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Editor-in-Chief: Dr Ravindra B Deokar

MD (FM), LLB, LLM(HR), ACME, PGDFAO, FAIMER, EPGDHA (TISS), MBA (HAHCM)

E-mail id: Jiafmeditor@gmail.com (M): +91-9423016325

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Recent Advances in Forensic Toxicology: Metabolomics and Toxicogenomics

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Ravindra B Deokar[1], Rajesh C Dere[2] and Harshal Thube[3]

Introduction

A field of biology dealing with the study of all organisms' DNA is termed genomics, which includes identification of its functional elements, characterization, and its interaction with the effect of environment.[1,2] Forensic toxicology has undergone transformative advancements, integrating advanced technologies that significantly enhance the precision, efficiency to aid in medico-legal investigations and justice in the court of law.[3,4] Recently, genomics applications revolutionized the field of forensic toxicology and crime investigations.[5] There is a revolutionary impact in forensic toxicology due to metabolomics and toxicogenomics, enabling experts to detect and analyze toxic substances more accurately.

Metabolomics

Metabolomics is the comprehensive study of the complete set of small molecules (metabolites) involved in various metabolic processes in a biological system, such as a cell, tissue, or organism. The comprehensive study involves the identification, quantification, and analysis of such small molecules (metabolites) for understanding the physiological and biochemical state of the biological system. It gives more accurate and better insight into the biochemical activity.[4]

Metabolomics in Context to Toxicology

Metabolomics can be used in forensic toxicology in various ways[5]:

1. Toxicity mechanism understanding: Metabolomics facilitates elucidating the molecular mechanisms of the toxic effects. It helps to know the underlying changes in metabolic pathways and networks.
2. Post-mortem analysis: It will facilitate to identification of potential toxic substances and thus, be helpful to determine the cause of death.
3. Toxicological analysis: It will be helpful to identify and quantify the toxic substances found in biological samples.
4. Biomarker's identification: Discovering novel biomarkers for exposure to toxic substances can be possible through metabolomics. It will facilitate disease diagnosis and treatment efficacy monitoring purposes.
5. Assessment of exposure level: It will be helpful to assess the level of exposure to environmental toxicants. It helps to understand the health effects and their consequences.
6. Toxicity prediction: It is helpful to develop predictive models for toxicity depending on metabolite profiles.

Toxicogenomics

It is a branch of pharmacology and an interdisciplinary field that deals with the collection, interpretation, and storage of information on the gene and protein activity consequent to exposure to toxic substances within a particular cell or tissue of an organism. It combines forensic toxicology with genomics, bioinformatics, and high molecular profiling technologies such as metabolomics, proteomics, and transcriptomics. It studies the response of genes to environmental toxins and the toxic effects of drugs. It deals with understanding the variable individualistic response to toxic substances, considering genetic variability.[6]

[1]Department of Forensic Medicine and Toxicology, Lokmanya Tilak Municipal Medical College and LTMG Hospital, Mumbai, Maharashtra, India
[2]Department of Forensic Medicine and Toxicology, Topiwala National Medical College and BYL Nair Hospital, Mumbai, Maharashtra, India
[3]Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, Nagpur, Maharashtra, India

Corresponding author:
Ravindra B Deokar, Department of Forensic Medicine and Toxicology, Lokmanya Tilak Municipal Medical College and LTMG Hospital, Sion, Mumbai, Maharashtra 400022, India.
E-mail: Ravideo803@gmail.com

Toxicogenomics in Forensic Toxicology[7]

1. Gene–environment Interactions: It refers to the complex interplay between environmental factors affecting traits, diseases, with the genetic makeup of the individual.
2. Drug development: It facilitates the identification of potential toxic effects of new compounds.
3. Environmental health: It understands the response of environmental toxins and facilitates understanding how genetic factors influence susceptibility to environmental pollutants.
4. Personalized medicine: It facilitates giving specific individual treatment based on an individual's genetic profile so that adverse effects can be minimized.
5. Risk assessment: It helps to assess the environmental toxin's risk by identifying influencing factors for genetic susceptibility.
6. Personalized toxicity assessment: It helps to understand personal variability in response to environmental toxicants, which facilitates personalized risk assessments.
7. Toxicogenomics: It integrates metabolomics, genomics, proteomics, and transcriptomics to study the adverse effects of xenobiotics and toxic chemicals.

Challenges

1. Ethical concerns: It involves the sensitive genetic information handling which may raise great concerns of privacy and confidentiality.
2. Data interpretation: Experienced experts are needed to analyze and interpret the large-scale genomic data. It is a complex process, and personal bias may be high initially.
3. Regulatory frameworks: There is a need for national and international policies and standardized norms for toxicogenomics data interpretation, use, and implementation.

Conclusion

Metabolomics and toxicogenomics have the potential to revolutionize forensic toxicology and personalized medicine. It stands at the forefront in biomedical research, providing a powerful lens to predict the individualistic response and facilitate disease prevention and personalized treatment. It will provide insights into genetic susceptibility to environmental toxins and drugs. The recent advancements and transformations in forensic toxicology will facilitate more accurate investigations, causing improved public health outcomes and aiding justice in the court of law.

Declaration of Conflicting Interests

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ORCID iDs

Ravindra B Deokar https://orcid.org/0000-0003-1539-1035
Harshal Thube https://orcid.org/0000-0002-5101-183X

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Original Research Article

PMCT Evaluation of Medial Clavicular Epiphysis Fusion for Age Estimation in the North Indian Population

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Balaji D[1], Zahid Ali CH[1], Gokul G[1], Abilash Srinivasa Murthy[1], Raveena Divya[1], Swati Tyagi[1], Abhishek Yadav[1] and Sudhir K Gupta[1]

Abstract

Age estimation is a critical component in forensic investigations. The fusion stages of bones, particularly the medial clavicular epiphysis, offer reliable markers for estimating age, especially in individuals below 25 years. Despite the available data in the literature, population-specific standards should be developed and validated using the contemporary geographical population. This study aimed to investigate the fusion patterns of the medial clavicular epiphysis in the North Indian population using post-mortem computed tomography (PMCT) scans. This study comprised 500 samples (327 males and 173 females) with ages below 25 years. Using PMCT scans, the ossification patterns of the medial clavicular epiphysis were classified into four stages: Stage 0 (absence of ossification center), Stage 1 (appearance without fusion), Stage 2 (partial fusion), and Stage 3 (complete fusion). This study revealed a significant correlation between fusion stages and chronological age, with Spearman's correlation coefficients of $\rho = 0.819$ for males and $\rho = 0.797$ for females, and statistically significant gender differences. Linear regression models were developed for both sexes, predicting age with mean absolute errors (MAEs) of 1.36 for males and 1.88 for females. Validation of these models demonstrated their utility in estimating age with high accuracy, though the models tended to slightly underestimate age, especially in females. This study confirms that medial clavicular epiphyseal fusion patterns are reliable indicators for age estimation in the North Indian population. The findings emphasize the importance of population-specific criteria in forensic age estimation, providing a precise tool for forensic practice.

Keywords

Age estimation, medial clavicular epiphysis, postmortem computed tomography (PMCT), virtual anthropology

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Introduction

Age estimation is essential in various fields, including age verification for legal compliance, identifying missing persons in law enforcement, immigration purposes, educational placement, fair sports competition, demographic research, and social service eligibility. It is a critical component of forensic investigations, particularly in establishing the identity of individuals. Forensic anthropology and radiology have made significant strides in utilizing the fusion stages of various bones as reliable indicators for age estimation.[1,2] Among the various bones of the human body, the clavicle has gained importance due to its relatively consistent fusion patterns, making it a useful indicator for age estimation, especially in young individuals.[3] The clavicle, commonly known as the collarbone, is a long, slender bone with two ends, the medial and lateral ends articulating with the sternum and acromion process of the scapula, respectively. The fusion of the medial clavicular epiphysis, where the epiphysis fuses with the diaphysis, provides crucial insights into an individual's age.[4] This progressive fusion process, which transitions from the absence of an ossification center to complete fusion, follows a predictable sequence that can be effectively assessed through radiological methods such as post-mortem computed tomography (PMCT) scans.[5,6] Understanding the fusion patterns of the medial clavicular

[1]Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, New Delhi, India

Corresponding author:
Gokul G, Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, New Delhi 110029, India.
E-mail: drgokug@gmail.com

epiphysis within specific populations is essential for precise age estimation in forensic contexts. In the context of the Indian population, characterized by its unique genetic and environmental factors, the development of a reliable age estimation method holds paramount importance. This study aims to investigate the fusion stages of the medial clavicular epiphysis in individuals aged 0–25 years within this population. By employing a brief four-stage classification system, this study seeks to evaluate and validate the medial clavicular epiphysis as a tool for accurately estimating the age of individuals below 25 years.

Methods

This retrospective study was performed using PMCT scans of cases brought for medicolegal autopsies at the Department of Forensic Medicine and Toxicology of our institute. This retrospective study comprised 500 samples (327 males and 173 females) with an age below 25 years belonging to the North Indian population. All cases brought for autopsy with a valid proof of age were included in this study. Cases with thoracic trauma, thoracic surgeries, developmental disorders, malignancies involving bone or bony metastases, and advanced decomposition were excluded from the study. The ossification patterns of the medial clavicular epiphysis were assessed. This study employed the following four-stage classification system to evaluate the PMCT scans of the clavicle (Figure 1).

Stage 0: The ossification center has not appeared.
Stage 1: Ossification center appeared, but fusion has not started.
Stage 2: Partial fusion of the ossification center.
Stage 3: Complete fusion of the epiphyseal ossification center with diaphysis. The epiphyseal scar might still be appreciable.

This system was employed in view of the image resolution generated by the specified technical parameters of the computed tomography (CT) scan machine. Non-contrast PMCT was done using a 16-slice multi-slice CT spiral scanner, Aquilion Lightning TSX-035A CT (Toshiba America Medical Systems, Tustin, CA). The scanner was operated at 120 kV with automatic mA settings. The bodies were scanned in a supine position with arms placed beside the body. The maximum dose length product (DLP), computed tomography dose index (CTDI) of the cases extended up to 1342.37 mGy. cm and 7.96 mGy, respectively. The scan covered the upper body in a single series, starting from the neck to the mid-chest (scan length varied in different individuals). The machine had a collimation of 16 × 1 mm, and image reconstruction employed the whole-body filter (FC18 Kernel) with a 1 mm slice thickness. The raw data were subsequently reconstructed into multiplanar and volume-rendered images, which were examined using the bone window of Vitrea 7.10 software. The collected data were statistically processed using STATA statistical software version 11 (StataCorp LLC, Lakeway Drive, College Station, Texas, USA).

Results

A total of 500 cases were evaluated, comprising 327 males (65.4%) and 173 females (34.6%). It is noteworthy that there was variability in the number of participants across different age groups. The majority of cases were in the older age categories, with the highest number of participants in both sexes falling within the 18–25 years age group. Figure 2 presents the number of male and female participants in each age category, providing insights into the demographic composition of our sample population.

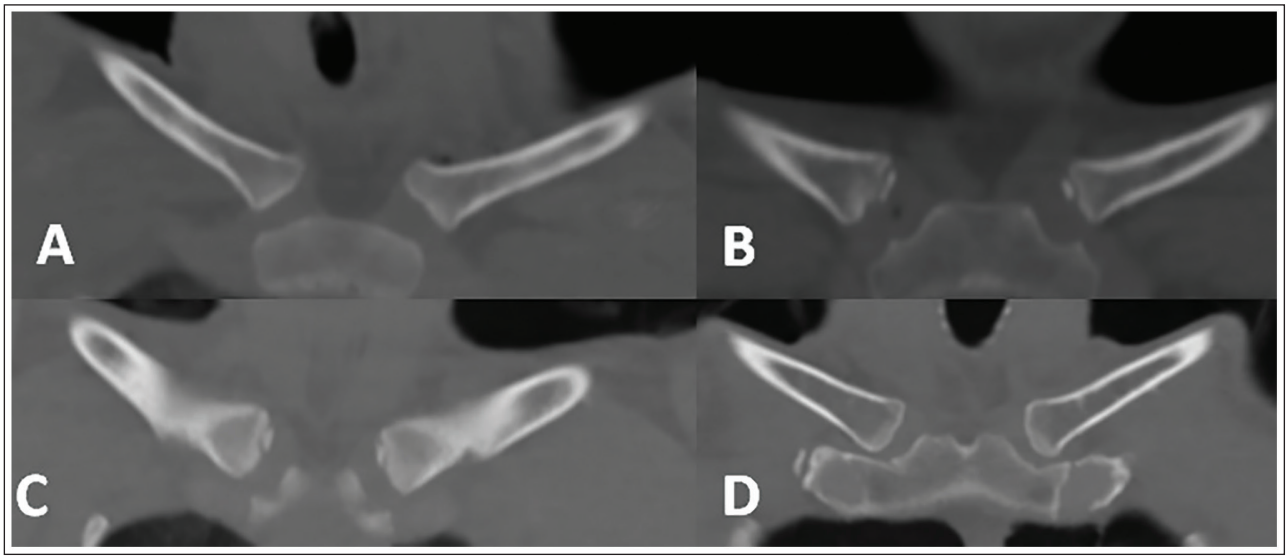

Figure 1. PMCT Scans Showing Stages of Fusion of Medial Clavicular Epiphysis: A, Ossification Center Not Appeared; B, Ossification Center Appeared, Not Fused; C, Ossification Center Partially Fused; D, Ossification Center Completely Fused.

For Males

The mean age of the male population was 19.264 years (*SE* = 0.245). The distribution of ages exhibited a median of 21 years and a mode of 24 years. The descriptive statistics for male participants across the four fusion stages are detailed in Table 1. The mean age progressed predictably from Stage 0 ($\bar{x}$ = 10.98 years, *SD* = 4.97) to Stage 3 ($\bar{x}$ = 23.08 years, *SD* = 1.58). The widest age range (0–20 years) and highest variability (*SD* = 4.97) were observed in Stage 0. Conversely, the fusion stages, particularly Stage 2 ($\bar{x}$ = 20.48 years, *SD* = 1.36) and Stage 3 ($\bar{x}$ = 23.08 years, *SD* = 1.58), exhibited lower variability, reflecting a narrower age window for active fusion and completion of growth. The distribution of cases per stage is visually represented in Figure 3.

