subjects based on age groups is depicted in **Table 1**. Across all categories, the independent sample t-test revealed no statistically significant gender differences in age. Young age group: t 0.125, p-value 0.901; old age group: t 0.246, p-value 0.807 and total: t 1.432, p-value 0.155. Since all p-values were greater than 0.05, gender differences in age was not significant.

The maximum superior-inferior height (MSIH) among males and females across different age groups is depicted in Table 2. The MSIH for males and females in various age groups was compared using an independent sample t-test. In every group, the results showed a highly significant difference (p-value < 0.01) **(Table 2)**.

The maximum anterior-posterior breadth (MAPB) of males and females in various age groups was also compared using an independent sample t-test. In both the old age and total groups, the results showed a highly significant difference (p-value < 0.01) between males and females **(Table 3)**.

Table 1: Categorization of Subjects based on Age Groups.

Group	Gender	Number of Cases	Minimum Age (Years)	Maximum Age (Years)	Mean Age (Years)
Young Age Group (18-30 years)	Male	20	18	30	22.6
	Female	29	18	30	22.7
Old Age Group (31-70 years)	Male	31	32	70	43.3
	Female	19	31	67	44.2
Total (18-70 years)	Male	51	18	70	35.2
	Female	48	18	67	31.2

Table 2: Comparison of MSIH between Young, Old & Total between Males and Females by Independent Sample t-test.

Group	Gender	N	Mean (mm)	SD (mm)	t-value	p-value
Young Age Group (18-30 years)	Male	20	16.2	1.5	9.270	0.0005 **
	Female	29	12.6	1.0		
Old Age Group (31-70 years)	Male	31	16.9	1.4	9.343	0.0005 **
	Female	19	13.9	1.1		
Total (18-70 years)	Male	51	16.6	1.5	14.216	0.0005 **
	Female	48	12.9	1.1		

*** Highly Statistical Significance at p < 0.01 level; MSIH: Maximum superior-inferior height*

Table 3: Comparison of MAPB between Young, Old & Total between Males and Females by Independent sample t-test.

Group	Gender	N	Mean (mm)	SD (mm)	t-value	p-value
Young Age Group (18-30 years)	Male	20	6.9	2.6	2.481	0.022 *
	Female	29	5.4	0.7		
Old Age Group (31-70 years)	Male	31	6.9	0.7	5.695	0.0005 **
	Female	19	5.8	0.6		
Total (18-70 years)	Male	51	6.9	1.7	5.096	0.0005 **
	Female	48	5.5	0.7		

** Significant at p-value < 0.05; ** Highly Statistical Significance at p-value < 0.01; MAPB: Maximum anterior-posterior breadth*

Table 4: Canonical Discriminant Function Coefficients.

Gender	Function and Variables	Standardized Canonical Discriminant Function Coefficients	Canonical Discriminant Function Coefficients*	Structure Matrix	Functions at Group Centroidsa
Young age group	**APB**	.004	.002	.294	-1.175 a
	SIH	.999	.803	1.000	1.703 a
	Constant	-11.297			
Old age group	**APB**	.048	.071	.609	-1.689 a
	SIH	.971	.727	.999	1.035 a
	Constant	-11.740			
Total	**APB**	.021	.016	.361	-1.461 a
	SIH	.993	.748	1.000	1.375 a
	Constant	-11.167			

**: coefficients used to calculate discriminant scores; a: Positive centroids define male and negative female; APB: Anterior-posterior breadth; SIH: Superior-inferior height*

Discriminant scores were computed using the canonical discriminant function coefficients. Discriminant score formulas were derived separately for young age group, old age group and total subjects. A positive and negative centroid defines male and female respectively **(Table 4)**.

The formulas for the discriminant scores are:

Young age group- (APB x 0.002 + SIH x 0.803 – 11.297); Old age group- (APB x 0.071 + SIH x 0.727 – 11.740);

Total subjects- (APB x 0.016 + SIH x 0.748 – 11.167).

The stepwise discriminant function analysis of Wilks' Lambda and Equivalent F ratios was performed for MAPB and MSIH across different age groups **(Table 5)**.

Table 5: Stepwise Discriminant Function Analysis for Mapb and Msih Across Different Age Groups.

Groups	Variable	Wilks' Lambda	Equivalent F ratio*
Young Age Group	MAPB	.847	8.488
	MSIH	.324	98.020
Old Age Group	MAPB	.597	32.435
	MSIH	.355	87.289
Total	MAPB	.789	25.972
	MSIH	.328	198.691

**: F ratio shows differences between the genders*

When comparing MSIH and MAPB between males and females, the Receiver Operating Characteristic (ROC) curve analysis produced statistically significant findings. With an Area under Curve (AUC) of 0.970 (95% CI: 0.944-0.997, p = 0.0005), a cutoff value of 14.5, sensitivity of 90.2%, and specificity of 91.7%, MSIH demonstrated outstanding diagnostic performance.

Similarly, MAPB had a cutoff value of 6, sensitivity of 74.5%, specificity of 81.3%, and an AUC of 0.852 (95% CI: 0.779-0.925, p = 0.0005) **(Table 6, Figure 1)**. The accuracy of prediction of sex varied by gender and age group. The correct prediction rate was higher for females (96.60%) in young age group, while it was higher for males (93.50%) in old age group **(Table 7)**.

Table 6: Comparison of MSIH & MAPB with Gender Diagnosis using RoC Curve.

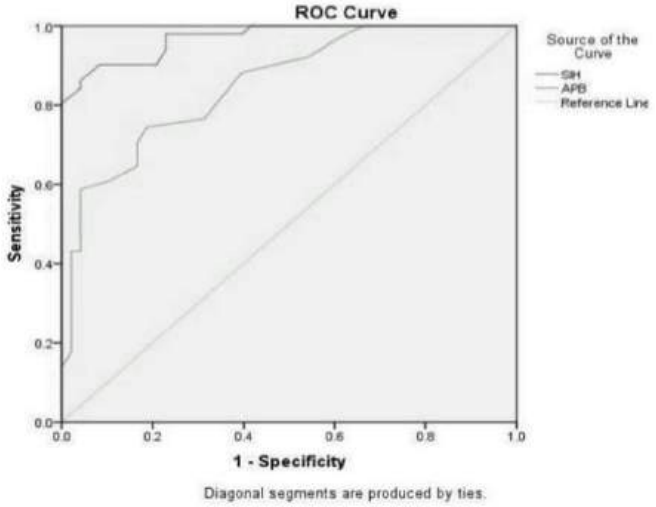
Test Result Variables	Area	Std. Error	p-value	95% C.I	
				LB	UB
MSIH	.970	.014	0.0005 **	.944	.997
MAPB	.852	.037	0.0005 **	.779	.925

*** Highly Statistical Significance at p < 0.01 level; MSIH: Maximum superior-inferior height; MAPB: Maximum anterior-posterior breadth*

Table 7: Percentage of Correct Prediction of Sex.

Age Group	Total	Female		Male		Average
	N	N	%	N	%	%
Young Age Group	49	28/29	96.60%	15/20	75.00%	85.80%
Old Age Group	50	16/19	84.20%	29/31	93.50%	88.85%
Total	99	44/48	91.70%	45/51	88.20%	89.95%

Figure 1: RoC Curve Demonstrates Gender Diagnosis using SIH & APB.
SIH: Superior-inferior height, APB: Anterior-posterior breadth



DISCUSSION

Medico-legal autopsies determine the cause, manner, and time of death while aiding identification, which becomes challenging with mutilated or fragmented remains. Sex determination is a key step in forensic identification. This study, the first in this area, used the sternal end of the fourth rib to examine 99 cases ranging in age from 18 to 70. To differentiate between the sexes, measurements of anterior-posterior breadth (APB) and superior-inferior height (SIH) were evaluated using discriminant function analysis. Discriminant function analysis has been used in forensic osteological studies to improve sexing accuracy using several bones. A researcher in the Spanish population also performed discriminant functions for sex estimation using the rib necks.[14] In Mexico City, Munoza et al. estimated sex and age at death using the sternal end of the fourth rib. From univariate and multivariate discriminant functions, they found that the height and width of the sternal end of the rib were sexually dimorphic (p-value 0.000) and permitted a proper sex assignment in 73.3% to 84% of the instances. They came to the conclusion that the sterna end of the fourth rib might be used to estimate age at death and sex in skeletal remains.[15]

Sweilum et al. determined sex from the sternum and fourth rib measurements using thoracic computed tomography (CT) images on 261 adult Egyptians. All sternal and fourth rib measurements were substantially higher in males, according to the results. They came to the conclusion that a quick and simple CT scan for the sternum and fourth rib can be used to identify a person's sex.[16]

The current study categorized subjects into three age groups: young (18-30 years), old (31-70 years), and total subjects. Several previous studies employed similar age-based classifications. Wiredu et al. divided subjects into young (under 30 years), old (30 years and above), and total groups.[13] Singh et al. used Group A (18-30 years), Group B (31-65 years), and a combined group (18-65 years).[17] Soni et al. and Kocak et al. classified young subjects as 15-32 years, old as 33-89 years, and total as 15-89 years.[18-19]

The present study used an independent sample t-test to compare age differences between genders in young, old, and total subjects. Results showed no statistically significant difference in any group. The present study found a highly significant statistical difference (p-value < 0.01) between males and females across all age groups, while comparing MSIH. These findings are consistent with previous studies conducted by Macaluso et al., Singh et al., Soni et al., Kocak et al., Khatari A and Chand et al., all of which reported statistically significant differences in MSIH between males and females across various age groups, reinforcing its potential for sex differentiation.[10,17-21]

On comparing MAPB, the present study found a highly significant statistical difference (p-value < 0.01) between males and females in the older age group and the total sample, while a significant difference also observed in the younger age group. These findings align with previous research done by Macaluso et al., Soni et al., Kocak et al. and Khatari A, which reported highly significant differences in MAPB between males and females across all age groups, highlighting its potential for sex differentiation.[10,18-20]

In the present study, stepwise discriminant function analysis was performed across different age groups. In the young group, MAPB had a Wilks' Lambda of 0.847 and an

Equivalent F ratio of 8.488, while MSIH had a Wilks' Lambda of 0.324 and an Equivalent F ratio of 98.020. For the old group, MAPB's Wilks' Lambda was 0.597 with an Equivalent F ratio of 32.435, and MSIH's Wilks' Lambda was 0.355 with an Equivalent F ratio of 87.289. In the total group, MAPB had a Wilks' Lambda of 0.789 and an Equivalent F ratio of 25.972, whereas MSIH had a Wilks' Lambda of 0.328 and an Equivalent F ratio of 198.691. Males and females differ significantly, according to their equivalent F ratios. The stepwise discriminant functional analysis for the young, old, and total samples was documented by Kocak et al. At p-value < 0.005, the equivalent F ratio indicated a significant difference between males and females.[19] The stepwise discriminant function analysis for younger, older, and total groups was also recorded by Chand et al. There was a significant difference between males and females at p-value < 0.005, according to the equivalent F ratio.[21]

In order to identify the best cut-off values based on sensitivity and specificity, the current study used Receiver Operating Characteristic (ROC) curve analysis to compare MSIH and MAPB in males and females. With an AUC of 0.970 (p = 0.0005, 95% CI: 0.944-0.997), a cut-off of 14.5, sensitivity of 90.2%, and specificity of 91.7%, MSIH exhibited the best diagnostic accuracy. With a cut-off of 6, sensitivity of 74.5%, and specificity of 81.3%, MAPB demonstrated an AUC of 0.852 (p = 0.0005, 95% CI: 0.779-0.925). According to these findings, MSIH is the most accurate metric for determining sex from the sternal end of the fourth rib, with MAPB coming in second. These results are further supported by a related study by Soni et al., which found SIH to be the best parameter with an AUC of 0.888.[18]

The present study achieved correct prediction rates of 96.60% for females, 75.00% for males, and 85.80% on average in the young age group. In the old age group, the accuracy was 84.20% for females, 93.50% for males, and 88.85% on average. Overall, the total subjects had prediction accuracies of 91.70% for females, 88.20% for males, and 89.95% on average. Similar results have been documented in earlier research. Singh et al. reported prediction rates of 88.5% for univariate SIH, 78.5% for univariate APB, and 89.5% for multivariate analysis.[17] Soni et al. found accuracy rates of 91.9% (females), 77.4% (males), and 84.65% (average) in the young group, and 84.60% (females), 78.90% (males), and 81.75% (average) in the old group. For the total group, predictions were 90.00% (females), 78.00% (males), and 84.00% (average).[18] Kocak et al. found accuracy rates of 85.1% for males, 90.5% for females, and 86.5% overall, with sex determination accuracies of 85.5% for males, 87.2% for females, and 86.1% overall.[19] Chand et al. reported similar trends, with overall accuracy rates of 82.45% for females, 82.85% for males, and 82.30% on average.[21] These findings align closely with those of the present study. Tyagi et al. in their study on estimation of age by morphological study of sternal end of fourth ribs in males studied studied three components i.e. pit depth, pit shape and rim and wall configurations. F- ratio and P value of all component scores were found to be statistically significant indicating that morphological changes at sternal end of fourth ribs are age dependent.[22]

Limitations of the Study:

The study's principal limitation is the small sample size for analysis and interpretation. Additionally, the distribution of cases across different age groups was uneven, with variations in the number of cases between younger and older individuals. Furthermore, the proportion of male and female cases within these age groups was not equal.

CONCLUSIONS

Our findings and observations led us to the conclusion that the most useful metric for sex differentiation was the mean difference in the maximum superior-inferior height (MSIH) of the sternal end of the right fourth rib, which was higher in males than in females across all three groups. In comparison to the anterior-posterior breadth (APB), which demonstrated an accuracy of 81.3%, the superior-inferior height (SIH) at the sternal end of the fourth rib revealed to be the best discriminant for sex determination, with an accuracy of up to 91.7%.

In summary, the sternal end of the fourth rib is a useful skeletal diagnostic for determining sex, particularly when no other bones are available. When other skeletal elements are absent, it can provide crucial insight into the biological sex of an individual. Future studies could be done on a larger sample size to validate these findings and incorporate other factors, such as the pit depth of the fourth rib, and may extend the research to include other ribs.

Conflicts of Interest/Source of Funding: Nil

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ORIGINAL RESEARCH PAPER

Effectiveness of Video Assisted Teaching Regarding Medico Legal Aspects on Knowledge and Attitude Among Staff Nurses Working in Selected Wards: A Pretest- Posttest Study

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ABSTRACT

Introduction: This study employed a quasi-experimental one-group pretest and post test design. Simple random sampling was used to choose 100 staff nurses in total. Information was gathered during February and March of 2024. Ethical clearance and administrative permission were obtained prior to the study. A self-designed questionnaire was used to evaluate the pretest knowledge and attitude about medico- legal aspects and a 5- point Likert scale to determine attitude. After pre test 20-minute video-assisted teaching session on medico-legal aspects was conducted using an audio and video recorded computer disc and a laptop. The same instruments were used for the post-test, which was administered 14 days after the intervention. The data was analyzed using Fisher's exact test, Wilcoxon signed-rank test, frequency, and percentage.

Results: Just 3% of respondents had sufficient understanding of medicolegal aspects in the pretest, compared to 93% in the post-test. Regarding medicolegal aspects, 6% of respondents had a positive attitude in the pretest and 77% in the post-test. The Wilcoxon Signed Rank test was used to determine how video-assisted teaching affected staff nurses understanding of medicolegal aspects. The Z value is – 8.667 and p value was < 0.001 it has statistical significance. The effect of video assisted teaching on attitude regarding medico legal aspects was calculated using Paired t test, the t value was – 16.562 and p value was < 0.001 it has statistical significance.

Discussion: The purpose of this study was to assess how video-assisted teaching affected the knowledge and attitudes of staff nurses working in certain wards regarding medico-legal aspects. The study's results demonstrated that staff nurses' knowledge and attitude scores significantly improved following the video-assisted teaching. The post-test knowledge scores (Mean = 13.94, SD = 0.98, IQR = 15.00–13.00) showed a statistically significant improvement above the results of the pretest scores (Mean = 8.42, SD = 2.00, IQR = 9.00–7.00). Similarly, the post-test attitude scores (Mean = 64.36, SD = 4.48) showed a statistically significant improvement above the results of the pretest scores (Mean = 51.95, SD = 6.06), indicating that the video-assisted teaching was effective in improving staff nurses' understanding of medico-legal aspects and positively influencing their attitudes toward these aspects.

Conclusion: The findings of the study suggested that staff nurses' knowledge and attitudes improved significantly after attending video-assisted instruction on medicolegal aspects.

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INTRODUCTION

Medico legal cases (MLC) make an important component in medical field. Improper care and inaccurate documentation of MLC lead to legal complications.[1] Globally World health organization, estimated 30 percent of women aged 15 and older, (736million) almost one in three women were affected by physical or sexual abuse by a non-partner or intimate partner, or both.[2] It is estimated that in the past year up to 1 billion children between 2–17 years aged Globally have experienced violence in physical, sexual, or emotional form or neglect.[2] S.S. Oberoi conducted a study comprising 100 assault cases presenting to the casualty department from January to December 2011. The most commonly affected age group was 21–30 years (36%). Males constituted 78% of the cases, while females accounted for 22%, with a male-to-

female ratio of 3.54.[3]

A medico legal Case will be immediately reported to the medical officer, and the medical officer will inform the police regarding the patient. The nurse has to make sure patients deaths within 24 hours of admission are reported to the police by the medical officer in written form.[1] A medico-legal report is the documentation of findings of the physician who has assessed the case and should be raised in all cases of physical assault, sexual assault, poisoning, road traffic accidents, burns, falls, and bites. It provides to the court important evidence documented by the medical expert, which, if documented incorrectly or incompletely, leads to a delay in legal proceedings.[4] In medico-legal autopsy the most significant concern is to decide whether the cause of death is unnatural or natural. It is highlighted that the performance of histopathology should always be done along with full post-mortem examination.[5-7]

Nursing encompasses the autonomous and cooperative treatment of both sick and healthy people in all contexts, across all age groups, families, and communities. Understanding the legal implications of patient care in a healthcare setting is a crucial qualification for nurses. There has been an increase in carelessness in recent years, and many people are reluctant to enter the health care industry due to their fear of being sued. Nursing's primary goals are to avoid patient injury and to offer high standards of care. Nurses must be aware of their activities and prepared to deal with the fallout. For the proper use of their knowledge and abilities in patient care, nurses must take responsibility for themselves.[8]

Understanding of criminal law and legal issues and its application helps to avoid errors, complications and patient complaints in many cases. Nurses need to know the legal proceedings and update their professional knowledge to give safe and appropriate nursing care to the patients.[9]

The current study's objectives are to evaluate staff nurses' knowledge and attitude regarding medicolegal aspects prior to video-assisted instruction, ascertain the impact of video-assisted instruction on staff nurses' knowledge and attitudes regarding medicolegal aspects, and ascertain the relationship between staff nurses' pre-test knowledge and attitude regarding medicolegal aspects and their chosen demographic variables.

MATERIALS AND METHOD

A quasi-experimental one-group pretest-post-test design was employed in this investigation. A sample of 100 staff nurses from the Pondicherry Institute of Medical Sciences in Puducherry was chosen at random from the 200 staff nurses employed in the critical care unit. The information was gathered during February and March of 2024. The investigator used three tools, to gather the data such as **Tool 1:** Demographic variables of study participants, **Tool 2:** Structured knowledge questionnaire on medicolegal issues for staff nurses consist of fifteen multiple-choice questions. There are four responses for each question, with one right answer and three wrong responses. Each right response receives one mark, while each wrong response receives zero. There is a minimum score of 0 and a maximum score of 15. The score is interpreted as adequate knowledge (Score 13 to 15), moderately adequate knowledge (Score8 to 12), and inadequate knowledge (Score 0 to 7). Tool 3: 5-point Likert scale to assess attitude on medico-legal aspects for staff nurses. It contains 15 items, which include 10 positive statements as well as five unfavorable ones. There are five choices for each statement: strongly agree, agree, neutral, disagree, and strongly disagree. There is a minimum score of 15 and a maximum score of 75.The resulting score was interpreted as favourable attitude (score 62 to 75), Neutral attitude (score 38 to 61), and Unfavourable attitude (score 15 to 37).

Ethical clearance and administrative permission were obtained prior to the study. Participants in the study were informed of the goal of the investigation and provided signed informed permission. Inclusion criteria were Male and female registered nurses who work in adult and paediatric critical care units, labour rooms, and emergency rooms. Exclusion criteria were nurses on long leave. Video-assisted teaching on medicolegal aspect was an independent variable. Level of knowledge and attitude on medicolegal aspect were dependent variable. The pre-test data was collected using the above tools. After the pretest 20 participants per day were gathered in lecture hall. A 20-minute video-assisted teaching session on medico-legal aspects was conducted using an audio and video recorded computer disc, and a lap top. After 14 days of intervention, the post test was conducted using the same tool

Frequency and percentage were used in the analysis of sociodemographic data. The frequency and proportion of staff nurses' attitudes and levels of knowledge about medicolegal aspects were examined. Because the data was not normally distributed, the Wilcoxon Signed Rank test

was used to analyse the impact of video-assisted instruction on staff nurses' level of knowledge on medico-legal elements. The paired sample t test was used to examine the impact of video-assisted instruction on staff nurses' attitudes about medico-legal aspects. The Fisher exact test was used to analyse the relationship between staff nurses' pre-test knowledge and attitudes on medico-legal elements and their chosen demographic characteristics.

A p-value of less than 0.05 is regarded as statistically significant. SPSS software version 29.0 was used for all analyses.

RESULTS

The majority of participants (63%) are between the ages of 21 and 30,most of them (83%) were females, 95 (95%) have B.Sc. (N) qualification, Maximum number of participants (37 %) have work experience of more than 5 years, maximum of (20 %) participants working in emergency ward, and only 2 (2%) of the participants have previous training in medico legal aspects. **(Table 1)**

In pretest only 3% had adequate knowledge, 68 % of them had moderately adequate knowledge, and 29% of them had inadequate knowledge. In post-test 93 % of them hadadequate knowledge, and 7 % of them had moderately adequate knowledge, and no one had inadequate knowledge. **(Figure 1)**

In pretest score 93(93%) had neutral attitude, 6 (6%) had favourable attitude, where as in post-test 77 (77%) had favourable attitude, and 23 (23%) had neutral attitude. **(Figure 2)**

The Wilcoxon signed rank test was used to evaluate the impact of video-assisted teaching on staff nurses' understanding of medicolegal elements both before and after the teaching.

The post-test mean knowledge score was 13.94 with standard deviation 0.98, median 14.00, interquartile range 15.00-13.00, while the pretest mean knowledge score was 8.42 with standard deviation 2.00, median 8.00, and interquartile range 9.00–7.00. The p value was less than 0.001 and the Z value was -8.667, both of which are

Table 1: Frequency and Percentage Distribution of Study Participants According to the Demographic Variables. (n=100)

S.No	Demographic Variables	Frequency (f)	Percentage (%)
1.	Age in years		
	21 – 30	63	63.0
	31 – 40	35	35.0
	41 – 50	2	2.0
2.	Gender		
	Male	17	17.0
	Female	83	83.0
3.	Educational qualification		
	GNM	5	5.0
	B.Sc. (N)	95	95.0
4.	Years of experience		
	< 2 years	28	28.0
	2– 5 years	35	35.0
	> 5 years	37	37.0
5.	Area of working		
	Emergency room	20	20.0
	Medical intensive care unit	16	16.0
	Emergency medicine	15	15.0
	Paediatric intensive care unit	13	13.0
	Labour Room	12	12.0
	Cardiac critical care unit	9	9.0
	Neonatal intensive care unit	8	8.0
	Surgical critical care unit	7	7.0
6.	Previous training in medico legal aspects		
	Yes	2	2.0
	No	98	98.0

Figure 1: Level of knowledge on Medico Legal Aspects among Staff Nurses before and After Video Assisted Teaching.

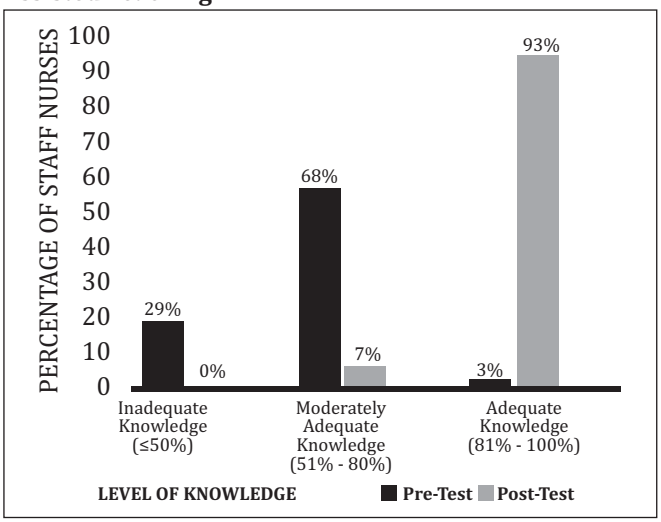
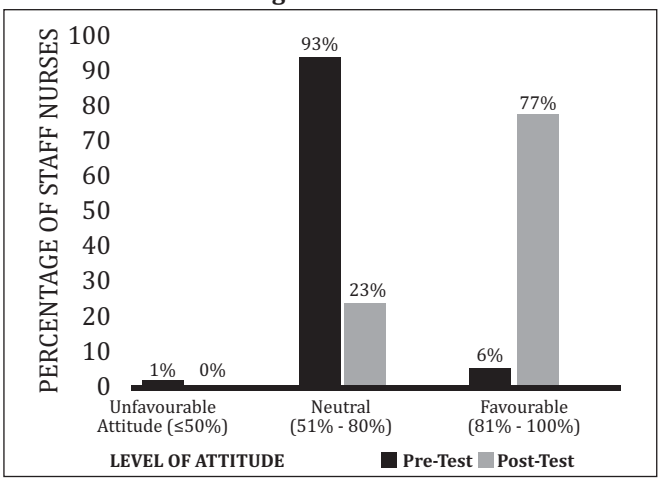


Figure 2: Level of Attitude on Medico Legal Aspects Among Staff Nurses before and After Video Assisted Teachings.



statistically significant **(Table 2)**.

Using a paired t test, the impact of video-assisted instruction on attitude on medicolegal elements was evaluated. The average attitude score on the pretest was 51.95 with a standard deviation of 6.06, while the average score on the posttest was 64.36 with a standard variance of 4.48. The p value was < 0.001 and the t value was -16.562, both of which are statistically significant. **(Table 3)**

There was a significant association between the level of knowledge and age. There were no significant association between the level of knowledge and selected demographic variables such as gender, educational qualification, years of experience, area of working, and previous training on medico legal aspects. Fisher's exact test was used to find out the association between the level of knowledge and selected socio demographic variable.

DISCUSSION

The present study showed that in the pre- test knowledge score only 3(3%) had adequately knowledge, 68(68%) had moderately adequate knowledge and 29(29%) had inadequate knowledge.

In one study, 50 staff nurses participated in a pre-experimental research to evaluate the efficacy of video-assisted instruction on knowledge regarding ECG alterations. According to the results, 78% of participants had low knowledge at the time of the pre-test, 22% had average knowledge, and none of the staff nurses had high knowledge. At the time of the post-test, 70% of participants had average knowledge, 30% had high knowledge, and none of the staff nurses fell into the group of low knowledge. The results show that staff nurses' knowledge was effectively increased by the video-assisted education module.[10]

There was a similar study conducted in 2017 by Ravi R on level of knowledge regarding medico legal aspects of

Table 2: Effect of Video Assisted Teaching on Level of knowledge on Medico Legal Aspects Among Staff Nurses before and After Video Assisted Teaching (n=100).

S. No.	Variables	Mean	Standard Deviation	Median	IQR	Z value	p value
1	Pre Test	8.42	2.00	8.00	9.00- 7.00	-8.667	<0.001 *
2	Post Test	13.94	0.98	14.00	15.00 – 13.00		

**- Statistically significant* *P value <0.005, IQR: Interquartile range*

Table 3: Effect of Video Assisted Teaching on Level of Attitude on Medico Legal Aspects among Staff Nurses. (n=100)

S. No.	Variables	Mean	Standard Deviation	t-value	p-value
1	Pre Test	51.95	6.06	-16.562	<0.001 *
2	Post Test	64.36	4.48		

**- Statistically significant, P value <0.05*

Table 4: Association between the Pre-test knowledge on Medico Legal Aspects among Staff Nurses with their Selected Demographic Variables (n=100).

S. No.	Demographic Variables	Level of Knowledge						Fisher's Exact Test p-value
		Inadequate Knowledge		Moderately Adequate Knowledge		Adequate Knowledge		
		f	%	f	%	f	%	
1.	**Age in Years**							
	21 – 30	22	75.9	40	58.8	1	33.3	0.045
	31 – 40	7	24.1	27	39.7	1	33.3	*
	41 – 50	0	-	1	1.5	1	33.3	
2.	**Gender**							
	Male	6	20.7	11	16.2	0	-	0.758
	Female	23	79.3	57	83.8	3	100.0	
3.	**Educational Qualification**							
	GNM	1	3.4	4	5.9	0	-	1.000
	BSc (N)	28	96.6	64	94.1	3	100.0	
4.	**Years of Experience**							
	< 2 years	12	41.4	15	22.1	1	33.3	0.233
	2– 5 years	10	34.5	24	35.3	1	33.3	
	>5 years	7	24.1	29	42.6	1	33.3	
5.	**Area of Working**							
	Emergency	3	10.3	16	23.5	1	33.3	0.560
	Medical intensive care unit	4	13.8	12	17.6	0	-	
	Emergency medicine	6	20.7	8	11.8	1	33.3	
	Paediatric intensive care unit	2	6.9	11	16.2	0	-	
	Labour room	5	17.2	6	8.8	1	33.3	
	Cardiac critical care unit	4	13.8	5	7.4	0	-	
	Neonatal intensive care unit	2	6.9	6	8.8	0	-	
	Surgical intensive care unit	3	10.3	4	5.9	0	-	
6.	**Previous Training in Medico Legal Aspects**							
	Yes	1	3.4	1	1.5	0	-	0.540
	No	28	96.6	67	98.5	3	100.0	

patient care among nurses working in selected hospital of Kerala, revealed that majority of (91.7%) study participants had inadequate knowledge and only 4.27 % has moderate knowledge. This study shows that most of the nurses had inadequate knowledge about medico legal aspects of patient care.[11] One more similar study done among doctors on awareness of medico legal issues 80% have marked correct answer and 20% have marked wrong answer for how to deal with brought dead cases.[12]

In the present study after the video assisted teaching program the mean knowledge score was increased from 8.42 to 13.94. Z score value for knowledge is – 8.667. The difference in thelevel of the knowledge was highly statistically significant at $p < 0.001$ level. This states that there is a significant difference between pre-test and post – test knowledge scores regarding medico legal aspects among staff nurses.

In another study, 60 staff nurses participated in a study that assessed the efficacy of a video-assisted teaching program on biomedical waste (BMW) management. Pretest was administered prior to the program's implementation, and a post-test was conducted seven days later. The mean knowledge score on the post-test was found to have grown from 17.383 to 26.033. Staff nurses' knowledge of BMW management has significantly improved, as indicated by the paired 't' value of 12.947 and the 'p' value < 0.001, which is regarded as highly significant. It is clear that staff nurses' knowledge is improved by the video-assisted education approach.[13]

The present study showed that in the pre- test attitude

Table 5: Association between the Pre-test Attitude on Medico Legal Aspects among Staff Nurses with their Selected Demographic Variables. (n=100)

S. No.	Demographic Variables	Level Of Attitude						Fisher's Exact Test p-value
		Unfavourable		Neutral		Favourable		
		f	%	f	%	f	%	
1.	**Age in Years**							
	21 – 30	0	-	59	63.4	4	66.7	0.547
	31 – 40	1	100.0	32	34.4	2	33.3	
	41 – 50	0	-	2	2.2	0	-	
2.	**Gender**							
	Male	0	-	15	16.1	2	33.3	0.397
	Female	1	100.0	78	83.9	4	66.7	
3.	**Educational Qualification**							
	GNM	0	-	5	5.4	0	-	1.000
	BSc (N)	1	100.0	88	94.6	6	100.0	
4.	**Years of Experience**							
	< 2 years	0	-	25	26.9	3	50.0	0.498
	2– 5 years	0	-	33	35.5	2	33.3	
	>5 years	1	100.0	35	37.6	1	16.7	
5.	**Area of Working**							
	Emergency	0	-	16	17.2	4	66.7	0.168
	Medical intensive care unit	0	-	15	16.1	1	16.7	
	Emergency medicine	0	-	15	16.1	0	-	
	Paediatric intensive care unit	0	-	13	14.0	0	-	
	Labour room	0	-	11	11.8	1	16.7	
	Cardiac critical care unit	0	-	9	9.7	0	-	
	Neonatal intensive care unit	0	-	8	8.6	0	-	
	Surgical intensive care unit	1	100.0	6	6.5	0	-	
6.	**Previous Training in Medico Legal Aspects**							
	Yes	0	-	2	2.2	0	-	1.000
	No	1	100.0	91	97.8	6	100.0	

score majority 93(93%) had neutral attitude, 6(6%) had favourable attitude and 1(1%) had unfavourable attitude. After administering the video assisted teaching program the mean attitude score was increased from 51.95 to 64.36, the t -score value for attitude is - 16.562. The difference in the level of attitude was highly statically significant at p<0.001 level. This states that there is a significant difference between pre and post-test attitude scores regarding medico legal aspects among staff nurses.

A quasi-experimental research was conducted at Pondicherry to examine the impact of video-assisted instruction on de-escalation and breakaway tactics for aggressive behaviour. A sample of 200 staff nurses were chosen using a convenience sampling approach. At the p value 0.001 level, the study discovered that video-assisted instruction had a statistically significant effect on staff nurses' attitudes and knowledge on de-escalation and breakaway tactics for hostile behavior. The results showed that staff nurses' knowledge and positive attitudes about de-escalation and breakaway tactics for aggressive behaviour improved with video-assisted instruction.[14]

Thus, it reveals that the video assisted teaching is effective in influencing the knowledge and attitude on medico legal aspects among staff nurses.