For Females

Table 1 presents the descriptive statistics for the female cohort. The mean age similarly showed a progression, beginning at Stage 0 ($\bar{x}$ = 8.38 years, *SD* = 5.83) and culminating at Stage 3 ($\bar{x}$ = 22.76 years, *SD* = 1.66). Stage 0 displayed the greatest age range (0–17 years) and the highest standard deviation (*SD* = 5.83). The fusion stages showed reduced variability, especially Stage 2 ($\bar{x}$ = 20.26 years, *SD* = 2.10) and Stage 3 ($\bar{x}$ = 22.76 years, *SD* = 1.66), indicating a more consistent age of maturation. The age distribution across stages is visualized in Figure 4.

Interobserver reliability was calculated using Cohen's κ, which amounted to 0.82, indicating near-perfect agreement. Spearman's correlation (ρ) was calculated between the fusion scores and the chronological age. Statistically significant correlation ($p < .001$) was observed in both sexes, with ρ = 0.819 in males and ρ = 0.797 in females. Using the Mann-Whitney *U* test, sex differences were assessed, and these were found to be statistically significant ($Z = 4.84$; $p = .001$). However, the magnitude of this difference (effect size: 0.22) is relatively small. Linear regression models were generated using the medial clavicular epiphyseal fusion score of the left clavicle for both males and females as:

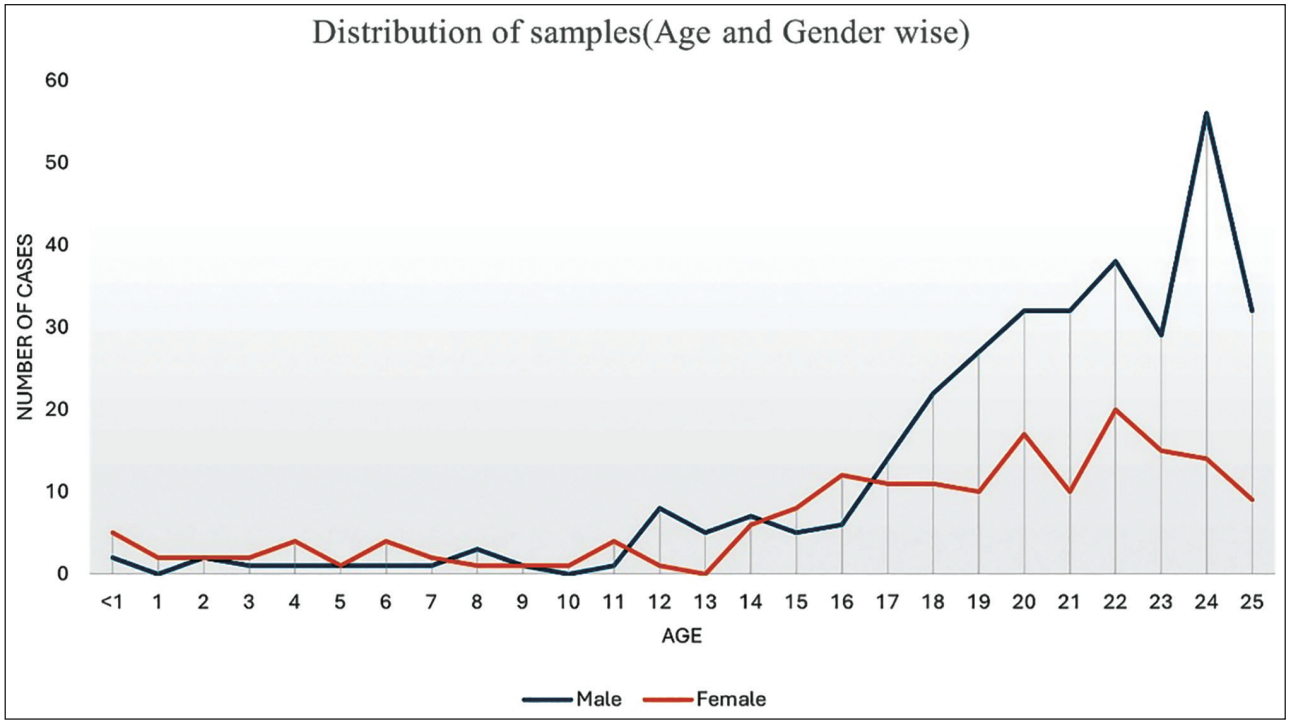

Figure 2. Line Chart Depicting the Distribution of Samples According to their Age and Sex.

Table 1. Descriptive Statistics of the Male and Female Subsets in the Present Study.

	Number of Cases (*n*)		Range (Years)		Mean Age (Years)		Standard Deviation (Years)		95% *CI* Mean (in Years)	
Stages	M (327)	F (173)	M	F	M	F	M	F	M	F
0	41	40	0–20	0–17	10.98	7.5	4.97	5.83	9.41–12.55	6.52–10.24
1	75	48	15–24	14–23	18.59	17.5	1.76	3.51	18.19–18.99	16.08–18.12
2	40	27	17–23	16–24	20.48	20	1.36	2.10	20.05–20.91	19.43–21.09
3	171	58	19–25	18–25	23.08	23	1.58	1.66	22.84–23.32	22.32–23.2

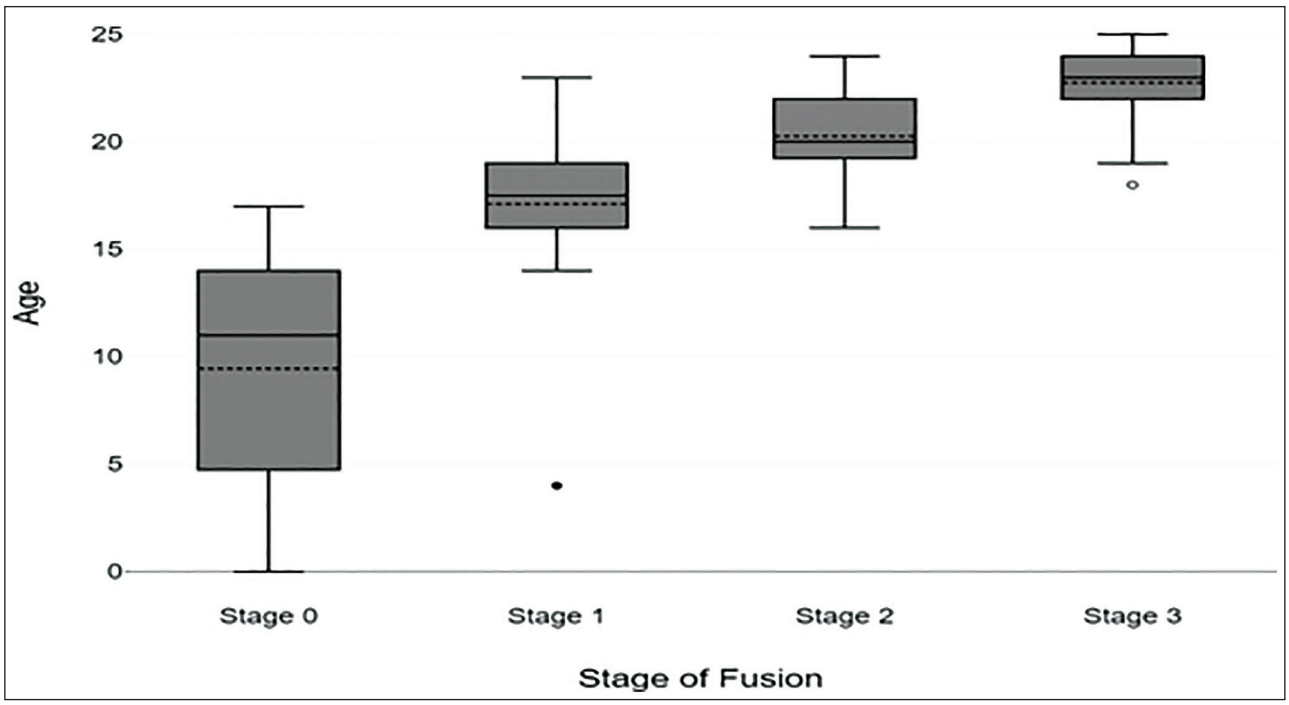

Figure 3. Stage-wise Age Distribution of Males.

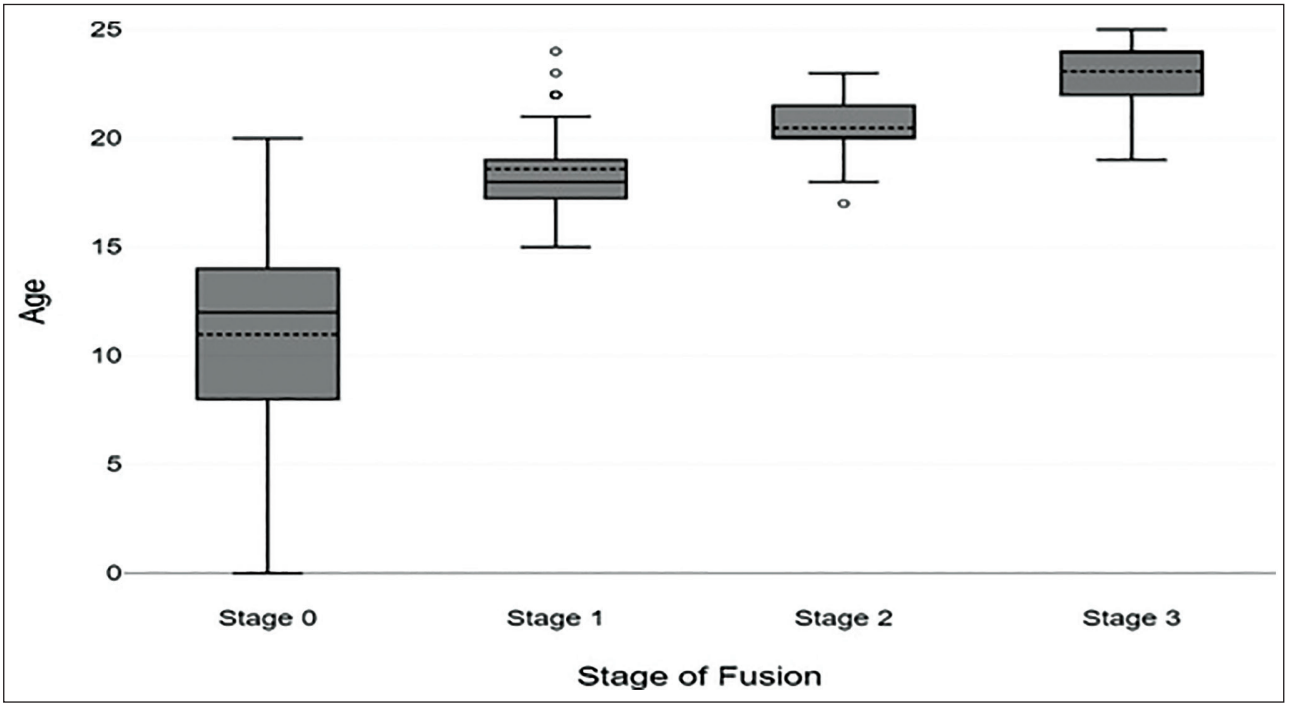

Figure 4. Stage-wise Age Distribution of Females.

Table 2. Mean Difference and Mean Absolute Errors Calculated After the Application of the Proposed Regression Model on a Test Set.

Dataset	Actual Age (Mean ± *SD*)	Estimated Age (Mean ± *SD*)	Mean Difference	Mean Absolute Error
Combined (*n* = 50)	18.36 ± 0.74	18.18 ± 0.65	0.64	1.62
Males (*n* = 25)	20.52 ± 0.52	20.44 ± 0.55	0.23	1.36
Females (*n* = 25)	16.2 ± 1.27	15.92 ± 1.01	0.63	1.88

Table 3. Age Ranges as Reported by Other Researchers Compared with the Present Study.

Researcher	Study Population (*n* [Sample Size])	Stage 0 (Mean ± *SD*)		Stage 1 (Mean ± *SD*)		Stage 2 (Mean ± *SD*)		Stage 3 (Mean ± *SD*)	
		M	F	M	F	M	F	M	F
El Morsi et al. (2015)	Egypt	15.62 ± 0.71	8 ± 0	17.66 ± 1.87	17.00 ± 1.15	19.47 ± 2.19	19.00 ± 2.36	22.26 ± 3.32	21.00 ± 1.49
Ufuk et al. (2016)	Türkiye	12.78 ± 1.74	11.67 ± 1.59	16.56 ± 1.79	15.20 ± 2.39	–	–	23.59 ± 2.11	23.55 ± 2.15
Ekizoglu et al. (2014)	Türkiye (503)	13.46 ± 2.11	11.92 ± 1.37	17.47 ± 2.08	16.77 ± 2.52	20.31 ± 2.24	20.52 ± 3.28	28 ± 4.06	26.46 ± 4.13
Wittschieber et al. (2013)	Germany (493)	12.9 ± 1.6	14.3 ± 1.5	17.4 ± 1.7	16.0 ± 1.5	22.2 ± 3.2	20.7 ± 2.5	29.7 ± 5.1	27.2 ± 4.2
Current Study (2024)	India (500)	10.98 ± 4.97	8.38 ± 5.83	18.59 ± 1.76	17.1 ± 3.51	20.48 ± 1.36	20.26 ± 2.10	23.08 ± 1.58	22.76 ± 1.66

For Males: Age = 13.3798 + 3.344SF, (R^2 = .67)
For Females: Age = 10.4114 + 4.4269SF, (R^2 = .64)

Where SF is the stage of fusion.

The generated regression equations were validated on 50 cases (25 males and 25 females) by quantifying the mean deviation and mean absolute error (MAE). The MAE of the males was 1.36, the MAE of females was 1.88, and that of combined males and females is 1.62 (Table 2).

Discussion

The need for novel methods of age estimation and refining the existing criteria is increasing in forensic practice. Most law enforcement agencies seek the opinion of forensic pathologists for age estimation in both living and dead bodies or skeletal remains. This is especially common in developing and underdeveloped countries where the rate of institutional births is relatively lower. Disputes regarding age occur most commonly in respect of criminal and civil responsibilities, which vary in every country. In India and most other countries, the age of 18 is considered a cut-off where individuals attain legal adulthood, civil rights and liabilities, and criminal responsibility. Hence, in age estimation scenarios, the forensic pathologists require reliable criteria to assert the age range in the later stages of the second decade. Nevertheless, multiple researchers have defined criteria for estimating age from ossification centers of the medial end of the clavicle; the geographical variation in anthropological studies should also be accounted for.[1] The present study is focused on addressing the reliability of existing criteria of age estimation using ossification of the medial end of the clavicle in the native Indian population. Radiological techniques such as X-ray, CT, and MRI are preferred tools for age estimation in both living and the dead. Computed tomography with minimal slice thickness is the preferred tool in current age estimation scenarios. Wittschieber et al recommended using <1 mm slice thickness in CT for evaluation of the medial ends of the clavicle. The present study has also used CT scans of 1 mm slice thickness to determine stages of ossification.[7]

The present study adopted a simplified four-stage classification (Stages 0–3) to ensure high interobserver reliability and consistency, given the retrospective nature and standardized CT parameters. Effectively, it is a pragmatic modification of the widely used Schmeling five-stage classification (Stages 1–5) and the even more granular Kellinghaus nine-substage system, both of which are central to the guidelines of the Arbeitsgemeinschaft für Forensische Altersdiagnostik (AGFAD).[8] Our Stage 3 ("Complete fusion of the epiphyseal ossification center with diaphysis; epiphyseal scar might still be appreciable") effectively consolidates the final stages of complete fusion (Schmeling's Stages 4 and 5: complete fusion with scar present and complete fusion with scar obliterated, respectively). While this simplification facilitated near-perfect interobserver agreement ($\kappa = 0.82$) and robust age estimation,

it is noted that the exclusion of the final stage differentiation (Schmeling Stage 5) and the exclusion of Kellinghaus's sub-stages (e.g., subdivisions of partial fusion/Stage 2) represent a trade-off. The more granular stages (Schmeling 4/5, Kellinghaus 3c) are specifically designed to increase precision when assessing the critical legal age thresholds of ≥18 and ≥21 years. The minimal slice thickness used in our study (≤1 mm) supports high-resolution assessment, which is necessary for applying these sub-stages, but we prioritized the established four-stage classification for broad applicability across our large sample. Future work could specifically evaluate the utility of the Kellinghaus sub-stages on our data to determine if they provide a significant improvement in the MAE for age prediction in this population.

In our study, the mean age of Stage 0 for males is 10.98 (±4.97), and that of females is 8.38 (±5.83). These values are considerably lower than the age ranges reported by other researchers; Ufuk et al from Türkiye (males: 12.78 ± 1.74; females: 11.67 ± 1.59), Ekizoglu et al. from Türkiye (males: 13.46 ± 2.11; females: 11.92 ± 1.37), El Morsi et al. from Egypt (males: 15.62 ± 0.71; females: 8 ± 0) and other studies.[9–12] However, in Stage 0, the age range of females in this study (8.38 ± 5.83) is almost similar to the findings of El Morsi et al. This difference can be explained by the variations in the lower age limits and the variable sample population in the lower ages. In our study, 37 cases were included in the under-10 age group, which is significantly higher than in other studies. The sample size has also been kept at a much higher level so as to reduce the overcrowding of samples in any specified age category. This also explains the high standard deviation restricted to Stage 0, while the *SD* in other stages is almost concordant with results reported by other researchers. Based on our study, the fusion patterns of males and females were distinct from birth to 25 years of age. Ekizoglu et al. reported significant differences between males and females in Stage 1 and Stage 4. In contrast, we observed significant differences between sexes only in Stage 1. Table 3 shows the comparison of age ranges of different stages in different populations.[13]

The regression equations can effectively age individuals with remarkable accuracy. The overall trend shows that the regression equation shows a tendency to underestimate actual age, with error rates particularly higher for females. The MAE of females (1.88) is considerably higher than that of males (1.36), which is almost similar to the pattern reported by Shedge et al. However, the combined MAE in this study is slightly higher than that of Shedge who also studied the Indian population.

Tozakidou et al. recommended the acquisition of CT scans in an arms-up position, as it decreases the patient dose (dose of X-rays required for penetrating the body) and provides better image quality.[4] Such dose regulations are a concern in clinical age estimation scenarios, which do not bother forensic age estimation practices using PMCT. Though scan parameters were specified in our study, no attempts were made to reduce the effective dose (CTDI/DLP) as obtaining high-resolution images was the only objective. Considering the AGFAD, (Study Group on Forensic Age Diagnostics) recommendations in the context of forensic age estimation, four parameters were implemented: (a) Schmeling et al main stages (though Stage 5 was not included separately); (b) utilizing ≤ 1 mm CT images; (c) using axial/coronal reformats; and (d) using bone window for interpretation. Kellinghaus et al. sub-stages could not be included in this study. Ruder et al. stated in their systematic review that patient position on the CT table and CT scan parameters were often heterogeneous and incomplete in the literature. To support further reviews, all the scan parameters and CT acquisition technique are specified in the present study.[14]

Conclusion

This study successfully investigated the fusion patterns of the medial clavicular epiphysis in a large North Indian cohort (n = 500) using PMCT. We observed distinct and predictable fusion patterns between males and females from birth to 25 years of age.

The fusion scores demonstrated a statistically significant, strong correlation with chronological age for both sexes, with Spearman's ρ coefficients of 0.819 for males and 0.797 for females. Despite the presence of statistically significant gender differences in fusion timing, the small effect size (0.22) implies a minor practical influence on the age estimation outcomes. The derived linear regression models for age prediction proved to be highly reliable, yielding low MAEs of 1.36 years for males and 1.88 years for females. These MAE values underscore the reliability of medial clavicular epiphyseal fusion as a key forensic age marker in the North Indian population. In summary, the research provides a region-specific and gender-based tool for age estimation, emphasizing the crucial need for population-specific criteria in forensic contexts.

Authors' Contribution

Dr. Balaji. D: Conceptualization, methodology, writing-original draft, visualization. Dr. Zahid Ali CH: Conceptualization, formal analysis, validation, writing-original draft. Dr. Gokul. G: Conceptualization, methodology, writing-original draft, visualization, formal analysis. Dr. Abilash Srinivasa Murthy: Methodology, writing-original draft, visualization. Dr. Raveena Divya: Visualization, validation. Dr. Swati Tyagi: Visualization, validation. Dr. Abhishek Yadav: Resources, supervision. Dr. Sudhir K Gupta: Resources and supervision.

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for Publication

Consent for participation in the study and publication was obtained from the first-degree relatives (legal heirs) of all subjects.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics Approval and Informed Consent

The ethical clearance was granted by the All India Institute of Medical Sciences Institutional Ethics Committee (IEC 577/02.11.2018, RP-29/2018).

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ORCID iDs

Gokul G https://orcid.org/0000-0001-8677-1989
Abhishek Yadav https://orcid.org/0000-0001-8396-497X

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Original Research Article

Hand and Handprint Insights in Estimating Stature and Gender Among Eastern Uttar Pradesh Population in India: An Observational Prospective Study

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Priya Devi[1], Payal Panwar[2], Roshna Sankar[1], Sharon John[1], Ankit Sharma[3] and Arushi Tomar[1]

Abstract

Useful piece of forensic evidence that can help identify suspects is a handprint. In order to reduce the number of possible suspects, anthropometric study of handprints offers vital information for calculating size and sex. The goal of the current study was to investigate how stature and hand and handprint dimensions relate to comparative human identification. One hundred adults from Eastern Uttar Pradesh—fifty males and fifty females—made up the study sample. A stadiometer was used to measure the participants' stature, and they provided handprints using ink pads. A digital vernier caliper was used to record eight anthropometric parameters for both hands. Males were 167.70 cm tall on average, while girls were 160.27 cm tall, according to statistical study. The right palm length was the best predictor of stature in females, whereas the first digit length in males had the highest connection. For both males and females, the standard error of estimation (SEE) varied from ±6.9 cm to ±8.17 cm. Measurements of handprints showed comparable dependability, with females showing smaller SEE ranges for both hands. The study demonstrates the usefulness of hand and handprint dimensions in forensic anthropology by highlighting how they can accurately predict sex and size. These results highlight the significance of region-specific anthropometric data for enhancing human identification accuracy, supporting investigations by lowering suspect pools, and aiding in the development of specialized forensic databases.

Keywords

Anthropometry, hand measurements, handprint measurements, multiple regression equation, linear regression equation, stature

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Introduction

A forensic anthropologist's job today entails more than just studying skeletal remains; with increased international migration (both legal and illegal), crime and natural disasters that result in large numbers of fatalities, it is frequently necessary to examine living people or deceased individuals' body parts. A practicing forensic anthropologist has a basic level of skill that includes the capacity to create a biological profile (autobiography—sex, age, ethnicity, and stature) for the identification of human beings, either by reconstruction of the remains found at the scenes or by comparing the existing records. A biological profile, along with other skeletal markers (such as antemortem pathology), can help determine the identity of unidentified skeletal remains. For investigating authorities, this profile efficiently reduces the number of probable matching individuals; subsequent identification can be accomplished using traditional markers.[1] For many years, forensic anthropologists and

[1]Department of Oral & Maxillofacial Pathology and Oral Microbiology, King George's Medical University, Lucknow, Uttar Pradesh, India
[2]Department of Oral Pathology and Microbiology, King George's Medical University, Lucknow, Uttar Pradesh, India
[3]Department of Anatomy, King George's Medical University, Lucknow, Uttar Pradesh, India

Corresponding author:
Arushi Tomar, Department of Oral & Maxillofacial Pathology and Oral Microbiology, King George's Medical University, Lucknow, Uttar Pradesh 226003, India.
E-mail: Arushitomar704@gmail.com

medical professionals have been fascinated by the close correlation between certain body components and stature. The dimensional relationship between body segments, which is frequently utilized in contemporary forensic practice,[2,3] enables the reconstruction of the body's original stature.

An examination of recent research indicates that height can be precisely forecasted based on the lengths of distinct long bones in the upper and lower limbs,[4,5] along with the width and length of the foot and footprints.[6–8] Moreover, linear measurements of the hand and handprints also play a role in this prediction,[9–11] along with the length and breadth of the foot, have proven to be reliable indicators for stature prediction.

Even in the absence of complete proof, the precise relationships between the measurements of different anatomical regions can be utilized to identify victims or body remains. The most frequent physical evidence found at crime sites is handprint evidence. The key to identifying a perpetrator is thought to be obtaining their distinctive fingerprint pattern,[12] although this may not always be possible. Handprints prove especially advantageous in determining an individual's gender and height as they originate from the most prominently visible part of the hand, offering insights into the actual size of the individual's hand that left them at a crime scene.[13] In a vast and diverse country like India, a universal formula for estimating stature may not apply due to the presence of different topographical terrains as well as heterogeneity in cultures and ethnicity across the entire subcontinent. Hence, the primary objective of this research was to assess the precision and dependability of using measurements of hand and handprint measurements for stature estimation within the Eastern Uttar Pradesh population. This is the first of its kind to be conducted for providing baseline data in the loco-regional population and to utilize this for further studies.

Material and Methods

Material

This cross-sectional study was carried out at a tertiary care hospital after taking ethical approval from the Institutional Ethics Committee. A total of 100 young and healthy individuals comprising 50 males and 50 females aged 19–26 years in Eastern Uttar Pradesh were taken as per calculated by the calculated sample size mentioned below. Before taking the measurements, informed consent was acquired from the participating individuals. Subjects with no obvious pathology or a history of previous surgical/cosmetic treatments on the hand were included. This study excluded participants with spine deformities such as kyphosis and scoliosis, as well as those with previous hand injuries as a result of accidents, congenital deformity, etc.

The sample size was selected to give sufficient power to identify gender differences in hand measurements as well as associations between hand/handprint measurements and stature.

$$n = \left(Z_{1-\alpha/2} + Z_{1-\beta/2} \right)^2 / Z_r^2 + 3$$

Using the Fisher z technique, ≈85 subjects were needed to detect a correlation of $r = 0.30$ ($\alpha = 0.05$, 80% power); 50 subjects per group are needed to detect a between-group standardized mean difference of $d \approx 0.56$. In order to find moderate correlations and moderate-to-large gender differences, we recruited 100 healthy participants (50 men and 50 females). This allowed for modest multivariable logistic modeling (≈5 predictors) without experiencing significant overfitting.

Method

Collection of Handprint

Every participant's right and left handprint was captured using an inkpad and nonreactive, non-indelible ink. Gently, the hands were pressed onto the ink pad, then gently pressed onto white paper to create the outline of a handprint. Following the paper's drying period, eight measurements in total were taken, as previously reported in previous studies.[7,11,14–16]

Measurement of Stature

A stadiometer was employed to ascertain the standing height of each participant. Subjects were directed to stand upright and barefoot on the level base, aligning their head with the Frankfurt plane and ensuring their back made contact with the stadiometer's vertical board. Following that, the measurement in centimeters from the heel to the highest point on the head was taken by adjusting the sliding bar.

Measurement of the Handprint

Anthropometric measurements for both the right and left hands of each participant were obtained utilizing a digital vernier caliper (Mitutoyo, Japan), adhering to the landmark criteria established in prior investigations.[7,8] All measures utilized in this study are depicted in Figure 1.

Hand breadth (HB): Distance between the outermost point on the head of the second metacarpal to the innermost point on the head of the fifth metacarpal.

Hand length (HL): Distance from the mid-point of the distal transverse crease of the wrist to the furthest forward projection of the skin on the middle finger.

Palm length (PL): The measurement from the wrist's distal transverse crease to the proximal flexion crease of the middle finger.

Thumb (1D); Index (2D); Middle (3D); Ring (4D); little (5D) Finger length: The distance from the proximal flexion crease of each finger to its respective fingertip.

Statistical Analyses

The data collected was entered into Microsoft Excel. The SPSS V 26.0 software was then used for statistical analysis.