In this present study there was a significant association between the level of knowledge on medico legal aspects with the study participants selected socio demographic variable, age (p = 0.045). There were no significant association found between level of knowledge and otherselected demographic variables such as gender, educational qualification, year of experience, area of

working, and previous training in medico legal aspects.

There was no correlation between the study participants' level of legal knowledge and the chosen demographic variables, such as age, sex, educational background, and years of experience, according to a study conducted by Shenai et al. to evaluate staff nurses' knowledge on legal aspects of patient care in Kerala.[15]

In this present study there was no significant association between the level of attitude on medico legal aspects with selected socio demographic variables such as age, gender, educational qualification, area of working, year of experience, and previous training in medico legal aspects.

Similar findings were observed on a researchdone to assess the knowledge and attitudes of Nurses'on Legal Obligations for Patient Care in Bangalore. The knowledge and attitudes of nurses were not statistically significantly correlated with the chosen factors.[16]

Limitation

Data were collected from a single tertiary care hospital, which may limit the applicability of findings to other health care settings. Larger multicentre studies are required for more generalisable conclusions.

CONCLUSION

The results of the study showed that staff nurses' knowledge and attitudes significantly improved after receiving video-assisted instruction on medicolegal aspects. Health care companies can lower legal risks and improve patient care by implementing this teaching strategy. The results of this study add to the increasing amount of data that supports the use of video-assisted instruction in nursing education.

Conflict of Interest/Source of Funding: Nil

The author states that there is no conflict of interest in the way this work was carried out. The study was conducted independently, and the findings were unaffected by any financial, personal, or professional motivations. For this study, neither the institution nor the subjects received any funding or outside sponsorship.

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REVIEW ARTICLE

Artificial Intelligence in Medical and Forensic Imaging: A Comprehensive Review

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ABSTRACT

Introduction: AI has unfolded as the transformed and revolutionary era in the contemporary aiding, mainly in diagnostics and medical imaging. The virtual brains such as multilayer representation learning, algorithmic modeling, neural networking, electronic design automation detection system has enhanced the efficiency and accuracy of radiology, histopathology, dermatology and pathology data interpretation & diagnosis. These computational models remodeled the clinical protocols by AI based forecasting, pre-symptomatic identification and customize healthcare plan management. Beyond therapeutic medicine, the cognitive revolution of automation in forensic radiomics had modified the litigation and examination procedures.

AI serves diverse functions across various domains of forensic science such as individuals' identification, forensic wound examination and medical jurisprudence. Artificial Intelligence (AI) and Deep Learning (DL) models serves a significant role in legal medicine by precisely detecting the postmortem artifacts. This uses various kinds digitalized representation technologies such as PM MRI, virtual autopsies, PMCT etc. Together, these contribute to more effective and trustworthy legal investigation and examination. These methodologies facilitate alternatives based on images and non-destructive 3D conventional autopsy as well as postmortem examination. AI based system enables individual's facial reconstruction, sex and age estimation through radiological evaluation by algorithms such as 3D convolution neural networks.

This research emphasizes the conspicuous forensic frameworks of data-based diagnostic imaging in litigation, technological revolution, contemporary applications, liabilities & ethical violations and obstacles in complete execution such as data integrity and statistical bias. It highlights the multidisciplinary collaboration of automated diagnostic systems to virtual autopsy & forensic imaging. This study concludes and outlines the future directions, emphasize optimized data sources and harmonized scanning protocols.

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INTRODUCTION

Artificial Intelligence (AI) is the technology for engineering cognitive systems, with the collaboration of algorithms or a rule set, that electronic systems execute to replicate reasoning & analytical abilities of living beings, including training and critical thinking.[1] The AI systems are capable to foresee problems or handle problems when they arise and, for this reason, run intentionally, intelligently and adaptively.

In addition, the systems are interactive and independent, learning and evolving with an increment of accessible information. Advance algorithms are not a single pervasive universal innovation, rather it is a number of subfields (such as ML and DL) that collectively or independently impart intelligence into applications.[2]

AI encompasses a range of technological advancements that allow computers or robots to perform cognitive tasks that are similar to those of humans. Early abstract models of intelligent robots were created in the 1940s, which

marks the emergence of AI.[3] ML algorithms like neural networks and decision trees emerged in the following decades, especially the 1950s and 1960s, which greatly increased the interest and enthusiasm in this field.[4-5]

AI had advanced from hypothetical conceptions of computing to an applied field that significantly enhances clinical decision-making and healthcare practice.[6] Since the 1950s, AI has played a significant role in medicine, with current advancements mostly attributable to the processing power and volume of digital data of contemporary gadgets.

Clinical, diagnostic, rehabilitative, surgical, and prognostic procedures are among the medical disciplines that AI is revolutionizing.[7-9] The feature extractor by artificial neural networks or CNNs, dense feed-forward layer, dimensionality aggregation layer, along with four multilayered presented in **Figure 2.**

2. Fundamentals of Artificial Intelligence

2.1 Artificial Intelligence (AI): Computational models that performs task which needs human ability to think and perform, such as perception reasoning, predictions, and perceptions transformed the sensory data into meaningful representations.[10]

2.2 Machine Learning: It is the branch of AI that enables computers to learn and gain new cognitive capabilities that mimic or exceed human intelligence.[11] The core of ML is the machine's capacity to adjust and improve its processes in response to the data it analyzes.[12]

2.3 Deep Learning: Deep neural learning is the sub field of AI & ML, primarily focusing on generating models with multiple layers of processing units able to understand the automated taxonomy metadata derivations.[13] It can be regarded as a computational approach which, by the use of Artificial Neural Networks (ANNs) comprising layers abstract features from a raw input, enabling machines to execute operations like visual interpretation, audio identification, and semantic linguistics interpretation with minimal human interference.[14] ANNs are computer models that mimic biological nerve cell activity, enabling them to display intricate behavior from simple building blocks.[15-16]

2.4 Neural Network: Deep neural networks are computer structures that resemble biological nerve systems by having several non-linear neural blocks. The input node and many nonlinear &and terminal layer make up their structure. Each hidden layer uses the downstream representation as it's input, enabling complicated data processing through simultaneous processes.

These layers are connected by nodes, also known as neurons.[17] **Figure 1** depicts the basic workflow of the deep neural network.

2.5 Convoluted Neural Networks (CNNS): Originally developed in the 1960s, ConvNets (CNNs) are the backpropagation to the multilayered neural networks. In fields including pattern identification, clustering, module identification, visual recognition, lexical process analyst, audio identification, they are now the most widely used kind of neural network for handling challenging visual tasks.[17]

Figure 1: Basic Workflow of Deep Neural Network.

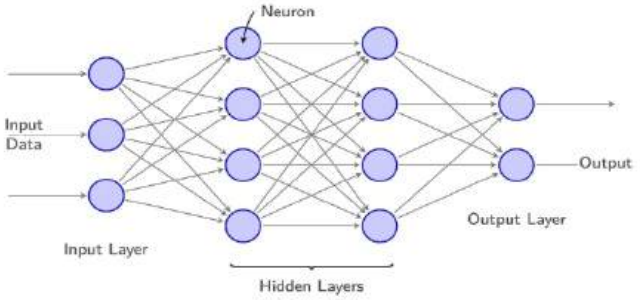
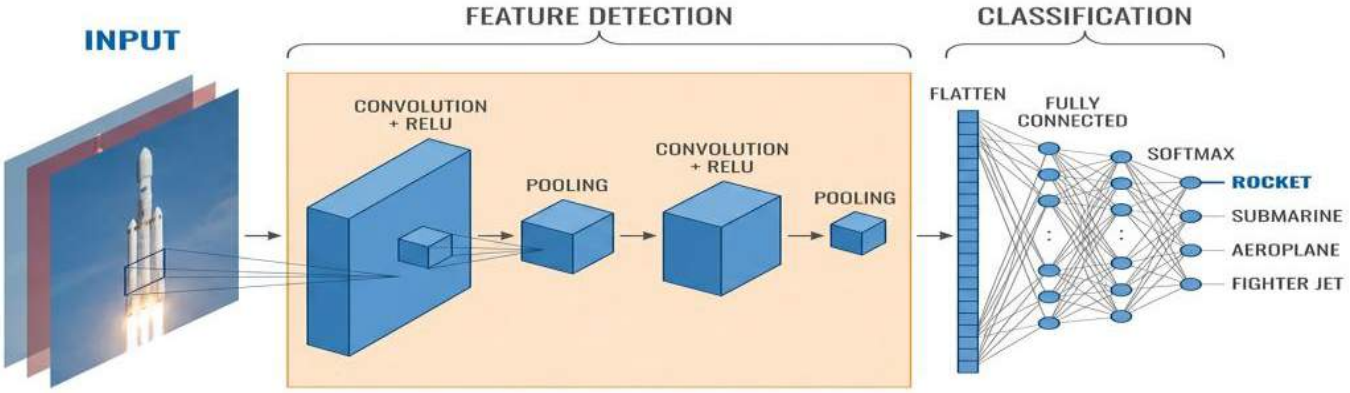


Figure 2: Architecture of a CNN.



3. ARTIFICAL INTELLIGENCE IN MEDICAL IMAGING

AI had brought a radical change into the area of interventional radiography. AI enhances scanning processes, maintains image quality, and allows advanced image interpretation in MRI, CT, and PET studies. AI in medical imaging improves automated diagnosis by enhancing the picture interpretation.[18] Among such advances, DL has quickened the process of MRI scanning, a balance between efficiency and quality, while equal improvement has been observed in the reconstruction of CT and PET images.

AI system reduced delivery time of interpretation from 11.2 days to only 2.7 days, giving further strength to digital predictive structures for standardization of administrative workflow & increasing standards of personalized patient care. Radiology has benefited from ML algorithms in electronic aided application devices for the last twenty years, showing strong robustness for true negative and productive rates.[19] Sadaghiani et al., (2021) demonstrated various studies focusing the use of AI in FDG- PET CT images.

A non-invasive functional imaging modality called Positron emission tomography (PET) provides vital information of the cancer patients for determination and necessary therapy for the neoplasia diagnosis in patients. The characterization of malignant pulmonary nodules, tumor detection and delineation, differentiating among lung cancer subtypes, staging of lung cancer, and evaluation of treatment response are just a few of the aspects of lung cancer imaging that have been improved by recent developments in AI powered PET imaging.[20]

Hong et al., (2022) demonstrated the implementation of AI-CAD to evaluate the presence of pulmonary nodules, pulmonary consolidation, and pneumothorax as shown in the **Figure 3**.[21] MRI (magnetic resonance imaging is an extensively used painless diagnostic analysis tool which aids in early identification examination and management of many diseases.

The existed forms of MRI: structural MRI & functional MRI both of which has substantial advances in the study of human brain anatomy and function, owing mostly to their high spatial resolution capabilities. The use of AI algorithms in MRI approaches in identifying brain related disorders such as Alzheimer's disease, depressive disorder, schizophrenia, etc.[22] Shin et al., (2022) reported that the CNN model shows potential in identifying and distinguishing between different types if meniscus injuries.

The model predicts the existence of meniscus tears based on coronal and sagittal MRI scans. This entails extracting characteristics from MRI scans using two different CNN models.[23] Aleid et al., (2023) have proposed an AI for predictive assessment technique for brain tumefaction by computed tomographic scans. This uses multilevel thresholder segmentation method optimized via the Harmony Search Optimization (HSO) algorithm. Multilevel HSO segmentation method provides accurate and time-efficient tumor localization.[24-25]

Figure 4 depicts the findings of the color segmentation for the multilevel threshold method. AI has long been used in medical ultrasonography, with deep learning greatly improving picture reconstruction and analysis. DL technologies have significantly improved ultrasonic beamforming, resulting in higher picture quality and

Figure 3: A. X–Ray Showing Pulmonary Nodule at Upper Right Corner B. AI Based CAD System Identifies Abnormality. Chest CT Obtained After 10 Days Depicts the Nodule to be Malignancy.[35]

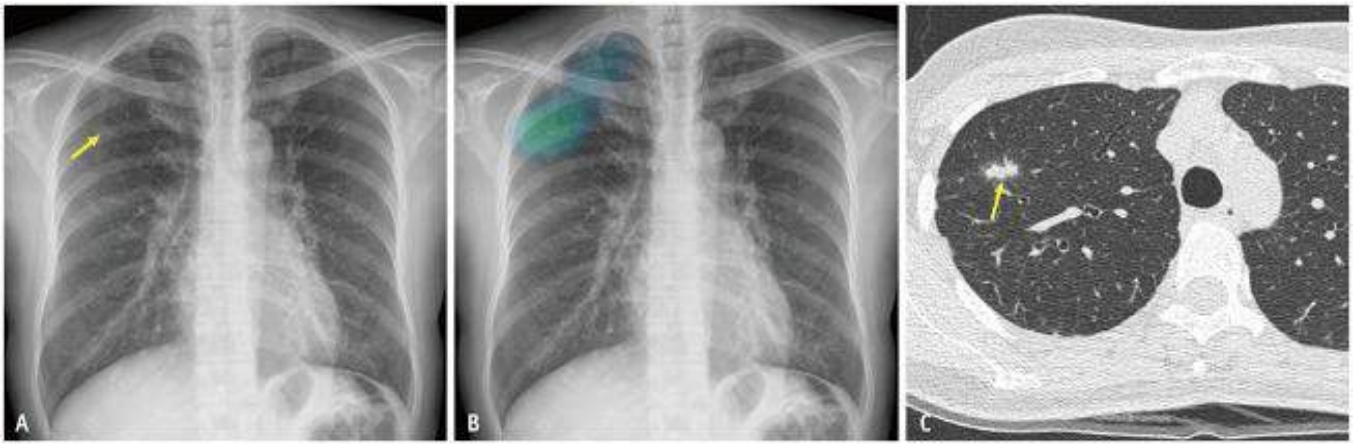
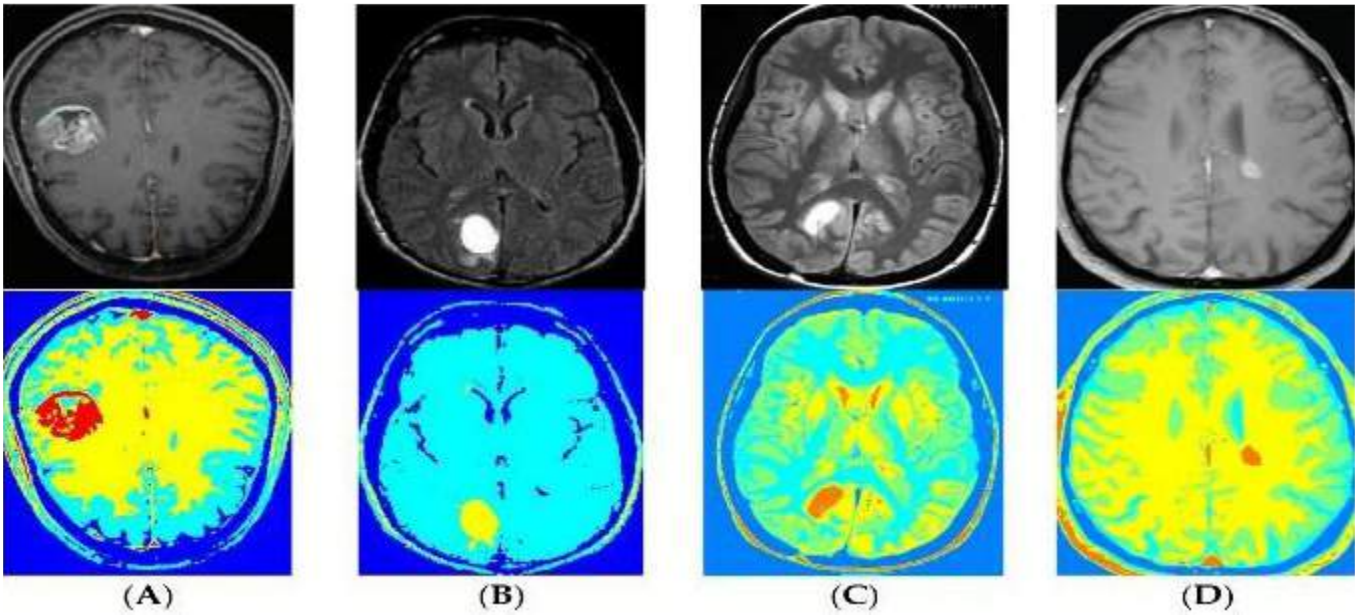


Figure 4: Findings of Color Segmentation for the Multilevel Threshold Method (A) The Red Portion Indicating the Tumor. (B) Yellow Portion Indicating the Tumor. (C) The Orange Part Depicts the Segmented Tumor (D) The Orange Portion Indicates the Suspected Tumor.[39]



computational efficiency. Beamforming is a method that combines data from different ultrasonic elements to produce focused pictures.

DL models can automate the identification and segmentation of lesions in ultrasound pictures. In the context of breast cancer, which is a severe health risk, DL applications in breast ultrasound help radiologists and physicians categorize the disease by analyzing ultrasound pictures and segmenting them into functional tissues using CNNs.[26] The universally widespread tomographic methods used in tumor studies are CT & MRI. These screening modalities generate sophisticated & refined visuals of the anatomical structures and physiological activities, allowing for more precise cancer diagnosis and therapy planning.

With the help of AI, assisted CT algorithms have improved nodule detection, malignancy classification, and staging accuracy in pulmonary and extra pulmonary tuberculosis in which diagnosis through regular CECT and ultrasound is sometimes limited as it may mimic the malignant pulmonary nodules. DL models are applied to breast MRI to enhance lesion segmentation and support early detection of small or occult tumor.

AI-based CT radiomics helps differentiate hepatocellular carcinoma (HCC) from benign liver lesions. CNNs trained on multiparametric MRI datasets assist in tumor grading and recurrence prediction.[27] Zhou et al., (2023) conceptualized the DL enabled AI prototype for automated identification of brain metastases using post contrast T1-weighted enhanced MRI screening. Intra-axial metastatic brain cancer is the lethal ramifications of metastatic cancers that affects around twenty percent of the individuals with carcinoma. Notably it is more common in people with lung cancer, with incidence rate reaching within fifty percent in individuals with metastatic non-small cell lung cancer (NSCLC).[28]

3.1 Clinical Advantages

Predictive data uses previous healthcare data to predict the risk and early detection of the future diseases' risks. It also enables the customized diagnosis and treatment plan. Biomarkers such as genetic, proteomic, and metabolic markers, coupled with imaging data from advanced techniques including MRI, CT, and PET scans, enable AI systems to learn subtle patterns and anomalies that could signify disease inception.[29] lately, DL has been used in the prediction of the survival in prostate cancer patients.

The ABSCI produced by bone scanning screening could recognize those at substantial peril and therefore may guide customized care management system. DL using cardiothoracic scanning data has been used to assess myocardial strain and support clinical management and post-acute coronary thrombosis. This provides the much more rapid self-operated assessment of heart function than previously possible.[30] In 2022, one study investigated

the application of AI to the interpretation of coronary CT angiograms compared to cardiac perfusion scans for the identification of the diseases related blockage of the coronary artery.

AI performs better in diagnosing and thus may contribute to an optimized selection of patients for invasive procedures.[31] This is critical for spotting urgent instances, which enables prompt treatment of diseases like cancer and stroke.[19] **Table 1** enlists the medical imaging of different diseases and conditions that were aided by the different AI algorithms.

4. FORENSIC IMAGING

Forensic imaging has emerged as a crucial element in modern forensic practice over recent decades. This technology has significantly transformed the methods used to examine both living and deceased subjects. Radiology now plays a supportive role in legal medicine, aiding practices in both clinical forensic medicine and forensic pathology.[32] During the late 1990s, post mortem imaging was gradually introduced as a substitute for traditional autopsy.

More and more studies assessed the diagnostic value of PMCT, and MRI with or without image guided biopsy. Over the last decade, the forensic field has witnessed a considerable shift from the classical invasive autopsy towards non-invasive imaging-based examinations, which are often referred to by the term "virtopsy" (minimal invasive autopsy with broad applicability).[33] Comparing virtopsy with conventional autopsy, many studies showed excellent agreements of diagnostic results on skeletal trauma and foreign-body detection, though in the case of organ pathology but intracranial injury, it is still not so easy for images only.

Virtopsy enhances sensitivity (93%) and specificity (83%) of diagnosis and offers several advantages like faster identification, good detection of foreign bodies, three-dimensional reconstruction, and non-invasiveness. But it has many limitations, such as difficulty in the evaluation of the infection status and internal characteristics of organs, operator dependency, insufficient legal basis, and high costs.[34]

4.1 Post Mortem Computed Tomography (PMCT):

PMCT is a computed tomography scanning performed post-mortem, mostly by whole-body spiral CT, for non-invasive examination of internal anatomy. PMCT can be used in traumatic assessment. PMCT can help better locate the cause of traumatic death, especially in detecting injuries which cannot be proved by traditional autopsy. PMCT can detect blood in the body cavity, such as pericardium or hemothorax, which showed high density fluid.

PMCT provides a quick overview of the interior cavities & illustrates the foreign substances and skeletal structure that are radiopaque.[35] This technology makes use of varied radiodensity produced by a revolving source, with data sent to a computer which uses algorithms to generates the tomographic or 3D pictures. In forensic scenarios, the body might be scanned partly e.g., thoracic cavity, head or completely all over top to bottom.

PMCT like regular X-ray may detect radiopaque foreign objects, which is especially useful in medico-legal investigations for detecting ballistic foreign bodies, primarily projectiles. PMCT is adequate for identifying blood in the presence or hemorrhage conditions like hemopericardium, hemothorax, hemoperitoneum and cerebral hemorrhage.[36]

Several researchers have worked on ML programs to automate pathological diagnosis especially using in vivo computed tomography (CT) imaging. Chilamkurthy et al., (2018) developed and established the set of multilayered neural network for the digital identification of various types of cranial hemorrhages specifically intracranial, intraventricular, intrapare-nchymal, subdural, subarachnoid & extradural as well as linear fractures using antemortem CT images.

The technique allows the automated categorization of cranial PMCT datasets into two categories one with fatal bleeding and other with neurologically healthy, using various ML and DL models.[37]

4.2 Post-Mortem Magnetic Resonance Imaging (PMMRI)

PMMRI outperforms CT in seeing soft tissue injuries and some organ diseases, such as identifying neck muscle hemorrhage and acute myocardial infarction, which may go undetected during an autopsy. However, it's application is limited, with it being used in conjunction with CT in certain circumstances due to time consuming processes, image contrast issues and ferromagnetic material hazards. Additionally, body temperature and breakdown may affect MRI contrast, confounding picture interpretation. MRI is increasingly applied in pediatric examination both in forensic medicine and pathology.

Table 1: Medical Imaging of Different Diseases and Conditions Aided by the Different AI Algorithms.

S. No	Disease	Imaging Modality	AI Model / Algorithm Used	Key Results	Ref.
1	COVID-19	Chest X-ray (CXR)	Deep learning CNN with Transfer learning and Adam optimizer model	Study of 3616 CXR pictures found accuracy and precision of 92%	[48]
2	Diabetic Retinopathy	Retinal fundus photographs	Adaptive Deep CNN with feature optimization	From 35,126 retinal fundus pictures, adaptive CNN successfully identified and graded diabetic retinopathy with 95.6% accuracy, 94.8 % precision and 95.1 % recall	[49]
3	Pulmonary nodules	CT scan	Retina U-Net combined with support vector machine (SVM) and CNN	On evaluating 1056 CT pictures, AI framework showed diagnostic accuracy of 90.58% and AUROC of 0.9058 in reliable detection and classification of pulmonary nodules.	[50]
4	Brain Tumor	MRI	2D CNN and convolutional auto encoder network	The model evaluated 3,264 brain MRI images to distinguish between healthy brain images and varieties of other brain malignancies such as gliomas, meningiomas and pituitary tumors with an accuracy of 96.47 % and an AUROC of 0.99	[51]
5	Breast cancer	Mammography	Deep CNN models (Inception V4, DenseNet 121, ResNet-164, VGG-11)	The collaborative model classified 1145 mammogram images into normal, benign and malignant with 99.37 % accuracy.	[52]
6	Melanoma (skin cancer)	Dermoscopic images	Custom deep learning model FCDS-CNN (Feature centered Deep skin CNN)	FCDS-CNN trained on 10,015 dermoscopic images that classified the images into 7 skin lesion classes with accuracy of 96% outperforming all the conventional CNN models.	[53]
7	Colorectal polyps (precancerous lesions)	Colonoscopy images	YOLO-V8 object Detection Network	Model achieved 95.6 % precision, 91.7% recall and 92.4% F1 score in locating and detecting colorectal polyps from a large dataset of colonoscopy images.	[54]
8	Hepatocellular carcinoma	Dynamic contrast-enhanced (DCE) MRI	Attention U-Net detection and segmentation trained on diverse MRI datasets	Trian among 363 patients and 247 lesions, model showed 80% sensitivity at the lesion level, producing about 1 false positive per patient, and AUC about 0.80	[55]
9	Tuberculosis	Chest X- ray images	CNN	The model distinguished the normal lungs from the tuberculosis lungs from the dataset of 1,196 chest X-ray images with accuracy of 94.1, precision of 96.85%, and F1 score of 0.941	[56]
10	Prostate cancer	Multiparametric MRI images	ResNet50 deep CNN with clinical features	Model evaluated the mpMRI images of 343 patients and classified the level of cancer into benign and malignant with grades from 1 to 5 achieving the accuracy of 94% when combining MRI and clinical data vs. MRI alone (88%).	[57]

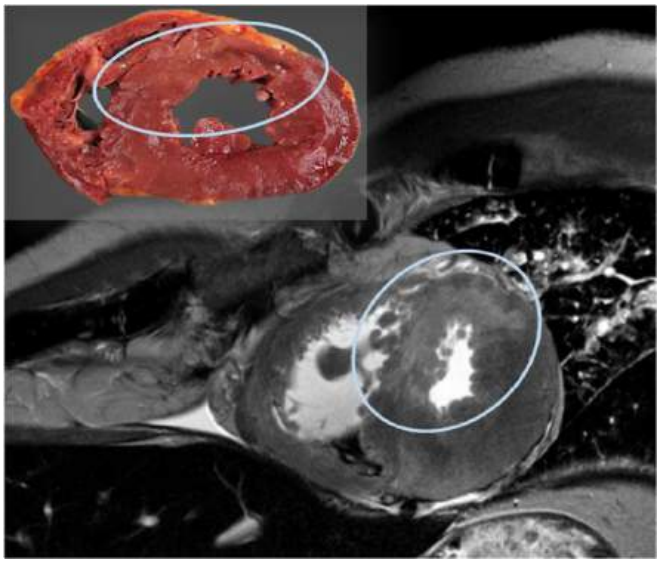
Figure 5 shows the PMMRI of heart with myocardial edema.[38] PMMRI applies the same physical basis as the clinical MRI strong magnetic field, radio-frequency pulses, measurement of proton relaxation (T1, T2)-to produce high-contrast soft-tissue images. However, in post-mortem, imaging parameters need to be adjusted for low body temperature, decomposition changes, absence of perfusion, and altered tissue relaxation properties.[39]

4.3. Forensic Applications of AI

Forensic science diagnoses are interdisciplinary, including elements from professions like thanatology and clinical forensic medicine. It also includes allied disciplines such as criminalistics, ballistics, anthropology, genetics and entomology. A diagnosis consists of three interrelated components: pathology classification, a collection of the indicators and matching of these indicators to pathology category.

AI can help with all three parts of diagnosis, including categorization, sign analysis, and matching. In forensic medicine, AI is most likely used for thanatology and cause of death estimation, measuring post mortem intervals (PMI) and dating the injuries from both antemortem and postmortem viewpoints.[40] Forensic odontology focuses on identifying persons from dental remains, notably teeth and jaw bones. AI application in this discipline is concerned into four areas: evaluating human dental impressions, sex & age estimation and odontological superimposition.[41]

Figure 5: PMMRI of the Heart Depicts a Bright Region in the Septum and Some Parts of Anterior Wall of the Left Ventricle on the T2-Weighted Image, Showing Myocardial Edema; Upper Left Image is the Autopsy Slice of Heart.[64]



AI, especially 3D Convolutional Neural Networks significantly improves accuracy, speed, and objectivity of forensic age and sex determination based on the analysis of medical images like CBCT (Cone-Beam Computed Tomography) scans. AI uses regression models to estimate a continuous age value from 3D cranial or skeletal images. The AI is trained on large datasets of medical images (e.g., CBCT, CT, X-rays) labeled with known ages.

It learns to identify age related features such as Dental development, Bone maturation, Skull and skeletal changes over time. Studies show AI can estimate age with a Mean Absolute Error (MAE) as low as 0.37– 5.15 years depending on body part and age group. For instance, the combination of femur and mandible data reduced MAE to 5.15 years.[42-43] By using AI, in a faster and more precise forensic identification, digital dental records can be processed, which may include 3D scans, dental molds, and intraoral images.

AI analyzes 3-dimensional odontological scans & scanning data compared with odontological data for the recognition of the individuals. This was specifically advantageous in 3-dimensional screening which are profoundly using digital records and thus afford high-resolution images to the forensic expert for analysis.[44] In the mass disasters cases, automated systems aid experts by managing the large odontological database for the comparison with recovered odontological evidences from the individuals, thereby increasing speed in the recognition of the victims.

Facial reconstruction in forensic anthropology is a process for developing the likeness of an individual's face from skull remains. The main purpose of this, apart from aiding the police, is to identify unidentified human remains where the other methods cannot be used or have failed, such as DNA, fingerprints, and dental records[45-46] Mohammed et al., (2024) suggested the DL approach for the facial reconstruction from the unidentified skull. A CNN is the DL model that automates the process of predicting the facial appearance of an individual from their skull through determining the complicated, dynamic association between cranial structures & facial features from large datasets.

For facial reconstruction and identification, the model CNN Skull Part with SIFT was used, which combined DL for the elemental extraction with the traditional computer vision algorithm (SIFT).[47] Oura et al., (2021) explained that the DL algorithms can identify and classify gunshot wounds from simple photographs with high accuracy. The

investigators compiled a dataset of 200 wound images and divided the wounds into four classes: negative control, intermediate range shot (20cm), contact range shot & distant range shot (100cm).

A Multilayered Perceptron model was trained with a set of images of wounds classified by shooting distance. The algorithm autonomously learned to differentiate visual patterns related to contact, close-range, and distant shots, accomplishing a 98% test accuracy. MLP 241624 was the best performing model that reached an astonishing 98% accuracy in the independent test set. The algorithm correctly recognized 100% of the contact range shots, negative controls and close shots. It misinterpreted solely single distant shot.[48] Wu et al., (2024) discuss how AI dramatically improves the estimation of the postmortem interval by analyzing high-throughput microbiome data of decomposing remains.

AI models, including random forests, CNNs, and RNNs, are trained to recognize specific temporal successions of microbial communities that correlate with time since death. These algorithms process complex sequencing data to identify key microbial biomarkers and dynamic abundance patterns that allow them to predict PMI with high precision, with a mean absolute error as low as 1.27±0.181.27±0.18 days within a 36-day decomposition window. Emergence of multidimensional facts & automation of features selection allows AI to conquer the disadvantages of conventional methodologies, offering a fast, objective, highly accurate tool that transforms microbial succession into a reliable forensic clock for PMI estimation.[49]

Kalinowska et al., (2025) suggested the ML context for the automatic segmentation of the bruises and abrasions in postmortem images. Their method consisted of the gathering of a dataset of the postmortem images, which were subsequently labeled and preprocessed by augmentation techniques for the purpose of enhancement and the universalization of algorithms. The deep learning architectures, namely U-Net, FPN, and Link Net, were applied with EfficientNetB3 and ResNet50 as backbone networks.

Their basic paradigm is semantic segmentation, in which a model learns to classify every pixel of an image as a member of a certain class. A custom loss function was implemented, combining Dice loss and Focal loss. These results demonstrated high performance, the best model (U-Net + EfficientNetB3) reaching 92.7% sensitivity and 98.9% specificity, while its results can be obtained very quickly compared to manual assessment, providing a base for objective, automated forensic analysis.[50] **Table 2** outlines the forensic imaging applications.

CONCLUSION

New diagnostic era was created by the combination of the forensic imaging, healthcare applications and AI technologies. This review explains the impact of the AI emerged technologies, which uses the CNN models for clinical pathology, radiology and in the virtual autopsy. AI based revolutionized the early disease detection in the various highly complicated diseases, customized medication and treatment plans. AI through PMCT allows in traumatic injury identification while estimation in postmortem interval.

The standardization in AI based technologies faces multiple challenges and needs more enhancement. Majorly all AI models need large data set to perform properly but it's difficult to obtain the required date set. The secure and larger framework by legal system required to authenticate the AI model systems. AI emerged with medical imaging through proper rules and regulation helps to completely revolutionized the health care system but it needs to maintain ethical integrity and larger data set.

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Table 2: Different Forensic Applications of the AI Based Forensic Imaging.

S. No	Disease	Imaging Modality	AI Model / Algorithm Used	Key Results	Ref.
1	Fatal cerebral heamorrhage detection	3D cranial CT (PMCT)	CNN (DenseNet 3D networks)	CNN model evaluated 81 PMCT images (36 haemorrhage, 45 normal brains) that achieved mean accuracy of 0.94	[77]
2	Drowning diagnosis	PMCT (whole body CT)	CNN classifiers (AlexNet, VGG16, Inception-ResNet-V2)	AI model classified 313 PMCT images into 153 drowning and 160 non-drowning cases with accuracy of 92% and AUC of 0.98	[78]
3	Gum shot wound classification	Digital colour wound photographs	Deep CNN (ConvNeXt- Tiny)	Model evaluated 2418 images from which it classified 2028 entrance and 1314 exit wounds with an accuracy of 87.99%, precision of 83.99%	[79]
4	Human age estimation (forensic odontology)	Panoramic dental radiographs (PRS)	Inceptionv4, that used data augmentation approaches	Model predicted the age using 12,827 dental panoramic dental images, with test mean absolute error of 3.1 years and R2 value of 95.5%.	[80]
5	PMI estimation from bone proteomics	LC-MS/MS based bone proteomics data	Supervised ML with SHAP (Shapley additive explanations)	From 25 human bone samples (15 rib fragments, 10 tibia fragments), model identified 3 protein biomarkers abundance (K1C13, PGS1, CO3A1) with 100% accuracy in distinguishing the PMI of 15 and 20 years.	[81]
6	Sex estimation	Cranial CT images	ML algorithms (Logistic regression, SVM, Random Forest, Linear discriminant analysis)	Model trained on 300 CT images (150 males and 150 females), in which Logistic Regression Model gave the best results with 90% accuracy, 90% precision, and 90% F1 score	[82]
7	Rib fracture detection	PMCT scans	Deep learning object detection model (nnDETPM)	Model was trained on 50 PMCT scans and achieved 70.2% sensitivity, and 78.1% precision in detection of rib fractures.	[83]
8	Mandibular sex determination	Lateral cephalometric radiographs and dental casts	Supervised ML models like SVM, multilayer perceptron (MLP), K-Nearest Neighbours (KNN), logistic Regression.	Trained on dataset of 108 individuals, the Logistic Regression model achieved 79% accuracy and AUC of 0.84 for sex determination through mandibular and dental measurements.	[84]
9	Sex determination from fragmented humerus	CT scans of distal ends of humerus	ML classifiers (Logistic regression, LDA, KNN, Decision Tree models)	Models analysed CT images of 310 adults (155 males and 155 females). Extra Tree Classifier achieved the highest accuracy of 97% and 97 % specificity.	[85]
10	Individual identification	PMCT and chest X-ray images	Generative contrastive DL framework (Neural boneprint)	Trained on 1315 paired PMCT-CXR images, “Neural boneprint” model correctly linked unknown post mortem skeletal photos to appropriate person in database with 84.79% accuracy.	[86]

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REVIEW ARTICLE

Fingerprints Detection on Firearms and Cartridges: A Review

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ABSTRACT

Introduction: One of the most epochal duties of the defence establishments is to safeguard the weaponry under their control. As a security measure, a tracing protocol should be in place so that if any piece of weapon goes missing, it can be tracked back to the armory.

Forensic Importance: Such a protocol relies on the identification marks on arms and armaments, including mainly, make, model, caliber, manufacturer and serial number. However, if the missing weapon has been used to commit a crime, then the integrated regulatory strategy mandates not only its tracking, but also institution of forensic leads to pin down the criminal. The most important forensic tool under these circumstances is to detect fingerprints on the recovered firearm, on the cartridges collected from the scene of crime and the unfired cartridges which the suspect loaded into the weapon.

Conclusion: The chemical methods which have the potential to lift fingerprints on firearms and cartridges are reviewed in this communication.

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INTRODUCTION

A firearm is a barreled weapon which serves to aim and discharge a projectile, generally a bullet. The latter is usually enclosed in a metal casing, called a cartridge case, along with a propellant and a primer. Normally the firearms and the cartridges are kept under guard at the defence arsenals, but should a weapon be found missing, it becomes the de rigueur to identify the subject who embezzled it to commit a crime.

The most infallible means of identification is to develop the fingerprints of the suspect on the stolen items. Fingerprints are formed by the sweat secreted by the glands embedded beneath the ridges on the fingertips.[1] The sweat deposition leaves a latent (or hidden) impression on the object which the finger touches. Sweat contains about 99% water, about 0.5% inorganic ions and about 0.5% organic molecules.[2]

The latent print is visualized by a chemical developing reagent which tags one or more components of sweat to produce a colored derivative. Although there are lot many methods to detect fingerprints on crime evidence,[3] but when it comes to firearms and cartridges, the choice becomes limited.[4-5]

There are several factors which preclude the detection of fingerprints on firearms: The weapon may have been recovered several days after the commission of crime and the constituents of sweat may have been degraded by sunlight, washed out by humidity and/or contaminated by wind action. The finishing of the firearm may have been rough because of which the sweat deposition may have become distorted. Multiple handling may have impinged overlapping impressions.[6]

The chances of developing latent impressions on fired cartridges too is meager. This may be attributed to such factors as the attrition between the cartridge and the barrel, high temperatures and pressures produced during firing and the gaseous blowback residue which becomes coated on the bullet as it oozes out of the firearm.[7] Even on unfired cartridges it is difficult to detect fingerprints due to their small and curved surface area.[8] Moreover, while loading the cartridge into the magazine, chances of pressure distortion of the sweat residue are quite high.[9]

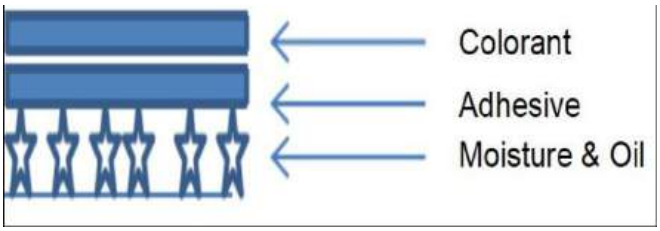
DETECTION OF FINGERPRINTS ON FIREARMS

Powder Method

The most simple and commonly used technique to detect fingerprints on metallic and polished wood items (the materials used in manufacturing the firearms) is to apply a powdered formulation on the latent impressions by gentle brushing. The powder, in turn, is composed of two broad chemicals: an adhesive and a colorant.[10-12]

The adhesive gets adsorbed on the moisture and oily components (low-boiling organic compounds) of sweat by pressure deficit mechanism.[1] The colorant gets adsorbed on the adhesive. The double layer adsorption phenomena is symbolically shown in **Figure 1**. The magnetic powder works on the same phenomena except that firstly, it contains a sprinkling magnetite in addition to adhesive and colorant and secondly, it is applied with a magnetized want, rather than a brush.

Figure 1: Mechanism of Powder Method.



Freeman[13] used both the non-magnetic and the magnetic powders to detect fingermarks on firearms, the latter giving better results. In fact, the magnetic compositions could develop latent impressions with ease even on the metallic parts of the firearms. The black, gray, red and green varieties of magnetic powders developed the most clear and sharp fingerprints.

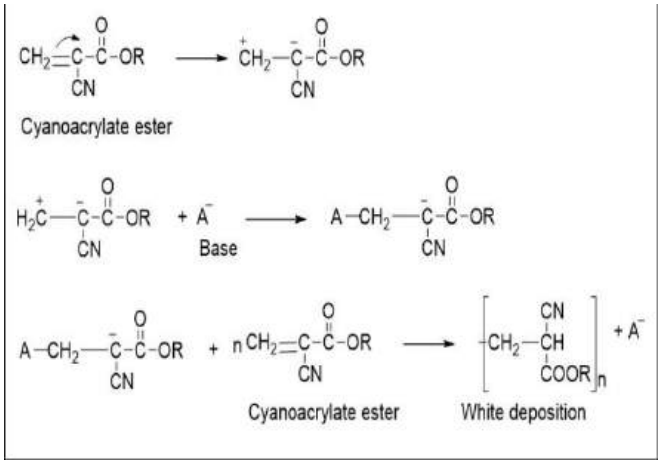
Likewise, Matov and Zazulya[14] applied three varieties of non-magnetic powders based on silica gel, polystyrene and aluminosilicate adhesives to detect latent impressions on firearms. The best results were achieved by the silica gel powder.

Cyanoacrylate Method

A fuming procedure, the cyanoacrylate method is based on the premise that when the monomer, ethyl 2-cyanoacrylate is allowed to vaporize in air, it polymerizes into a white product which, in turn, gets deposited on the sweat residue.[15] The polymerization reaction is initiated by a Lewis base, such as ammonia or water vapors. The mechanism of polymerization is displayed in **Figure 2**.

The development time may be curtailed by installing a

Figure 2: Mechanism of Cyanoacrylate Polymerization.



battery-operated fan within the fuming chamber, so as to disperse the vapors at a fast pace.[16] The white deposition is difficult to discern on pale colored surfaces. For this reason, the cyanoacrylate-developed fingerprints are generally post-treated with a luminescent dye, such as gentian violet or basic yellow 40, followed by illumination under long-wavelength ultraviolet light.[17]

By this method it has been possible to develop fingerprints even on a trigger of a firearm.[18] The possibility of this venture is quite low firstly, because there are chances of finding multiple fingerprints on trigger, superimposed one on the other, and secondly, because the surface area in question is so small that only a portion of fingertip will come into contact with it. Klasey and Barnum[19] carried out detection of latent impressions on a set of nine firearms using vacuum and atmospheric cyanoacrylate methods, after a gap of 24 hours from the time the test prints were impinged on the weapons.

With vacuum technique, the developed prints were not as white as expected, but the over-development, which usually occurs with atmospheric technique, was averted. The vacuum cyanoacrylate method worked well with blue-steel firearms. For firearms polished with pale colors, the vacuum cyanoacrylate fuming, followed by atmospheric cyanoacrylate fuming, enhanced the fingerprints to an optimum level.

Electropolymerization Method

Fingerprints may be detected by electrochemically controlled deposition of conducting polymers on the metallic components of the firearms. The electropolymerization proceeds with the oxidation of monomer to yield a radical cation. The latter reacts with the monomer, propagating the polymer chain by an electron transfer

process. The electron transfer is, however, inhibited by the segments containing the ridge details.[20]

The sweat lining along the ridges acts as an insulating area. The covalent, organic constituents of sweat-mainly fatty acids and lipids – prohibit the transfer of electrons from one species to the other. As a consequence, the polymer gets selectively deposited in between the ridges, and not on the ridges, producing negative fingerprints. However, the negative prints have as much potential to individualization as the positive prints. By varying the applied potential, the contrast of the fingerprints may be enhanced.[21]

The commonly used conducting polymers used in this endeavor are, polypyrrole,[22] polyaniline[23] and poly (3, 4-ethylenedioxythiophene.[24] The structures of these polymers are displayed in **Figure 3**.

Sapstead et al.[25] carried out the simultaneous oxidation of pyrrole and 3, 4-ethylenedioxythiophene to produce a copolymer, the deposition of which produced negative fingerprints on stainless steel surface. The developed fingerprints had a sharp contrast vis-à-vis the background. By this method it was possible to detect aged fingerprints, as well as those exposed to elevated temperatures and water.

DETECTION OF FINGERPRINTS ON CARTRIDGES

Electrochemical Method

Fingerprints on cartridges may be visualized electrochemically with the aid of scanning Kelvin probe which, in turn, is non-destructive in nature.[26] It elucidates the potential difference between a wire probe and the metallic surface of the cartridge. The potential difference, in turn, is attributed to the reaction between the ionic constituents of latent sweat and the cartridge.

The fact that the ionic compounds are non-volatile makes it possible to develop the fingermarks even at elevated temperatures. This implies that fingerprints may be detected on fired cartridges as well by Kelvin probe method.[27] Moreover, the reaction between sweat deposition and the metal initiates as soon as the finger touches the cartridge. Therefore, fingerprints may be developed even on unfired cartridges. Rubbing the cartridge with a tissue or a towel does not impede visualization.[28]

Bond[29] advocated that the reaction between the ionic compounds in the sweat and the cartridge causes corrosion at the surface, thereby revealing the ridge details. The rate of corrosion, and hence the clarity of fingerprints increases with temperature. The clarity is also dependent on the composition of the casing: If the proportion of copper is greater than 40%, the ridges that are visualized are more clear and sharp.[30] The corrosion reaction is initiated by anions, generally chloride ions. Their reaction with copper content of cartridge may be depicted as follows.

$Cu + 2Cl^- \rightarrow CuCl_2 + 2e^-] x2$

$2H_2O + O2 + 4e^- \rightarrow 4OH^-$

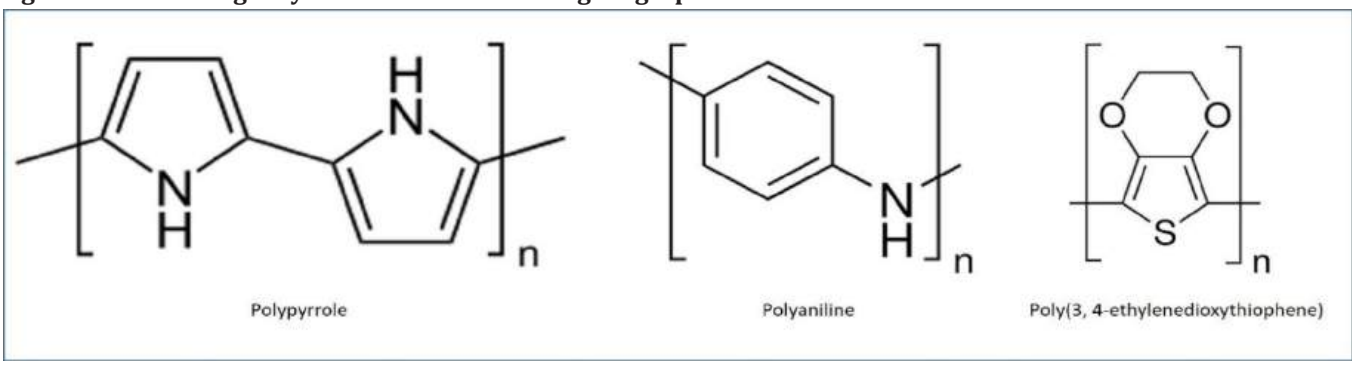
Net reaction: $2Cu + 4Cl^- + 2H_2O + O_2 \rightarrow 2CuCl_2 + 4OH^-$

In an extension of this technique, Bond and Heidel[31] heated the cartridge to 700°C (so as to imitate a fired cartridge) to increase the rate of corrosion and thereafter applied a potential of 2.5 kV. Subsequently, a conducting carbon powder was applied, which enhanced the contrast of the fingerprint against the background.

Redox Method

As stated in the previous section, the reaction between the inorganic ions present in sweat and the active metals in cartridge results in a corrosion pattern on the casing, which is a replica of the fingerprints of the shooter. This pattern can be seen both on unfired and fired cartridges, although it is more prominent in the latter due to elevated temperatures. The ridge details may be enhances with the

Figure 3: Conducting Polymers used for Detecting Fingerprints on Metallic Surfaces.



aid of a potentiometric probe.

In redox method, the enhancement is brought about not by an instrumental technique, but by a strong oxidant. The oxidizing agent dissolves the active metal(s) from the outer surface of the casing and exposes the paler underneath coating. However, it leaves out the ridges since the sweat coating thereon resists oxidation. By default, the ridge pattern becomes pronounced.

Given[32] used fuming nitric acid as an oxidizing agent on brass and nickel plated cartridges. Copper, being more active than nickel, responded better to oxidant treatment and manifested a sharper ridge detail. The redox reaction between copper and fuming nitric acid may be displayed as follows.

$$Cu \rightarrow Cu^{2+} + 2e^-$$

$$NO^-_3 + 2H^+ + e^- \rightarrow NO_2 + H_2O \,]\, x2$$

$$\text{Net Reaction: } Cu + 2NO^-_3 + 4H^+ \rightarrow Cu^{2+} + 2H_2O + 2NO_2$$

A cartridge coated with a thin layer of copper may be treated with an acidified solution of potassium permanganate for 30-60 seconds, whereupon the ridge pattern can be discerned.[33]

$$Cu \rightarrow Cu^{2+} + 2e^- \,]\, x5$$

$$MnO^-_4 + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O \,]\, x2$$

$$\text{Net reaction: } 5Cu + 2MnO^-_4 + 16H^+ \rightarrow 5Cu^{2+} + 2Mn^{2+} + 8H_2O$$

Likewise, a mixture of silver nitrate and sulfuric acid causes oxidation of the outer layer of copper in a brass cartridge.

$$Cu + 2Ag^+ \rightarrow 2Ag^+ Cu^{2+}$$

The non-ridge area becomes plated with silver, thus manifesting negative fingerprints.[34]

Gun Bluing Method

Gun bluing is a spray-polish that is applied on the metallic components of firearms to prevent rusting.[35] It comes in several varieties, but its main ingredients are selenious acid and a copper salt. The most important variety is perma blue which contains 3% selenious acid and 3% copper sulfate; yet another composition, super blue is a mixture of 5% selenious acid and 4% copper nitrate.[36]

The gun bluing spray may also be used to visualize fingerprints on fired cartridges. The ingredients of the composition undergo the following sequence of reactions on coming in contact with air.

$$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$$

$$Cu^{2+} + 2e^- \rightarrow Cu$$

$$H_2SeO_3 + 4H^+ + 4e^- \rightarrow Se + 3H_2O$$

$$Cu + Se \rightarrow CuSe$$

The copper selenide forms a vaneer on non-ridge area, revealing negative fingerprints.[37] Gun bluing has the potential to develop fingermarks on a host of of fired cartridges, including those made of brass, nickled brass, aluminium, copper and lacquered steel.[38] For example, Morrissey et al.[39] developed fingermarks on fired, as well as on unfired 9 mm brass Luger cartridges by three methods. Of these, two were sequential methods: cyanoacrylate, followed by basic yellow 40 staining; and cyanoacrylate, followed by gun bluing reagent.

The third used gun blue as a standalone reagent. It was observed that enhancement with a 50% v/v gun blue alone gave the best results with both fired and unfired cartridges. The developing time varied between 20 to 42 seconds. Moreover, gun blue reagent may be electrochemically deposited on cartridge cases to reveal fingerprints.[40] An electric current is passed through the cartridge case which, in turn, is dipped into a dilute solution of gun blue. A good quality ridge detail is visualized at a fast pace.

Disulfur Dinitride Method

Vacuum deposition of disulfur dinitride reveals fingerprints on metallic and alloy surfaces by getting adsorbed on the corrosion pattern arising due to the chemical reaction between the sweat residue and the base material. It is therefore a method of choice in cases where fingerprints are to be developed on items subjected to harsh environment.[41] It is specifically useful for fired cartridges, since these are exposed to high temperature, as well as blowback residue.[42] Wilkinson et al.[43] developed fingerprints on .233 fired cartridges by this method. Identifiable prints were obtained in 12% cases.

Sequential Method

The retrival of latent marks on cartridges which were inducted in the firearm (irrespective whether these were fired or not) depends on the nature of their surface material, as well as on the methodology of visualization. Very often a single technique may not reveal optimum quality fingerprints, and for this reason a sequence of methods may be resorted to. For example, Dominick and Laing[44] attempted to lift fingerprints from unfired cartridges of different sizes and found that the sequence which gave the best result was cyanoacrylate fuming, followed by gun bluing reagent, followed by basic yellow 40 staining. On the other hand, Bentsen et al.[45] advocated

that on fired cartridges, the sequence, cyanoacrylate fuming, basic yellow 40 staining and gun bluing reagent, gave the best results.

For cartridges which were loaded, but not fired, the sequence, cyanoacrylate fuming and gun bluing reagent gave optimum results; cyanoacrylate fuming, followed by basic yellow 40 staining gave the next best results.[46] Edmiston and Johnson[47] determined an optimal sequence for chemical development of latent prints on fired cartridge casings and fired shotgun shells made of brass and nickel. For brass cartridges, the best sequence proved to be: Cyanoacrylate fuming, black powder, acidified hydrogen peroxide, rhodamine 6G staining.

For nickel cartridges, the following sequence gave the most appropriate results: Cyanoacrylate fuming, rhodamine 6G staining, acidified hydrogen peroxide, black powder. In both cases, fluorescence was observed under 515 nm radiation.

CONCLUSION

In a criminal cases involving shootouts, an investigator may come across a wide variety of firearms and cartridges. One of the most useful forensic tools which can help solve such crime cases is to develop latent fingerprints on ammunition. Although there are a large number of methods to detect fingermarks on different types of evidence, this venture on firearms and cartridges is problematic.

Due to the multiple handling of firearms, small size of casings and surface degradation of cartridges associated with firing process, the number of fingerprint development methods that may be used on arms and ammunition becomes severely limited. These scarce methods are described in this review article.

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REVIEW ARTICLE

Paranasal Sinus Morphometry for Forensic Sex Determination: A Systematic Review of Conventional Radiography, Cone-Beam Computed Tomography, and Computed Tomography

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ABSTRACT

Introduction: The paranasal sinuses are paired air-filled cavities within the craniofacial skeleton that exhibit considerable individual variation in size, shape, and morphology, making them valuable structures in forensic identification. Among these, the frontal and maxillary sinuses are of particular importance because their radiographic features can provide useful biological information when conventional identifiers are unavailable or compromised.

Aim: To systematically review the published literature on radiographic morphometric analysis of the paranasal sinuses for forensic sex determination and critically evaluate the evidence regarding frontal sinus assessment using digital paranasal sinus radiography (PNS) and maxillary sinus assessment using cone-beam computed tomography (CBCT) and computed tomography (CT).

Materials and Methods: A systematic literature search from 2015 to 2025 was performed in accordance with the PRISMA 2020 guidelines using predefined search terms, eligibility criteria, and a structured study selection process A total of 18 studies (7 studies with digital paranasal sinus (PNS) radiography, 5 studies with cone-beam computed tomography (CBCT) and 6 studies with computed tomography (CT)) met the inclusion criteria. Using PNS, studies of frontal sinus morphometry have consistently shown that the frontal sinus dimensions are larger in males. The majority of the studies of CBCT and CT focused on the morphometry of the maxillary sinus. Males showed significantly greater sinus height, width, length, and volume than females in all populations. All the included studies reported statistically significant sexual dimorphism of the evaluated paranasal sinuses supporting their potential utility as adjunctive tools for forensic sex determination, despite the heterogeneity of the imaging protocols and morphometric parameters used.

Conclusions: A major limitation identified in the present review is the paucity of CBCT- and CT-based studies evaluating frontal sinus morphometry. Most three-dimensional imaging studies have focused on the maxillary sinus, precluding a direct modality-wise comparison of frontal sinus measurements obtained using PNS radiography, CBCT, and CT. This highlights an important research gap and underscores the need for future comparative studies specifically investigating frontal sinus morphometry across different imaging modalities.

To best of our knowledge this is the first systematic review synthesizing evidence on radiographic assessment of the paranasal sinuses (frontal and maxillary) for forensic sex determination using PNS, CBCT, and CT.

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INTRODUCTION

Forensic identification of unknown individuals is critical in cases of mass disasters, road accidents, fires, and criminal investigations, where anatomical uniqueness plays a central role. The paranasal sinuses are known for considerable variation among individuals in their size, degree of pneumatization, and asymmetry, which has made them an area of interest in forensic anthropology.[1] Since these structures are surrounded by bone, they are often preserved even when trauma, burning, or

decomposition destroys softer tissues, thereby increasing their value in sex estimation and identification of unknown or degraded remains.[2-3]

Their forensic utility is rooted in development: at birth, the paranasal sinuses are minimally developed and then enlarge gradually during growth through pneumatization of the adjacent bone, usually attaining near-adult dimensions by 18–20 years of age. Once maturity is reached, they tend to remain relatively constant, although minor alterations may occur later in life because of bone remodeling, tooth loss, and age-related changes in the maxilla.[4-5]

Among the structures used for this purpose, the frontal sinuses have gained particular significance due to their highly variable and individual-specific morphology, making them valuable for both personal identification and gender determination.[6] The frontal sinus, one of the four paranasal sinuses, is highly variable and unique to each individual, making it valuable for personal identification.[7] "Anatomically, the frontal sinuses are two pneumatic cavities covered by mucosa, which is embryonically developed from an ethmoidal cell, situated in the posterior part of superciliary arcs, between the internal and external cortical bones of the frontal bone." They are rarely symmetrical, there is usually a septum between both, which usually deviates from the midline. They are not seen at birth, but they begin to develop in the second year of life.[8] The frontal sinuses are highly variable in size, ranging from a few cubic centimeters to almost the entire area of the frontal lobe. The mean height of the frontal sinuses is 24.3 mm with a mean extent of 29mm from the midline to the lateral wall of the sinus.[9]

The application of frontal sinus in forensic science requires a certain amount of precautions as some environmental factors such as the hyperpneumatization due to sport activities, disease, trauma, postmortem changes and mainly variations in techniques and radiographs such as distance, angle and orientation of the cranium can modify the image of the frontal sinus distorting its anatomical characteristics and hampering the identification of the individual.[10]

Previous researchers have highlighted that the frontal sinus develops during early childhood, reaches full size by approximately 20 years of age, and remains relatively stable until old age because of their low frequency of aplasia and their unique structural variability, frontal sinuses serve as a highly reliable morphological characteristic for establishing individual identity.[11]

The frontal sinus exhibits considerable inter-individual morphological variability, a characteristic well documented in anatomical, radiological, and anthropological literature. Even monozygotic twins possess distinct frontal sinus morphologies, reinforcing its utility as a reliable anatomical marker for forensic identification.[12]

Another important paranasal sinus that is considered helpful in forensic gender determination is the maxillary sinus. It is an important anatomical structure because it demonstrates measurable sexual dimorphism in multiple morphometric parameters, including height, width, length, and volume, with males typically showing larger dimensions than females. Its forensic value becomes particularly significant in cases where other skeletal elements are fragmented, burned, or otherwise unavailable, as the maxillary sinus can still be evaluated reliably on CT and CBCT images for comparative analysis.[13-14] Several studies have reported satisfactory predictive accuracy for sex estimation based on maxillary sinus morphometry, supporting its use as an adjunctive aid in forensic identification rather than a standalone criterion.[15-16]

Research study findings indicate that once the maxillary sinus achieves complete pneumatization in early adulthood, its dimensions remain relatively unchanged over time. Even with advancing age, the coronal CBCT images showed no notable evidence of remodeling or resorption. This suggests that sinus size is largely preserved after skeletal maturity.[17]

The aim of this systematic review was to examine the published literature on the radiographic morphometric analysis of the paranasal sinuses for forensic sex determination and to critically evaluate the evidence on frontal sinus assessment using digital paranasal sinus radiography, as well as maxillary sinus assessment using cone-beam computed tomography (CBCT) and computed tomography (CT).

MATERIALS AND METHOD

A systematic literature search was conducted to identify studies evaluating sex based differences in frontal sinus dimensions using digital paranasal sinus radiographs. Electronic databases including PubMed/MEDLINE, Scopus, Web of Science, and Embase were systematically searched using a combination of controlled vocabulary

(MeSH/Emtree terms) and relevant free text keywords. The search string incorporated terms related to "frontal sinus," "paranasal sinus radiograph," "digital imaging," "sex determination," "sexual dimorphism," and "forensic identification." No language restrictions were applied at the search stage in order to limit retrieval bias, although final inclusion was restricted to studies with English language full texts. The search was supplemented by manual screening of reference lists of included studies and relevant review articles to identify additional eligible records.

Studies from 2015 to 2025 were included, screening was performed in two stages: (1) title and abstract screening against the predefined inclusion/exclusion criteria, followed by (2) full text assessment of potentially eligible articles. Conflicts in eligibility decisions were resolved through discussion or by a third reviewer, and the entire process was documented in a PRISMA style flow diagram **(Figure 1)** to ensure transparency and reproducibility. The eligibility criteria based on the PICOS framework **(Table 1)**.

INCLUSION CRITERIA

Studies were included if they fulfilled all of the following criteria:

1. Original research articles evaluating the use of paranasal sinus morphometry for forensic sex determination or sex estimation.
2. Studies assessing frontal sinus and/or maxillary sinus morphology using radiographic imaging modalities, including:

- Conventional paranasal sinus (PNS) radiography,
- Cone-beam computed tomography (CBCT), or
- Computed tomography (CT).

3. Human studies conducted on living individuals or skeletal remains with clearly defined male and female study groups.
4. Studies reporting quantitative morphometric measurements (e.g., height, width, length, area, volume, or other linear/volumetric parameters) of the frontal and/or maxillary sinus.
5. Studies evaluating diagnostic performance for sex determination using statistical analyses such as prediction accuracy, sensitivity, specificity, discriminant function analysis, or regression models.
6. Full-text articles published in peer-reviewed journals.
7. Articles published in the English language.

Exclusion Criteria: Studies were excluded if they met any of the following criteria:

1. Review articles, systematic reviews, meta-analyses, narrative reviews, editorials, letters to the editor, conference abstracts, case reports, and book chapters.
2. Animal or experimental studies not involving human subjects.
3. Studies evaluating paranasal sinuses for purposes other than forensic sex determination (e.g., surgical planning, sinus pathology, trauma, developmental anomalies, or age estimation alone).
4. Studies using imaging modalities other than conventional PNS radiography, CBCT, or CT (e.g., MRI or ultrasonography).
5. Studies lacking quantitative morphometric measurements or sufficient statistical data for interpretation.
6. Duplicate publications or studies with overlapping datasets, in which case the most comprehensive or recent study was included.
7. Articles not available in full text or published in languages other than English.

Various studies done in last decade using PNS, CBCT and CT images studying frontal sinus and maxillary sinus different dimensions and volumes have been tabulated in table 2,3 and 4 in detail. These tables highlights various methodologies used and results shown by the researchers for sex determination using these imaging techniques, which can be used for gender determination.

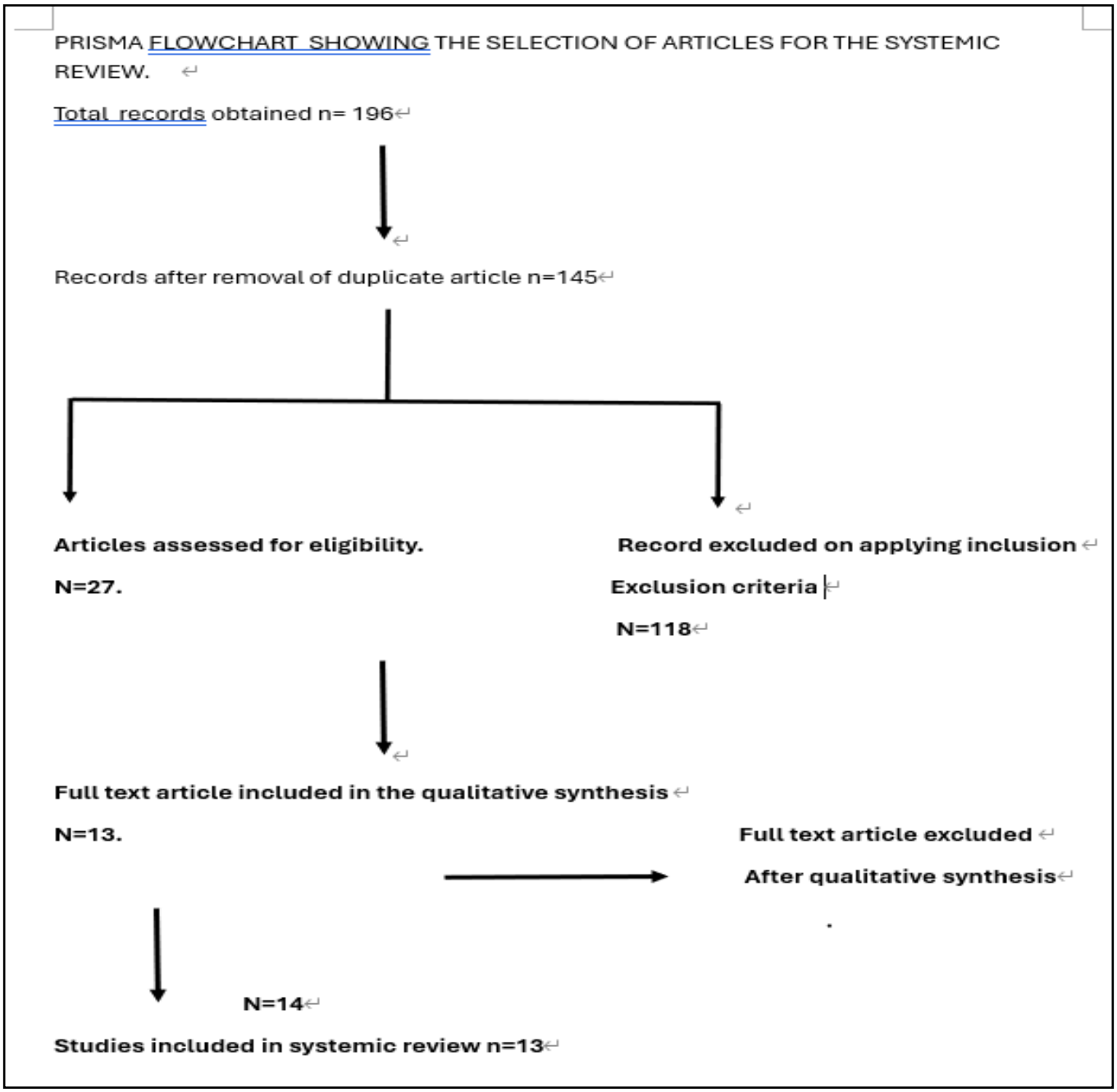
REVIEW OF LITERATURE

DISCUSSION

The present systematic review evaluated the application of radiographic imaging modalities for sex determination using morphometric analysis of the paranasal sinuses. The available evidence demonstrates that both frontal and maxillary sinuses exhibit measurable sexual dimorphism, supporting their role as adjunctive anatomical structures for forensic human identification. However, the reviewed studies differed substantially with respect to the sinus evaluated, imaging modality employed, morphometric parameters measured, and study population, precluding direct quantitative comparison.

Gender determination using paranasal sinus radiographs is a growing area of forensic research.[18] Reliable human

Figure 1: PRISMA Flow Chart Showing the Selection of Articles for the Systematic Review.



identification using paranasal sinus morphometry depends entirely on a tripartite framework: understanding sinus developmental anatomy, mastering their radiographic visualization, and applying established forensic identification principles. Without these foundations, accurate antemortem–postmortem comparison remains unachievable.[38]

In disaster victim identification, frontal sinus analysis is especially valuable because the sinus shows strong individual variation and can often be compared reliably between ante-mortem and post-mortem radiographs, even when remains are fragmented or heavily damaged. Its forensic usefulness is further strengthened by the fact that the frontal sinus is frequently preserved in the skull and may remain visible when other identifying features are destroyed by fire, trauma, or decomposition, making it a practical radiographic marker in mass fatality settings. This makes frontal sinus dimensions and morphology an important adjunct to primary identifiers such as fingerprints and DNA, particularly when those methods are unavailable, delayed, or compromised.[39-40]

Measurements of certain morphological and dimensional

Table 1: PICOS Framework.