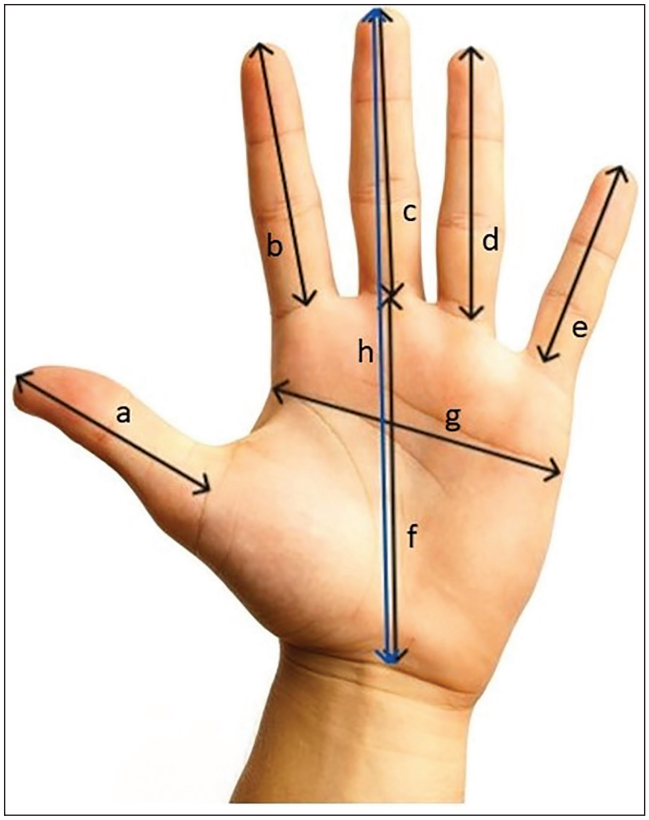

Figure 1. Human Hand Showing Various Hand Measurements. a: 1st Digit, b: 2nd Digit, c: 3rd Digit, d: 4th Digit, e: 5th Digit, f: Palm Length, g: Hand Breadth, h: Hand Length.

The dimensions of the hand and handprint that showed a significant link with stature were put into a regression model for the assessment of stature. Stepwise regression analyses were conducted to formulate a regression equation for predicting stature based on diverse hand and handprint measurements. The standard error of estimate (SEE) was determined by the disparity between the measured stature and the stature estimated through the application of the regression equation.

Results

Descriptive Statistics

The average height measured for males was 167.70 cm (SD 8.33), while for females, it was 160.27 cm (SD 7.20). Tables 1 and 2 present the mean, standard deviation, and stature correlation for each of the eight hand and handprint measurements (left and right for both sexes). The mean, Standard deviation and standard error are shown in Table 1. Among males, the hand measurements that showed the highest correlation with stature were the first digit of the right hand and in females, it was the right palm length.

Variability in Hand and Handprint Dimensions on Both Sides (Bilateral Variation)

A two-sample *t*-test was employed to examine bilateral variance in hand and handprint measurements. Among males, significant differences ($p < .05$) were observed in right-hand breadth (RHB), right-hand length (RHL), palm length (RPL), first digit (R1D), second digit (R2D), third digit (R3D), fourth digit (R4D) and fifth digit (R5D) measurements of their right hands and left-hand length (LHL), left first digit (L1D), third digit (L3D), fourth digit (L4D), and fifth digit (L5D) of their left hand. Similarly, females exhibited significant differences ($p < .05$) in RHB, RHL, RPL, R2D, R3D, R4D and R5D of their right hand and LHB and LPL of their left hand (Tables 1 and 2).

Correlation Between Stature and Hand and Handprint Measurements

The correlation coefficients (r) between stature, hand, and handprint measurements are reported in Table 1. In males, LHB ($r = 0.6218$) had the highest correlation with stature, followed by RHL ($r = 0.564$). Similarly, among females, R5D had the highest correlation value ($r = 0.466$), followed by LHL ($r = 0.416$), while RHB had the lowest association with stature. In terms of handprint measurements, the RHL showed the strongest correlation in males ($r = 0.663$), while the R2D showed the strongest association in females ($r = 0.487$) (Tables 1 and 2).

Simple Linear Regression

Tables 3 and 4 show the simple linear regression equations used to determine stature by measuring the hands of the subjects and handprints individually for sex and side. The standard error of estimation (SEE) forecasts the discrepancy between the estimated and actual stature. A low SEE suggests higher reliability in the estimated stature. In this investigation, the SEE of simple linear regression equations for males ranged from ±6.9 to ±8.17 cm for right and ±6.6 to ±7.98 left-hand measures, respectively. SEE for females for right-hand measurements ranged from ±6.32 to ±7.1, and for left-hand measurements showed ±6.62 to ±7.2. Handprint measurements for males ranged from ±6.29 to ±7.9 cm for right and ±6.09 to ±8.31 cm for left handprint measurements, and for females, right handprint measurements ranged from ±6.32 to ±7.1 cm and left handprint measurements ranged from ±6.62 to ±7.2 (Table 4).

Multiple Regression

Tables 5 and 6 show sex-specific bilateral multiple regression models for estimating stature using various combinations of variables for hand and handprint measurements. Only the most accurate models developed through stepwise analysis are shown. Multiple regression models based on hand measures,

Table 1. Descriptive Statistics (Hand Measurement).

Males (*n* = 50)						**Females (*n* = 50)**				
	Mean	***SD***	**Std. Error**	***r***	***p* Value**	**Mean**	***SD***	**Std. Error**	***r***	***p* Value**
Stature	167.70	8.331	1.178	1	.000	160.27	7.205	1.019	1	.000
RHB	7.52	0.74	0.10	0.430	.000	7.32	0.54	0.07	0.00	.017
RHL	16.96	1.228	0.174	0.564	.000	16.36	1.274	0.180	0.287	.002
RPL	9.478	0.80	0.1135	0.431	.000	9.562	0.51	0.0729	0.409	.002
R1D	6.09	0.63	0.1525	0.232	.000	6.29	0.788	0.1720	0.388	.179
R2D	6.598	0.787	0.113	0.353	.017	6.614	0.45	0.0639	0.241	.000
R3D	7.31	0.79	0.1118	0.393	.000	7.236	0.59	0.082	0.328	.000
R4D	6.71	0.788	0.1115	0.375	.000	6.67	0.53	0.0753	0.379	.001
R5D	5.41	0.788	0.115	0.366	.000	5.454	0.49	0.0697	0.466	.000
LHB	7.63	0.98	0.1383	0.618	.119	7.26	0.61	0.087	0.360	.002
LHL	17.08	1.32	0.187	0.544	.000	16.34	1.27	0.180	0.416	.593
LPL	9.696	0.84	0.1189	0.396	.320	9.534	0.54	0.0769	0.360	.003
L1D	5.88	0.82	0.1153	0.439	.002	5.85	0.58	0.082	0.020	.142
L2D	6.72	0.82	0.1157	0.439	.376	6.64	0.43	0.0606	0.090	.307
L3D	7.31	0.81	0.1139	0.421	.006	7.35	0.44	0.0617	0.009	.257
L4D	6.64	0.74	0.1043	0.320	.009	6.63	0.47	0.0658	0.214	.334
L5D	5.38	0.77	0.1092	0.391	.003	5.38	0.43	0.0612	0.175	.180

Notes: Descriptive statistics and correlation of hand and handprint measurements (in cm) to stature in males and females.

SD = Standard deviation, RHB = Right-hand breadth, RHL = Right-hand length, RPL = Right palm length, R1D = Right 1st digit, R2D = Right 2nd digit, R3D = Right 3rd digit, R4D = Right 4th digit, R5D = Right 5th digit, LHB = Left-hand breadth, LHL = Left-hand length, LPL = Left palm length, L1D = Left 1st digit, L2D = Left 2nd digit, L3D = Left 3rd digit, L4D = Left 4th digit, L5D = Left 5th digit.

Table 2. Descriptive Statistics and Correlation of Handprint Measurements (in cm) to Stature in Males and Females.

Descriptive Statistics (Handprint Measurement)										
Males (*n* = 50)						**Females (*n* = 50)**				
	Mean	***SD***	**SE**	***r***	***p* Value**	**Mean**	***SD***	**SE**	***r***	***p* Value**
Stature	167.76	8.31	1.176	1	.000	160.21	7.16	1.103	1	.000
RHB	7.676	0.66	0.0930	0.483	.062	7.114	0.63	0.0888	0.355	.000
RHL	17.12	1.17	0.166	0.663	.012	16.24	1.08	0.153	0.434	.000
RPL	9.346	0.74	0.1040	0.547	.460	8.822	0.74	0.1046	0.419	.000
R1D	6.134	0.73	0.1020	0.366	.21	5.81	0.65	0.09215	0.193	.537
R2D	7.01	0.56	0.797	0.375	.385	6.70	0.49	0.0695	0.487	.000
R3D	7.85	0.63	0.0888	0.351	.975	7.426	0.56	0.0798	0.289	.004
R4D	7.318	0.62	0.0881	0.618	.481	6.75	0.61	0.0861	0.412	.000
R5D	5.87	0.61	0.860	0.554	.656	5.45	0.48	0.0680	0.396	.000
LHB	7.52	0.89	0.1258	0.396	.891	6.94	0.95	0.1345	0.177	.004
LHL	17.10	1.15	0.162	0.493	.011	16.06	1.04	0.147	0.345	.000
LPL	9.274	0.94	0.1325	0.421	.155	8.76	0.99	0.1400	0.251	.000
L1D	5.90	1.09	0.9837	0.222	.844	5.5	0.79	0.1124	0.331	.000
L2D	6.84	0.83	0.1178	0.222	.376	6.49	0.7	0.0986	0.384	.005
L3D	7.74	0.87	0.1228	0.266	.926	7.28	0.81	0.1150	0.471	.000
L4D	7.15	0.84	0.1186	0.289	.808	6.66	0.82	0.1156	0.366	.000
L5D	5.87	0.77	0.1084	0.320	.702	5.48	0.71	0.1	0.233	.000

Table 3. Simple Linear Regression Used to Predict Stature Using Hand Measurement (Univariate Analysis).

Male Equation Right	*R*2	SE	*p* Value	Female Equation Right	*R*2	SE	*p* Value
Stature = 130.842 + 4.899 × RHB	0.185	7.6	.002	Stature = 138.988 + 2.909 × RHB	0.050	7.05	.119
Stature = 101.553 + 3.899 × RHL	0.319	6.9	.000	Stature = 124.365 + 2.194 × RHL	0.156	6.65	.005
Stature = 125.99 + × 4.41 × RPL	0.186	7.6	.002	Stature = 76.7 + 8.727 × RPL	0.366	5.76	.000
Stature = 152.085 + 2.665 × R1D	0.054	8.17	.105	Stature = 160.970 − 0.0124 × R1D	0.001	7.23	.861
Stature = 142.742 + 3.786 × R2D	0.124	7.86	.012	Stature = 117.897 + 6.408 × R2D	0.178	6.56	.002
Stature = 136.995 + 7.224 × R3D	0.155	7.72	.005	Stature = 13.139 + 3.45 × R3D	0.082	6.93	.044
Stature = 146.136 + 3.987 × R4D	0.141	7.9	.007	Stature = 130.034 + 5.546 × R4D	0.167	6.60	.005
Stature = 144.637 + 3.019 × R5D	0.123	7.87	.012	Stature = 145.594 + 2.02 × R5D	0.03	7.12	.226
Male Equation Left				**Female Equation Right**			
Stature = 99.423 + 3.992 × LHB	0.382	6.6	.000	Stature = 129.283 + 1.898 × LHB	0.115	6.80	.016
Stature = 113.465 + 5.588 × LHL	0.307	7.0	.000	Stature = 130.654 + 3.017 × LHL	0.060	7.0	.087
Stature = 168.10 + 0.93 × LPL	0.084	7.84	.023	Stature = 145.64 + 1.67 × LPL	0.05	6.68	.072
Stature = 148.514 + 3.274 × L1D	0.154	7.98	.024	Stature = 144.710 + 1.65 × L1D	0.046	7.1	.133
Stature = 138.255 + 4.378 × L2D	0.177	7.62	.002	Stature = 122.814 + 5.646 × L2D	0.130	6.75	.010
Stature = 133.948 + 4.617 × L3D	0.193	7.7	.001	Stature = 107.086 + 7.242 × L3D	0.218	6.4	.001
Stature = 134.328 + 5.024 × R4D	0.192	7.55	.001	Stature = 147.14 + 21.93 × L4D	0.143	6.69	.007
Stature = 144.023 + 4.391 × L5D	0.157	7.7	.004	Stature = 133.461 + 4.993 × L5D	0.107	6.83	.020

Note: $p < 0.05$ is considered significant. Marked with *.

Table 4. Simple Linear Regression Used to Predict Stature Using Handprint Measurement (Univariate Analysis).

Male Equation Right	*R*2	SE	*p* Value	Female Equation Right	*R*2	SE	*p* Value
Stature = 87.239 + 4.703 × RHB	0.223	7.4	.00	Stature = 114.184 + 2.834 × RHB	0.110	6.8	.019
Stature = 110.026 + 6.177 × RHL	0.439	6.29	.000*	Stature = 125.115 + 3.979 × RHL	0.183	6.54	.002*
Stature = 143.979 + 3.877 × RPL	0.299	7.03	.000*	Stature = 148.139 + 2.078 × RPL	0.169	6.60	.000*
Stature = 101.146 + 9.503 × R1D	0.113	7.9	.017*	Stature = 112.805 + 7.070 × R1D	0.036	7.1	.187
Stature = 109.653 + 7.402 × R2D	0.414	6.42	.000	Stature = 116.796 + 5.847 × R2D	0.235	6.32	.000*
Stature = 116.073 + 7.115 × R3D	0.312	7.0	.000	Stature = 112.838 + 5.537 × R3D	0.212	6.42	.001
Stature = 125.595 + 7.118 × R4D	0.305	6.69	.000	Stature = 125.831 + 6.313 × R4D	0.221	6.38	.001*
Stature = 152.065 + 2.087 × R5D	0.276	7.15	.000	Stature = 156.094 + 0.593 × R5D	0.180	6.55	.002
Male Equation Left	***R*2**	**SE**	***p* Value**	**Female Equation Left**	***R*2**	**SE**	***p* Value**
Stature = 82.340 + 4.995 × LHB	0.030	8.2	.119*	Stature = 115.573 + 2.780 × LHB	0.006	7.2	.586
Stature = 155.594 + 1.273 × LHL	0.475	6.09	.000*	Stature = 147.125 + 1.494 × LHL	0.162	6.62	.004*
Stature = 146.488 + 3.603 × LPL	0.021	8.31	.320*	Stature = 153.074 + 1.298 × LPL	0.043	7.07	.150*
Stature = 141.484 + 3.840 × L1D	0.182	7.6	.002	Stature = 149.516 + 1.647 × L1D	0.021	7.2	.318
Stature = 142.548 + 3.257 × L2D	0.148	7.8	.006*	Stature =151.304+1.223 × L2D	0.026	7.14	.266*
Stature = 142.548 + 3.257 × L3D	0.116	7.9	.016	Stature = 151.304 + 1.223 × R3D	0.019	7.2	.336*
Stature = 141.961 + 3.607 × R4D	0.132	7.83	.009	Stature = 149.129 + 1.665 × R4D	0.036	7.1	.186*
Stature = 141.672 + 4.444 × R5D	0.168	7.66	.003	Stature = 148.826 + 2.080 × R5D	0.042	7.1	.152*

Note: $p < .05$ is considered significant. Marked with *.