Component	Eligibility Criteria
Population (P)	Human subjects (living individuals and/or skeletal remains) with identifiable sex
Intervention/Index Test (I)	Radiographic morphometric evaluation of the frontal and/or maxillary sinus using PNS radiography, CBCT, or CT
Comparator (C)	Male versus female morphometric measurements; comparison among radiographic imaging modalities where applicable
Outcomes (O)	Sex determination accuracy, morphometric parameters, discriminant analysis, sensitivity, specificity, predictive values
Study Design (S)	Original observational studies (cross-sectional, retrospective, prospective, case-control)

parameters of maxillary sinus can be useful for gender determination and hence human identification as shown in previous research studies done by Mathew and Jacob,[41] Paknahad et al.,[42] Soares et al.,[43] Waluyo et al.[44] Situations where decomposed, burnt and highly fragmented remains, are the only evidence available the maxillary sinuses if found intact, it can be used as a method for gender determination in the absence of the conventional gender indicators.[45-46]

The measurement of the maxillary sinus is population-specific but is affected by race, genetics, maternal health culture, and environmental quality conditions during prenatal development.[47] The maxillary sinus reaches its full size after puberty, and its measurement has become a trustworthy factor in gender determination. In men, compared to women, statistically significant larger mean osseus volume is been reported by Biggerstaff R.H.[48] Thus ante-mortem and post-mortem radiographs of the paranasal sinuses can provide a practical comparison method, especially in large-scale incidents where DNA,

Table 2: PNS Frontal Sinus Views for Gender Determination.

Author	Age years	Sample size: Gender & Population	Methodology	Result	Conclusion
Chaudhary S etal. 2016[18]	20-40 years	50 Haryana	Water's radiographs were made according to Caldwell technique. Markings of frontal sinus based on Riberro Fde's measurement criteria.	Frontal sinus is bigger and wider in males as compared to females.	The frontal sinus is a highly variable and unique anatomical structure that can be utilized for human identification.
Sheikh NN etal, 2018[6]	20 years	50M: 50F Maharashtra population	PNS views -Height and width of maxillary and frontal sinuses were measured and compared between genders and between the sides.	Maxillary sinus height was greater on the left, while width was greater on the right.	The width of left maxillary sinus and frontal sinus accuracy 59% & 58% respectively
Nethan ST etal. 2018[19]	20 years	50M:50F Uttar Pradesh population	Digital PNS view radiographs, to record the frontal sinuses.	Technique was found to be 62% accurate in predicting females and 46% accurate in predicting males	frontal sinuses can be utilized
Garhia P etal.2019[9]	20-50 years	38M:26 F New Delhi	PNS view radiographs selected and the frontal sinuses were analysed using GIMP based on Ribeiro Fde's measurement criteria	Frontal sinus were greater in males as compared to females.	The frontal sinus is a highly variable and unique anatomical structure that can be utilized for human identification.
Kumar S etal.,2020[20]	20-30 years	50M:50F Bihar population	Digital Paranasal Sinus view taken by Caldwell technique	Significant differences were observed for frontal sinus height and width between males and female	Frontal sinus measurements can be used
Shah S etal, 2021[7]	20 years	75M:75F Uttar Pradesh population	Digital measurements of the height, width and area of the frontal sinuses were recorded using AutoCAD 2014 software	It was noted that the right height of the frontal sinus was a better predictor than any other parameter assessed for identifying the gender. Accuracy rate of 68.6%	PNS views can be used
Srivastava C etal.2023[21]	20 years	20M:30F Moradabad	frontal sinuses were examined using Adobe Photoshop CS3 software using Ribeiro fde's measuring standards.	Gross dimension of frontal sinus was found to be greater in males than females.	The frontal sinus is a highly variable and unique anatomical structure that can be utilized for human identification.

Table 3: CBCT for Gender Determination.

Author/year	Age	Sample	Methodology	Result	Conclusion
Vrushali R G etal. 2024[22]	20 - 60 years	159 M :159 F Mumbai	Bilateral measurements of the volume, height, width, and length of the maxillary sinuses	Left width showed the highest sex estimation accuracy (74.21%), while left height showed the lowest (49.37%) Right Length (70.07%) and left volume (66.66%)	Good indicator of sex estimation
Ola M R etal.2025[23]	3 group. group 1:- 18-29years ,30-41years and 42-60years	90M:90F Egypt	Medio-lateral (ML), superior-inferior (SI), anteroposterior (AP), antero-lateral angle (ALA), volume (Vol.) of both right (R) and left (L) maxillary sinuses (MS), intermaxillary distance (IMD), and bizygomatic distance (BZD) were measured and compared	Superior-inferior right showed the highest sex prediction accuracy (69.44%Intermaxillary distance showed highest age prediction value (R^2 = 0.143).	The use of maxillary sinus dimensions and BZD may be valuable for sex determination.
Tahreem F etal. 2023[24]	18 years	50 M: 50 F Chennai	Width and height of the maxillary sinus	The mean sinus width in males varied from 27.5 ± 1.56 whereas in females was 19.7 ± 4.95, the mean sinus height ranged from 35.12 ± 2.56 in males and 31.45 ± 3.17 in females	reliability, usability and accuracy of CBCT for evaluating maxillary sinus dimensions
Shamim R etal. 2023[25]	18 years	40M : 40 F Northern india	Width and height of the maxillary sinus	Male sinuses are higher, longer, broader, and larger than female ones	Sexual dimorphism is helped by right sinus volume.
Deshpande, Anuja A etal.2022[26]	18 years	30M:30 F rural areas	height, length, and width of the maxillary sinus	Statistically significant differences observed between the males and females for height and length of maxillary sinus. Accuracy 71.3%.	Maxillary sinus height can be used for sex identification.
Mathew, Anju; Jacob etal, 2020[27]	18 years	100 Tamilnadu population	maxillary sinus parameters: width, length, height, intermaxillary distance, bizygomatic distance in axial and coronal view.	maxillary sinus dimensions greater in males as compared to females	Maxillary sinus can be used as an aid in forensic anthropology for gender determination
Omaiya Abu El-Dahab etal. 2018[28]	20-70years	50M:50 F Egyptian population	Maxillary sinus width, depth, bizygomatic distance and intermaxillary distance were measured from axial images and height was measured from coronal images.	All measurement of males showed statistically significantly higher mean values than females.	Maxillary sinus can be used for gender determination
C T Ravali etal.2017[29]	18 years	15M:15 F Hyderabad	Different parameters (width, length, height, area, perimeter and volume) were measured and evaluated. Mean and standard deviation of both maxillary sinuses measurements were calculated and compared.	No significant sex differences were observed in maxillary sinus measurements, although females showed comparatively lower values than males.	Maxillary sinus can be used for gender determination.

fingerprints, or visual recognition may be delayed or unavailable.[40]

Among the conventional radiographic studies, digital paranasal sinus (PNS) radiography was mainly used for the evaluation of the morphology of the frontal sinus. Most researchers found that males showed significantly larger frontal sinus dimensions than females. Shah et al.[7] noted that the right frontal sinus height was the best predictor of sex with an overall prediction accuracy of 68.6%. Similarly, Kumar et al.[20] Garhia et al.,[9] Chaudhary et al.[18] and Srivastava et al.[21] have consistently shown larger dimensions of the frontal sinus in males, which suggest that the frontal sinus morphometry does demonstrate reproducible sexual dimorphism in different Indian populations. The prediction performance, however, was quite variable among the studies, with Nethan et al.[19] reporting lower accuracy (62% in females and 46% in males), suggesting that the frontal sinus measurements from two-dimensional radiographs should be considered supplementary and not definitive forensic evidence.

The advent of three-dimensional imaging has greatly improved the morphometric assessment of the paranasal sinuses. The reviewed literature indicates that most of the studies using CBCT have investigated the maxillary sinus and showed statistically significant difference between male and female. Vrushali et al.[22] found that the left maxillary sinus width was the best predictor of sex (74.21%). Rehan OM et al.[23] found that the superior-inferior dimension of the right maxillary sinus was the best discriminating parameter (69.44%). Similarly, significantly greater maxillary sinus height, width and length in males were reported by Tahreem et al.,[24] Shamim et al.[25] and Deshpande et al.[26] The results indicate that CBCT allows accurate linear and volumetric measurements in the three spatial dimensions, thus improving the reproducibility of morphometric analysis.

CT studies demonstrated comparable observations. Belaldavar et al.,[30] Vaishnavi et al,[31] Sashisaroj et al.,[32]

Table 4: CT Scan for Gender Determination.

Author / Year	Age	Sample	Methodology	Result	Conclusion
B P Belaldavar et al. 2025[30]	45.39 years and 33.43 years	150 patient North Karnataka	Medial-lateral (ML), superoinferior (SI), anteroposterior (AP) dimensions, and the volumes of both right and left maxillary sinuses were recorded using the ITK SNAP DICOM viewer.	Significant difference of males having higher volume measurement than females on the right side.	Gender discrimination in sinus shape assessment
Vaishnavi M et al. 2024[31]	20 years	92 M: 92 F South Indian population	PACS (Picture archiving and communication system)	Maxillary sinus dimensions (length, width, height, and volume) showed statistically significant sexual dimorphism, with higher values in males compared to female	Statistically significant discriminate ability with good sensitivity and specificity for sex determination
Sashisaroj et al. 2022[32]	18-55 years	49 M: 51 F Karnataka	Anteroposterior (AP), superioinferior (SI), mediolateral (ML) diameter, volume of MS, and the distance between two MS were measured on	MS dimensions and volume were greater in males, with significant gender differences in AP diameter, SI diameter, and volume. No significant age-related differences were observed, though the 41–55 years group showed higher mean values.	2D or 3D CT good for gender determination
Mehreen Fatima et al. 2021[33]	20-40 years	45 M: 52 F Karachi	The anthropometric measurements predicted by a formula of maxillary sinus volume=(width×Depth×height)×0.5	Accuracy to determine sex: 78% in females and 100% in males	CT measurements of maxillary sinuses are useful to determine sex in forensic identification
Mukul Prabhat et al. 2016[34]	20-50 years	15 M: 15 F Modinagar, Uttar Pradesh	Mediolateral, superoinferior, and anteroposterior dimensions and the volume of the maxillary sinuses	Gender with an accuracy of 80.0% in males and 86.7% in females, with an overall accuracy rate of 83.3%	Gender determination with a fair degree of accuracy when the whole skeleton is not available.
Muthukumaravel et al. 2016[55]	20 - 50 years	100 M: 100 F Tamil Nadu	The maxillary sinus volume of each side were calculated formula: Maximal width X Maximal height X Maximal depth X 0.5.	The maxillary sinus volumes of the males were found to be significantly higher than that of the females	Reliable for gender determination
Ranjith K et al. 2015[36]	20 years	17 M: 13 F Andhra Pradesh	The dimensions height, length, width, and volume measured using SYNGO software	Statistically significant results with a higher percentage of sexual dimorphism in the case of volume	Volume of the right maxillary sinus can be used as accurate diagnostic parameter for sex determination.
Suresh K et al. 2014[37]	20-60 years	61 M: 41 F Gwalior	All measurements of maxillary air sinus dimensions (AP, width and height) were done directly on computer on DICOM images using Electronic Caliper inbuilt in the DICOM viewer software	Male maxillary sinus dimensions and volume were significantly larger than females, with AP dimension showing the highest sex prediction accuracy (69.81%) and an overall accuracy of 67.03%.	Identification of gender possible

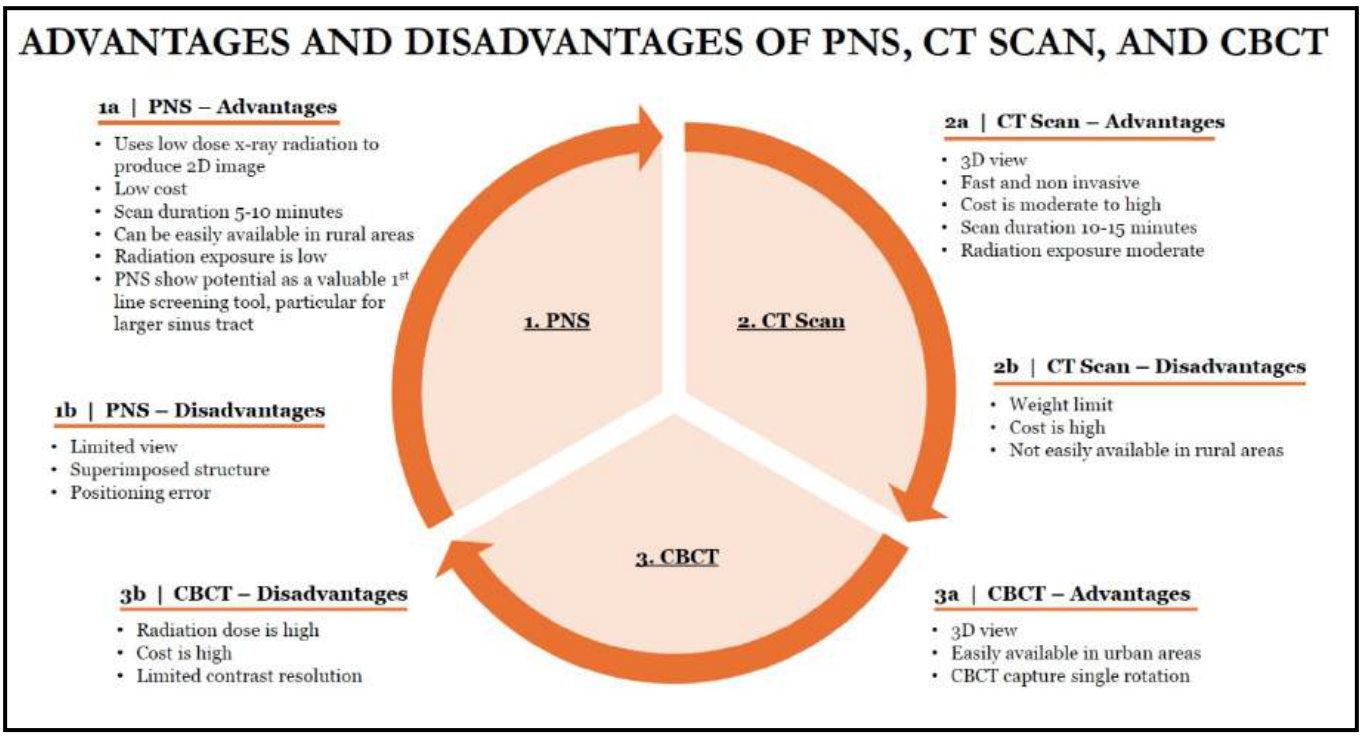
Mehreen Fatima et al.,[33] Mukul Prabhat et al.,[34] and Muthukumaravel et al.[35] consistently reported significantly larger maxillary sinus dimensions and volumes in males. Several authors emphasized that volumetric analysis provided greater discriminatory ability than individual linear measurements. Mehreen Fatima et al.[33] achieved sex prediction accuracies of 100% for males and 78% for females using maxillary sinus volume, while Mukul Prabhat et al.[34] reported an overall classification accuracy of 83.3%. These findings suggest that CT-derived volumetric measurements may provide greater diagnostic performance than conventional two-dimensional morphometric analysis.

Sexual dimorphism was significant for all imaging modalities, but significant methodological differences were found in all studies included. The conventional radiographic studies mainly relied on the measurements of frontal sinus height, width and area by employing computerized software like AutoCAD, Adobe Photoshop and GIMP.[6-7,9,18-21] CBCT and CT studies, in contrast, used more detailed 3D parameters, such as mediolateral, superoinferior, and anteroposterior dimensions, sinus volume, and intermaxillary distances.[22-37] This methodological shift mirrors the growing importance of volumetric analysis, which offers a more representative picture of overall sinus morphology than isolated linear measurements.

Another important observation was the marked influence of population-specific variation. Nearly all studies were conducted in geographically distinct Indian populations, with one Egyptian[23] and one Pakistani[33] study. Because paranasal sinus morphology is influenced by genetic, ethnic, and environmental factors, universally applicable morphometric thresholds cannot currently be recommended. Consequently, population-specific reference standards remain essential for accurate forensic application.

From a practical perspective, each imaging modality offers distinct advantages. Digital PNS radiography remains inexpensive, widely available, and suitable for preliminary forensic investigations, particularly in resource-limited settings. However, its inherent two-dimensional nature introduces image distortion and anatomical superimposition, potentially limiting measurement accuracy. Conversely, CBCT and CT provide multiplanar reconstruction, accurate volumetric assessment, and

Figure 3: Advantage and Disadvantages of PNS, CT Scan & CBCT



superior reproducibility, making them preferable when advanced imaging facilities are available. Nevertheless, increased radiation exposure, higher cost, and limited accessibility may restrict their routine use.[49-50,55]

Overall, the evidence suggests that radiographic morphometric assessment of the paranasal sinuses represents a valuable adjunctive approach for forensic sex determination. While frontal sinus analysis using conventional PNS radiographs demonstrates moderate discriminatory ability, three-dimensional imaging modalities enable more comprehensive evaluation of maxillary sinus morphology and generally report higher predictive accuracies. The findings suggest that although the frontal sinus exhibits morphological individuality at the person-specific level, the degree of sexual dimorphism observed within the studied population is insufficient to support reliable biological sex determination through dimensional analysis exclusively. Thus, frontal sinus analysis is best used as a supplementary tool in conjunction with other forensic methods.[21] Furthermore, such inconsistencies highlight the need for population-specific standards and larger sample sizes.[6] The variable difference of each research could be caused by the effect of environmental and genetic factors on the frontal sinus. The frontal sinus morphology in each population is influenced by systemic factors such as craniofacial configuration, frontal bone thickness and growth hormone levels.[8] Even though there are drawbacks as mentioned but still in rural and resource-limited settings where only conventional X-ray machines are available, PNS view radiographs remain the most feasible option for such analyses.[6] **Figure 3**, provides a comparative summary of the advantages and limitations of conventional PNS radiography, CBCT, and CT for forensic evaluation of the paranasal sinuses. The figure is intended to facilitate evidence-based selection of the most suitable imaging modality according to its availability and the condition of the recovered remains. Where preserved, the frontal sinus and/or maxillary sinus may be subjected to morphometric analysis to support forensic sex determination and antemortem–postmortem human identification.

Frontal sinus pattern matching can produce conclusive identifications in actual forensic cases, and reviews of paranasal sinus imaging emphasize its value for human identification and sex estimation, which can narrow the search pool during disaster victim profiling.[21] This makes frontal sinus analysis a cost-effective, noninvasive, and objective adjunct to other DVI methods, particularly in settings where rapid triage of unknown remains is essential.[52]

Similarly this systematic review evidence indicates that maxillary sinus dimensions can support sex estimation as an auxiliary method in human identification, with several

studies reporting moderate to good accuracy and consistent male predominance in sinus size. Its forensic usefulness is further enhanced in cases involving fragmented, burned, or decomposed remains, where the maxilla and surrounding structures may still be preserved. Overall, maxillary sinus morphometry should be considered a practical adjunct to established identification methods rather than a standalone marker, but one that strengthens the biological profile when conventional identifiers are unavailable.

CONCLUSION

Overall, the available evidence suggests that PNS radiography provides an accessible, low-cost, and clinically practical method for frontal sinus assessment, whereas three-dimensional imaging modalities offer superior morphometric accuracy for paranasal sinus evaluation. The improved performance of maxillary sinus for gender determination using CBCT and CT can be attributed to their ability to provide distortion-free multiplanar visualization, precise linear and volumetric measurements, and elimination of anatomical superimposition.

Future research should focus on well-designed comparative studies evaluating the same frontal sinus parameters using PNS, CBCT, and CT within identical study populations, together with standardized measurement protocols and artificial intelligence-assisted automated morphometric analysis, to establish the optimal imaging modality for frontal sinus-based forensic sex determination.

DECLARATIONS

Ethics approval and consent to participate: Not applicable. This study is a review of previously published literature and did not involve human participants or animals.

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REVIEW ARTICLE

Rethinking Human Subject Protection in Clinical Trials: Legal, Ethical and Scientific Challenges

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ABSTRACT

'Life and Death' is the most challenging part in the jurisprudence of law and medicine. Life, the very crux of human existence, needs to be guaranteed through a constitutional mandate. The Supreme Court, while interpreting Article 21, has stated that "Right to Life includes right to Health". The progress in biomedical science and technology, and its application in the practice of medicine, has provoked a great deal of interest and anxiety among the public and the scientific world alike. Although breakthroughs are being made in healthcare, the ethical downside of unethical research and subject abuse continues to plague society. The predominant concern is protecting individuals from injury and exploitation by the relatively more powerful scientists and physicians. Research activities such as the Tuskegee syphilis and similar studies, the thalidomide case, and numerous other examples from around the world have kept alive the public perception that biomedical research is related to essentially unethical practices on human subjects. To develop new treatments and new drugs, one must conduct extensive research, and once new drugs are developed, the next step is testing their efficacy and safety for patient use. To assess its efficiency and safety, the drug must first be tested on animals and then on humans. So, clinical trials are inevitable, but the important consideration is that they must not be misused and that innocent people must not be treated as guinea pigs. It should be conducted in accordance with proper rules and regulations. This research paper discusses the various problems encountered in clinical trials and the available solutions.

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INTRODUCTION

The development of new drugs involves several complex steps, including lab experiments, preclinical studies, and clinical trials with humans. Only after preclinical results support the safety and effectiveness of a drug can it move forward into the clinical trial phase.[1] Clinical trials are planned by researchers to measure the safety and effectiveness of a drug, vaccine, or other therapeutic intervention prior to its development for routine clinical use.[2] According to the Clinical Trials Directive (CTD), the term clinical trial refers to any clinical study conducted with human subjects to assess the therapeutic, clinical, pharmacological, and pharmacodynamic effects of a study drug and its safety and effectiveness.[3] The Medicines and Healthcare Products Regulatory Agency (MHPRA) uses a similar definition, describing a clinical trial as a study of the safety or efficacy of a drug through clinical investigations with human patients. The results of clinical trials serve as the basis for establishing the safety and efficacy of new medical treatments before entering routine clinical use.[4]

BACKGROUND

There has been little ethical regulation of human testing for more than 2000 years. For most of human experimentation, there was little or no effort made to obtain informed consent from the subjects. Although there was significant improvement in medical research in the 1800s, the ethical safeguards then available for subjects were inadequate. The use of human subjects in medical

research grew rapidly in the 20th century. Large numbers of the human subjects used were vulnerable individuals, including prisoners, persons who were in institutions, patients in hospitals, and orphan children, and very few (if any) of these individuals were enrolled without their knowledge and consent. The discovery of unethical treatment of human subjects in World War II led the country and the world to develop an international ethical standard of care for human subjects.[5]

Pre-Clinical Research and Scientific Basis

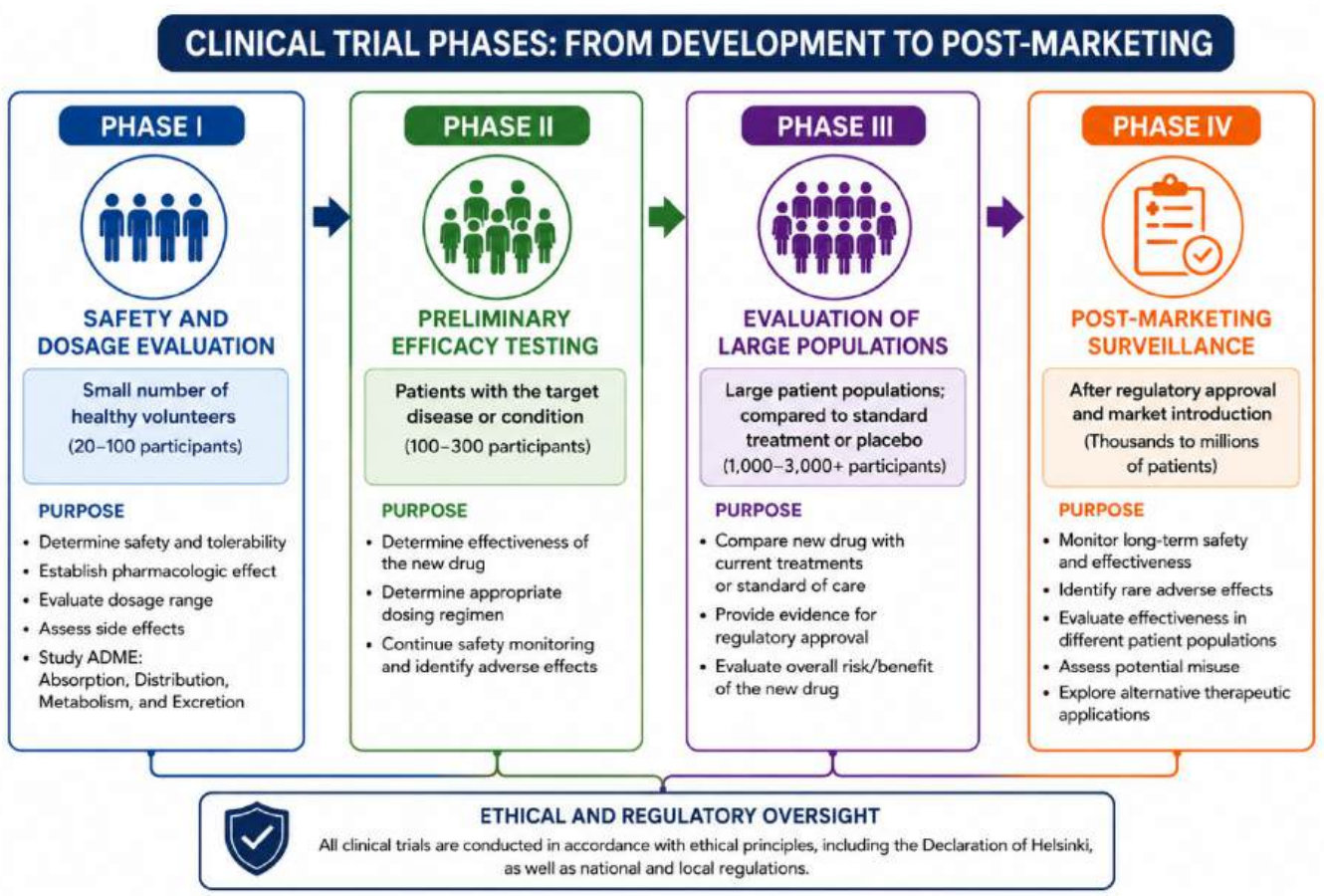
Preclinical research is the initial phase of drug development; it includes studies to determine a drug's safety and efficacy before it is tested in humans. The goals of preclinical studies include establishing appropriate dosages and providing early indications of therapeutic action by evaluation of pharmacological, toxicological, and pharmacokinetic properties of the drug. During preclinical studies, scientists will evaluate the drug's potential therapeutic uses, dose-dependent toxicity, effects on reproduction, and potential long-term health risks. Although findings obtained from animal models cannot be completely relied upon to predict drug response in humans because of the extensive biological and metabolic variances between species, preclinical research does provide critical evidence to assess potential risks associated with future clinical use; to determine optimal dosage regiment before clinical studies; and to establish whether or not a drug is approved to move forward into human clinical trials.[6]

Phases of Clinical Trials

Traditionally, clinical studies are divided into four phases, based on the type of evidence being generated.[7]

Scientific Design and Trial Protocols

To generate the greatest trust and reliability, clinical research must be conducted scientifically with high rigor, using strict scientific methodology, including randomization, control groups, placebo(s), and blinding. Randomly assigning participants to their appropriate intervention and control groups will minimize/avoid selection bias.[8] Blinding will reduce performance assessment bias. Control groups receiving placebo, standard treatment, or no treatment provide a basis for determining the efficacy of the investigational



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intervention. While placebo-controlled clinical trials are the foundation of scientific validity, they can raise ethical concerns when effective therapies are available, as they require more extensive oversight to protect participants' safety, dignity, and welfare throughout the study.[9]

Ethical Guidelines for the Use of Placebos in Clinical Trials

Placebos can be used in Clinical Research if there is a scientific justification, and no alternative treatment is equally effective. Established treatments cannot be replaced by a placebo if there is a risk of serious harm to the participant. Trial participants must be aware of the likelihood of receiving a placebo; they must also be informed of the related risks and give their informed consent prior to the trial. Continuously monitor participant safety through rigorous safety monitoring methods, including establishing prompt means of providing treatment to participants who suffer from unacceptable harm, is required in all clinical trials. Use of Placebos in Vulnerable Populations at an Increased Level of Ethical Scrutiny is required, and all Placebo-Controlled Studies must be reviewed by an Ethics Committee and must be subject to a thorough Ethics Committee review to determine that the scientific advantages outweigh any risk, while protecting the safety, dignity, and welfare of the participants being studied.[10]

Monitoring and Safety Mechanisms: Adverse Event Reporting and Oversight

The primary goal of conducting clinical trials is protecting the participant from risk through ongoing monitoring of the participant(s) for safety and independent monitoring of the participant(s) for ethics. Researchers routinely review each adverse event to determine the risk to the participant and whether it relates to the investigational product. Any adverse event defined as serious death, life-threatening condition, hospitalization, permanent disability, or birth defect must be reported immediately to the appropriate regulatory authorities, ethics committees, and sponsors of the study. Oversight is provided by independent committees such as the Institutional Ethics Committee (IEC), Institutional Review Board (IRB), and Data Safety Monitoring Board (DSMB). In addition, these committees may suggest protocol amendments or suspend or terminate a clinical trial if they determine that the risk to the participant outweighs the potential benefit. Phase IV post-marketing surveillance is conducted to continue monitoring both the long-term safety and effectiveness of approved treatments, to find rare or delayed adverse events, and to provide an open and transparent system that supports accountability and public confidence in clinical research.[11]

Legal Framework Governing Clinical Trials: International and National Regulatory Regimes

Clinical trials are regulated by national and international ethical and regulatory standards to protect participants' rights and prevent fraudulent scientific practices. The Nuremberg Code (1947) established the requirement that research subjects participate voluntarily and with comprehension of consent; while the Declaration of Helsinki established the ethical basis for the conduct of research involving human participants by protecting their welfare and providing for the validity of research through ethics review by an independent committee, and protecting the validity of each project's scientific integrity through ethics review. In addition to these internationally recognized documents, there are also the International Council for Harmonisation Good Clinical Practice (ICH-GCP) guidelines, and the Council for International Organizations of Medical Sciences (CIOMS) guidelines; each of which also provide for many of the same types of protections for participants. In addition, there are national regulations, such as the regulations promulgated by the Food and Drug Administration (FDA) in the United States and the Medicines and Healthcare products Regulatory Agency (MHRA) in the United Kingdom, which govern the scientific conduct and approval of clinical trials in those countries and/or parts of the world.[12] In India, the New Drugs and Clinical Trials Rules, 2019 were established under the Drugs and Cosmetics Act, 1940, and are executed by the Central Drugs Standard Control Organisation (CDSCO). Like their other global counterparts, Indian regulations require that subjects provide informed consent before participating in clinical trials, that each clinical trial is reviewed for ethical conduct through an ethics committee, and that subjects receive compensatory damages for injuries related to their participation in a clinical trial. Vulnerable populations have additional protections in place under Indian law.[13] The comprehensive ethical principles and regulatory requirements are meant to ensure that progressive scientific discovery occurs with ethical safeguards for the dignity, autonomy, safety, and fairness of subjects who participate in research.

Ethical Principles in Human Subject Protection

Informed consent is fundamental to successful and ethical clinical research. The researcher has an obligation to obtain voluntary, fully informed, and uncoerced consent from every participant; the foundation for this obligation is the Nuremberg Code (1947), which requires that participants provide their informed consent to participate in research studies or to undergo any medical procedure. The Declaration of Helsinki also supports this principle, requiring that the researcher provide adequate information to the participant prior to obtaining their consent and obtain an independent ethical review of the research protocol.[14] Several court cases also highlight the ethical obligation of researchers to provide participants with relevant (material) information about the risks of participating in research studies, including: Chatterson v Gerson (1981), Halushka v University of Saskatchewan (1965), Sidaway v Royal Bethlem Hospital Governors (1985), and Pearce v United Bristol NHS Trust (1997). In addition, the courts provide protection to vulnerable populations, including children, through legislation, such as the Family Law Reform Act 1969 and the Mental Capacity Act 2005, and through judicial decisions in Gillick v West Norfolk (1985, Re W (1992) * and Re F (1990). Valid informed consent requires researchers to disclose information related to the research study, including a full description of the purpose of the research study; the research study procedures; and the risks and benefits of participating in the study; any alternative procedures that could be used to achieve the study's purpose; how the confidentiality of a participant's information will be maintained; whether a participant will receive compensation if they are injured while participating in the study; and that a participant has the right to withdraw from the study at any time. The ethical principles of respect for persons, beneficence, and justice established in the Belmont Report (1979) provide additional support for the ethical requirements of researchers and are considered fundamental principles guiding ethical clinical research.[15]

Issues and Challenges

A key aspect of clinical research is correct informed-consent; this represents a major obstacle for researchers trying to recruit people into trials. The amount of information provided about a clinical trial can make it difficult or complicated for participants to comprehend prior to deciding whether or not they wish to participate.[16] Other factors that affect participants' voluntary participation include expected benefits from treatment, anticipated financial compensation, and altruism. Researchers must communicate clearly with prospective participants regarding the purpose(s), procedures, potential risks, potential benefits, alternative options available, and participant's right to discontinue participation at any time without penalty. While there are ethical concerns with these issues, ethical concerns are stronger in developing countries, where limited access to healthcare and poverty can create situations of undue inducement and/or exploitation.[17]

Therapeutic misconceptions can also create an ethical dilemma for researchers. Some people believe the primary purpose of clinical trials are to provide them with treatment, rather than to collect data for scientific purposes.[18] Concerns related to the ethics of conducting clinical studies globally, driven by advancements in artificial intelligence, digital health technologies, and genetics, and the collection of large quantities of data, raise additional ethical issues regarding regulatory language consistency, participant privacy, confidentiality, and data protection.