Table 5. Multiple Linear Regression Used to Predict Stature (cm) Using Hand Measurement (Multivariate Analysis).

	Formula	*R*2	SEE	F-value	*p* Value
Male right equation	Stature = 99.748 + (1.519 × RHB) + (3.331 × RHL)	0.330	6.95	11.5	.000
Male left equation	Stature = 98.453 + (0.631 × LHB) + (3.766 × LHL)	0.387	6.64	14.80	.000
Female right equation	Stature = 123.411 + (0.265 × RHB) + (2.134 × RHL)	0.156	6.91	4.34	.019
Female left equation	Stature = 128.173 + (0.302 × LHB) + (1.832 × LHL)	0.116	6.89	3.08	.055

Table 6. Multiple Linear Regression Used to Predict Stature (cm) Using Handprint Measurement (Multivariate Analysis).

	Formula	*R*2	SEE	F-value	*p* Value
Male right equation	Stature = 76.384 + (1.785 × RHB) + (0.991 × RHL) + (2.834 × RPL) + (12.458 × R2D) + (−8.928 × R3D) + (3.409 × R4D) + (−1.415 × R5D)	0.585	5.54	8.24	.000
Male left equation	Stature = 91.529 + (−1.174 × LHB) + (4.379 × LHL) + (−1.008 × LPL) + (1.236 × L1D) + (−0.082 × L2D) + (−1.398 × L3D) + (0.228 × L4D) + (3.745 × L5D)	0.531	6.22	5.813	.000
Female right equation	Stature = 95.363 + (−0.563 × RHB) + (0.413 × RHL) + (2.381 × RPL) + (1.448 × R2D) + (0.549 × R3D) + (3.056 × R4D) + (1.236 × R5D)	0.337	6.3	3.05	.011
Female left equation	Stature = 111.43 + (−1.736 × LHB) + (2.938 × LHL) + (1.571 × LPL) + (−1.848 × L1D) + (−2.194 × L2D) + (1.626 × L3D) + (2.742 × L4D) + (−1.042 × L5D)	0.199	7.0	1.27	.286

males have the lowest SEE at ±6.64 cm, while females have the lowest at ±6.89 cm (Table 5). For handprint, males have the lowest SEE at ±5.54 cm and females at ±6.3 cm (Table 6).

Discussion

Forensic inquiry involving the anthropological profile of unknown human remains must include the determination of stature. When hand impressions are provided, our findings can assist in identifying an individual who has been involved in or harmed in a crime. Conventional forensic and archaeological human remains examination is well-known to be based on estimation of bio-demographic factors such as stature, age, weight, and gender. Stature is regarded as the most important attribute for identifying an unknown person and is typically measured using the lengths of the limb bones. Recent research by Jasuja and Singh, as well as Ahemad and Pukait, have employed handprint measurements to correlate with stature.[9,17] In forensic sciences, it is essential to statistically quantify both error and uncertainty. This pertains not only to the level of error linked with forensic standards but also to the accuracy and precision of the raw data, such as measurements, from which these standards are derived.

Aligned with previous research findings, the present study identified statistically significant bilateral asymmetry in diverse hand and handprint measurements for both males and females. Significant differences were found between males in various metrics, including RHB, RHL, RPL, R1D, R2D, R3D, R4D, and R5D on the right hand and LHL, L1D, L3D, L4D, and L5D on the left hand. Similarly, females showed significant differences in RHB, RHL, RPL, R2D, R3D, R4D, and R5D on the right hand and LHB and LPL on the left. This bilateral variance implies that while hand and handprint measures can be utilized for stature assessment, the side of the body assessed should be taken into account for improved accuracy.

In men, the strongest link was identified between stature and left-hand breadth (LHB), with a correlation coefficient (r) of 0.6218, followed by right-hand length (RHL), which had a correlation of 0.564. These findings are consistent with those published by Abdel-Malek et al., who found that hand breadth and length are strong predictors of stature in many populations, emphasizing the stability of these measurements across demographic groupings.[18] The correlation of stature with HL is in accordance with the previous studies by Krishan & Sharma in the North Indian population, Rastogi et al. in South India, Ishak et al. in Western Australia, and Laulathaphol et al. in Thai populations.[7,11,15,19] Furthermore, Trotter and Gleser revealed that long bone measurements, including those of the hand, are robust markers of an individual's height, further supporting the significant correlations found in the current study.[20] Females showed the strongest link with fifth digit length (R5D) (r = 0.466) and left-hand length (LHL) (r = 0.416). This is congruent with the findings of Habib and Kamal,[10] who discovered that finger lengths, particularly the fifth digit, are accurate predictors of stature in Egyptian populations. Moreover, Williams and Rogers discovered that specific cranium and hand measurements, including finger lengths, are efficient for sex determination and stature estimation in forensic instances.[21]

The establishment of a positive linear relationship among stature, hand and handprint measurements facilitated the creation of multiple regression equations applicable for accurate stature estimates within the Uttar Pradesh population. In the context of simple linear regression, the observed range of SEE for measurements of both left and right hands, as well as handprints, was comparatively lower for females than for males. This outcome aligns with the findings of Nandi et al.,[22] who similarly reported that females exhibited a stronger correlation between hand, handprint measurements, and stature. Also, the slight reduction in SEE suggests a marginally higher reliability for stature estimation in females compared to males. The study by Rastogi et al. supports these findings, as their research indicated that hand dimensions are reliable predictors of stature, especially in females.[19] The observed gender disparities in the growth and development of the skeletal system may be attributed to the impact of both genetic and environmental factors.[23] As a result, new sex-specific stature estimation models based on hand and handprint measurements can be developed. Multiple linear regression was used to predict stature from hand measures. Supporting the perspectives of earlier scholars (Krishan & Sharma; Ishak et al.; Zulkifly et al.), the multiple regression equations formulated for both men and women exhibited enhanced predictive accuracy compared to equations derived from single variables. Right-hand measurements showed a significant difference between the genders. SEE was observed for the male right hand at 6.95 and the left hand at 6.64, and for females, SEE was observed for the female right hand at 6.91 and the left hand at 6.89. As a result, the findings indicate that right-hand measurements were more accurate for identifying stature from hand measurements. Multiple regression models demonstrated even more precision when measuring handprints. Males had the lowest SEE at ±5.54 cm, while females had ±6.3 cm. This improved accuracy is comparable with the findings of Giles and Klepinger, who discovered that integrating numerous handprint dimensions into regression models considerably increased the reliability of stature estimations in forensic situations.[24] Their findings demonstrated the reliability of handprint measures as predictors of stature, particularly when utilizing multiple regression approaches. The current study's findings demonstrate that the projected accuracy of stature estimation differs by population. Moreover, these equations exhibit optimal performance when applied to the population from which they were derived. This underscores the importance of establishing criteria specific to each population for precise stature determination. Additionally, the results underscore that measurements of hand and handprint offer a dependable and accurate means of estimating stature. The limitations of the current study are notably tied to its relatively small sample size. To enhance the robustness and applicability of the conclusions, further research with larger and more diverse samples, particularly encompassing various ethnic groups within Uttar Pradesh, is warranted. This study provides one of its kind to provide data for Eastern Uttar Pradesh, which can be used as baseline data for conducting further research and providing anthropological measurements for identification.

Conclusion

This study revealed a noteworthy positive correlation between participant stature and handprint parameters, as evident by the student's *t*-test and correlation coefficient. Moreover, it demonstrated that handprint and phalangeal length print measurements exhibit high reliability in estimating stature for forensic applications. While the precision of anthropometric hand measurements for determining stature is firmly established in specific populations, the use of handprint data remains relatively novel. This study presents credible statistical methods for estimating stature using hand and handprint measurements, emphasizing the significance of bilateral variances and the use of multiple regression models. These findings will not only benefit forensic anthropology by improving the accuracy of stature assessment from incomplete remains but will also help in constructing more precise, population-specific models for use in forensic and anthropometric investigations.

Abbreviations

cm: Centimeter
Ref no: Reference number
SD: Standard deviation

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

The study was approved by the University Research Ethical Committee, King George's Medical University (Ref. No. 2567/ethics/2023).

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Informed Consent

Written consent was obtained from all participants who voluntarily agreed to take part in the study, in accordance with the principles of the Helsinki Declaration.

ORCID iDs

Sharon John https://orcid.org/0000-0002-1722-6810
Arushi Tomar https://orcid.org/0009-0001-9274-4036

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Original Research Article

Socio-demographic Profile of Snakebite Deaths and its Medico-legal Aspect: An Autopsy-based Retrospective Study at Tertiary Care Hospital

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Suresh Kumar[1], Avinash Kumar[2], Anil Shandil[1] and Shiv Ranjan Kumar[1]

Abstract

Snakebite is a significant public health concern in tropical and subtropical regions. Globally, it is estimated that 4.5–5.4 million snake bites occur each year, of which 1.8–2.7 million results in clinically evident envenomation, with an estimated mortality ranging from 81,000 to 138,000 annually. India has 52 species of venomous snakes and accounts for nearly 50% of the global deaths attributed to venomous snakebite. The incidence and pattern of snakebite vary across different geographical areas and are influenced by factors such as climate, ecology, biodiversity, snake distribution, and human population density. The present study included fatal snakebite cases subjected to medico-legal autopsy at the Department of Forensic Medicine and Toxicology, Patna Medical College, Patna. Information about demographic profile (age, sex, occupation, and socioeconomic status), geographical area, seasonal trends, site and pattern of bite, local tissue changes, and manner of bite was documented in a standardized proforma and analyzed accordingly. In this study, the majority of victims were males in the 21–30 year age group, predominantly engaged in agricultural work, and most bites were accidental in nature. Hands and feet were the most common sites affected. Most cases occurred during the rainy season. In the majority of victims, two fang marks were identified at the bite site, accompanied by subcutaneous hemorrhage, necrosis, swelling, and local cellulitis. Snakebite burden is highest among males aged 21–30 years, most of whom belong to economically weaker rural populations engaged in farming occupations.

Keywords

Snakebite, farmer, fang marks, adolescents, anti-snake venom

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Introduction

Although venomous snakes have been recognized in India since ancient times, the nation continues to face significant challenges in reducing mortality associated with snakebite envenomation.[1] In recognition of its major global health impact, snakebite was included in the World Health Organization (WHO) priority list of neglected tropical diseases in June 2017. Worldwide, more than 3,000 snake species have been identified; however, only around 250 are classified by the WHO as medically important due to the clinically significant toxicity of their venoms.[2] Snakebite represents a significant public health concern and medico-legal problem, particularly in tropical and subtropical regions of the world. Globally, it is estimated that 4.5–5.4 million people are bitten by snakes each year, of which approximately 1.8–2.7 million cases progress to clinically evident envenomation. The estimated global mortality attributed to snakebite ranges from 81,000 to 138,000 deaths annually. Regarding global variation in envenomation and snakebite mortality, the highest burden is observed in sub-Saharan Africa, South Asia, and

[1]Patna Medical College, Patna, Bihar, India
[2]Uttar Pradesh University of Medical Sciences (UPUMS), Saifai, Uttar Pradesh, India

Corresponding author:
Avinash Kumar, Uttar Pradesh University of Medical Sciences (UPUMS), Etawah, Saifai, Uttar Pradesh 206130, India.
E-mail: staravinash008@gmail.com

South-East Asia.[3] In India, there are 52 species of venomous snakes,[4] of which 24 are considered as most important.[5] India is responsible for nearly 50% of the estimated worldwide mortality resulting from venomous snakebite envenomation.[6] As per the Registrar General's Million Death Study, India reports nearly 50,000 snakebite deaths every year, whereas the global mortality estimate is about 125,000 deaths annually, of which more than 75,000 occur in Asia.[7]

Incidence and frequency of snakebites vary in different geographic regions, depending on several factors such as climate, ecology, biodiversity, distribution of snakes, and human density.[8] Although snakebite is a frequent medical emergency, it predominantly affects rural communities, where individuals often initially seek treatment from local traditional healers rather than accessing formal healthcare facilities, thereby contributing to increased mortality. When the bite or subsequent signs of envenomation are not promptly recognized, victims may delay presenting to a healthcare provider. Snakebite-related mortality has been shown to correlate strongly with poverty, misidentification of the offending species, inappropriate management by untrained traditional practitioners, inadequate transportation and referral systems, delayed arrival at medical centers, and improper or suboptimal administration of anti-snake venom therapy. The present socio-demographic study was conducted on fatal snakebite envenomation cases subjected to medico-legal autopsy at Patna Medical College, Patna, Bihar, to illustrate the prevailing situation in the state.[9]

Materials and Methods

This retrospective, hospital-based study was conducted on fatal snakebite victims who underwent medico-legal autopsy in the Department of Forensic Medicine and Toxicology, Patna Medical College, Patna, from July 2020 to November 2023, and included a total of 46 cases.

Inclusion Criteria

Only those hospitalized cases with a confirmed history of snakebite documented in the treatment records, along with corresponding systemic and local clinical findings consistent with snakebite envenomation, were included in the study.

Exclusion Criteria

Brought dead cases with a history of snakebite were excluded.

The details regarding age, sex, and residence were obtained from the inquest papers. Occupation, the circumstances of the bite (manner), area of occurrence of instances, socioeconomic status, identification of snake, time of snakebite, season, and pattern of local changes were gathered from treatment records retrieved from the Medical Record Department. During the autopsy, sites of bites and the pattern of bite marks on the body were noted.

The data were compiled into a structured proforma and analyzed using descriptive (mean, standard deviation) and inferential statistics (chi-square (χ^2) test for association and p value). Statistical processing was carried out with Statistical Package for the Social Sciences (SPSS) Statistics version 31, and findings have been displayed using tables, graphs, and charts.

Observations and Results

A total of autopsies were conducted between July 2020 and November 2023; the hospitalized snakebite cases that proved fatal and were sent for autopsy were 46 (1.8%).