Policy Implications

To better protect individuals involved in clinical trials, there needs to be an adequate regulatory environment that encourages scientific progress while providing ethical and responsible participation. Examples of significant policy initiatives that will achieve this are: Enhancing the independence, transparency, and accountability of (EC) and (IRB) Review Boards. Changing the informed consent process to provide the best opportunity for participants to understand by communicating with them using participant-centric language and terms. Improving monitoring of clinical trials through required reporting of adverse events, periodic audits, and providing fair compensation for injuries due to research. Developing enhanced safeguards for individuals at risk e.g. children; prisoners; low income; people with impaired decision-making ability will prevent individuals from becoming victims of coercion; undue influence; and exploitation.[18] Finally, legal frameworks with respect to the identified issues should be updated on a regular basis to respond to new challenges created by artificial intelligence, genetic research, biobanking, digital health technology, and cross-border sharing of data, while also protecting the privacy and data of the participant from the beginning to the end of the research process.

CONCLUSION

Ultimately, only clinical research that adheres to ethical obligations and governmental regulations can provide the basis for valid scientific conclusions. There have been material developments in regulatory structures for clinical trials since the time of regularly referred-to historical abuses of human experimentation. There remain challenges in the protection of clinical trial participants due to their vulnerability; in assuring that trial subjects provide informed consent which affords them the opportunity to make decisions about their participation based upon complete and accurate information; in protecting subjects' data; in providing uniform standards for regulatory oversight across multiple jurisdictions so that trials can be designed and conducted in accordance with acceptable minimum standards of conduct; and, in ensuring that all clinical investigators conduct their investigations in accordance with Ethics and Law-Based Medicine Principles. The legitimacy of clinical research will ultimately be determined by valid scientific outcomes and by responsible ethical behavior that complies with socially agreed-upon ethical and legal standards, supported by transparent, accountable, and scientific regulatory oversight.

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REVIEW ARTICLE

Contemporary Legal Landscape of Tele-evidence Post - Enactment of the New Criminal Laws in India

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ABSTRACT

Introduction: Tele-evidence is increasingly redefining judicial proceedings in India, offering a viable and efficient alternative to traditional in-person court appearances. This is particularly relevant for healthcare professionals who are frequently summoned as expert witnesses, often at the expense of clinical duties and patient care. Despite its clear benefits such as conserving time and resources, reducing travel, enhancing sustainability, and minimizing professional disruption, it remains significantly underutilized across much of the country. This review critically examines the evolving legal landscape governing tele-evidence in India, with a focus on reforms introduced through the Bharatiya Nagarik Suraksha Sanhita (BNSS), Bharatiya Sakshya Adhiniyam (BSA), and Bharatiya Nyaya Sanhita (BNS), enacted in 2024. These legislations supersede the Indian Penal Code (IPC), Code of Criminal Procedure (CrPC), and Indian Evidence Act (IEA), and provide formal recognition of audio-visual technology for purposes such as evidence presentation, summons issuance, and witness examination. In the context of a judicial system burdened by extensive case backlogs including over 80,000 pending cases in the highest tribunal, tele-evidence represents more than a technological advancement; it serves as a critical tool for enhancing judicial efficiency, accessibility, and timeliness. However, widespread implementation faces persistent challenges, including inadequate digital infrastructure, inconsistent protocols, cybersecurity concerns, and limited digital literacy. This paper advocates for the standardized, secure, and mandatory adoption of tele-evidence, particularly within public institutions. As India advances towards a more digitized justice system, tele-evidence stands as a pivotal mechanism to uphold the principles of timely, equitable, and accessible legal redress.

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INTRODUCTION

"Until we can manage time, we can manage nothing else"

The above quoted line by Peter F Drucker, known as the - Father of modern management makes us ponder how technology could help buy the constantly moving time.

Judicial Backlog and Case Pendency

The Indian legal system is dealing with a severe case backlog that compromises the fundamental idea of prompt justice delivery. As of June 2025, the Supreme Court, the apex court in the legal system, has 85, 204 pending cases, which is the record breaker of the highest pendency of the year, and the graph is still on rise.[1]

According to Ministry of Law and Justice, over 4 crores cases are pending nationwide where a major proportion of more than 3 crores pertain to the criminal courts. The number of cases that are pending due to unavailability of counsel, that attributes to highest amongst the reason for delay amounts to 6,270,778.[2]

Doctor and Expert Witness attendance challenges

A medical practitioner dedicates most of his life to serving the health and welfare of the patients. Apart from the demands of medical duty, and attending court calls to give expert testimony, the medicolegal part is also closely entangled with it. Despite it being a very essential requirement in the administration of justice, it often interferes with the valuable time that not only purloins their significant hours but is exhaustive when made to travel to distant areas or wait for long hours due to judiciary deficits. Doctors don't always get the opportunity to present their evidence in all the cases they travel to court due to a variety of reasons such as the late arrival of the presiding officer, either or both the public prosecutor and

defense lawyer, ongoing strike or curfew within the court or the city, uninformed rescheduling of the case. In toto, any personal or professional matter of the authority concerned leads to absence on the day of trial. The medical practitioner must get back with nothing but a waste of valuable hours that could have been invested in some other important tasks within the medical facility.[3]

In cases where the designated court and practitioner aren't in the same city, a day or two are lost, the travel expenses, their invaluable time, money, and importantly energy ultimately leading to a void outcome.

Through the years, technology has evolved constructively, and humans should keep up and make an ultimate utilization to maximize efficiency and productivity, particularly in the field of medicine. We should indulge in the correct utility of available advancements instead of availing of draining platforms and wasting more time. Since 1983, when the formal birth of the Internet occurred, it has been a beneficial medium connecting people all over the globe, bridging distance and time zones.

The Pre-reform Judicial Landscape

"National Policy and Action Plan for Implementation of Information & Communication Technology (ICT) – 2005" established by the e-Committee of the Supreme Court of India, implemented virtual courts in 3 phases starting from 2011 to 2023, by the end of which majority of the jails and courts have been equipped with video conferencing and almost all of the court records have been computerized.[4] However, 2023 has already passed and the goals still remain unfulfilled.

Indian states like Delhi, Punjab, Haryana, Maharashtra, Madhya Pradesh, Karnataka, Kerala, Tamil Nadu, Uttar Pradesh and the union territory Chandigarh have initiated the practice of tele evidence yet not in full-fledged way till date. Certain guidelines and preparatory measures prior to the video conferencing as per, Section 5, given by HC, Delhi were established in the year 2020 which mandates the requirement of a coordinator at both the court & remote area, especially in cases where a suspect or witness is being investigated.[5]

Practices & Lacunae

The idea of recording evidence through technology is not entirely new to the Indian judicial system. Initially courts had experimented with tele-evidence, though mostly in isolated instances. For example, medical experts from institutions such as PGIMER, Chandigarh, were permitted to depose through video conferencing in cases like the CBI v. Col B.S. Goraya, evidence of an ailing witness[6] and State of Punjab v. Mohinder Singh, 2018[7] amongst the pioneering instances which were the landmark rulings that led to the institutionalization of tele-evidence facilities. In the case Shashim Das vs State of NCT of Delhi and ANR, 2023,[8-9] the statement of the victim was deposed through video conference. However, this practice was never uniform. Its utilisation was in pieces either for witnesses, medical experts, or sometimes police officials depending on convenience and infrastructure. **Table 1** given below summarises the timeline of changes in the implementation of tele-evidence over time.

Post-reform Changes and Implementation Framework

Since the enactment of the modified laws replacing the old IPC, CrPC, and IEA that came into force in July of 2024, many newer relevant sections and some replacing the older ones have been incorporated. These changes are tabulated in **Table 2, 3, and 4** given below.

What we can deduce while reflecting on the new laws are that electronic evidence has the same status as electronic records, including audio, video, and digital communications and now are officially granted the same evidentiary value as conventional physical documents by the BSA. This facilitates the use of tele-evidence, such as video conferencing and remote testimony, and speeds up acceptance. Digital and electronic records, including electronically delivered oral statements, are now explicitly covered by the enlarged definition of "document." This makes it possible to easily admit video testimony, conduct remote cross-examination, and submit expert affidavits digitally, all of which are essential components of tele-evidence in forensic and medical practice. The new laws introduce greater flexibility and clearly laid scope of tele-evidence. To increase the credibility and dependability of legally admissible electronic evidence (video, audio, and digital records), the BSA and related procedures require dual certification by the device handler and an expert. This is essential for cases that depend on tele-evidence and remote evidence, certification is streamlined. The laws promote and mandate the use of audio-video electronic devices for judicial procedures, police investigations, and court appearances. The system minimizes delays and logistical bottlenecks while enabling effective tele-evidence by connecting digital and legal workflows. Trial procedures are made quicker, more transparent, and less expensive using secure digital records, remote expert

Table 1: Timeline of Significant Developments Pertaining to Tele-evidence (2003-2024)

Year	Significant Change
2003	1. In the groundbreaking case "The State of Maharashtra vs Dr. Praful B Desai" when one of the respondents questioned the admissibility of producing evidence via video conferencing, SC ascertained that this practice doesn't violate section 273, presence doesn't necessarily have to mean physical, it could be virtual as well.[10-11] 2. Further, the apex court established that although the deposition of evidence is made at the place where the witness is available, the means of video conferencing has enabled the recording of evidence in the area the court is placed at unless the witness resides in a country which has an extradition treaty.
	In the civil case "Twentieth Century Fox Film Corporation vs. NRI Film Production Associates (P) Ltd", it was ascertained that the evidence could be documented mechanically thereby integrating video conference as a medium.[12]
2004	In the civil case, "Amitabh Bagchi vs. Ena Bagchi", the mode of video conference for evidence deposition was affirmed in civil proceedings.[13-14]
2008	The amendment of CrPC with inclusion of Audio-Video electronic means.[15]
2012	In the case that led to nationwide uproar -"Nirbhaya", video conference was used for the deposition of a statement made by Dr Paul Chui, Senior consultant in Forensic Pathology at Mount Elizabeth Hospital.[16]
2017	In the case "Santhini vs. Vijaya Venkatesh", the Supreme Court permits the utility of VC in family courts.[17]
2018	In the case "Swapnil Tripathi vs Supreme Court of India", SC stated that in cases of constitutional & national importance, the proceedings should be live streamed.[18]
2020	As a consequence of COVID 19 pandemic, courts initiated the usage of video conferencing technology.[19]
2024	Implementation of BNSS, BNS, BSA and incorporation of electronic means within the reformed laws.[19-21]

testimony, and real-time presentation and sharing of digital evidence. As courts and forensic institutions improve their electronic infrastructure, tele-evidence is now more widely accessible, better integrated, and less likely to be contested on technical grounds.

DISCUSSION

Although numerous technological reforms have been introduced in judicial processes, the number of pending cases still corresponds to the figures mentioned earlier.[2] This necessitates the utilization of appropriate measures all over the country to facilitate the promptness of the judicial system.

Several existing provisions under the Criminal Procedure Code (CrPC) and the Indian Penal Code (IPC) have been renumbered and modified under the new legal framework. For instance, Sections 68, 91, 164, and 275 of the CrPC have now been revised and renumbered as Sections 70, 94, 183, and 310 respectively. Similarly, Section 204 of the IPC has been replaced with Section 24. Each incorporating certain modifications to align with the current technological needs.

It took an immense amount of time & effort, almost 20 years, for the official guidelines in regard to telemedicine to come into power in the year 2020 because of severe health crisis faced as a result of the pandemic.[22] Although there are available guidelines on the official website "e-committee, the supreme court of India",[23] regarding tele-evidence enlisting terms, fundamental concepts, necessary equipment, preliminary measures, coordinator at the designated area, plan of action, service of summon, examination of people, documents, etc., request form and so forth. However, due to its bare minimum utilization, it hasn't gained much attention.

Measurable impact that could be accessed have been tabulated below that indicates impact assessment in a quantitative manner.

While the use of tele-evidence has been successfully adopted in many civil cases making proceedings smoother and more efficient, the same cannot be said for criminal cases, where its usage remains limited. Given the challenges in securing timely witness and expert testimonies in criminal trials, there is a growing need to

Table 2: Newer Sections Incorporated in the BNSS, 2024 Relevant with or Pertaining with Tele-Evidence.

BNSS (Bharatiya Nagarik Suraksha Sanhita)[19]		
S.No.	**Sections**	**Modifications**
1	Section 2	Introduction of the definition of 'Audio - Video electronic means'.
	Section 2 (1)(i)	Definition of 'Electronic communication'. Accentuated the importance of technology in view of investigation, trial & court proceedings encompassing summons, notice, production of evidence, via Audio Video conference, search, seizure, etc.
2	Section 63	Inclusion of technology for the act of summon.
3	Section 64	Maintenance of registering including address, email ID, phone number etc. in court & police station.
4	Section 70	The act of summoning could be done via Audio - Video conference.
5	Section 94	Inclusion of communication devices that could contain digital evidence.
6	Section 183	The recording of confession or statement by suspect via audio - video electronic means in presence of his / her advocate.
7	Section 193 (3)(i)	Police reports can be forwarded to the magistrate through the investigating officer supervising the police station via electronic means.
	Section 193(3)(i)(h)	If an electronic device mandates the inclusion of a chain of custody.
	Section 193 (3)(ii)	Use of electronic means to keep the victim/informant updated with the progress of the investigation within 90 days.
	Section 193 (8)	Inclusion of electronic means for distribution of police reports & other documents to the accused.
8	Section 208	Production of documents via electronic means in the event of crime perpetrated outside India.
9	Section 210	Inclusion of electronic mode for presenting police reports for consideration of offenses by the magistrate..
10	Section 227	Utilization of electronic mode for allotment of summons and warrants.
11	Section 230	Inclusion of electronic means for disbursement of necessary documents by magistrate to suspect within 14 days of the appearance of the suspect.
12	Section 231	Utilization of electronic mode for forwarding of copies of statements & documents in the event of session's triable cases.
13	Section 251 (2)	Usage of Audio Video facility to illustrate the charges applied to the accused.
14	Section 254	Police officers or public servants can produce evidence electronically, i.e., via audio-video conferencing.
15	Section 265 & 266	Inclusion of electronic means to investigate witnesses for the trial of warrant cases.
16	Section 308	Utilization of electronic means i.e., Audio - Video conferencing for investigation of accused at the facility designated by the state government.
17	Section 310	The statement of evidence given by witness can be recorded via audio - video means in presence of an advocate representing the accused.
18	Section 316	The signature of the suspect investigated via video conferencing must be taken within 72 hrs.
19	Section 336	In the absence, relocation, resignation, or demise of a government servant, expert, or officer who is to present any document or report as evidence, their assistant can depose such evidence via Video-Audio conference.
20	Section 392	Allowance of the suspect detained to take part in judgment via electronic means.
21	Section 530	Inclusion of technology for conducting all trials, inquiries, & proceedings and utilization of Audio-Video mode for communication.

Table 3: Newer Sections Incorporated in the BNSS, 2024 Relevant with or Pertaining with Tele-Evidence.

BNS (Bharatiya Nyaya Sanhita)[20]		
1	Section 241	Any documents or electronic evidence, presented to either court/public servant etc would be penalized with imprisonment for a term with the possibility of extension up to three years/fine extending up to 5000 or both.

Table 4: Newer Sections Incorporated in the BSA, 2024 Relevant with or Pertaining with Tele-Evidence.

BSA (Bharatiya Sakshya Adhiniyam)[21]		
1	Section 2 (1) (d)	The inclusion of electronic or digital records, server logs, documents on computers, laptops or smartphones, texts, websites, cloud, locational evidence, and Audio files stored on digital devices in the definition of "Documents".
	Section 2 (1) (e)	Inclusion of details given electronically in the definition of "Evidence" & 'Digital records' as documentary evidence.
2	Section 57	Incorporation of electronic/digital evidence within primary evidence simplifying the process, for authentication of electronic contents.
3	Section 61	Electronic/digital evidence will be given the same weightage as other documents in terms of credibility & implementation.
4	Sections 62 & 63	Establishing guidelines upon the relevance of electronic evidence which ascertain the necessity of a certificate proving the authenticity of the same.

Table 5: Quantitative Assessment of Economic Impact and Cost Savings Reported in Previous Studies.

PARAMETER	AUTHOR/ORGANISATION	REPORTED VALUE	IMPLICATION
Savings in terms of money	K Kishore et al. [24]	INR 5,72,135	Significant economic benefits
	Aggarwal A et al.[4]	Rs 2620 (Per case) and and Rs 1,263,000 annually	
	PGIMER, Chandigarh [25]	Rs 48.3 lakhs (In terms of fuel consumption)	
	Dipesh Juneja (Additional Director General, Uttar Pradesh) [26]	20 crores (Annually)	
	Florida, USA [27]	> $ 40,000 to $ 1,15,000	
	Texas, USA [27]	> $ 1,25,000	
Time reserved	S Bari et al.[28]	28.4% decline in man hours spent (Per month)	Enhancement in healthcare productivity
	Aggarwal A et al.[4]	4 hrs & 12 min	
	PGIMER, Chandigarh [25]	30,000-man hours	
Distance/Travel avoided	K Kishore et al.[24]	34,876 Km	Environmental and Time benefits
	Aggarwal A et al.[4]	181 Km (Per case)	
Carbon footprint	Aggarwal A et al.[4]	The credit points obtained were around +10.68	Enhancement in environmental conditions

extend and normalize the use of tele-evidence in the criminal justice system as well.

Despite being the most practical and effortless practice, technology could sometimes accompany unexpected hindrances, some of which are connectivity & security issues. Establishing good internet connections could help overcome unexpected delays which might intervene with the ongoing procedure. The unanticipated loss of power supply is another factor that could further derange the already established connection and stretch the formal gathering. Moreover, it is extremely pivotal to establish a secure connection between both parties including the

possible entry of any third party given the ever-increasing cyber attacks but with coherent measures such minor setbacks could be tackled.

This approach could benefit not just the medical practitioners but also the judicial system in expediting the cases, cutting costs, and preventing the drainage of valuable hours. Since some of the states have already begun this cost-effective initiative and provided evidence as to how handy this could be, initiation of analogous measures wherever possible could take us a step forward in tackling the pendency and awarding of timely justice.

The importance lies in its potential to increase efficiency by eliminating travel time, fatigue, and associated costs; enhancing accessibility by the facility to give remote testimonies expanding geographical reach; reduce delay by helping expedite legal proceedings, minimizing scheduling conflicts & logistical challenges associated with in-person testimony; improves cost-effectiveness for both the legal system and healthcare providers by reducing travel expenses and time away from clinical practice.

Suggestions to the inclusion of definitive mention of expert witnesses be it medical/forensic or other technical experts, secure handling of evidence whether document/image/video ensuring proper encryption/ watermarking, compulsory implementation of tele evidence in instances of government/other institution where physical presence could consume resources unnecessarily. This approach ensures flexibility for medical practitioners. Despite the admissibility, feasibility, and reliability of tele-evidence in a court of law as per the above-mentioned sections, the practice of tele-evidence is still questionable. This reflects the ways in which we are lagging. It proves how evolution with time doesn't necessarily mean the application of associated advancements per the upcoming improvements in the field of justice.

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REVIEW ARTICLE

Analysis of Motives and Weapons in Homicidal Deaths: A Systematic Review

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ABSTRACT

Introduction: In India, homicide continues to be a major concern; however, homicide also has wide implications for law, medicine and society overall. Furthermore, homicide is indicative of how culture, the economy, and personal relationships can all influence and cause homicide, thus demonstrating the many different motives for homicide. This review combines insights that have been obtained from the various autopsy-based studies conducted in different Indian regions from 2013 to 2025 to be able to tell the main motives and the types of weapons used in homicide cases.

The major reasons for homicides, most cited by studies, were conflicts between people, household disputes, and disagreements over property. Most of the homicides involved sharp and blunt instruments such as knives, axes, and sticks, while the deaths by guns showed more cases in urban areas. Moreover, factors such as Alcohol drinking and financial problems were also part of the equation. On the back of the interstate differences, it becomes necessary to combine the legal-medical and the sociological methods to tackle the root causes and limit the occurrence of violent deaths in India.

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INTRODUCTION

Homicide, the deliberate killing of one person by another, is still a major medico-legal issue and public health problem in India. The examination of homicidal deaths through post-mortem provides important information about the cause, manner, and mechanism of death, and at the same time, it showcases the social and cultural dynamics behind such crimes.[1-2] The research conducted in India has shown that homicide patterns change from one region to another based on different factors like economic level, culture, and the situation.[3-5] The case studies carried out in Kota, Indore, and Ambala recognized domestic disputes, personal enmity, and property conflict as the main reasons for homicides.[6] It is mentioned that young males are the most affected group as they normally get to see and experience violence between people and in their workplaces.[7] The use of sharp and blunt weapons for assault has been the case for a long time but now in cities like Delhi and Maharashtra, deaths due to firearms are also increasing.[8-10] The studies based on autopsy conducted in Haryana, Kerala, and Belagavi have also shown that attacks on important parts of the body like the head, chest, and abdomen are very common, which indicates that the victims are being hunted.[11-12] Although many local studies have been done, there is still a huge gap in national data synthesis; thus the present review of motives and weapons used in homicide throughout India is justified.

In addition, the analysis of homicide patterns is a must for not only forensic investigations but also the implementation of efficient prevention strategies. By analyzing motives and the weapons used, authorities and policymakers can underscore the social and psychological underpinnings that drive violent behavior. This expertise can underpin community level interventions, better law enforcement practices and conflict awareness programmes designed to reduce interpersonal disputes.

Hence, this review is a significant step in correlating forensic evidence to social realities and hence evolving a more all-embracing method for homicide prevention in India. The patterns of these crimes can also be of great help in the process of improving the justice system and making sure that the criminals do not escape their fate while the innocent ones suffer.

MATERIALS AND METHOD

A systematic review was conducted to examine the motives, weapons used, and medico-legal characteristics of homicidal deaths reported in India. Relevant literature was identified through electronic databases including Scopus, PubMed, Web of Science, ResearchGate, and Google Scholar. The search strategy employed combinations of the keywords "homicide", "homicidal deaths", "autopsy pattern", "weapon used", "injury pattern", "homicidal motive", and "India". Only peer-reviewed articles published between 2013 and 2025 were considered for inclusion.

The literature searches initially identified 32 records. Following the removal of duplicate and clearly irrelevant articles, 25 studies were subjected to title and abstract screening. Full-text assessment was subsequently carried out for all potentially eligible studies. Five studies were excluded because they did not satisfy the predefined eligibility criteria, including studies conducted outside India, articles not based on autopsy findings, and publications lacking sufficient information relevant to the objectives of the review. Consequently, 20 studies fulfilled all eligibility requirements and were included in the final qualitative synthesis.

Inclusion Criteria

- Original research articles published between 2013 and 2025.
- Peer-reviewed studies conducted in India.
- Autopsy-based studies focusing on homicidal deaths.
- Studies reporting demographic characteristics, motives, weapons used, injury patterns, or medico-legal findings.
- Full-text articles available in the English language.

Exclusion Criteria

- Studies conducted outside India.
- Review articles, editorials, conference abstracts, letters to the editor, and commentaries.
- Duplicate publications.
- Studies not directly related to homicidal deaths.
- Articles with insufficient data relevant to the objectives of the review.

Data were extracted from the selected studies regarding geographical location, study characteristics, demographic profile of victims, motives for homicide, weapons used, and injury patterns. The extracted information was comparatively analyzed to identify common trends and regional variations in homicidal deaths reported across different parts of India.

Observation of Studies (Table 1)

DISCUSSION

A comprehensive review of studies published between 2013 and 2025 was undertaken to provide a contemporary understanding of patterns of homicidal death in India. The review included studies from the Indian states of Kerala, Haryana, Punjab, Karnataka, Madhya Pradesh, Delhi NCR, Maharashtra and Manipur. These studies consistently found similar patterns in the characteristics of the homicidal deaths. Most researchers have concluded that quarrels among family members and between people living in the same household were the major factors causing homicide, which mostly resulted from emotional outbursts, discord in marriage, or the like.[3-4,6-7,12] The findings of the studies suggest that homicides in India are predominantly acts of passion and opportunity instead of planned or organized killing.[3-4,5-6,12] Property and land disputes constituted 18.4% of homicide cases in the Kota study[3] and 15.2% in the Ambala study,[6] indicating that conflicts related to land ownership remain an important motive for homicide in several regions of India. Sharp-edged weapons were used in 45.2% of homicide cases in Kota[3] and 51.6% in Belagavi,[11] whereas blunt weapons accounted for 32.4% and 28.7% of cases, respectively. Knives, blades, sickles, sticks, rods, and stones were among the commonly reported weapons.[3,11] The presence of firearms was noted in 8.5% of homicide cases in the Delhi NCR study[9] and 6.2% of cases in the Maharashtra study.[10] But these incidents were more likely to occur in urban areas or regions that are adjacent to state borders, where access to such weapons is less restricted.

In the studies reviewed, most homicide victims were male, and the highest incidence was in the 21- to 40-year-old age group.[1,3,5,7,12,15] In studies that reported on occupational status, many of the victims worked in blue-collar or other working-class occupations.[3,6,15,17] However, the studies

Table 1: Summary of Homicide Studies Regarding Motives and Weapons used (As Attached Separately in Tables and Figure Section).

S.No	Authors and Study Name	Geographical Area of the Study / Sample	Predominant Motive(s)	Primary Weapon(s) Used
1	Verma LC, Tiwari PK, Tatwal B, Joshi RB. Analysis of homicidal deaths at MBS Hospital associated with Government Medical College Kota- An autopsy-based study.[3]	This study was conducted at MBS hospital associated with Govt. Medical College Kota. The study was conducted from Jan.2018 to Dec.2018. Out of 1043 autopsies, 37 cases of homicidal deaths were reported.	The principal cause of the killings was argument in 10 cases (27%), land disputes came second (9 cases, 24%), followed by love affairs (7 cases, 19%), revenge (3 cases), and property conflicts (5 cases).	The use of blunt weapons was observed in mostcases (43%), sharp weapons accounted for the second most common method (32%) and firearms were used incases (11%). Strangulation, poison, and burning were rarely practiced methods of killing.
2	Verma LC, Punia R.K., Yadav A. Analysis of Homicidal Deaths at SMS Hospital, Jaipur-A Prospective Autopsy Study.[1]	This research was done on the deaths occurred due to alleged homicide according to the Inquest at the mortuary of SMS hospital, Jaipur during the study period May 2012 to April 2013.	Land dispute was the main motive in 33 cases (40.2%), financial dispute came second to 13 cases (15.8%) followed by impulse 11 cases (13.4%), revenge and sexual jealousy 7 cases (8.5%) each.	The use of blunt weapons in a significant number of cases (58.55%). Sharp weapons and firearm weapons were used in 12.1% of each case. Strangulation, poison, and burning accounted for 8.5%, 7.3% and 1.2% respectively.
3	Sonawane SS, Sukhdev RB, Tyagi S, Kolle SR. Autopsy evaluation of homicidal deaths in Western Mumbai region: A two-year prospective study.[2]	This study was performed in the Department of FMT at H. B. T. Medical College located in Juhu, Mumbai, India. The study period was from Jan. 2015 to Dec. 2016, during which, deaths due to homicide were about 2.11%.	Most of the murders were due to arguments and fights (45.45%) Still, other reasons were infidelity (15.15%), revenge, robbery, and financial conflicts (each 9.09%), and property disputes (6.06%).	The most common types of weapons used were hard and blunt (39.39%), while sharp-edged weapons came second (36.36%). Other less common weapons included ligature materials (15.15%), and very rare cases involved thermal burns or combined methods.
4	Kumar A, Gurudut KS, Malagar SN, Shetty AK. Study of pattern of injuries in homicidal deaths autopsied at Belagavi Institute of Medical Sciences, Belagavi: A prospective study.[11]	Belagavi Institute of Medical Sciences, Belagavi (Karnataka, India) – the study was conducted from January 2016 to June 2017; 54 deaths due to homicide among 1265 autopsies (4.26%).	The paper did not give clear motives for homicide (e.g., revenge, property, etc.) but rather emphasized the injuries' patterns and types and not the social or psychological reasons.	Sharp weapons were the most common (in 31.48% of cases) Next were blunt weapons. There were also cases of asphyxia, strangulation, burns, and firearms (1.85%).
5	Hossain DI, Jeba TR, Dey S, Tasnim Z, Tabassum T. Homicidal deaths due to weapons: an autopsy-based study.[19]	Dhaka, Bangladesh- A total of 120 autopsies was investigated during the period of January 2021 to December 2023.	Majority of cases were non-intentional (60%), reflecting impulsive or situational acts of violence rather than premeditated murders.	Knives were the most frequently used weapon (51.67%), followed by blunt objects (38.33%), with few cases involving firearms, ropes, or bare hands.
6	Sam NM, Harish S. Pattern of homicide cases in a coastal district of Central Kerala over the last ten years: an autopsy-based study.[12]	Alappuzha, Kerala (Coastal district of Central Kerala); 10-year record-based autopsy study (2012–2022); homicidal deaths accounting (2.29%) cases.	Quarrel (27.32%); Rivalry (25.85%); Partner killing (9.76%); others like robbery (3.41%) and financial dispute (2.93%) were minor.	Sharp weapons (knife, sword, axe) – 39.5%; Blunt weapons (rods, pipes, stones) – 39%; Asphyxia (11.27%); Firearm, burns, drowning (rare)

Table 1: Summary of Homicide Studies Regarding Motives and Weapons used (As Attached Separately in Tables and Figure Section).

S.No	Authors and Study Name	Geographical Area of the Study / Sample	Predominant Motive(s)	Primary Weapon(s) Used
7	Sharma S, Pan AK, Kohli K, Anand A, Aggarwal KK. Profile of homicidal cases at the mortuary of a tertiary care hospital in Ambala, Haryana: A ten-year autopsy-based retrospective study.[6]	The study was conducted at Maharishi Markandeshwar Institute of Medical Sciences and Research,Mullana (Ambala), Haryana, India. (2.3%) deaths occurred due to homicide during the period of Jan. 2014 to Dec. 2023.	The study did not provide clear reasons for the murders (like revenge, property, or domestic disputes) However the discussion highlights poverty, social stress, and aggression common among lower socioeconomic and labor-class people were linked as underlying causes.	The major means of killing were blunt weapons (38.9% of cases), followed by ligature materials (19.4%) and sharp-edged weapons (19.4%). Other methods included combined blunt + sharp weapons (11.1%), firearms (8.3%), and burn/acid burn (2.8%).
8	Sangwan S, Sharma G, Sangwan A, Duhan R, Sharma N. Pattern and distribution of injuries in homicidal deaths in Rohtak, Haryana: An autopsy-based study.[5]	The study was conducted at Pt. B. D. Sharma Post Graduate Institute of Medical Sciences Rohtak, Haryana. A total of 100 homicidal cases were investigated by autopsy during the period from January 2017 to November 2019.	The most common motive was found to be previous enmity with 34% cases, property dispute 22% was the second most frequent reason. A few motives like revenge, women issues and personal quarrels were also there but to a lesser extent.	The use of hard and blunt weapons such as iron rods and dandas was the most common (26%) followed by firearms (21%), axes (10%) and knives (9%).
9	Yadav N, Jakhar JK, Kaushik G, Chopra L, Singh M, Dhattarwal SK. The pattern of homicide in Haryana – A retrospective study.[7]	Study conducted at Pt. B.D. Sharma PGIMS, Rohtak, Haryana conducted this research. An analysis of 100 homicide cases done in the period from 1st Jan. 2017 to 10th Nov. 2019	The most common motive was previous enmity with 34%, followed by a dispute over property which accounted for 22%, sudden provocation, 16%, and love affairs 8% cases.	Hard and blunt weapons were the most used (26%), with firearms (21%), Sharp (19%) following them.
10	Gupta N, Agrawal NK, Verma SK. Pattern of homicidal deaths in Northeast Delhi and NCR.[9]	The study was conducted at department of FMT UCMS and Guru Teg Bahadur Hospital, Delhi and 85 victims of homicidal deaths were analyzed.	In 25.9% deaths the motive was personal enmity followed by Money/Robbery accounted for 15.3%, and sudden provocation, 5.9% deaths. The motive was unknown in 37.6% homicidal deaths.	The most common weapon used was sharp, 43.7% cases than blunt, 23% cases, followed by firearm, 19.5%, Asphyxia, 5,7% and burn in 4.4% cases. In 1.1% cases combined method of asphyxia and burn was used.
11	Mohite PM, Mohite DP, Dixit PG, Anjankar AJ, Keche AS. Autopsy evaluation of defence wounds in homicidal death in Central India.[13]	This study was conducted at Government Medical College and Hospital, Nagpur, Central India (Maharashtra). In this research, 205 cases of homicide autopsy were analyzed during a three-year interval from Jan. 2003 to Dec. 2006.	The aims of the research did not include an explicit categorization of motives such as revenge or property disputes. Nonetheless, the argument points out land and family disputes, personal conflicts and alcohol related violence as the Central Indian region's main factors.	The most usual cause of injuries was sharp cutting weapons (60.3% of cases), then hard and blunt objects (33.3%). Sharp weapons (knives, swords) left the victim with more active defence wounds, while the blunt ones mostly produced passive and less active wounds.

Table 1: Summary of Homicide Studies Regarding Motives and Weapons used (As Attached Separately in Tables and Figure Section).