Gender

Out of 46 cases, 33 (72%) were male and 13 (28%) were female. The majority of the victims were male; the male-to-female ratio was 2.53:1. In 2022, there was a maximum fatal snakebite case. The mean of snakebite cases during these 3 years in males and females was 8.25 and 3.25, respectively. The χ^2 test showed degrees of freedom, $p \approx .003$, which was statistically highly significant that indicating less than 0.3% probability that the observed male–female difference occurred randomly (Table 1, Figure 1). This suggests that male predominance in snake bite cases is not due to random variation but likely reflects greater exposure risk. The mean age of snakebite victims in this study was approximately 27 years, indicating that young adults (21–30 years) were the most commonly affected age group, followed by 11–20 years in 10 (22%) cases, and the least was seen in the age group of more than 50 years in 1 (02%) cases (Table 2).

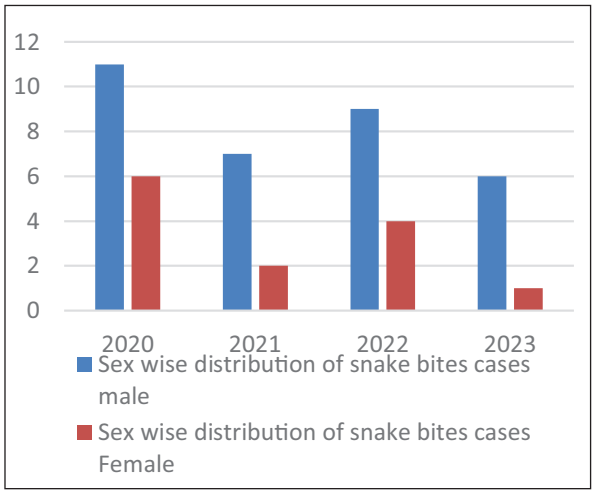

Figure 1. Sex-wise Distribution of Snakebite Cases.

Table 1. Sex-wise Distribution of Snakebite Cases.

Year	Male	Female	Total (Year-wise)
2020	11	06	17
2021	07	02	09
2022	09	04	13
2023	06	01	07
Total	33 (72%)	13 (28%)	46
Mean	8.25	3.25	18.4
Standard deviation	2.21	2.21	4.42
p value χ^2 test		.003 (<.05)	

Table 2. Age Group Distribution.

Age Group	Case	%
0–10 years	02	4
11–20 years	10	22
21–30 years	21	45
31–40 years	08	17
41–50 years	05	10
>50 years	01	2
Mean age group	27 years	

Locality and Season

Forty (87%) were from rural areas and 6 (13%) were from urban areas, indicating that rural populations are at significantly higher risk ($p < .001$) (Table 3). The highest number of snakebite cases (76%) occurred during the rainy season (July–October), followed by summer (19.5%) and winter (4.5%). The predominance of cases during the monsoon period was statistically significant ($p < .001$) when compared to other seasons (Table 4).

Occupation

The majority of snakebite victims were farmers (61%), followed by laborers (17%), housewives (13%), and students (7%). The predominance of farmers indicates that individuals engaged in outdoor and agricultural activities were at a significantly higher risk ($p < .001$) of snakebites (Table 5).

Socioeconomic Status

The snakebite victims mostly belonged to the lower socioeconomic class 26 (56.5%), followed by the lower middle class 11 (23.9%), middle class 7 (15.2%), and upper class 2 (4.3%). The relationship between lower socioeconomic status and higher snakebite incidence was statistically significant ($p < .001$) (Table 5).

Table 3. Distribution of Snakebite Cases According to Area of Occurrence & Manner of Death.

Area of Occurrence		
Area	**Case**	**%**
Rural	40	87
Urban	06	13
Manner of Death		
Manner	**Male**	**Female**
Accidental	36	10
Homicidal	0	0
Suicidal	0	0

Table 4. Season-wise Distribution of Snakebite Victims.

Season	Month	Cases	%
Summer	March to June	9	19.5
Rainy	July to October	35	76
Winter	November to February	2	4.5

Table 5. Occupation and Socioeconomic Status of the Diseased of Snakebite Cases.

Occupation		
	Cases	**%**
Farmer	28	61
Laborer	8	17
Housewife	6	13
Student	3	7
Others	1	2
Socioeconomic Status		
Lower class	26	56.5
Lower middle class	11	23.9
Middle class	7	15.2
Upper class	2	4.3

Pattern of the Bite/Fang Marks

Out of various pattern of bite or fang marks of poisonous snake the most common, two pin point fang marks were present in 36 cases (69.2%), followed by arc pattern in 7 cases (13.5%), scratch mark in 5 cases (9.6%) and rare pattern of absent bite or fang marks in 4 (7.7%) (Table 6).

Site of Bite on Body

Most common bite marks were present over hands, 13 cases (28.2%), followed by feet, 10 cases (21.7%), forearm, 5 cases (10.8%), leg, 7 cases (15.2%), back of body, 4 cases (8.6%), thorax and abdomen, 3 cases (6.5%). In 8.6% of cases, bite marks were not identified (Table 6).

Pattern of Local Changes

Out of various local signs and symptoms after snakebite, necrosis was the most common in 14 cases (30.4%), followed by subcutaneous hemorrhage in 11 cases (23.9%), swelling and cellulitis in 10 cases (21.7%), and bleeding in 6 cases (13%). There were 5 cases (10.8%) in which no local changes were evident (Table 6). The overall site and local changes showed a statistically significant association with occupational exposure and outdoor activity ($p < .001$).

Manner of Death

All snakebite cases were accidental in nature. No homicidal or suicidal cases were observed. Among accidental deaths, males (78%) were more affected than females (22%) (Table 3).

Discussion

In the Indian medico-legal system, deaths resulting from snakebite are considered unnatural, and statutory regulations mandate that such cases must be subjected to medico-legal post-mortem examination.[10] In India, snakebite mortality has historically been predominantly linked to the "Big Four" species, namely the Russell's viper, Indian cobra, saw-scaled viper, and common krait.[11] Venomous snakes are predominantly classified within the families Viperidae (vipers), Elapidae, Atractaspidae, and Colubridae. Among these, Colubridae represents the largest group, accounting for nearly 60% of all snake species. The Atractaspidae, which have more recently been grouped under the Viperidae family, include species adapted for burrowing and are characterized by the unique ability to protrude their fangs laterally without fully opening the mouth.[12] The snakes most commonly associated with human mortality in India are cobra (Najanajanaja), krait (Bungarus caeruleus), Russell's viper (Viperarusselli), and saw-scaled viper (Echiscarinatus).[13] From a clinical perspective, venomous snakes are commonly grouped into hemotoxic types (vipers) and neurotoxic types (cobras and kraits).[14] Snake venom is a complex mixture predominantly composed of proteins and peptides, both enzymatic and non-enzymatic in nature, which collectively account for more than 90% of its dry weight.[15]

Table 6. Site of Bite on Body, Pattern of Bite/Fang Marks, and Pattern of Local Changes at the Site of Bite Mark of Snakebite.

Site of Bite	**Cases**	**%**
Hand	13	28.2
Feet	10	21.7
Forearm	5	10.8
Leg	7	15.2
Back of body	4	8.6
Thorax and abdomen	3	6.5
Absent bite mark	4	8.6
Pattern of Bite/Fang Marks	**Cases**	**%**
2 puncture wounds	36	69.2
Arc pattern	7	13.5
Scratch mark	5	9.6
Absent/no fang marks	4	7.7
Pattern of Local Changes	**Cases**	**%**
Subcutaneous hemorrhage	11	23.9
Bleeding	6	13
Necrosis	14	30.4
Swelling and cellulitis	10	21.7
No change	5	10.8

Clinical manifestations of snakebite in humans vary considerably depending on the species involved, but in general consist of local pain, edema, blistering, and necrosis. Systemic effects of neurotoxic species include blurred vision, ptosis, and respiratory paralysis. Haemostatic toxins, such as the hemorrhagins, cause spontaneous bleeding in the gingival sulci, nose, skin, and gastrointestinal tract. Fatalities result from cerebral hemorrhage or massive retroperitoneal bleeding. Renal involvement in snakebite envenomation may present as glomerulopathy, vasculopathy, tubular necrosis, or interstitial nephritis, and is commonly associated with bites from both hemotoxic and neurotoxic species. Although identification of the offending snake can be valuable for guiding management in certain regions, it is often not feasible in routine clinical practice.[16] The outcome of a snakebite is influenced by multiple variables, such as the species involved, the anatomical site of the bite, the volume of venom delivered, and the individual's underlying health status. In most cases—irrespective of whether the snake is venomous or non-venomous—some degree of local tissue reaction is usually observed.[17]

Snake venom is an extremely complex mixture composed of proteins, peptides, non-protein toxins, lipids, carbohydrates, amines, and various other bioactive molecules. Its biochemical composition demonstrates considerable variability across different taxonomic levels.[18] Furthermore, venom composition may vary substantially among snakes from different geographical regions, and even among individuals within the same population. These biochemical differences may also be influenced by factors such as diet, age, season, and environmental conditions. To some extent, the wide spectrum of clinical manifestations observed following snakebite can be attributed to this complexity and variability in venom composition.[19]

According to the WHO, snakebite is one of the most neglected tropical diseases and primarily affects the rural poor population.[20] In the present study, the male-to-female ratio was 2.53:1, indicating that males were more frequently affected, likely due to greater outdoor occupational exposure. This finding is consistent with previous studies reported from Madhya Pradesh,[21] Maharashtra,[22] and Karnataka.[23]

Although fatal outcomes were observed across all age groups in the present study, the 21–30-year age group was most commonly affected. Similar findings have been reported in earlier studies, in which individuals between 21 and 50 years of age were identified as being at the greatest risk.[24] The marked reduction in fatalities beyond the age of 50 years is likely related to decreased involvement in agricultural activities among older individuals. An additional contributory factor may be reduced outdoor exposure during evening hours in this age group.[25]

Globally, snakebite disproportionately affects populations residing in rural regions.[3,26,27] In the present study, snakebite mortality was approximately 6.6 times higher in rural settings compared to urban areas. Previous literature has reported several contributors to this increased rural mortality, including poorly constructed housing, greater agricultural exposure, preference for traditional healers, and limited accessibility to timely anti-venom therapy.[28]

Most human snakebites occur during the monsoon season because of flooding of the habitat of snakes and their prey. The breeding habits of frogs closely follow the monsoons, and rats and mice are always close to human dwellings.[29] The highest number of cases was recorded during July, August, September, and October, which coincides with the monsoon period in Bihar. In contrast, very few cases were observed during November, December, January, and February, likely due to reduced snake activity and relative hibernation during the winter season.

Hands (28.2%) were the most frequently affected site, followed by feet (21.27%), and this pattern aligns with findings from earlier research.[29–31] This may be attributed to manual field work and barefoot farming during the monsoon season, where poor visibility and the likelihood of accidentally stepping on snakes—especially when fields are abundant with prey—increase the risk of bites. Harrison et al.[9,32] demonstrated a positive association between snakebite envenomation and poverty. In the present study as well, the lower socioeconomic group constituted the majority of victims (56.5%).

Snake poisoning is mostly accidental, 46 (100%); however, homicidal and suicidal snakebites are very rare. In ancient Egypt, snakebite was historically described as a method of execution, where victims were reportedly exposed to venomous snakes intentionally. Homicidal use of snakes has occasionally been documented in literature, wherein an agitated snake was directed toward a victim with harmful intent. However, such cases are extremely rare, and in the published record, only one documented instance exists in which an elderly couple was killed in an attempt to simulate accidental snakebite envenomation.[33] Few cases were reported to commit suicide by snake bite, namely Queen Cleopatra,[34] and others.[35-39]

Bleeding manifestations are frequently observed following bites by viperine species.[40] Local bleeding and swelling are primarily caused by the action of venom enzymes (proteases, phospholipases) and vasoactive toxins, which enhance vascular permeability.[41] Systemic bleeding occurs as a consequence of thrombocytopenia along with an associated defibrination syndrome.[42] Cerebral vascular involvement after snakebite is rare. In a study by Mosquera et al.[43] cerebrovascular complications were documented in 2.6% of 309 cases, predominantly hemorrhagic in nature, with ischemic events being infrequently observed.

Conclusion

Snakebite mainly affects male individuals of low socioeconomic status, particularly those residing in rural areas who are primarily engaged in farming activities. The 21–30 years age group is most challenged, whereas people above 50 years are less affected. Although snakebite incidence fluctuates throughout the year, the majority of cases occur during the rainy season. Public awareness initiatives are essential to encourage victims to seek immediate medical attention at hospitals rather than resorting to traditional healers, so that the crucial initial hours after envenomation can be appropriately utilized at tertiary care centers. Farmers should also be motivated to use protective gear during agricultural activities, and governmental agencies must ensure adequate safety measures for this high-risk group. There is a strong need for the formulation and implementation of a national program for snakebite prevention, focusing on improving quality of care, enhancing health education, providing financial support to reduce dependence on non-mechanized farming practices, and ensuring the implementation of WHO guidelines for snakebite management in the South-East Asia Region.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval and Informed Consent

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ORCID iD

Avinash Kumar https://orcid.org/0000-0001-5613-7557

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A One-year Prospective Study of Epidemiological Profile of Medico-legal Autopsy Cases Conducted at a Center in Chennai

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Sivakumar S[1], Chandrasekar P[1], Ravi Hosaholalu L[2] and Hariharan A[3]

Abstract

Forensic autopsy is of great importance in various processes of the criminal justice system. The death of a person may be natural or unnatural, and autopsy findings have considerable bearing on the legal implications. Trauma resulting from accidents, assaults, and violent asphyxia fatalities is the primary cause of unnatural deaths in India. This was a prospective descriptive study aimed to analyze the epidemiologic profile of medico-legal autopsies (*n* = 1510) conducted at a Government Royapettah Hospital, Chennai, during the year 2024. Natural death was seen in 51.58% (*n* = 779) of cases, with the respiratory system (36.8%) and cardiovascular system (34.7%) involved in most of these cases. Male predominance was observed, and most cases belonged to the age group between 41 and 50 years (*n* = 587), followed by 31–40 years (*n* = 291). Among unnatural deaths (*n* = 731), asphyxia deaths formed the bulk of cases, with 346 cases of hanging and 74 cases of drowning. Other major contributors were road traffic accidents (*n* = 139), followed by falls from height (*n* = 41), poisoning (*n* = 39), and electrocution (*n* = 27). Deaths due to assault, mechanical injuries, and snakebites formed the rest. The results reflected the prevailing mortality pattern in the region. Respiratory and cardiovascular causes formed the bulk of natural deaths. Among the unnatural deaths, a high frequency was noticed in young married males, attributable to various social stressors, family responsibilities, and work conditions. Such deaths could have been prevented or minimized by creating safety awareness and hazard alertness among the population at risk.