S.No	Authors and Study Name	Geographical Area of the Study / Sample	Predominant Motive(s)	Primary Weapon(s) Used
12	Das NG, Singh TB. An Autopsy Based Study on Pattern of Injuries in Homicidal Deaths in Imphal.[14]	This study was conducted from Oct. 2013 to Aug. 2015 at regional institute of medical science, Imphal. Total 97 (18.65%) homicidal deaths were analyzed, out of 520 autopsies.	The authors did not discuss motives behind homicides.	Blunt weapons were used in about 30% of deaths followed by firearms, about 28%, bomb blast, 17.5% and sharp weapons, 12.3% deaths. Ligature and manual strangulation were used in 6.18% deaths each.
13	Sashikanth Z. A comparative study on homicidal deaths in a tertiary health-care institution in Nallore, Andhra Pradesh.[15]	The study was done at ASCR medical college, Nellore from March 2019 to Feb.2020. Out of 902 autopsies 39 (4.3%) homicidal deaths were studied.	The motive of homicide was quarreled in 35.8%, extramarital affairs, 12.8%, property disputes, 18%, financial disputes, 10.2%, love affair, 2.5%, revenge, 5.1% and 7.8% cases were related to dowry.	About 28% deaths the blunt weapons were used and in about 23% cases the weapons were sharp. Poison was found in 15.4% cases, strangulation accounting 15.4% deaths and 18% deaths were due to burn.
14	Rathod VV, Choudhary UK, Ghormade PS, Keoliya AN. Study of characteristics of victims and alleged accused in cases of deaths due to homicide.[17]	This prospective research was conducted at institute of Maharashtra University of Health science Nashik from Jan. 2013 to Oct. 2014.	In 26.2% deaths quarrel was the main motive followed by enmity 25.7%, elicit relationship 12.2%, property and financial disputes about 14%, family disputes 4.4% and robbery about 3.9%. in 34% deaths the motive remains unknown.	Sharp and pointed weapons were used in 31.28% deaths followed by blunt and hard 28.4% cases, heavy sharp 17.8% deaths. In 10.6% cases death caused by ligature strangulation. The combined blunt and sharp weapons were used in 6.14% cases and only in 1.6% cases were firearm weapons used.
15	Basra S, Singh JP. One-year prospective study of pattern of homicide deaths- An autopsy-based study.[18]	Conducted at Govt. Medical College, Amritsar, Panjab from Jan.2021 to Dec.2021. total 39 cases of homicidal deaths were analyzed by researcher	The authors did not discuss clear reasons for the homicides (like revenge, property, or domestic disputes) However the discussion highlights aggression in youth and planned homicide motivated by revenge and robbery	About 41% cases the weapons were sharp followed by blunt and sharp both in about 36% cases, 15.4% cases blunt weapons used and in 7.7% cases the weapons were firearm.

reviewed failed to provide sufficient evidence to establish a direct association between occupational status and the underlying causes of homicidal behaviour. The southern part of the country, especially Kerala and Karnataka, had a bigger share of homicide cases linked to family or domestic problems. On the contrary, the northern states of Haryana and Madhya Pradesh reported incidents of property disputes and caste-based conflicts as the main reasons for murders. Alcohol was one of the common factors mentioned in these cases, as it was an incident that turned the verbal quarrels into deadly confrontations.

Interpersonal disputes, family conflicts, marital discord and personal enmity were important motives for homicide, as reported in several studies.[3-4,6-7,12] For example, in the study by Sikari et al., it was reported that personal disputes accounted for 551 cases (28.7%) and peer altercations accounted for 259 cases (13.5%) among 1918 homicidal deaths reviewed in the National Capital Region.[20] Likewise, interpersonal family conflicts and

impulsive behaviour have been identified as common reasons for homicidal deaths in studies from Kota, Indore, Ambala, Haryana, Kerala and South Gujarat.[3-4,6-7,12,21] These findings indicate that a large proportion of homicide motives in the reviewed literature are interpersonal conflicts.

Cultural and regional traditions affect the character of homicide. In some areas, society still accepts the demand for revenge, honour killings and similar actions as legitimate practices especially when the issue is about the reputation of a family or the pride of a community. These customs, so ingrained in the culture, are the ones that perpetuate the cycle of violence and require major social reform to be done. Moreover, the absence of early mediation in solving conflicts and the unavailability of counselling or legal aid have pushed people to violent ways of resolving conflicts. However, it is possible to prevent such incidents gradually over time, through the introduction of community-level intervention and support systems.

Indeed, our results suggest that homicide in India is a very social and situational activity rather than just a criminal one. The strong association of interpersonal conflict, drinking and gun possession suggests that violence often stems from unresolved emotional and social problems. The problem, therefore, is not only one of effective forensic and law enforcement measures, but also of social consciousness, counselling, and community approaches to violence that aim to reduce conflict and promote peaceful means of resolution. The authorities' understanding of these patterns could, in turn, help address the root causes rather than the outcomes, through the creation of policy to prevent the occurrence of homicides.

CONCLUSION

The present review synthesizes evidence from autopsy-based studies conducted across different regions of India and highlights the major demographic, medico-legal, and situational characteristics of homicidal deaths. The reviewed literature consistently demonstrated that young adult males constituted the majority of homicide victims. Sharp-edged and blunt weapons were the most frequently reported means of assault, whereas firearm-related deaths accounted for a comparatively smaller proportion of cases. Interpersonal disputes, family conflicts, personal enmity, marital discord, and property-related issues emerged as the predominant motives associated with homicide across the studies.

The findings also revealed considerable similarities in injury patterns, with fatal injuries commonly involving vital regions such as the head, neck, chest, and abdomen. Although regional variations were observed, the overall patterns of homicide remained broadly comparable across the reviewed studies. The inclusion of studies from diverse geographical settings strengthens the understanding of homicide trends and their medico-legal significance in the Indian context.

The review underscores the importance of continued surveillance of homicide patterns through systematic documentation and analysis of autopsy findings. Strengthening data collection systems, promoting intersectoral collaboration, and undertaking multicentric research may contribute to a more comprehensive understanding of homicidal deaths and support the development of informed preventive and policy measures.

Limitations of the Study

The review included only fifteen studies, which may not fully represent the diversity patterns of motive and used weapons in homicidal deaths across all regions of India. The data of many studies depend on police records, medico-legal reports, and autopsy findings. |The article included only autopsy-based studies; therefore, homicide cases not subjected to medicolegal autopsy or cases with incomplete investigations were not represented.

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A CASE SERIES

Discrepancies between Autopsy Findings and Police Investigations in Sensitive Cases

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ABSTRACT

Introduction: Autopsy plays a pivotal role in forensic medicine to aid the delivery of justice to the deceased. While the statements of police and eyewitness lay groundwork for understanding the intricacies of a death case, discrepancies in such accounts may create doubt to the pathologist. The authors highlight three instances where meticulous autopsy examinations surfaced truth that was at odds with the initial investigations in these cases.

Case Findings: In the first case, a 19-year-old woman was suspected to have undergone a criminal abortion at five months' gestation. Autopsy revealed a full-term delivery, with death of the baby resulting from ante-mortem head trauma-suggesting accidental death rather than abortion which was confirmed after thorough police investigation. The second case involved a woman who died after five days of hospitalization, reportedly due to a femur fracture from a fall. Postmortem examination revealed undiagnosed intra-abdominal bleeding, with evidence of femoral fracture, pointing to a missed injury and possible medical negligence. In the third case, police suspected accidental drowning, with an estimated postmortem interval of 48 hours. Autopsy showed no signs of drowning and revised the time since death to less than 24 hours. Genital trauma and the presence of semen indicated sexual assault. A negative diatom test confirmed drowning was not the cause of death.

Conclusion: Forensic experts must remain vigilant and independent, avoiding exact reliance on statements in the inquest proceedings.

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INTRODUCTION

The opinions formed by autopsy surgeon based on postmortem findings are pivotal in guiding medico-legal investigations and judicial proceedings. While contextual information from law enforcement agencies and relatives may help in establishing preliminary narrative, such accounts may diverge from objective autopsy findings. Overreliance on potentially biased or inaccurate external narratives risks distorting the forensic interpretation and undermining the integrity of conclusions. Though statements by police and family can inform the scope of examination, they must not override empirical evidence. A methodical and scientifically grounded autopsy that is guided by independent clinical judgment remains essential for verifying or refuting alleged circumstances of death. Prioritizing direct anatomical and pathological findings ensures not only analytical credibility but also safeguards against miscarriages of justice.[1]

The primary objective of police investigation is to collect evidence, identify potential suspects, and reconstruct the sequence of events surrounding a case of death in suspicious circumstances. Investigators aim to determine who was involved and the possible motive, with an ultimate goal of solving the case and ensuring accountability. However, while law enforcement plays an indispensable role in the investigative process, forensic findings-particularly those derived from autopsy-offer a crucial, objective counterbalance. Autopsy results can either corroborate or refute the initial investigative assumptions, thereby contributing to a more accurate and

just determination of the circumstances of death.[2] The postmortem examination is primarily aimed at determining the cause, manner, and time since death. Through systematic internal and external assessment, the autopsy facilitates the collection of forensic evidence and provides a medically grounded explanation for the cause of death. The findings form foundation for investigations and legal proceedings, ensuring that conclusions are supported, objectively and scientifically.[3]

The autopsy is centered on the thorough examination of a dead. This includes documentation of physical injuries, collection of samples for histopathological analysis, toxicological testing, and review of relevant medical records-all aimed at uncovering the precise cause and manner of death. An inaccurate or biased postmortem opinion can have serious legal consequences, potentially resulting in the acquittal of a guilty party or the wrongful conviction of an innocent individual.[4] In this series, authors present cases in which detailed and methodical autopsy findings significantly contradicted the police investigations and the statements by eyewitnesses.

CASE 1

History: A male fetus was brought for medico-legal autopsy. As per inquest, the mother - A 19-year-old unmarried female-was approximately five months pregnant when her boyfriend allegedly administered unknown abortifacient medication, leading to termination of pregnancy. The mother reportedly underwent an unsupervised abortion at home and accused her partner of being responsible of her to suffer abortion.

Autopsy: Postmortem examination was conducted on the same day. Externally – The dead body of a male fetus with an intact umbilical cord measuring 55 cm and attached placenta weighing approximately 150 grams. The fetus weighed 1800 grams, with a crown-to-heel length of 47 cm and a head circumference of 30 cm. The eyes were closed; eyebrows and eyelashes were present. Fingernails extended beyond the fingertips, and rigor mortis was generalized. Hypostasis was evident over the dorsal aspect of the body. Scalp hair was dark, measuring 3–4 cm. The external male genitalia were well developed, with a wrinkled scrotum containing both testes. There were no signs of decomposition or injuries. Internally - Contusions were identified in the bilateral frontal and parietal scalp regions, as well as over the vertex. Diffuse subdural hemorrhage was observed throughout the cranial cavity. Arched chest and diaphragm positioned at the level of the fifth rib. Both lungs were pink, mottled, and completely filled the thoracic cavity. Hydrostatic test was positive, confirming live birth. The stomach was empty, with healthy mucosa, and meconium was present in the large intestine. The centers of ossification were seen at lower end of the femur and upper end of the tibia. The right femur was sealed and handed over to the police for DNA profiling. The estimated time since death was approximately twenty four hours. The cause of death was determined to be cerebral damage consequent upon blunt force trauma (ante-mortem), consistent with impact from a hard, blunt object or surface **(Figure 1A-1C)**.

CASE 2

History: The dead body of a 59-year-old woman was brought following allegations of medical negligence raised by her relatives. According to the initial police report, she had been admitted to the orthopedic unit of a private hospital for surgical management of a mid-shaft femur fracture. On the fifth day of hospitalization, she reportedly collapsed and died at approximately 2:30 PM while being transferred to the operating theatre. A medico-legal

Case 1: Figure 1

Figure 1A **Figure 1B** **Figure 1C**

Case 2: Figure 2

Figure 2A

Figure 2B

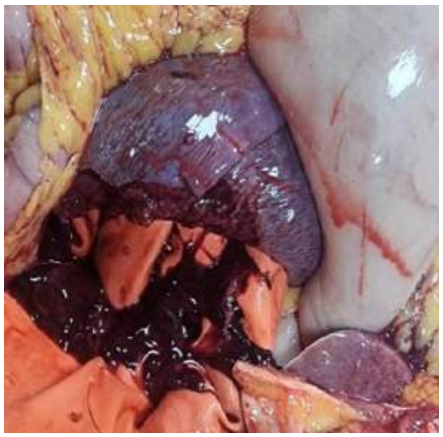

Figure 2C

autopsy was conducted on the same day under videography.

Externally - The deceased was an average-built adult female, pale look, attired in hospital gown. Two puncture wounds, each measuring 0.2 cm × 0.2 cm and extending to the bone, were noted on the medial and lateral aspects of the right lower leg, approximately 4 cm distal to the knee joint. A greenish contusion was observed on the anterior surface of the right thigh. Internally - On internal examination, mid-shaft fracture of the right femur was confirmed, surrounded by clotted blood. Cerebral edema was noted. The lungs appeared pale and purulent fluid suggestive of infection, oozed out on sectioning. The heart weighed 420 grams and demonstrated multiple petechial hemorrhages over the pericardium. The coronaries showed moderate atherosclerosis with approximately 40% of luminal narrowing; and left ventricular wall measured 1.5 cm thick. The abdominal cavity contained approximately 2500 mL of clotted blood. Multiple lacerations were present over the liver and spleen. Both kidneys appeared pale, and the external genitalia were within normal limits. The estimated time since death was within six hours. The cause of death was determined to be hemorrhagic shock due to ante-mortem blunt force trauma to the abdomen **(Figure 2A-2C)**.

CASE 3

History- A 9-year-old female child was brought with an alleged history of accidental drowning being swept away due to a sudden surge in the water flow while swimming with her friends in a nearby river. Her body was recovered floating in the river at a location downstream. Externally – The body was received un-attired, with a wet and torn yellow kurta and brown salwar received separately. The sclerae were congested, and facial congestion was evident. Both eyes and mouth were closed. "Washerwoman" changes, indicative of prolonged immersion in water, were observed on the hands and feet. Dried mud deposits were present on various body areas, but no signs of decomposition were visible. Contusions with clotted blood were noted at the 3, 6, and 9 o'clock positions around the vaginal introitus, along with the presence of blood-stains in the perineal region, as the potential findings of sexual assault. Internally - The trachea and larynx were intact, with no signs of injury or obstruction. Notably, there was no froth, water, or mud in the airways and the lungs appeared pale without edema or congestion. The time since death was estimated to be approximately twenty hours. Forensic analysis confirmed the presence of semen on the clothing but revealed no toxic substances or seminal fluid in the vaginal swabs or viscera **(Figure 3A-3B)**.

DISCUSSION

The significance of post-mortem examinations in criminal investigations is profound. These examinations determine the definitive cause and manner of death and provide critical forensic evidence, establish timelines, aid in the process of victim identification, and ultimately contribute to the pursuit of justice to the deceased. Additionally, post-mortem findings direct the workable aspects of forensic sciences as well, by requirements of refining investigative techniques and thereby deepening the understanding of death-related aspects for members of either specialty.

In forensic medicine, objective medical evidence holds the power to challenge eyewitness testimony being compelling, conclusive, and thus excluding the rarest possibility of eyewitness account being accurate. Forensic pathologists offer impartial, scientifically grounded insights, ensuring that investigations are conducted with integrity and fairness, to safeguarding justice.[4]

Case 3: Figure 3

Figure 3A

Figure 3B

In the first case, the post-mortem findings contradicted the initial narrative that the fetus was stillborn at five months' gestation. The expert asserted to enquire the case afresh, from the angle of scientific investigations. Then after, upon gentle pressure exerted by the police, the mother admitted to delivering the baby alone at home and that the newborn had accidentally fallen to the ground. This admission prompted reevaluation of the death manner-whether accidental during unattended labor or potentially infanticide. DNA profiling ultimately excluded the alleged boyfriend as the biological father. The case, initially registered under Sections 87–90 of the Bharatiya Nyaya Sanhita (BNS), was reclassified in light of the autopsy findings, which raised the possibility of either accidental trauma or intentional harm.

In the second case, upon guiding directions by the forensic expert, fresh police investigation revealed that the deceased had complained of abdominal pain on the first day of admission, following which she became progressively semiconscious. Despite the apparent severity of her abdominal injury, she was managed conservatively within the orthopedic ward. On the fifth day, she was scheduled for operative fixation of the femur fracture but collapsed during transfer to the operating room. Investigators expressed concern regarding how the patient had survived for five days despite extensive intra-abdominal injury. It was ultimately concluded that there had been a significant delay in diagnosing and managing her abdominal trauma. The initial medico-legal context of a road traffic accident was reclassified to reflect a combination of accidental injury and contributory medical negligence, with failure to recognize and treat intra-abdominal bleeding being a central factor in the fatal outcome.

In the third case, the post-mortem findings ruled out ante-mortem drowning as the cause of death, and thus the police was compelled to brace up for re-investigations. It was then revealed that the victim, an orphan, was living with her grandfather and was dependent on neighbors for her basic needs. On the fateful day, she visited her paternal uncle's residence, where the accused admitted to consuming alcohol and viewing explicit content. He later confessed to have sexually assaulted her and then smothered her with a pillow, which led to her death. He disposed of the body by throwing it in the river downstream. Following expert consultations regarding the feasibility of smothering without external injuries, and considering the postmortem findings of scleral and facial congestion, the cause of death was determined to be asphyxia due to smothering, compounded by sexual assault. Initially classified as accidental drowning, the case was reclassified to be booked as homicide with sexual assault after a thorough investigation and the receipt of postmortem and forensic evidence. The investigation successfully identified the perpetrator, and the case was resolved.

A doctor's testimony of postmortem findings is considered as 'expert evidence', emphasizing importance in judicial proceedings5. This legal framework highlights the pivotal role of medical professionals in offering scientifically grounded insights that aid the court of law in establishing facts. Medical expert testimony is vital in solving factual disputes during criminal investigations. While postmortem reports are often considered corroborative,

they can significantly redirect an investigation by uncovering new leads or details about the death, as seen in these three cases. When medical evidence is definitive, it can render conflicting eyewitness testimony unreliable. Thus, a thoroughly objective postmortem examination is crucial for ensuring delivery of justice6.

These three cases underscore the vital role of impartial and thorough postmortem examinations in ensuring justice. Had the investigations relied solely upon the initial inquest, the perpetrators may have escaped punishment. A detailed analysis, meticulous observation, and scientifically grounded conclusions are essential to guide investigations and ensuring administration of justice.

CONCLUSION

Every minor injury and piece of evidence should be noted, and opinions must be based on scientific facts.

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A CASE SERIES

Sudden Unpredictable Deaths Due to Cardiac Tamponade: An Autopsy - Based Case Series

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ABSTRACT

Introduction: Sudden unexpected natural deaths frequently present as medico-legal cases, especially when occurring in apparently healthy individuals. Cardiac tamponade is a rapidly fatal condition that often remains clinically undiagnosed and is commonly detected only during autopsy.

Objectives: To analyze autopsy findings in cases of sudden death due to cardiac tamponade and emphasize the role of medico-legal autopsy in determining the cause of death.

Materials and Method: Time period of study : 3 years, 2022 to 2025 This retrospective autopsy-based case series includes five cases of sudden death due to cardiac tamponade examined at a tertiary care center. Circumstantial history and gross autopsy findings were evaluated.

Results: The age of the deceased ranged from 22 to 84 years. Hemopericardium ranging from 200 ml to 1000 ml was observed. The causes included rupture of cardiac chambers, coronary artery rupture, and aortic arch tear, commonly associated with myocardial infarction, hypertension, and atherosclerosis.

Conclusion: This case series indicates that myocardial rupture, coronary arteries, or aortic rupture can result in cardiac tamponade, which is a major cause of sudden natural death. The fact that there were no external injuries in any of the instances emphasizes how essential a comprehensive medicolegal autopsy is in identifying the source of bleeding and determining the cause of death.

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INTRODUCTION

The pericardial cavity normally contains approximately 15–20 ml of fluid, allowing smooth cardiac movements. Rapid accumulation of fluid or blood within this cavity overwhelms the limited distensibility of the pericardium, resulting in cardiac tamponade and acute circulatory failure. [1]

Hemopericardium most commonly results from rupture of the cardiac chambers, coronary arteries, or major vessels such as the aorta. Non-traumatic causes include myocardial infarction-related ventricular rupture and spontaneous aortic rupture, while traumatic causes include blunt or penetrating chest injuries.[2-3]

Cardiac tamponade frequently causes sudden death without antecedent symptoms, making such cases medico-legally significant. In unwitnessed deaths, autopsy is often the only method to establish the precise cause of death and rule out external violence.[4]

This study presents five autopsy-confirmed cases of cardiac tamponade resulting in sudden unexpected death.

MATERIALS AND METHOD

This retrospective study included five medico-legal

autopsies conducted at Government Medical College & Hospital, Chandigarh from the year 2022 to 2025. Police inquest reports, hospital records, and circumstantial details were reviewed. Complete autopsies were performed as per standard forensic protocol. Gross examination of the heart, pericardium, and major vessels was conducted.

CASE SERIES

CASE 1

A 49-year-old male, a tailor by profession, after having his lunch, went to his room and became unconscious. His family members took him to the nearby hospital, where he was declared brought dead. He had prior history of a heart attack and was on medication for the last 2 years.

Postmortem Findings

The deceased was well nourished (165 cm, 72kg), without any evidence of external injury. On opening the chest cavity and the pericardium, about 1000 ml of clotted blood & liquid blood was present in the sac. The heart (670 g) was hypertrophic with extensive transmural infarction of the right ventricle. A rupture of size 2.5 cm in diameter was found 4 cm from the apex **(Figure 1)**.

On further dissection, the left anterior descending artery **(Figure 2)** showed severe atherosclerotic change with a focal area of thrombosis causing complete luminal occlusion of about 0.5 cm in length and situated 3 cm from the coronary ostium. The left ventricular wall thickness was 18 mm. Rest of the viscera were unremarkable. Stomach contained around 300 ml semi digested food without any characteristic odour, mucosa congested.

Cause of Death: Sudden cardiac death due to cardiac tamponade following rupture of myocardial wall

CASE 2

Figure 1: Rupture of Apex of Heart

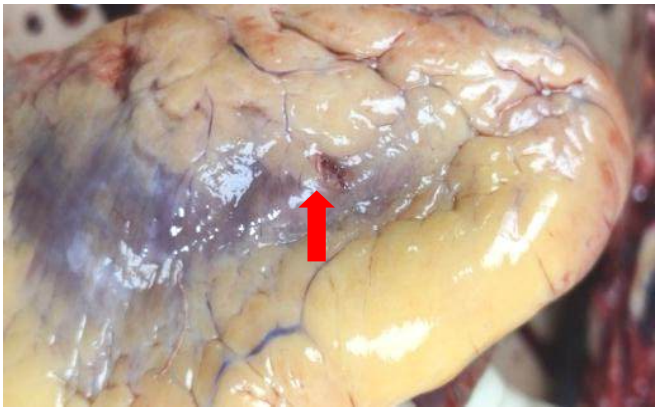
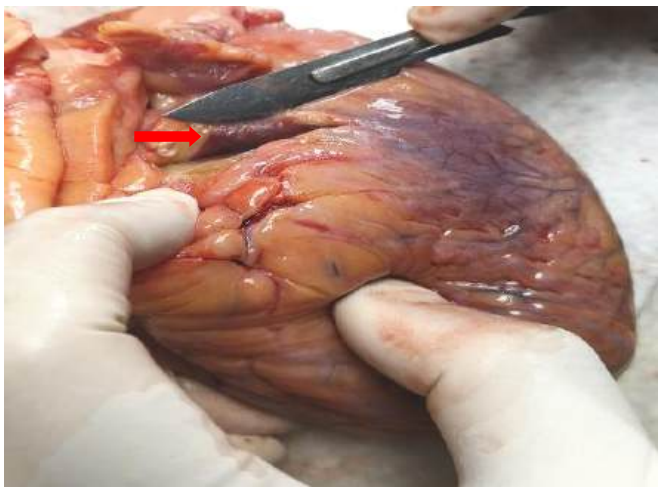


Figure 2: Left Anterior Descending Artery Atherosclerosis.



A 46-year-old married female homemaker with history of hypertension, was uncompliant on medication. On 15th October, 2024, she while climbing the stairs to third floor, got tired and sat on the stairs and became unconscious. She was taken to the hospital, where the doctor declared her brought dead.

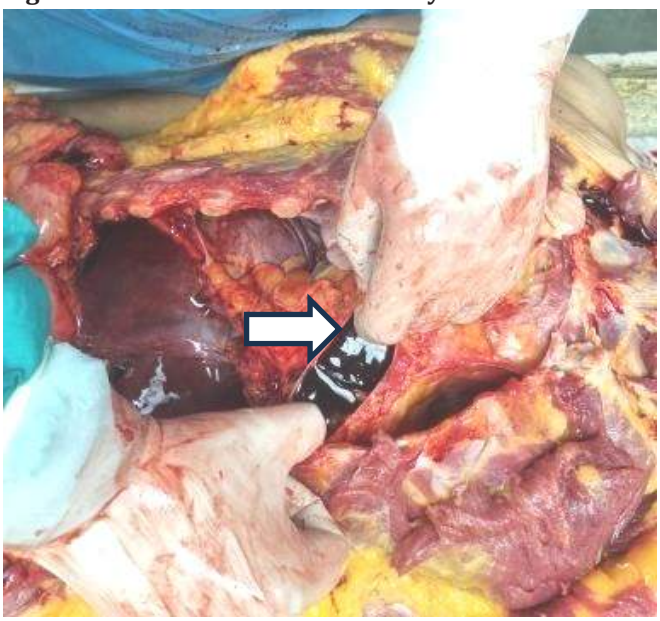
Post Mortem Examination

The deceased was well-nourished, muscular (162cm, 68kg) with no evidence of any external injury. A collection of fluid and clotted blood of about 200 ml was observed in the pericardial cavity and the enlarged and hypertrophied left ventricle wall measured 2.8 cm and the intraventricular septum measured 2 cm.

There walls of the arch of aorta were thinned out and a tear of size 1.5 cm was present around the arch of aorta. **(Figures 3-4)** Stomach contained around 50 ml reddish fluid, without any characteristic no odour, mucosa was

Figure 3: Arch of Aorta Tear.

Figure 4: Blood in Pericardial Cavity.



congested

Cause of Death: Sudden cardiac death due to cardiac tamponade following rupture of arch of aorta.

CASE 3

A 56-year-old self-employed male was driving back home after completing his work. His car suddenly lost balance and collided with a tree. An unknown person called the police control room, and the police came and took him to a hospital, where the doctor declared him brought dead.

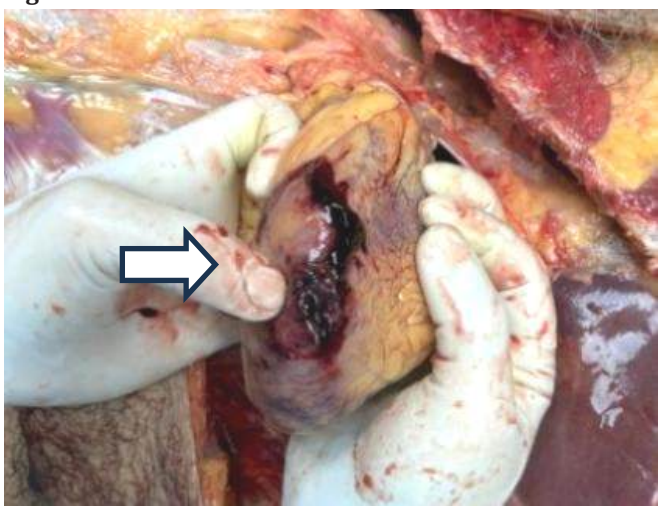
Postmortem Examination

The deceased was well-nourished, (174cm, 82kg) with no evidence of any external injury. A collection of fluid and clotted blood of about 200 ml was observed in the pericardial cavity. Tear of size 2 cm x 0.2 cm x cavity deep was present over the wall of left ventricle. **(Figure 5-6)**

Cause of Death: Sudden cardiac death due to cardiac

Figure 5: Blood in Pericardial Cavity.

Figure 6: Tear of Left Ventricle.



tamponade following rupture of left ventricle wall.

CASE 4

A 33-year-old self-employed male went for his cousin's marriage. There, he complained of leg pain for which he took an analgesic. He then developed chest pain and difficulty in breathing, followed by unconsciousness. His family members took him to the hospital, where the doctor declared him brought dead.

Postmortem Findings:

The deceased was well-nourished, (170cm, 80kg) with no evidence of any external injury. A collection of fluid and clotted blood of about 500 ml was observed in the pericardial cavity and tear was present over the anterior wall of left ventricle. **(Figures 7-8)**

Cause of Death: Sudden cardiac death due to cardiac tamponade following rupture of left ventricle.

CASE 5

A 84-year-old male after his breakfast went to his son room, where he became unconscious. His family members took him to a hospital, where the doctor declared him dead.

Postmortem Examination

The deceased was average built, (166cm, 70kg) with no external injury. A collection of fluid and clotted blood of about 500 ml was observed in the pericardial cavity and rupture of left circumflex artery was present **(Figure 9-10)**.

Cause of Death: Sudden cardiac death due to cardiac tamponade following rupture of left cicumflex artery.

DISCUSSION

Sudden and unexpected deaths occurring in apparently

Figure 7: Tear of Left Ventricle.

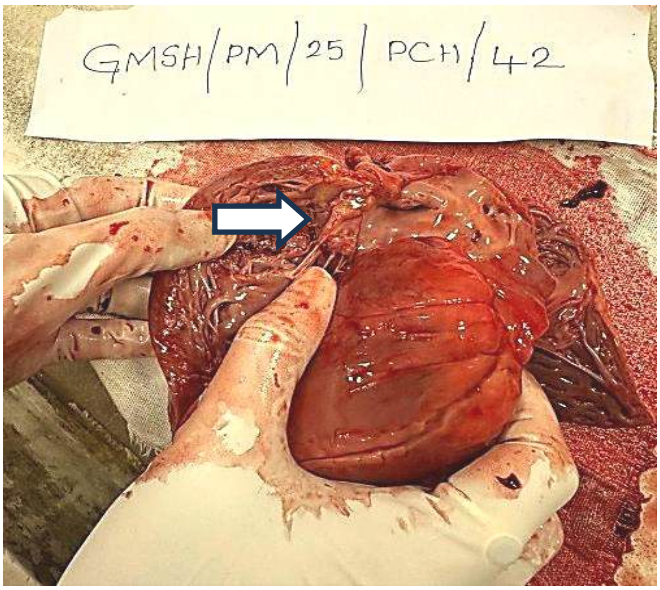
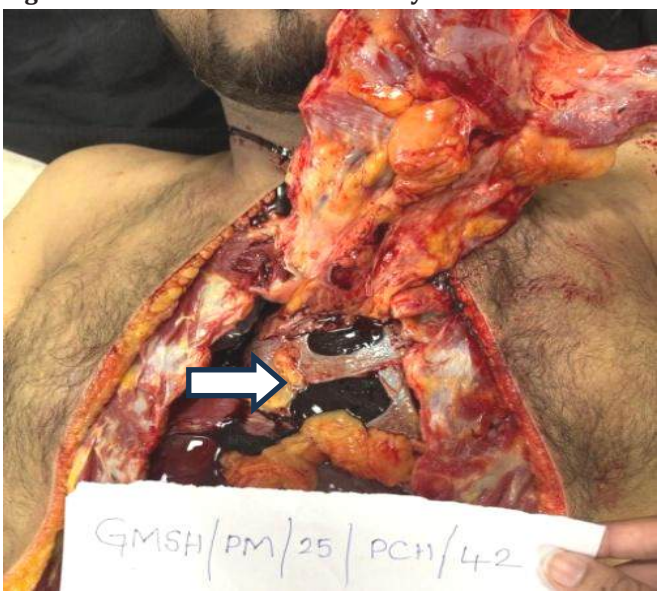


Figure 8: Blood in Pericardial Cavity.



stable individuals pose a significant diagnostic challenge in forensic practice. Among the various cardiac causes, cardiac tamponade remains a critical yet often under-recognized mechanism of sudden cardiac death, particularly when death occurs outside a hospital setting. In the present series of five cases, cardiac tamponade due to rupture of myocardial, coronary, or aortic structures was identified as the final common pathway leading to death.

Cardiac tamponade results from rapid accumulation of blood or fluid in the pericardial sac, producing acute compression of the heart and restriction of diastolic filling. This leads to a sudden fall in cardiac output and circulatory collapse, often before any effective medical intervention can be instituted. Literature emphasizes that the rate of accumulation is more crucial than the absolute volume, as even 150–200 ml of rapidly collected blood may be sufficient to cause death, a finding also observed in the present study where fatal tamponade occurred with volumes as low as 200 ml in some cases.[1-2,8]

Myocardial rupture following myocardial infarction remains one of the most common natural causes of hemopericardium encountered at autopsy. In Case 1, extensive transmural infarction with rupture of the ventricular wall was identified, along with severe atherosclerotic disease and thrombosis of the left anterior descending artery. Such ruptures typically occur due to weakening of necrotic myocardium and are well documented in pathological and clinical literature.[3,9] The presence of prior history of myocardial infarction in this case further supports this mechanism.

Cases 3 and 4 demonstrated rupture of the left ventricular

Figure 9: Clotted Blood in Pericardial Cavity.

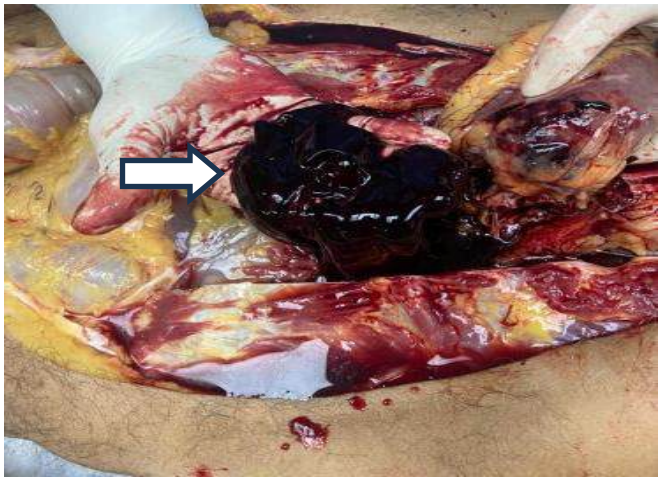
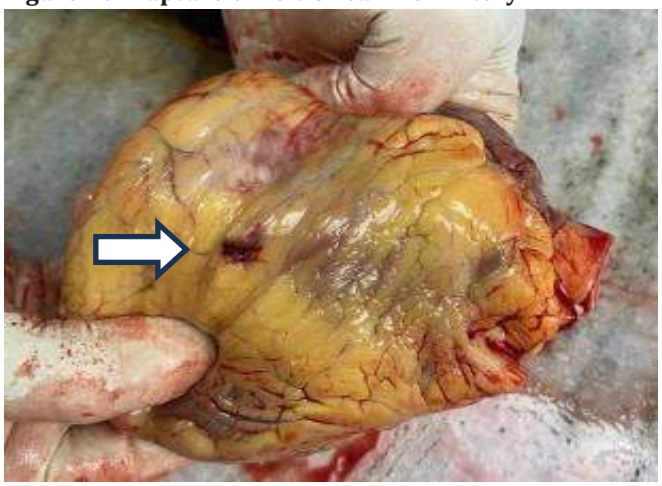


Figure 10: Rupture of Left Circumflex Artery.



wall without evidence of external trauma. These cases are of particular medicolegal importance, as sudden collapse in situations such as road traffic incidents may initially raise suspicion of traumatic injury. However, careful autopsy examination revealing absence of external injuries and presence of hemopericardium with myocardial tear confirms a natural cause of death. Similar observations have been reported in forensic autopsy studies emphasizing the necessity of meticulous internal examination in sudden deaths.[4,11-12]

Rupture of the aorta is another well-known cause of acute cardiac tamponade. In Case 2, rupture of the arch of the aorta was identified in a hypertensive female who collapsed during physical exertion. Hypertension contributes to degenerative changes in the aortic wall, predisposing it to rupture even in the absence of trauma. The relatively small amount of pericardial blood in this case was sufficient to produce fatal tamponade, highlighting the catastrophic nature of aortic rupture.[5,7,10]

Case 5 illustrates a rarer cause of cardiac tamponade-rupture of the left circumflex coronary artery. Coronary artery rupture is uncommon but may occur in elderly individuals due to severe atherosclerosis or degenerative vascular changes. Such lesions can easily be overlooked unless coronary arteries are systematically dissected during autopsy. Previous studies and case reports have stressed the importance of careful coronary examination in sudden cardiac deaths.[6,8]

Across all cases, the absence of external injuries and the presence of nonspecific gastric findings, such as semi-digested food, indicate death occurring suddenly during routine daily activities. These findings are consistent with sudden cardiac death rather than poisoning or trauma. The series underscores the indispensable role of autopsy in establishing the cause of death in brought-dead cases, where clinical information is often limited or unavailable.

In forensic practice, identification of cardiac tamponade and its underlying cause not only establishes the manner of death as natural but also prevents unwarranted legal suspicion. The present case series highlights the varied pathological mechanisms leading to tamponade and reinforces the need for thorough examination of the heart, pericardium, coronary arteries, and great vessels in all cases of sudden unexpected death.

CONCLUSION

The cases presented in this series illustrate how cardiac tamponade can lead to sudden and unexpected death, often without any obvious warning signs. Each individual was carrying out routine activities when they suddenly collapsed, leaving family members and healthcare providers with little indication of the underlying cause. In the absence of significant external injuries, the true nature of these deaths became apparent only after a careful medicolegal autopsy.

Examination of the heart and great vessels revealed bleeding into the pericardial sac due to rupture of the ventricular wall, coronary artery, or aorta. The resulting pressure on the heart prevented it from functioning effectively, leading to rapid circulatory failure and death. In several cases, underlying conditions such as coronary artery disease, previous myocardial damage, hypertension, or age-related vascular changes were identified as important contributing factors.

These findings highlight the hidden and often catastrophic consequences of cardiovascular disease. They also demonstrate the crucial role of forensic autopsy in uncovering the exact cause of sudden natural deaths, particularly when external examination provides few clues. Accurate identification of the source of bleeding not only helps explain the mechanism of death but also assists in excluding trauma or other unnatural causes.

Overall, this case series emphasizes that cardiac tamponade, although relatively uncommon, should always be considered in cases of sudden unexpected death. Thorough postmortem examination remains essential for establishing the cause of death, providing clarity to grieving families, and ensuring accurate medicolegal conclusions. The series also serves as a reminder of the importance of recognizing and managing cardiovascular risk factors before they progress to fatal complications.

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A CASE SERIES

Animal Scavenging in Medicolegal Death Investigations: A Case Series of four Cases from Punjab, India

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ABSTRACT

Introduction: Postmortem animal scavenging of human remains is a well-recognised taphonomic variable in forensic casework that can obscure inflicted injuries, impede identification, and confound determinations of cause and manner of death. Systematically analysed case series from the Indian subcontinent remain sparse in the peer-reviewed literature.

Case Summary: We present a series of three cases involving significant postmortem animal activity (PMAA) recovered from open agricultural settings in the Punjab region of India. Case 1 involved a homicidal sharp-force cut-throat injury concealed by stray dog scavenging of the neck and scalp. Case 2 featured near-total scavenging of cervical soft tissues resulting in near-decapitation, in an individual with healed needle puncture marks over bilateral cubital fossae and the left abdomen and a urine toxicology screen positive for opioids. Case 3 presented as suspected case of homicide following kidnapping and sexual assault where body was recovered from a paddy field, partially skeletonised, badly decomposed and teaming with maggots. Case 4 presented as advanced decomposition with extensive blow fly larval infestation and multi-site animal soft tissue loss, including complete absence of abdominal viscera and bilateral distal extremities. Each case posed distinct diagnostic challenges in differentiating antemortem injury from postmortem animal artefact.

Conclusion: This series underscores the primacy of vital reaction assessment in distinguishing antemortem injury from Postmortem animal activity, and the necessity of routine ancillary investigations-including radiology, toxicology, and forensic entomology-in all such cases.

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INTRODUCTION

Postmortem animal activity (PMAA) is a significant and regularly observed both in outdoor and indoor setting in forensic casework worldwide.[1-2] When human remains are exposed to vertebrate or invertebrate scavengers before medicolegal examination, the resulting modifications can massively alter cadaveric appearance: genuine inflicted injuries may be concealed or destroyed, and postmortem animal artefacts may simulate antemortem or perimortem trauma with potentially serious medicolegal consequences.[3-4] Among vertebrate scavengers, domestic and stray dogs are most frequently implicated in outdoor settings.[3,5]

In the Indian subcontinent, free-roaming stray dog populations are ubiquitous in rural and peri-urban environments. Isolated agricultural settings frequently result in delayed discovery of human remains, allowing extensive PMAA to develop prior to scene attendance and autopsy examination. This context creates a recurring medicolegal challenge for forensic practitioners in the region, yet documented case series from India specifically addressing the spectrum and medicolegal implications of PMAA are limited.

The reliable separation of PMAA from genuine, inflicted injury rests on established macroscopic and histological criteria: pale wound margins without hemorrhagic

infiltration, irregular and ragged tissue edges, tissue tags, characteristic claw-mark abrasion morphology, and the absence of vital reaction at any site of tissue disruption.[4-6] However, these criteria are most challenging to apply when genuine antemortem injuries coexist with, and are partially destroyed by, overlying postmortem modifications.

We present three cases that collectively illustrate the forensic spectrum of PMAA encountered in regional medicolegal practice in Punjab, India. The cases address three interrelated forensic themes: (i) differentiation of antemortem and perimortem injuries from postmortem animal artefacts; (ii) Obscuring evidence of physical injuries; (iii)challenges of victim identification in the absence of intact soft tissue landmarks; and (iv) the broader medico-legal implications of PMAA, including the contributions of toxicology and forensic entomology.

CASE SERIES

Case 1: Homicidal Cut-Throat Injury with Extensive Canine Scavenging

A partially decomposed adult male was discovered in an open field in Mansa district, Punjab in March 2025. Police were alerted following reports of stray dogs congregating at the location. On arrival, active scavenging was concentrated over the neck region. Preliminary identification was established through miscellaneous personal documents recovered from the clothing, corroborated by multiple distinctive tattoos and a congenital deformity of the right foot.

Autopsy was conducted on the same day. Clothing examination revealed generalised dried mud staining and irregular tearing of the shirt across its upper half. Grey and brownish-black hairs consistent with dog fur were recovered from the clothing surface. Following removal of clothing, rigor mortis was found to have completely resolved, and greenish discolouration of the anterior abdominal wall was present, indicative of early putrefactive decomposition.

External examination revealed complete absence of skin, subcutaneous tissue, and facial musculature on the right side of the face and over the scalp, exposing the periosteum of the skull vault. Anteriorly and anterolaterally, the cervical soft tissue structures were absent, with the underlying posterior cervical musculature and fascia exposed and mud-covered. The dominant injury comprised a single confluent wound measuring 41.2 cm × 16.4 cm × 8 cm, traversing the scalp, right hemi-face, and the anterior and lateral neck. In the neck zone of the wound, the tongue, pharynx, larynx, thyrohyoid complex, oesophagus, and all anterolateral cervical visceral structures were absent up to the sternoclavicular joint level. Residual tissue fragments, tracheal cartilage rings, and cervical vessels were disrupted with irregular margins and prominent tissue tags. Fragmentation of the transverse processes of C5 and C6 and the spinous processes of C6 and C7 was noted, with complete absence of haemorrhage at the fracture sites, confirming their postmortem mechanism.

Internal dissection of the cervical spine demonstrated a focal wedge-shaped defect on the anterior surface of the C5 vertebral body (1.2 cm × 0.2 cm × 0.5 cm) with clean-cut margins, inferior-edge bevelling, and superior-edge undermining-features characteristic of a sharp-force incised wound penetrating bone. Hemorrhagic infiltration was confirmed at the defect margins, establishing this as a perimortem or antemortem injury. Radiological examination of the head, neck, and chest revealed no metallic fragments or projectiles. Visceral examination and visceral organ toxicology were unremarkable. The cause of death was certified as cut-throat injury to the neck inflicted by a sharp-edged weapon, with the manner of death determined to be homicide. The extensive cervical and scalp soft tissue loss and the posterior vertebral

Figure 1:

fragmentation were attributed to postmortem canine scavenging. **(Figure 1)**

Case 2: Near-Decapitation by Animal Scavenging in a Presumed Intravenous Drug User

The second case involved an adult male body discovered in an open farm setting in the month of March, 2025. On scene examination and autopsy, the head was found to be nearly detached from the torso, maintained only by a posterior bridge of residual skin and soft tissue. This zone of near-decapitation exhibited characteristic nibbling and gnawing marks extending into the upper third of the anterior chest, with irregular wound margins and interconnecting fibrous tissue bridges-morphological features consistent with sustained canine scavenging rather than sharp-force transaction.[4-6]

The soft tissues of the anterior scalp were absent over approximately half of the scalp surface, with the free margins of residual skin and subcutaneous tissue showing nibbling and gnawing changes at multiple sites. The margins were pale and irregular, with no vital haemorrhage identified at any scavenged surface, confirming all soft tissue disruption as postmortem in nature.

Of significant medicolegal importance, healed needle puncture scar marks were identified over the bilateral antecubital fossae and over the left lateral abdominal wall. These healed injection stigmata are recognised as characteristic cutaneous features of chronic intravenous drug use and may reflect progressive migration of injection sites to abdominal superficial veins as upper extremity venous access becomes compromised by repeated injection-related scarring.[7] Urine toxicological screening performed at autopsy was positive for opioids.

The combination of healed injection marks at classical and non-classical sites of intravenous access, alongside a positive opioid urine screen, is consistent with a background of chronic intravenous opioid dependence. This raises the possibility that acute opioid intoxication may have rendered the individual incapacitated outdoors, contributing to the circumstances of death. Urine positivity for opioids documents recent exposure but requires correlation with quantitative blood toxicology and autopsy findings for a definitive medicolegal interpretation, as established in published guidelines for the investigation of opioid-related deaths.[8-9] The full toxicological workup and comprehensive autopsy findings were reviewed in this context. **(Figure 2)**

Case 3: Partially Skeletonised Female Body Following Alleged Kidnapping and Sexual Assault

In July 2025, partially skeletonised body of a female was discovered in paddy field in Shardulgarh, Punjab. The deceased had been reported missing five days earlier, and her family had lodged a complaint of suspicious kidnapping by a male friend of hers.

Questions were raised regarding the identification of the deceased, time since death, whether sexual assault including oral sex took place had occured, whether the wounds/injuries on the body were antemortem or postmortem in nature and whether body was taken out and thrown away after being buried somewhere else or not.

On examination, Skull, facial bones, pelvic bones were exposed with soft tissue at places, bilateral tibia and fibula show presence of only soft tissue at knee joint, 10th to 12th ribs have splintered and crushed medial ends. Missing phalanges of the right foot, phalanges, metatarsals, and

Figure 2:

foot bones of left foot. No abdominal and pelvic viscera present in cavity. Maggots teaming over the body measuring 1.5–2.1 cm in length

Free margin of remaining tissue shows semicircular arch defect with pale margin with skin tags in the form of tear at multiple places possible of animal bites.

Advanced decomposition and partial skeletonisation obscured assessment of genital injuries at autopsy. All biological samples, including vaginal, cervical, anal and external genital swabs could not be collected to rule out sexual assault. Oral swabs were collected and sent to forensic science laboratory. All the injuries except 2 were antemortem in nature and pointed towards animal attack based on their appearance. Remaining available samples were sent for chemical and histopathological examination and teeth were taken for DNA Analysis.

This case highlights strategical intent of criminal to delay recovery of body and enabling scavenging animals to feed on the remains and thus creating challenge in establishing identity of deceased as well as the cause of death. Such locations are often selected with expectation that scavenging by stay dogs, rodents and vultures will accelerate postmortem destruction of soft tissue thus reduce the likelihood of establishing the cause and manner of death. **(Figure 3)**

Case 4: Advanced Decomposition with Extensive Insect Infestation and Multi-Site Animal Activity

In March 2026, body was discovered in a farm area in Bathinda, Punjab. A strong odour of decomposition was noted by the responding officer before visual contact. Autopsy examination revealed the following.

Generalised greenish discolouration was present over the entire body surface, consistent with advanced putrefactive decomposition. Fly larvae were distributed throughout the body, with individual maggots measuring 1.3–1.5 cm in length. This size range corresponds to second- to third-larval instar blow fly larvae of forensically relevant calliphorid species. Given that calliphorid females typically oviposit on accessible cadavers within minutes to hours of death and that larval development proceeds in a predictable, temperature-dependent fashion, the developmental stage of the oldest larvae provides a basis for minimum postmortem interval estimation using the accumulated degree hour or accumulated degree day methodology.[10-11]

The Dental examination documented generalised loosening of teeth from their sockets. The upper left second molar and all three upper right molars were absent; in the lower jaw, the left second premolar, right second premolar, and right first and second molars were fractured. These specific dental findings were documented for potential odontological comparison, though their diagnostic utility is contingent on the availability of antemortem dental records.[12]

Bilaterally, all forearm soft tissues were absent, with the underlying radius and ulna exposed on both sides. The free margins of residual skin and subcutaneous tissue around the arms were irregular, pale, and ragged, with exposed muscles and vessels lacerated at multiple sites with irregular margins.

Figure 3:

Both feet were absent. The distal portions of both lower legs showed complete soft tissue loss, with bilateral exposure of the distal tibia and fibula. The free margins of residual skin and subcutaneous tissue over the lower legs were irregular and pale, demonstrating arch-shaped defects with skin tags-a pattern described in the forensic literature as characteristic of canine bite-and-traction forces applied to soft tissue edges, arising from the shearing biomechanics of canid dentition.[4-5] The abdominal cavity was exposed, with all abdominal organs absent, consistent with progressive visceral scavenging. **(Figure 4)**

DISCUSSION

These Four cases collectively illustrate the range of medicolegal complexity arising from PMAA in a regional Indian forensic setting. Each case challenges a distinct dimension of forensic practice: the attribution of injuries to antemortem versus postmortem mechanisms; mask physical injury obscuring vital evidence; the identification of victims when soft tissue landmarks are absent; and the integration of toxicological and entomological findings into the overall medicolegal assessment.

3.1 Differentiating Antemortem from Postmortem Injuries. The diagnostic cornerstone in all four cases was the assessment of vital reaction-haemorrhage, vascular congestion, or inflammatory infiltrate at wound margins-which constitutes the definitive criterion for distinguishing an antemortem injury from a postmortem artefact.[4-5] In Case 1, the haemorrhagic infiltration at the margins of the C5 vertebral defect, combined with the clean-cut margins and characteristic bevelling pattern of a sharp-force wound penetrating bone, allowed the homicidal cut-throat injury to be identified and separated from the overlying scavenging damage. The pale, bloodless, irregular-margined soft tissue wounds with tissue tags were recognised as postmortem canine artefacts on the basis of established morphological criteria.[4-6] This case is analogous to published cases in which postmortem canine scavenging of the neck region has produced findings sufficiently extensive to initially obscure a homicidal injury.[5-6]

In Case 2, the appearance of near-decapitation could superficially suggest mechanical cutting of the cervical structures. However, the absence of vital reaction throughout, the characteristic nibbling-gnawing margin morphology, the presence of tissue bridges, and the extension of the wound pattern into the anterior chest-consistent with progressive canine feeding behaviour-established PMAA as the mechanism responsible for all observed tissue disruption. In Case 3 and 4, the arch-shaped skin defects with skin tags at the margins of the lower limb stumps, the irregular pale bone margins without haemorrhage, and the overall pattern of multi-site soft tissue loss from accessible distal extremities and visceral cavities were collectively consistent with an established pattern of carnivore scavenging documented across the forensic taphonomic literature.[1,4,6]

3.2 Obscuring Evidence of Physical Injuries. When a body is left exposed, scavengers are drawn to areas of already-compromised tissue, and their feeding activity often concentrates right at the site of an existing wound. This creates a real problem for investigators: teeth marks, gnawing, or claw scrapes left by an animal can look remarkably similar to lacerations or punctures caused by a

Figure 4:

weapon. The overlap gets worse when scavenging happens directly over or immediately around the original fatal injury, since the animal's activity can chew away the very margins, making it difficult to tell a knife wound from a bite, or a gunshot entry from torn flesh. Defensive wounds-cuts and bruises on the hands or forearms that typically point to a struggle-are especially vulnerable to being erased or disguised this way, sometimes wiping out one of the clearest signs that a death was violent rather than natural or accidental. By disposing body in open, less frequented fields, criminals intent to exploit natural decomposition process to conceal the crime. Advanced decomposition, insect activity and animal induced injuries and mutilation affects the identification, estimation of postmortem interval and reduce the availability of biological evidence like fingerprint, trace evidence etc thus break the chain linking the crime to themselves. Because of this, scavenged remains should be treated with added caution, cross-checking bite patterns against known animal dentition, considering the timeline of exposure, and being deliberately slow to label a wound as human-inflicted until postmortem interference has been ruled out.[13]

3.3 Forensic Identification Challenges. PMAA significantly impedes victim identification by destroying the soft tissue features required for visual and morphological recognition and by disarticulating or removing skeletal elements. In Case 1, identification was achieved through the convergence of multiple independent indicators-personal documents, tattoos, and a congenital deformity-illustrating the importance of multi-modal identification strategies in cases where a single modality would be insufficient.[12] In Cases 2,3 and 4, facial soft tissue loss precluded visual identification. The systematic dental documentation in Case 4, recording specific patterns of tooth absence and fracture, generated a potential odontological record; however, the availability of antemortem dental data remains a significant obstacle in rural populations. The injection stigmata in Case 2 constitute an additional physical identifier that may assist in tracing missing person reports from communities where drug dependency is known or suspected.

3.4 Medico-Legal Implications of PMAA. The medico-legal implications of PMAA extend beyond injury characterisation. In Case 2, the healed injection marks at bilateral cubital fossae and the left abdomen, combined with a positive urine opioid screen, provide convergent evidence of chronic intravenous opioid dependence. The medicolegal significance is dual: first, acute intoxication may have caused incapacitation outdoors, creating vulnerability to death in an isolated setting with subsequent extensive PMAA; second, the forensic determination of whether opioid toxicity contributed causally to death requires quantitative blood toxicological analysis and full autopsy correlation-a standard mandated in published guidelines for opioid-related death investigation.[8-9] Urine screening alone establishes recent exposure, not lethality, and this distinction is of direct relevance to the certification of manner of death.[9]

In Case 4, the entomological findings offer a meaningful opportunity for minimum postmortem interval estimation. Calliphorid blow flies colonise accessible cadavers within minutes to hours of death, and larval size and developmental stage can be used to calculate a minimum PMI using accumulated degree hour or accumulated degree day models calibrated to regional temperature data.[10-11] The observed larval length of 1.3–1.5 cm is consistent with second- to third-instar larvae and, integrated with ambient temperature data for bathinda, Punjab for the relevant period, could yield a minimum PMI estimate. Forensic entomology has been shown to provide a reliable complement to conventional autopsy-based PMI estimation when traditional post-mortem changes are no longer interpretable,[10-11] yet the discipline remains significantly underutilised in Indian medicolegal practice.

Collectively, these cases highlight the medico-legal risks of inadequately characterised PMAA: the misattribution of scavenging injuries as inflicted wounds may generate erroneous homicide investigations, while the failure to recognise genuine homicidal injury beneath overlying scavenging may prevent accountability-a dual risk that has been articulated in both the forensic pathology and forensic anthropology literature.[1,5] The systematised application of ancillary investigations-radiology to exclude retained metallic fragments, toxicology to identify contributory intoxication, and entomology to estimate minimum PMI-is essential for rigorous medicolegal practice in cases involving significant PMAA.

CONCLUSION

This four-case series from the Punjab, India documents the forensic spectrum of postmortem animal scavenging encountered in a regional medicolegal practice. The cases demonstrate that vital reaction at injury margins remains the definitive criterion for differentiating antemortem

injury from postmortem animal artefact; the confusion and masking of physical injuries by animal activity; that multi-modal identification strategies are essential when facial and soft tissue landmarks are destroyed by scavenging; and that systematic toxicological and entomological investigations must be integrated into the assessment of all such cases. The concurrent identification of a homicidal sharp-force wound beneath extensive dog scavenging in Case 1, the medico-legal complexity of chronic opioid dependence and near-decapitation in Case 2, and the forensic entomological opportunity presented in Case 3 and 4 collectively underscore the need for comprehensive, systematic, and multi-disciplinary medicolegal assessment in all cases involving significant PMAA. Enhanced forensic training and investigative infrastructure in rural Indian settings are necessary to ensure that such cases receive the rigorous examination they require.

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A CASE REPORT

Using 360° Camera (Omni-Directional Camera) at Scene of Crime

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ABSTRACT

Photography and videography are considered main components at the scene of occurrence/crime scene. Photography and videography combine to constitute documentation of a crime scene, which makes a physical crime scene virtual and viewable anywhere by lawyers, judges, investigation officers, etc. The use of a 360-degree camera in crime scene documentation can be proven as a new innovation or development in the field of forensic science.

This camera is also known as an omnidirectional camera, which is a camera having its field of view, which covers one complete circle (360°). Normally, the cameras already available in the market have a field of view ranging from some degrees to 180° (maximum). Using an omnidirectional camera at a scene of crime would be helping in combining different angles or perspectives of the scene of occurrence/crime at one single click, thereby offering a complete view.

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INTRODUCTION

1.1 Crime Scene:

It can be defined as an incident that occurred or a physical location where a crime took place or a physical location that can help to link a suspect with a crime. It is not just limited to a physical location but can even include a place, person, object, vehicle, etc. It can even be defined as the primary source of evidence, which requires utmost care and precision to be employed while examining it. In general words, a crime scene can be understood as a lock with a key (which is to be found by the crime scene investigator) so as to link the suspect with the crime.[1] As soon as a call is received regarding a crime case, the first responding officer needs to ensure that he/she follows certain guidelines. **(Flow Chart 1)**

Every crime scene is unique in its nature and is to be preserved "As it was, as it is". According to Locard's exchange principle which states that 'Every contact leaves a trace' or can be understood as whenever two objects or persons come in contact with each other.[2-4]

1.2 Crime Scene Procedure

The 7S's of crime scene are as follows:-

1.3 Type of Crime Scene

It can be classified as an indoor or outdoor scene of occurrence/crime scene.

(a) Indoor Crime Scene: A crime scene that took place in

Flow Chart 1:

Providing medical help/treatment to the victim and/or suspect.

⇩

Cordoning off the scene of occurrence with crime scene tape, barricades etc.

⇩

Ensuring only authorized personnel are allowed to enter the SOC.

⇩

Establishing a crime scene entry log.

⇩

Witnesses are to be separated and individual statement should be taken.

⇩

Keeping away the passer-by and onlookers.

⇩

Ensuring media briefing is away from SOC and isn't interfering with the investigation.

the interior of, say, a house **(Figure 1)**.

(b) Outdoor Crime Scene: A crime scene that took place outside or in an open area **(Figure 2)**.[5]

1.4 Searching Patterns of the Crime Scene: As already discussed before, a crime scene requires utmost precision and care while being investigated. It includes various searching patterns, which are discussed as follows:

a. Strip Method: Crime scene personnel follow a pattern from one end to the other and then come back in the same manner. Example-Classrooms, Warehouses

b. Grid Method: Crime scene personnel follow different routes both horizontally and vertically at the same time, then switch places with one another. Example-Park, Vehicle Accidents

c. Spiral Method: Crime scene personnel start either from the center to the periphery or from the periphery to the center. Example-Beaches, Lakes

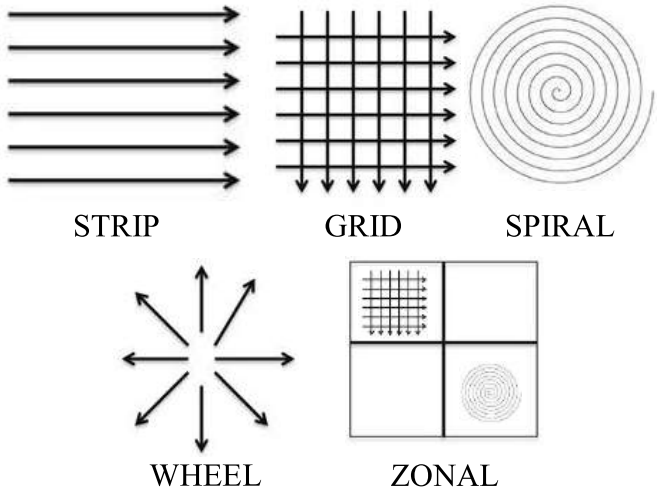
d. Wheel Method: Crime scene personnel congregate in the center of a hypothetical circle, and each investigator then travels straight out from the core, resembling the spokes of a bicycle. Example-Plane Crash, Deserts.

e. Zonal Method: The crime scene is virtually divided into different zones, and then the divided zones are searched using any of the above-discussed search methods. Example-Multi-room buildings, offices.[6]

Figure 1: Showing Indoor Crime Scene.

Figure 2: Showing Outdoor Crime Scene.

Figure 3: showing different crime scene searching patterns



2. Evidence: It is any item or substance that helps connect a crime scene to a criminal or a crime with a suspect. It holds greater significance in law enforcement agencies such as police stations, courts, and forensic science laboratories.[7-8] Evidence can be broadly classified as physical, chemical, biological, digital, etc. **(Table 1)**

3. Photography: It can be defined as 'a thousand words' or 'writing with light.' In the field of forensic science, it is considered much more significant. The photographs of the crime scenes are taken so as to create a visual record, which can be accessed easily and can be viewed by the law enforcement agencies. It helps in understanding the scene of occurrence as it was during the time of the visit. A photo log is even created with the time, date, file name, aperture, shutter speed, and other details. It is done both with and without a scale.

3.1 Types of Photographs taken at Crime Scene:

A. Overall Photography: It captures the global aspects of the crime scene. It displays the wide-angle view, which depicts the complete scene of the crime. **(Figure 4 (A))**

B. Mid-range photography: It provides context to show spatial relationships between evidence and the surroundings. Shows 4-5 pieces of evidence in one frame. **(Figure 4 (B))**

C. Close-up Photography: It is the purposeful presentation of certain pieces of evidence. It must clearly display any annotations and present all sides of the evidence. Typically, each image is captured twice: once with and once without scale.[9-10] **(Figure 4 (C))**

4. Omni-Directional Camera: Omnidirectional vision sensors are devices that can capture a 360-degree view of the surrounding scene. Various constructions of such devices exist today, each of which is characterized by different projective geometry and thus requires a specific approach to analyze the captured visual information. According to their construction, omnidirectional vision sensors can be classified into three types-Systems that use multiple images (i.e., image mosaics), devices that use

Figure 4: Showing Types of Photography

Figure 4 (A): Overall

Figure 4 (B): Mid-Range.

Figure 4 (C): Close-up.

Table 1: Showing Physical, Chemical, Biological and Digital Evidences.

PHYSICAL	CHEMICAL	BIOLOGICAL	DIGITAL
Soil	Petroleum Products	Hair	Mobile Phone
Bullet	Explosive	Blood	Laptop
Glass	Drugs	Semen	DVR
Paint Chips	Poison	Nail Scraping	Hard Disk

special lenses, and catadioptric devices that employ a combination of convex mirrors and lenses. The images acquired by traditional perspective cameras can be used to construct an omnidirectional image, either by rotating a single camera or by the construction of a multi-camera system. Obtained images are then aligned and stitched together to form a 360-degree view.

"Omnidirectional cameras" refer to cameras that have a larger field of view than the normal cameras (more than 180° and ideally 360°). This includes cameras with a horizontal 360° field of view (FOV) and cameras with an FOV spanning a 360° horizontal and more than 90° (ideally 180°) vertical field of view (FOV). An omnidirectional camera (from "omni," meaning "all") is a camera with a 360° field of view in the horizontal plane or with a visual field that covers a hemisphere or (approximately) the entire sphere.

There are designs proposed to achieve a 360° field of view. Cameras that use only a special lens to refract light such that the field of view is more than 90° vertically and 360° horizontally. One common example of such a type of camera is a fisheye camera. Cameras that use a combination of the lens (to refract light) and mirrors (to reflect light) with a normal camera to generate a 360° horizontal and more than 90° vertical field of view.[11]

5. Advantages of Using a 360° Camera at a Crime Scene : Using a 360° camera at a crime scene provides several significant advantages that make it a valuable tool for forensic documentation and later analysis. One of the main benefits is complete scene documentation, since a single 360° image can capture the full environment and preserve the overall layout of the scene more effectively than a limited series of standard photographs.

This reduces the likelihood of overlooking important evidence, contextual details, or the positions of objects that may later become relevant to the investigation. Another major advantage is accurate scene preservation, because the image serves as a permanent visual record that can be revisited long after the scene has been cleared, making it useful for case review, report preparation, expert analysis, and courtroom presentation. It is also time-efficient, allowing investigators to record a large amount of visual information quickly, which is especially important when a scene is unstable, weather-sensitive, or needs to be processed rapidly.

In addition, 360° imaging supports virtual scene reconstruction, enabling investigators, prosecutors, and experts to move through the scene later in a digital environment and better understand what was present at the time of documentation. This technology also improves evidence visualization by showing the spatial relationships among evidence items, victims, entry points, and other scene features, which can help reconstruct events and identify patterns that may not be obvious in separate flat images. Overall, the use of a 360° camera enhances completeness, efficiency, and clarity in crime scene recording, making it a useful complement to conventional forensic photography.

6. Disadvantages of Using a 360° Camera at a Crime Scene: 360° imaging can be highly valuable in forensic documentation, but it also presents several practical limitations that must be considered before it is used routinely at crime scenes. One of the most significant drawbacks is the creation of large file sizes, especially when images are captured at high resolution or with video, because these files require substantial storage space, backup systems, and processing power to manage efficiently.

In addition, viewing and analyzing 360° imagery often depends on specialized software, which can make the workflow more complex than conventional photography and may require compatible devices or platforms for proper access. Another important limitation is the need for training, since investigators must know how to capture the scene correctly, avoid errors during recording, and interpret the imagery in a meaningful way. Without proper training, the images may not provide reliable documentation and could even lead to misunderstandings during analysis.

The initial cost is also a concern, because purchasing the camera, software, storage infrastructure, and training can be expensive, which may limit practical use in smaller agencies or resource-constrained settings. Overall, while 360° imaging offers clear benefits, these technical, financial, and operational challenges can affect its efficiency and widespread adoption.

7. Application of 360-Degree Camera at Scene of Crime (SOC): A 360-degree or omnidirectional camera, such as the Insta360 X4, can be used at the crime scene in the field of forensic science. Normally the cameras, such as DSLRs, which are already being used in crime scene photography, have a field of view of a maximum of 180 degrees, thereby making the photographer take multiple photos at different angles of the crime scene.

But on the other hand, new technology involving omnidirectional cameras has a field of view of one complete circle, i.e., 360 (degrees). And would thus be reducing the need for clicking multiple photographs of the crime scene. Only one 360-degree photo would be sufficient for the visual representation of the crime scene wherein we would be able to move in all directions: up, down, left, and right.

An omnidirectional camera works by using two or more lenses to capture a 360° view. Can be understood as having multiple cameras in one, where the camera then stitches these images together into a 360° sphere (12).

Not many technicalities are required to use an omnidirectional camera. We just have to press the circle button. It then automatically shoots in all directions, giving us a 360° photo or video (depending on the mode selected). Once captured, the footage can be exported as a traditional photo (JPG, PNG) or video (MP4) format. There are many benefits of 360 camera at the SOC, some points are discussed below:-

a. Multipurpose: The camera can be used in both ways, i.e., 360-degree photos/videos and single-lens photos/videos. We can also pan in different directions in the video.

b. The Invisible Camera: Another benefit is the invisible camera or selfie stick. It's invisible as the camera or stick falls between the two lenses and is stitched out of the shot on its own.

c. Single-lens camera: The 4K single-lens mode may be used to employ an omnidirectional camera as a regular camera (13). **(Figure 5)**

Figure 5: Showing the Insta360 X4 Camera

MATERIAL AND METHOD

Insta360X4 Camera is using Photography/ Videography at

8.1 A

Figure 6: Showing Photo Taken with 360 Degree Camera - Just Requires Capturing of One Single Photo.