Keywords

Autopsy, mortality pattern, forensic medicine, unnatural death

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Introduction

An autopsy is performed to find out whether the cause of death was natural or unnatural and, if unnatural, whether it was homicidal, suicidal, or accidental. In medico-legal autopsies, often the clinical history is absent, sketchy, doubtful, or misleading. If an autopsy is not done, the exact cause of death, the presence and extent of injury or disease, and whether there was any pain and suffering become mere speculations.[1] Autopsy also serves as an important epidemiologic tool to identify potential disease outbreaks and establish risk factors for specific infections. Autopsy findings have served to elucidate the pathogenesis of diseases and to establish the manner of causation of injuries.[2]

Profiling medico-legal autopsies is a vital cog in the fields of public health and forensic medicine, going beyond just recording details of previous incidents to actively averting further casualties. Though the main purpose is to determine the cause of death, it also helps interpret and relate the facts and circumstances surrounding the death, recover and preserve evidence, reconstruct the manner of injuries, provide accurate medical findings, and assist in addressing the

[1]Department of Forensic Medicine, Government Kilpauk Medical College and Hospital, Chennai, Tamil Nadu, India
[2]Department of Forensic Medicine and Toxicology, ACS Medical College and Hospital, Dr M.G.R. Educational and Research Institute, Chennai, Tamil Nadu, India
[3]Department of Forensic Medicine, ACS Medical College and Hospital, Dr M.G.R. Educational and Research Institute, Chennai, Tamil Nadu, India
Corresponding author:
Ravi Hosaholalu L, Department of Forensic Medicine and Toxicology, ACS Medical College and Hospital, Dr M.G.R. Educational and Research Institute, Chennai 600095, Tamil Nadu, India.
E-mail: ravimysor@gmail.com

medico-legal aspects of public safety, public health, and criminal court proceedings.[3]

WHO's Global Health Estimates (GHE) provide the latest available data on causes of death and disability globally, by region and country. The world's biggest killer is ischemic heart disease, responsible for 13% of the world's total deaths. Since 2000, the largest increase in deaths has been for this disease, rising by 2.7 million to 9.0 million deaths in 2021. Lower respiratory infection ranked as the fifth leading cause of death in 2021.[4] Road traffic accidents (RTAs) cause most of the casualties in India, especially among young people. According to the Ministry of Road Transport and Highways (MoRTH), 168,491 persons died in road accidents in India in the year 2022, and Chennai city recorded 499 fatal accidents, which resulted in 504 deaths in 2023.[5]

Different people respond differently to stressful situations, and the responses are determined by genetics, past experiences, personality, social support, access to resources, and cultural background. Life pressures that can overwhelm a person include illness or injury, work pressures or job loss, harassment and traumatic events, financial crises, and family or relationship issues.[6] Suicide by hanging happens to be a top cause of death among youth. As per NCRB data, 1.71 lakh suicide deaths were recorded in the year 2022, indicating an increase of 4.2% over 2021.[7] Not much has been narrated in forensic literature about recent patterns or trends of unnatural deaths in our region. This profiling study enhances the comprehensiveness of mortality statistics by providing important details regarding the cause, age group at risk, manner, and nature of deaths. Monitoring the yearly number and pattern of deaths helps to address the causal factors and adapt health systems to react effectively, triggering responses from multiple sectors.

Aims and Objectives

1. To establish the demographic profile of autopsied cases in terms of age, gender, manner, and cause of death for a one-year period.
2. To assess the pattern of deaths and their distribution based on the main system involved.

Materials and Methods

The present study was an analysis of all medico-legal autopsies conducted at the mortuary of Royapettah Government Hospital in Chennai, during the period of one year, from January 1st, 2024, to December 31st, 2024.

Study Design: Descriptive & Prospective.

Ethical clearance was obtained from the Institutional Ethics Committee. (No. 813 /2023/1EC/ACSMCH, dated April 10, 2023).

About 1,510 cases, which fulfilled our criteria of selection of study cases among the total 1,527 autopsied in the study period, formed the study material. All the cases were evaluated in detail with a medico-legal perspective on various parameters.

Inclusion Criteria

All cases autopsied at the mortuary in the study period of the year 2024, with

- the required demographic data retrievable.
- cause of death ascertainable.

Exclusion Criteria

- All dismembered bodies or mutilated or skeletonized bodies.
- Highly decomposed bodies.
- Unknown bodies with vague history.

Procedure of Data Collection

Preliminary data were collected from the history of the case, and the medico-legal documents, such as the inquest form, first information report, accident register, death report, hospital records/clinical data. Relevant information required for the study was also collected from the investigating police personnel and bystanders of the deceased. The focus of this study was to determine the number and pattern of deaths, their causes, and their distribution age-wise and gender-wise. The type of injuries or pathological lesions, on external/internal organs, if any, their location, size, and number would be noted during autopsy. Based on the history and findings of the autopsy, the cause of death would be determined. Finer details like injury type, the manner of death, and the main organ/system involved (head, neck, thorax and abdomen, and extremities) contributing to the fatality would also be noted in a proforma prepared for the study purpose.

The data was entered in Excel sheets, and statistical analysis was done using IBM SPSS Statistics software version 28.0 to determine the mean, frequency and proportion so that they can be compared with other studies. Cases studied were broadly classified into natural and unnatural deaths, and their individual causes of death were noted down to correlate with the respective case findings.

Observations and Results

Among the study sample of 1,510 autopsies performed during a one-year duration (2024), natural death was observed in 779 (51.58%) of cases, with the respiratory system (36.8%) accounting for the greatest number of these cases. The data is presented in tables as follows.

Table 1 shows the involvement of natural deaths ($n = 779$), of which 552 (36.5%) belonged to the male category and 15% of cases to the female gender. Among unnatural deaths ($n =$

Table 1. Broad Categorization of Cases According to the Nature of Deaths.

Mode of Deaths	Male	Female	Number and Percentage
Natural deaths	552 (36.5%)	227 (15.0%)	779 (51.5%)
Unnatural deaths	595 (39.4%)	136 (9.1%)	731 (48.5%)
Total	1,147 (75.9%)	363 (24.1%)	1510

Table 2. Distribution of Natural Death (ND) Causes (n = 779).

Main System Involved	Cause of Death: Disease/Pathology in ND	No. Cases	Sum	%
Respiratory system	Pneumonia and respiratory failure	203	287	36.84
	Diseased lung-ARDS/ALI/Pulmonary embolism/Pulmo. hemorrhage/edema.	61		
	Lung mass: Carcinoma/Infections (TB, Sarcoidosis, others)	17		
	Others: Choking, asthma/COPD	06		
Cardiovascular & blood	Myocardial infarctions/ACS	189	271	34.78
	Pericarditis/Myocarditis/Cardiomyopathies: (HOCM, Dilated Myopathy/HHD)	40		
	Heart rupture/Cardiac tamponade/dissection of Aorta	19		
	Others: Coronary occlusion, congenital anomalies/septal defects	23		
Septic shock	Multi-organ failure-MODS/post-systemic illness/wound-infection/ Necrotizing fasciitis, diabetes, urosepsis, post-surgery	135	135	17.33
GIT and urogenital system	Liver related (Hepatitis, cirrhosis, Hepatic failure/encephalopathy)	22	41	5.26
	Pancreatitis (acute/chronic)/Peritonitis/Hemoperitoneum	10		
	Others: GI/Colon bleed, GI Perforation/GI malignancy, nephritis, uterine bleeding	09		
CNS	CVA (Stroke), ICH/IVH/SAH/embolism	21	29	3.72
	Tumors/metastasis/epilepsy (edematous brain)	5		
	Infection (Meningo-encephalitis), HIV, etc.	3		
Others	Stillbirth, senility, acute anaphylaxis	3	3	0.38
Obscure	Undetermined/inconclusive	13	13	1.66
Total		**779**	**779**	**100**

Note: ALI = Acute lung injury, HOCM = Hypertrophic obstructive cardiomyopathy, HHD = Hypertensive heart disease, CVA = Cerebro-vascular accident, ICH = Intra-cerebral hemorrhage, IVH = Intra-ventricular hemorrhage, SAH = Sub-Arachnoid hemorrhage.

731), 595 cases (39.4%) were accounted for by men, indicating the male predominance.

Table 2 comprehensively shows the system primarily involved in natural deaths. Most cases had involved either the respiratory and cardiovascular systems or both, accounting for almost 70% of the natural deaths. The multi-organ failure was the reason in 17% of cases, and 13 cases remained undetermined as obscure autopsies.

Male subjects constituted 75.9% of cases overall, with a male-to-female ratio of 3.25:1. Table 3 shows that the maximum number of cases belonged to the age group of 4th and 5th decades of life. From the study sample, 587 cases were from the age group 41 to 50 years, followed by 31–40 years (291 cases), and males have always outnumbered the females across all age groups.

Table 4 shows that asphyxia-related deaths (48%) accounted for maximum deaths, followed by RTAs (19.2%), falls from height (5.6%), and poisoning (5.4%).

Table 5 shows there were only 10 cases (0.71%) from railway injuries, followed by mechanical asphyxia (n = 5, 0.35%), and only two cases of snake bite and firearm injuries each that were autopsied.

Table 6 showed that the number of traffic-related deaths was 149 (9.8%) of the study sample, and two-wheelers were involved in over 50% of cases of RTA, while four-wheelers were responsible for over 22% of fatalities.

Table 3. Distribution of Cases According to Age and Gender (*n* = 1510).

	Male		Female			
Age Group (in Years)	**ND**	**Un-D**	**ND**	**Un-D**	**Total**	**%**
1–10	02	05	01	3	11	0.73
11–20	07	37	06	10	60	3.97
21–30	31	55	16	21	123	8.15
31–40	69	151	42	29	291	19.27
41–50	214	243	87	43	587	38.87
51–60	101	51	39	15	206	13.64
61–70	98	47	22	10	177	11.72
71–80	22	05	11	03	41	2.72
80 & above	08	01	03	02	14	0.93
Total	**552**	**595**	**227**	**136**	**1510**	**100**

Note: ND = Natural death, UnD = Unnatural death.

Table 4. Distribution of Unnatural Death Cases (*n* = 731).

Cause of Death	**Male**	**Female**	**Total**	**%**
Hanging	286	60	346	47.33
Road traffic accidents (RTA)	128	11	139	19.01
Drowning	68	6	74	10.12
Fall from height	34	7	41	5.61
Poisoning	04	35	39	5.38
Electrocution & burns	28	08	36	4.92
Murder/Assault	21	05	26	3.52
Miscellaneous	26	4	30	4.08
Total	**595**	**136**	**731**	**100**

Discussion

City of Chennai, often called the "Detroit of India," is a major industrial hub in India, especially for the automotive industry. It is also known for its software exports, medical tourism, textiles and apparel, petrochemicals, and hardware manufacturing. Thus, it has led to rapid urbanization and migration of workers into the city. Chennai is the third most densely populated city in India, with 26,903 people per square kilometer,[8] which could be one of the reasons behind a high all-cause mortality rate in the region.

In the present study, natural deaths (*n* = 779) outnumbered unnatural deaths (*n* = 731). Among the cardiac causes, coronary artery disease/myocardial infarction was the most common cause, while pneumonia and other chest infections were predominantly observed among the respiratory causes. Among the gastrointestinal (GIT) causes, both acute & chronic liver diseases were reported in most cases, followed by pancreatitis and peritonitis. These findings suggest that GIT conditions should be taken seriously, though the patient might look alright and stable. This study contrasted with a study by Patel JB et al.,[9] which showed the natural type of death in only 21.65% of cases, with predominance of respiratory system-related deaths.

In the present study, the maximum number of cases was males (75.9%) as compared to females (24.1%). Similar findings were reported by Sundarm et al.[10] and Dayanand et al.[11] This was attributed to the fact that males are more involved in outdoor activities and ambulatory compared to females, which makes them more vulnerable to accidents or injuries. Most cases in our study belonged to the age group of 41–50 years (*n* = 587) in both genders, followed by the age group of 31–40 years (*n* = 291). This finding was in slight contrast with a study by Patel et al.,[9] which had the maximum number of cases (615, 28.3%) in the age group of 21–30 years, and injury-related deaths were more in number (989, 45.6%). However, a few studies[11,12] differed claiming that many deceased individuals were in their 3rd decade, followed by their 4th decade.

Table 4 shows the magnitude of both natural and unnatural causes of death, inclusive of the various causes and nature of deaths. Regarding the primary cause among natural deaths,

Table 5. Distribution of Miscellaneous Cases (*n* = 30).

No.	Pattern of Cases	Male	Female	Total
1	Train traffic (railway incidents)	7	3	10
2	Wall collapse (mechanical asphyxia)	5	–	5
3	Accidental cut (mechanical injury)	2	–	2
4	Self-fall	8	1	9
5	Snake bite	2	–	2
6	Gunshot injury	2	–	2
	Total	**26**	**4**	**30**

Table 6. Distribution of Traffic-related Cases (*n* = 149, Road = 139 and Railway = 10).

Sl. No.	Type of RTA Cases	No. of Cases	%
1	Pedestrian	11	07.3
2	2-wheeler & auto	79	53.0
3	4-wheeler	33	22.1
4	Truck/heavy vehicle	16	10.7
5	Train traffic (railway)	10	06.7
	Total	**149**	**100**

most cases belonged to respiratory causes (36.8%) and the cardiovascular system (34.7%), followed by multi-organ failure (17%) in our study. This finding was consistent with a study by Rahul Agarwal et al.[13] in which cardiac and lung pathologies were the major causes, followed by intracranial hemorrhages. People in middle age groups are more exposed to environmental factors because they must go to work for a living, travel, and participate more in sports and outdoor activities.