8.1 B

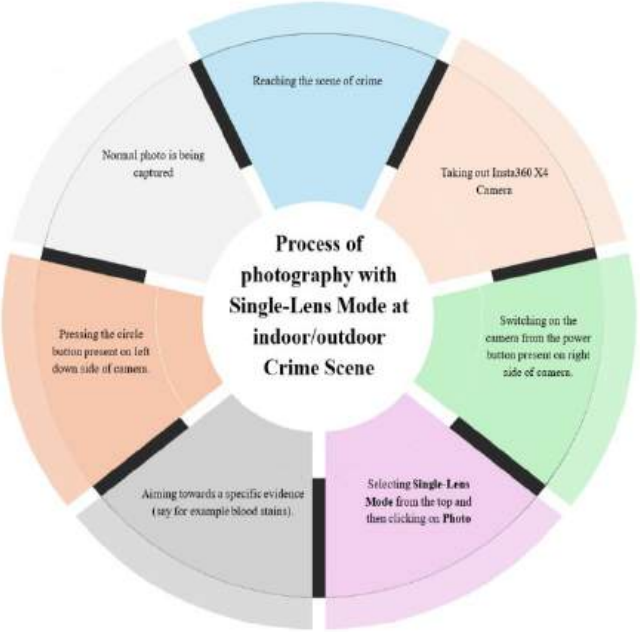
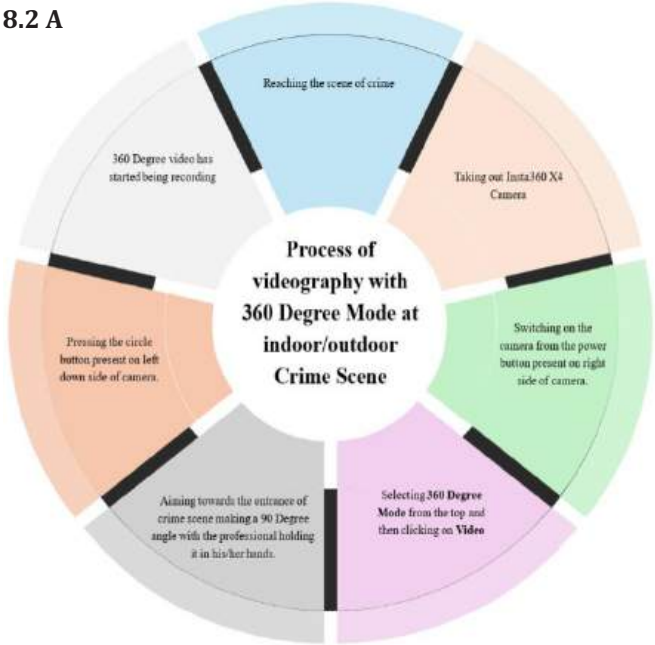


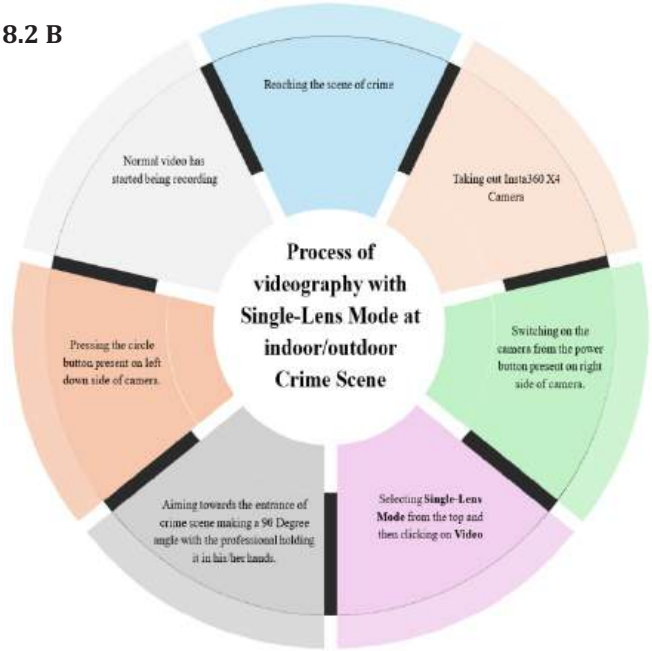
Figure 7: Showing Photo Taken with DSLRs Cameras-which Requires Capturing of Multiple Photos.

Figure 8: Showing Photo Taken with Single-Lens Mode of 360 Degree Camera.

8.2 A



8.2 B



the scene of crime, different modes are given below (14).

8.1 Photography

A. Photography with 360 mode

B. Photography with Single mode

8.2 Videography

A. Videography with 360 mode

B. Videography with Single mode

Result (8.1A)

Figure 6 showing an omnidirectional photo would be capturing one single photo with a field of view of 360 degrees. Whereas DSLRs, like Nikons **(Figure 7)**, capture multiple photos at different angles of indoor/outdoor crime scenes. Hence, omnidirectional cameras can be much better than DSLR cameras.

Result (8.1B) Thereby catering our need of a mid-range and close-up photography (as discussed previously) and ultimately eliminating the requirement of carrying DSLRs along with 360 Degree Cameras.

Results (8.2A): An omnidirectional video would be capturing one single video with a field of view of 360 degrees. Thereby allowing us to travel or visit the crime scene virtually (by panning up, down, left, or right) while sitting in the comfort of our place. The 360-degree video can be played in any already available VR media player app on the Google Play Store/App Store and then put in a VR handset, ultimately converting the physical crime scene into a virtual crime scene.

Result (8.2B): Thereby eliminating the requirement of carrying DSLRs along with 360 Degree Cameras.

Limitations of Using a 360° Camera at a Crime Scene:

360° imaging is a valuable tool for forensic documentation, but it has several important limitations that must be

recognized when using it in investigations. Although it can provide an overall view of a scene and help preserve spatial context. Its effectiveness is also influenced by lighting conditions, since poor illumination can reduce image quality and obscure critical features that may be important in a case.

In addition, high-resolution 360° images and videos create large files that require significant storage space, backup systems, and careful digital management. Investigators may also need specialized software and compatible hardware to view, process, and analyze the imagery properly, which adds to the complexity of its use. There is also the risk of stitching errors, technical malfunctions, battery failure, and software problems, any of which can interfere with scene documentation.

DISCUSSION AND CONCLUSION

The use of a 360-degree camera in crime scene documentation can be proven as a new innovation or development in the field of forensic science. It has numerous benefits over already existing practices using DSLRs: handy equipment, lightweight, easy user interface, compatibility with Android, iOS, and Windows, battery backup approx. 135 mins, reasonable cost, multipurpose camera with both modes-360 & single lens, etc.

With both 360-degree mode and single-lens mode, the omnidirectional camera is catering to our need for all 3 types of photography being carried out in the scene of the crime. Overall photography is being done by 360-degree mode, and mid-range and close-up photography is being done by single-lens mode.

Videography of a crime scene can even be done using this camera in both modes, viz., 360-degree and/or single-lens mode. Ultimately, converting a still crime scene to a virtual moving crime scene and allowing us to visit the actual crime scene by sitting at our place of comfort. It also can be helpful for personnel associated with crime scenes, such as police officers, lawyers, judges, investigation officers, etc., to become virtually present at the scene of the crime.

The output photo/video can be even viewed in a virtual reality headset, which would be making the viewer feel as if he/she were present at the scene of the crime. The viewer can even move his/her head in up, down, left, and right directions so as to have an idea of the crime scene in 360 rotations.

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A CASE REPORT

Fatal Tyre Blast - A Case Report

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ABSTRACT

Explosions and blasts can occur in various forms, and tyre blasts represent a type of mechanical explosion. Injuries from tyre explosions may result from the direct impact of flying fragments, barotrauma, tertiary injury, or a combination of these mechanisms. During servicing, tyre explosions can cause injuries directly from metal rims or from high-pressure barotrauma, sometimes both. Such incidents have important workplace safety implications. Despite their significance, there is limited forensic literature on tyre blast injuries. Fatalities due to tyre bursts, however, have been reported. We present a case involving a 35-year-old truck driver who suffered fatal injuries when a tyre exploded during servicing.

At the time of the incident, the truck was elevated on a jack for replacement of the inner rear tyre, with the outer rear tyre already removed. Slight displacement of the jack caused the partially inflated inner tyre to explode upon contacting the ground, propelling the victim approximately 10 feet and causing multiple injuries, including a fatal head injury. The victim was declared dead on arrival at the emergency department, followed by a medico-legal autopsy, which concluded that death resulted from the combined effects of direct impact from the metal rim and intracranial hemorrhage due to barotrauma/shock wave.

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INTRODUCTION

Explosions can occur in different forms, and tyre blasts are classified as mechanical explosions. Injuries from such events may result from direct impacts of flying debris, barotrauma due to high-pressure air, tertiary injury, or a combination of these factors.[1-2]

Injuries are most severe during servicing of large tyres[3-4] and often occur at service stations or roadside locations.[5] Factors influencing injury severity include tyre size, air pressure, and proximity of the victim to the tyre.[4]

A literature review analysing 763 cases of tyre blast injuries revealed that most victims were young male mechanics, with incidents frequently occurring during tyre inflation or servicing. The head and face were the most commonly affected regions (48%), followed by the upper limbs (20%). Multi-trauma occurred in about 25% of cases. Overall mortality was high (19%), primarily due to head injuries.[6]

Despite their relevance, forensic literature on tyre blast injuries remains scarce. We report a fatal case involving a truck driver injured by a tyre explosion during servicing.

Case Report: A 35-year-old truck driver suffered fatal injuries when a tyre exploded during servicing. The truck was supported by a jack for replacement of the inner rear tyre, with the outer rear tyre already removed.

Slight displacement of the jack caused the partially inflated inner tyre to explode upon contacting the ground, propelling the victim approximately 10 feet. The victim sustained multiple injuries across the body, with a fatal injury to the head. He was declared dead upon arrival at the emergency department, and a medico-legal autopsy was performed.

Autopsy Findings: Postmortem staining was present on the back, except at points of contact, and was fixed. The corneas were hazy, and pupils were dilated. Dried, clotted blood was noted around the nostrils and right ear. The face

and right hand were bloodstained, with black grease-like material on both hands. The deceased wore a half-sleeved t-shirt, which was also bloodstained.

Injuries:

- A vertical laceration (15 cm × 2.5 cm) extended from the mid-upper lip to 2 cm left of the glabella. Dissection revealed ecchymosed underlying soft tissues. Skull fractures involved the maxilla, nasal bones, left zygomatic bone, and left anterior frontal bone, with blood infiltrating the bony trabeculae.

  Brain parenchyma in the frontal region was shattered, with epidural, subdural, and subarachnoid hemorrhage in both cerebral and cerebellar hemispheres.
- Multiple abrasions, contusions and lacerations were also there all over the body at places especially over the bony prominences. All viscera were pale. Stomach mucosa was pale with mucoid content. Cause of death was craniocerebral injury, with death occurring immediately after the incident.

DISCUSSION

Tyre blasts are mechanical explosions, with injuries resulting from flying debris, barotrauma, or tertiary injury or combination of mechanisms.[1] Fatalities from tyre explosions, while uncommon, are documented in forensic literature.

- Gilbert (1995)[7]: An army mechanic suffered mandibular fracture and atlanto-occipital dislocation from a bursting military truck inner tube, resulting in instantaneous death (death due to direct effects of flying missile).
- Rautji et al. (2003)[8]: A fatal incident occurred during fitting of a crane tyre locking rim. The victim was struck by the iron rim and thrown against a wall, sustaining skull and brain injuries (death due to direct effects of flying missile with associated tertiary injury).
- Murty (2009)[2]: A bus tyre exploded at a bus stand, killing a bystander via barotrauma and tertiary injury (death due to barotrauma with associated tertiary injury)
- Kumral et al. (2014)[6]: Tyre explosion during inflation caused death from internal hemorrhage due to aortic rupture and internal organ lacerations (death due to barotrauma and direct effects of flying missile).

  In the present case, the truck driver's fatal injuries resulted from the combined effect of the metal rim impact and barotrauma.

CONCLUSION

Tyre blasts can cause fatal injuries through direct impact of flying missile, barotrauma, tertiary injury, or a combination. In this case, the fatal head injury was caused by the metal rim, with a contributory component of intracranial hemorrhage from barotrauma/shock wave.

Meticulous post-mortem examination, including witness statements, police reports, and history from relatives, is essential for accurate determination of cause and manner of death.

HIGHLIGHTS

- Tyre bursts are common, particularly when tyres are partially filled, but literature is limited.
- This report details the mechanisms and types of injuries in tyre blast cases.
- The manuscript serves as a reference for medico-legal experts interpreting injuries from tyre explosions.

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SHORT COMMUNICATION

Simultaneous Thin-Layer Chromatographic Detection of Chlorpyrifos and Cypermethrin in a Commercial Insecticide Formulation

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ABSTRACT

Introduction: Chlorpyrifos and cypermethrin are commonly used insecticides and may be encountered in agricultural formulations as well as in forensic and toxicological investigations. A simple screening method for their simultaneous detection in a commercial formulation may be useful in laboratories with limited analytical resources.

Aim: To evaluate a thin-layer chromatographic (TLC) system for simultaneous detection of chlorpyrifos and cypermethrin in Sultan 505® insecticide.

Materials and Method: Sultan 505®, a commercial emulsifiable concentrate formulation containing chlorpyrifos and cypermethrin, was serially diluted in water and directly applied to silica gel TLC plates along with analytical standards of chlorpyrifos and cypermethrin. Chromatographic separation was carried out using cyclohexane: acetone (8:2, v/v) as the mobile phase. The developed plates were air-dried and visualised under short-wave ultraviolet light (254 nm). TLC analysis was performed in triplicate, and the observed Rf values were recorded.

Results: The selected mobile phase enabled separation of spots corresponding to chlorpyrifos and cypermethrin in the diluted formulation. In serially diluted Sultan 505® samples, the chlorpyrifos-associated spot remained visible up to the 1/64 dilution, whereas the cypermethrin-associated spot remained visible up to the 1/32 dilution. An additional spot was also observed in lower dilutions of the formulation. The reported Rf values represent the mean ± standard deviation of triplicate runs.

Conclusion: Cyclohexane: Acetone (8:2, v/v) provided a simple TLC system for simultaneous detection of chlorpyrifos and cypermethrin in a commercial insecticide formulation. The method may serve as a rapid and economical preliminary screening approach in forensic and toxicological laboratories.

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INTRODUCTION

Pesticides are widely used in agriculture and domestic pest control, and exposure to these compounds remains a significant toxicological and forensic concern. Among them, chlorpyrifos, an organophosphorus insecticide, and cypermethrin, a synthetic pyrethroid, are commonly employed for the control of a broad range of insect pests.[1–3] Commercial formulations containing combinations of such insecticides are extensively used in agricultural practice, and their easy availability has also led to their implication in accidental, suicidal, and occasionally homicidal poisoning cases.[3–6] In forensic and toxicological investigations, rapid preliminary identification of pesticide formulations can therefore be of practical importance.

Chlorpyrifos and cypermethrin have been analysed by different chromatographic techniques, including thin-layer chromatography (TLC), high-performance thin-layer chromatography, and instrumental methods.[1, 7–10] Although instrumental techniques offer higher sensitivity and confirmatory capability, TLC remains attractive as a simple, rapid, and economical screening tool, particularly in laboratories with limited analytical resources.[11–13] Previously reported TLC methods have described the detection of chlorpyrifos in biological or residue samples,[1,8] the analysis

of pyrethroid formulations,[7,10] and the separation of pyrethroid insecticides using different solvent systems.[9] However, a simple TLC procedure for the simultaneous screening of chlorpyrifos and cypermethrin in a commercial insecticide formulation is of practical relevance in routine forensic and toxicological examinations. Sultan 505® is a commercially available emulsifiable concentrate insecticide formulation containing chlorpyrifos and cypermethrin. In the present study, a TLC method using cyclohexane: acetone (8:2, v/v) as the mobile phase is described for the simultaneous detection of chlorpyrifos and cypermethrin in Sultan 505®. The aim of the present study was to evaluate whether a simple TLC system could provide satisfactory simultaneous separation and preliminary detection of chlorpyrifos and cypermethrin in the diluted commercial formulation.

MATERIALS AND METHODS

Study Design

This study was designed as a laboratory-based analytical short communication to evaluate a thin-layer chromatographic system for simultaneous detection of chlorpyrifos and cypermethrin in a commercial insecticide formulation.

Place of Study

The study was carried out in the research laboratory of Karunya Institute of Technology and Sciences, Coimbatore, India.

Study Period

The experimental work for the present study was carried out from January 2023 to June 2023.

Ethical Considerations

The present work involved laboratory analysis of a commercially available insecticide formulation and analytical standards and did not involve human participants, biological samples, cadavers, or animals. Therefore, institutional ethical approval was not applicable to the present laboratory-based analytical study.

Chemicals and Reagents

Sultan 505® insecticide, a commercial emulsifiable concentrate formulation labelled to contain chlorpyrifos 50% w/w + cypermethrin 5% w/w EC, was obtained from a local agrochemical supplier. Analytical-grade chlorpyrifos and cypermethrin standards were procured from Supelco®. Cyclohexane, chloroform, and acetone were purchased from HiMedia, Mumbai, India. Ethyl acetate was used for preparation of the standard solutions. Pre-coated aluminium-backed silica gel TLC plates (Merck) were used for chromatographic analysis.

Preparation of Standard and Test Samples

Standard solutions of chlorpyrifos and cypermethrin were prepared in ethyl acetate. For analysis of the commercial formulation, serial dilutions of Sultan 505® were prepared in water. Briefly, 1mL of the formulation was mixed with 1mL of water to obtain the first dilution (1/2), and subsequent serial dilutions were prepared by transferring 1mL of the preceding dilution into 1mL of water to obtain 1/4, 1/8, 1/16, 1/32, 1/64, 1/128, and 1/256 dilutions. Since Sultan 505® is an emulsifiable concentrate formulation intended for dilution in water before field application, the formulation was diluted directly in water to simulate field-use conditions. The diluted samples were directly applied to the TLC plate without any additional extraction step.

Thin-Layer Chromatographic Conditions

Thin-layer chromatography was carried out on silica gel TLC plates (2×4cm). A small aliquot of each standard and test sample was applied as a spot using a glass capillary. The chromatographic chamber was pre-saturated with the mobile phase for 15–20 min prior to development. Cyclohexane: acetone (8:2, v/v) was used as the mobile phase. The plates were developed to a solvent front distance of approximately 2.6cm, air-dried, and examined under short-wave ultraviolet light (254nm). No spraying reagent was used for visualisation of the spots.

Identification of Spots and Repeatability

The spots obtained from the diluted Sultan 505® samples were compared with those of the chlorpyrifos and cypermethrin standards run under the same chromatographic conditions. Retention factor (Rf) values were calculated for the visible spots. The TLC analysis was performed in triplicate, and the reported Rf values represent the mean ± standard deviation of the three runs.

Statistical Analysis

As the study was intended as a qualitative TLC screening evaluation, the observations are primarily descriptive. Rf values obtained in triplicate were summarized as mean ± standard deviation.

RESULTS

The mobile phase consisting of cyclohexane: acetone (8:2, v/v) enabled separation of the spots corresponding to chlorpyrifos and cypermethrin in Sultan 505® insecticide under the experimental conditions used. Comparison of the spots obtained from the diluted formulation with those of the analytical standards showed that the chlorpyrifos-associated and cypermethrin-associated spots were observed at Rf

values broadly corresponding to the respective standards. An additional spot was also observed in the lower dilutions of the formulation. The TLC analysis was performed in triplicate, and the Rf values reported represent the mean ± standard deviation of the three runs.

In the serially diluted Sultan 505® samples, the chlorpyrifos-associated spot remained visible up to the 1/64 dilution, whereas the cypermethrin-associated spot remained visible up to the 1/32 dilution. The additional spot was observed up to the 1/16 dilution and was not visible in higher dilutions.

Under the chromatographic conditions employed, the chlorpyrifos-associated spot showed mean Rf values in the range of approximately 0.74–0.76 in the visible Sultan 505® dilutions, while the cypermethrin-associated spot showed mean Rf values in the range of approximately 0.66–0.67. The additional spot observed in the lower dilutions showed greater variation in Rf values across runs.

DISCUSSION

Thin-layer chromatography continues to be used as a rapid and economical analytical technique for preliminary screening of pesticides in forensic, toxicological, and environmental investigations.[11–13] In the present study, cyclohexane: acetone (8:2, v/v) provided satisfactory separation of chlorpyrifos and cypermethrin in Sultan 505® insecticide under the experimental conditions employed. The spots corresponding to chlorpyrifos and cypermethrin were observed at Rf values consistent with the respective standards, while an additional spot was also detected in the formulation at lower dilutions.

Previous studies have reported different TLC solvent systems for the analysis of chlorpyrifos, cypermethrin, or pyrethroid insecticides in different matrices. Chauhan et al.[1] reported a TLC-FID method for residual chlorpyrifos analysis, while Yadav[8] described TLC detection of chlorpyrifos in human blood. TLC and HPTLC-based approaches have also been used for the analysis of pyrethroid formulations and related compounds.[7,9-10] In the present work, several solvent systems were examined during method development on the basis of available literature and preliminary trials. This included cyclohexane: diethyl ether: acetone (7.5:1.5:0.5), ethyl acetate: chloroform (4:2), diethyl ether: acetone (6:3), cyclohexane: acetone (9:1), and hexane: diethyl ether: acetone (7.5:2:0.5), along with ratio variations of these combinations. However, these systems did not provide satisfactory separation of the spots corresponding to chlorpyrifos and cypermethrin in the diluted Sultan 505® formulation under the present experimental conditions. Among the solvent systems examined, cyclohexane: acetone (8:2, v/v) produced the most satisfactory separation and was therefore selected for further analysis.

A notable observation in the present study was that the chlorpyrifos-associated spot remained detectable up to the 1/64 dilution, whereas the cypermethrin-associated spot remained detectable up to the 1/32 dilution under the adopted TLC conditions. The reason for this difference cannot be conclusively established from the present data alone; however, it may reflect differences in chromatographic behavior, visibility of the developed spots under short-wave UV, or formulation-related factors affecting spot intensity in the diluted sample. In addition, an extra spot was consistently observed in the lower dilutions of the formulation, although its Rf values showed greater variation across the triplicate runs than those of the chlorpyrifos- and cypermethrin-associated spots. Since this spot did not correspond to the chlorpyrifos or cypermethrin standards under the conditions used, it may represent another component of the commercial formulation; however, its identity was not investigated in the

Table 1. Mean Rf Values of the Spots Observed in Serially Diluted Sultan 505® Insecticide and Corresponding Analytical Standards (mean ± SD, n = 3)

Sultan 505® Dilution	Spot Corresponding to Chlorpyrifos (Rf)	Spot Corresponding to Cypermethrin (Rf)	Additional Spot (Rf)	Chlorpyrifos Standard (Rf)	Cypermethrin Standard (Rf)
1/2	0.76 ± 0.02	0.67 ± 0.01	0.21 ± 0.06	0.76 ± 0.02	0.67 ± 0.01
1/4	0.74 ± 0.02	0.66 ± 0.01	0.30 ± 0.01	0.74 ± 0.02	0.66 ± 0.01
1/8	0.75 ± 0.03	0.66 ± 0.00	0.28 ± 0.01	0.75 ± 0.03	0.66 ± 0.00
1/16	0.74 ± 0.02	0.66 ± 0.01	0.21 ± 0.05	0.74 ± 0.02	0.66 ± 0.01
1/32	0.74 ± 0.03	0.66 ± 0.00	–	0.74 ± 0.03	0.66 ± 0.00
1/64	0.74 ± 0.03	–	–	0.74 ± 0.03	0.65 ± 0.02
1/128	–	–	–	0.76 ± 0.01	0.65 ± 0.02
1/256	–	–	–	0.73 ± 0.03	0.65 ± 0.00

present work.

The present study reports a simple TLC system for simultaneous screening of chlorpyrifos and cypermethrin in a commercial pesticide formulation. The method may be of practical value in laboratories where rapid preliminary examination of pesticide formulations is required and access to more advanced instrumentation is limited. At the same time, certain limitations of the study should be acknowledged. The work was confined to a single commercial formulation, the additional spot observed in the formulation was not characterized, and the method was evaluated as a qualitative screening approach rather than a confirmatory or quantitative analytical method. Accordingly, further studies involving additional formulations, biological or environmental matrices, and confirmatory analytical techniques would be useful for extending the applicability of the method.

LIMITATIONS

The present solvent system was used for the commercial formulation containing chlorpyrifos and cypermethrin. Therefore, the use of the developed solvent system for the detection of other pesticides remains to be established.

The migration of spots, development and visualisation may be affected due to the presence of formulation additives in the commercial sample.

CONCLUSIONS

The present study demonstrates that cyclohexane: acetone (8:2, v/v) can be used as a simple TLC mobile phase for the simultaneous detection of chlorpyrifos and cypermethrin in Sultan 505® insecticide. Under the experimental conditions employed, spots corresponding to chlorpyrifos and cypermethrin were observed at Rf values consistent with the corresponding standards and remained detectable in serially diluted samples up to the 1/64 and 1/32 dilutions, respectively. An additional spot was also observed in lower dilutions of the formulation. Although the present work is limited to qualitative screening of a commercial formulation, the method offers a simple, rapid, and economical approach for preliminary examination of this pesticide combination and may be useful in forensic and toxicological laboratories where access to advanced instrumentation is limited.

Conflict of Interest/Source of Funding: Nil

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Format of Application for Membership

To

The General Secretary
Punjab Academy of Forensic Medicine & Toxicology (PAFMAT)

Dear Sir,

I wish to become a Life Member / Annual Member of PAFMAT. I am furnishing the required particulars below with a request to enrol me in the academy. The fee of Rs. 2500 / Rs. ---- for Life Membership / Annul Membership is enclosed as a Demand Draft with No_____ Of _____Bank, in the name of PAFMAT, SBOP Chandigarh along with my two passport size photographs.
I have gone / will go through the rules and regulations of the academy and I agree to abide by the same.

PARTICULARS

1. Full Name (in block letters)
2. Father's / Husband's name
3. Date of Birth
4. Qualification (with name of university & date of passing)
5. Official Designation & Place of Posting
6. Permanent Address
7. Address for Correspondence (subsequent change of address to be intimated)
8. Phone No. & Email

Place Yours Sincerely

Date

(Signature)

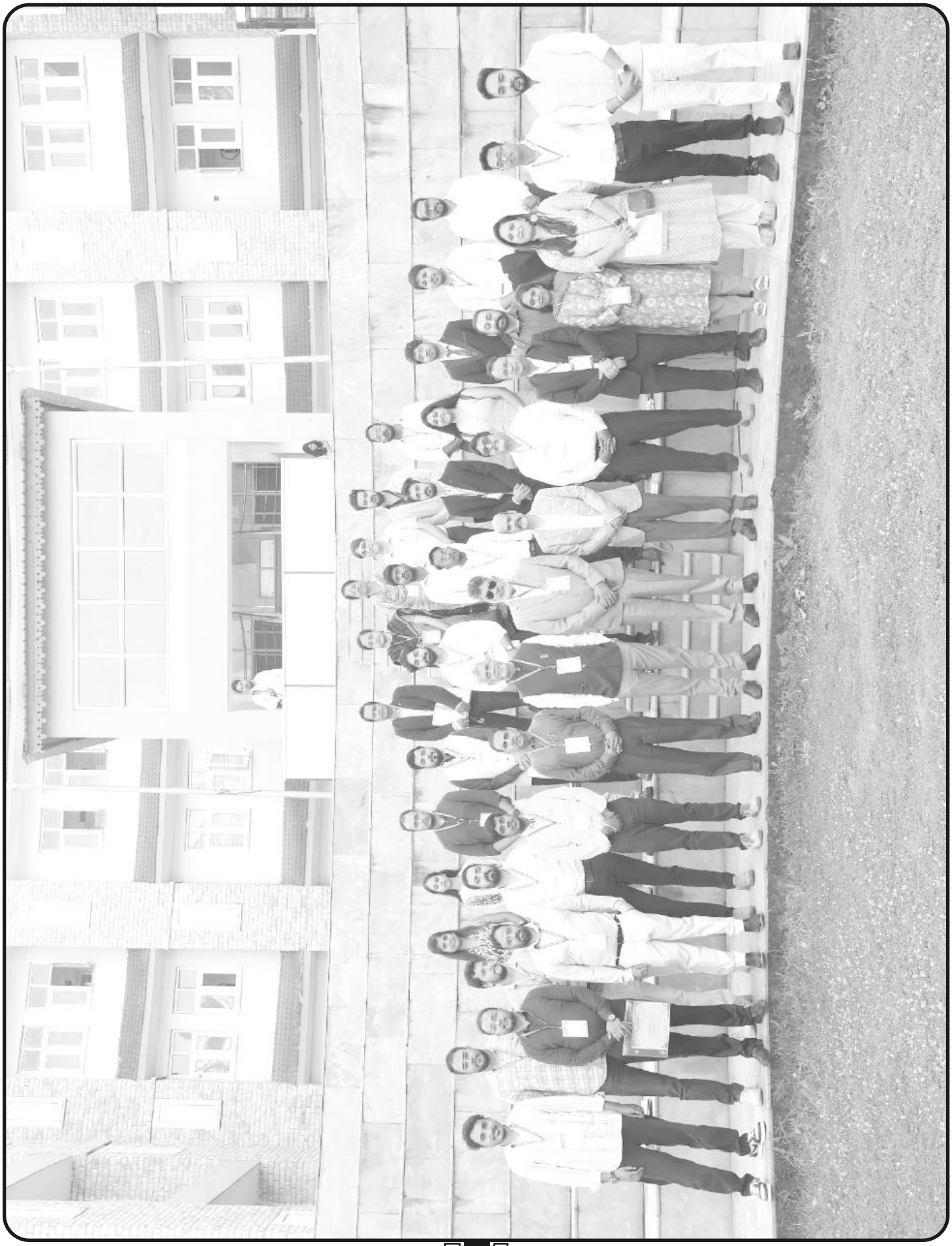
FOR USE OF PAFMAT

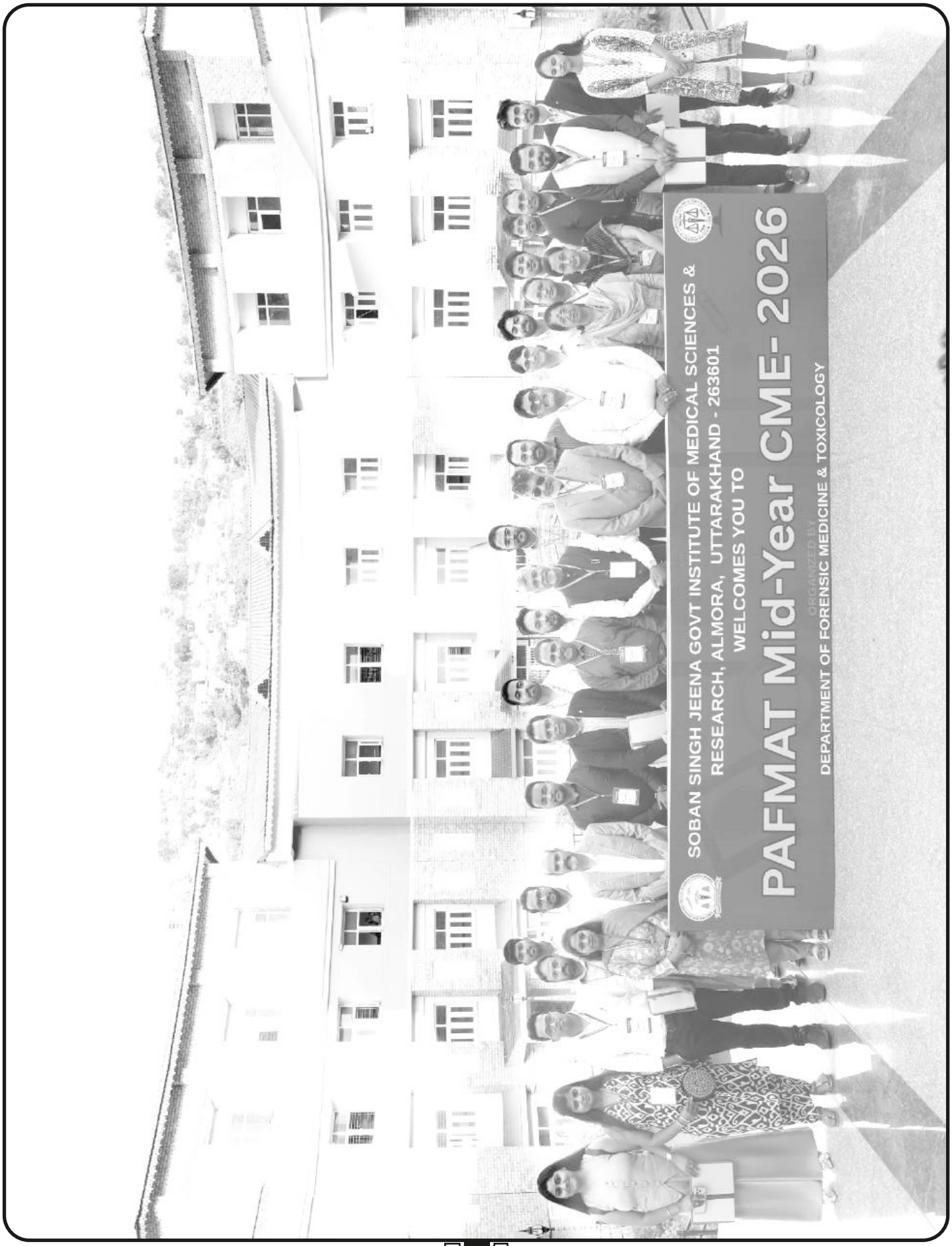
Membership Accepted with Life / Annual membership No. / PAFMAT / /

Dated

Treasurer **Secretary** **President**

Note: Payment can be made by NEFT in the account of academy (A/c No. 2082101026802, IFSC Code: CNRB0002082, Canara Bank, Gopal Nagar, Amritsar) after telephonic talk with President/Secretary/Treasurer. Scanned copy of the filled form can be send by E-mail to secretary.

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