Regarding causes of unnatural deaths, the maximum number was contributed by hanging (*n* = 346), trauma in RTAs (*n* = 139), and drowning (*n* = 74). Poisoning cases (*n* = 39), burns including electrocution (*n* = 36), and train traffic accidents (*n* = 10) were the other events leading to deaths. The hanging cases proportion was around 10%–12% of the cases in some studies.[13,14] But a study. by Biradar G et al.[15] revealed a higher prevalence of hanging, with 39% of the cases found among the persons aged 31–40 years, and male dominance was observed at 66%. This can be attributed to the observation that female victims tended to suffer from somatic or mental illnesses, whereas male victims were more likely to have financial stresses or experience marital problems. In addition to chronic alcoholism, chronic illness also acts as a major risk factor for suicide in the middle-aged group.

Our study differed from a study from Jaipur,[16] which reported that 47.24% of the autopsy cases in the year 2021 were related to RTAs. Among them, 85% of cases were male victims, and most of them were between 21 and 40 years of age. Almost 25% of them were brought dead when they arrived at the emergency department within 6 hours of the event. Our study found that two-wheelers accounted for more than 50% of cases, while four-wheelers contributed to about 22% of road fatalities. This finding was in accordance with Saini et al.[16] and Sahu et al.[17] The deaths due to RTAs were 82 (52.5%), followed by natural death with 27 cases (17.3%) in their study. But our study contrasted with the study by Pati et al.,[18] which attributed only 13.1% of deaths to RTAs in Brahmapur, and 75% of them had died of head injuries.

Drowning is the third leading cause of unintentional injury death worldwide, claiming about 236,000 lives each year. Drowning cases (10.2%) in this study, too, kept third place in the table of unnatural deaths, which has been reflected in many studies in South India. But a study in Jammu[19] found a greater number of drowning cases in lakes/rivers (*n* = 60), 24 in house tanks, than in wells and swimming pools (*n* = 12 and 4). Drowning was more frequently observed in men than women, except for suicide, where there is not much of a difference between genders. India is a vast country having plenty of water bodies like rivers, ponds, lakes, wells, house tanks, septic tanks, swimming pools, etc. Proper fencing of pools and the use of life jackets can prevent drowning during water activities, especially boating and swimming. It is noteworthy that, in a study by Patel JB[9] thermal injuries accounted for 12.5% of cases, followed by poisoning (8.5%), which contrasts with our study, where both burns and poisoning accounted for about 5% of cases each. Only two cases of death from gunshot injuries and snake bites were brought for autopsy.

In the present study, 39 cases (5.38%) of poisoning were found, and most of them had consumed pesticides and rodenticide poisons, which are common household poisons. This finding matches the study of Goswami et al.[20] who

found that organophosphates (OP) were the main compound found in 151 (61.9%) fatal cases, followed by carbamate in 45 (18.4%) cases. But a few studies in India have shown a prevalence of 10%–15% of fatal poisoning cases among the overall autopsies. Gunjan NK et al.[21] in Delhi identified that most patients died within 2 hours of poison consumption (60.31%); only 6% survived for more than 24 hours. Most cases were suicidal (77.7%), and organophosphorus (54.76%), aluminum phosphide (28.57%), and alcohol (8.73%) were the common poisons noted in chemical analysis reports. Pesticides are the leading cause of poisoning in India due to factors such as an agriculture-based economy, poverty, unsafe practices, illiteracy, and ignorance. They are frequently utilized as suicide tools owing to their easy accessibility, affordability, and deadly properties. Less than 2% of cases (n = 26, 1.72%) were homicidal in nature in our study, which aligns with a study in Ambala (n = 18, 2.24%) by Mann GR.[22] This indicated a relatively lower murder rate in these regions when compared to the study in Nellore, Andhra Pradesh,[23] which had 39 homicides (4.32%) among the 902 cases autopsied in 2019.

Conclusion

Profiling of the autopsies plays an important role in assembling mortality-related statistics, which bear social and legal implications. An autopsy surgeon is expected to be aware of the pattern and quantum of regional medico-legal cases and deaths, as he needs the skill and knowledge to differentiate between natural deaths and unnatural fatalities. This research tried to analyze the various types of medico-legal autopsy cases that occur in a region of Chennai city. Accidental deaths, followed by suicidal deaths, have become the primary causes of mortality among today's adolescents and youth. Natural deaths continue to be the leading cause in the middle-aged and elderly populations. In the present study, lung infections and coronary syndromes were identified as the two major contributors to natural deaths, while hanging and RTAs were the leading causes among unnatural fatalities. It is regrettable to observe that a high number of fatalities were caused by RTAs and in the form of suicides, which were largely and practically preventable deaths.

Hanging, drowning, and poisoning should be considered major public health problems in India. Awareness programs about the risk factors of accidents and suicides, and strict enforcement of law and order, will help in reducing unnatural death rates. Employing evidence-based strategies like restricting access to lethal methods and recognizing depression, both at the individual level and the population level, should be the main emphasis of suicide prevention. Our study findings offer insights to policymakers and administrative authorities, prompting them to examine the specific elements of these cases and implement measures that benefit the community and the public at large.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval and Informed Consent

The study had obtained an approval from the Institutional Ethics Committee (No.813/2023/IEC/ACSMCH, dated 10/04/2023) and faced no issues with informed consent.

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ORCID iD

Ravi Hosaholalu L https://orcid.org/0009-0000-3206-6520

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Estimation of Stature from Foramen Magnum Dimensions in a Western Indian Population: A Medicolegal Autopsy Study*

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Sachin Sudarshan Patil[1], Vina Vaswani[2] and Ravindra B Deokar[3]

Abstract

Stature estimation is an essential component of forensic anthropology, aiding in personal identification from skeletal remains. While appendicular skeleton measurements are commonly used, in cases of mutilation or trauma, alternative reliable indicators such as the foramen magnum (FM) become crucial. To determine the correlation between stature and the dimensions of the FM and to derive regression equations for stature estimation in the Western Indian population. This prospective observational study was conducted on 106 medicolegal autopsies (76 males and 30 females) in a tertiary care center in Mumbai. Cadaveric stature was measured in the supine position. Anteroposterior (AP) and transverse diameters of the FM were measured post-brain removal using vernier calipers. Data were analyzed using SPSS v17.0 to derive regression equations. Strong positive correlations were observed between FM dimensions and stature in both sexes. In males, AP and transverse lengths showed very strong correlations ($R = 0.89$ and $R = 0.91$, respectively), while in females, correlations were slightly lower ($R = 0.84$ and $R = 0.75$). Regression equations were derived for each sex. The FM offers a valuable parameter for stature estimation, especially in cases involving fragmented or mutilated remains. This study provides population-specific regression equations useful for forensic investigations in the Western Indian population.

Keywords

Stature estimation, foramen magnum, forensic anthropology, sex characteristics, skull base, regression analysis

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Introduction

Stature is one of the vital parameters in forensic analysis, useful for personal identification. Numerous methods have been employed for estimating stature from skeletal remains, using both anatomical and mathematical approaches. Previous studies suggest considerable correlations between measurements of the bones of the appendicular skeleton and stature. Even then, it is essential to ascertain regression formulas using other parts of the skeleton, because there are conditions in which the limb bones are not offered in criminal cases.[1]

The possibility of survival of the basal region of the occipital bone due to mechanical trauma is greater than the other parts of skull. This could be due to maximum soft tissue covering as well as more skull thickness in this part, and its comparatively more sheltered anatomical position. Therefore, even in cases of rigorous injury, base of skull can be available intact, which can serve as an important clue in identification.[2] The foramen magnum (FM) is a significant signpost of the base of the skull and can contribute intensively to stature estimation related to identification and various anthropological studies. In spite of this, very less research work in this relation has been conducted so far in relation to stature estimation.[3]

Considering the structural integrity of base of skull, this parameter can be well preserved even in cases of bomb explosions, aircraft accidents and fire tragedies.[4–12] These important markers can dole out as a funnel for stature estimation.

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[1]Seth G.S. Medical College and KEM Hospital, Mumbai, Maharashtra, India
[2]Yenepoya Medical College (Deemed to be University), Mangaluru, Karnataka, India
[3]Lokmanya Tilak Municipal Medical College and General Hospital, Mumbai, Maharashtra, India

Corresponding Author:
Sachin Sudarshan Patil, Seth G.S. Medical College and KEM Hospital, Mumbai, Maharashtra 400022, India.
E-mail: sspfmt7@gmail.com

No such study has been carried out in the western part of India for stature estimation using dimensions of FM. The majority of the studies conducted on FM are for the estimation of sex of the individual.

Hence, this study is carried out to derive an influential relationship between stature of an individual and the dimensions of FM and also to discover the regression equations for the estimation of stature from FM measurements. We can expect that this study will enhance available knowledge and serve as an incitement to future researchers conducting studies in this area, and will also help forensic experts in the field of identification.

Study Objective

1. To determine the correlation between the stature of the individual and dimensions of FM.
2. To derive a regression equation for estimating stature from FM dimensions.

Material and Methods

The research study was conducted in the Department of Forensic Medicine and Toxicology in a tertiary health institution in Western India. A study was conducted on a minimum of 106 individuals, comprising 76 males and 30 females. The birthplace of the deceased will also be obtained from the relatives of the deceased.

Study Design

Prospective observational study.

Inclusion Criteria

Dead bodies of individuals above 25 years of age and individuals born and raised in the Mumbai region are brought to the post-mortem center at this hospital for medicolegal autopsies.

Exclusion Criteria

1. Dead bodies of people aged less than 26 years.
2. Decomposed, mutilated, burnt/charred bodies and those with morphological abnormalities.
3. Deceased with rickets or other bony diseases.

Measurement of stature was done from the vertex of the head and the heel, with cadaver placed in a supine position, with a steel measuring tape to the nearest 0.1 cm, as shown in Figure 1. After removal of brain and dura mater attached to base of skull, measurements of FM were done using vernier calipers as follows.

1. Maximum anteroposterior length (APL) along the sagittal line, that is, the distance between basion and opishthion. Basion and Opisthion are the points in the midsagittal plane intersecting the anterior margin and the posterior margin of the FM, respectively, as shown in Figure 2.
2. Maximum breadth or transverse length (TL) along coronal line- distance between the lateral margins of FM at the point of maximum lateral curvature as shown in Figure 3.[13]

Due precaution was taken to remove soft tissues and expose the bone to prevent errors in measurements. To avoid intra-observer error, two repeated measurements were done, and the average of the two was considered for calculation. If the error is more than 0.1 mm, then a third measurement is done.[3]

Analysis of data was done using SPSS for Windows v17.026 to develop a linear regression equation for stature assessment from the dimensions of FM. Also, the strength of association of stature with dimensions of FM was compared between males and females. IEC (Institutional Ethical Committee) approval was taken before starting the study.

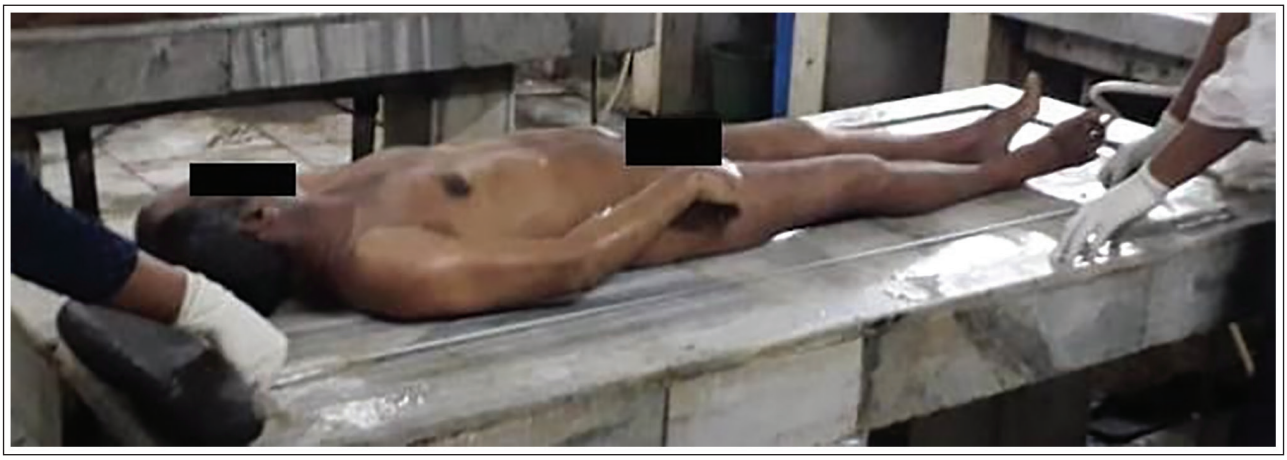

Figure 1. Showing Measurement of Cadaveric Length (Stature).

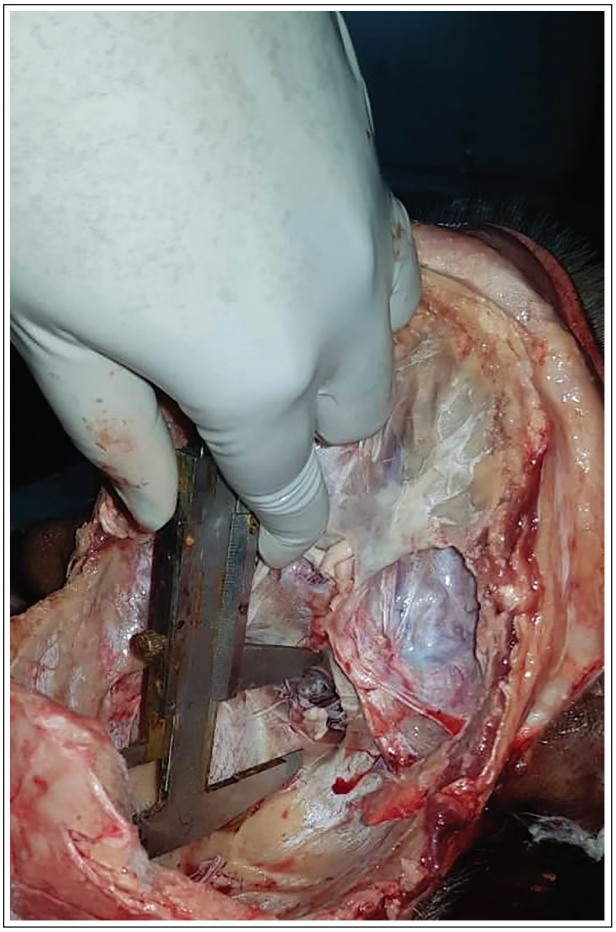

Figure 2. Showing Measurement for APL of Foramen Magnum.

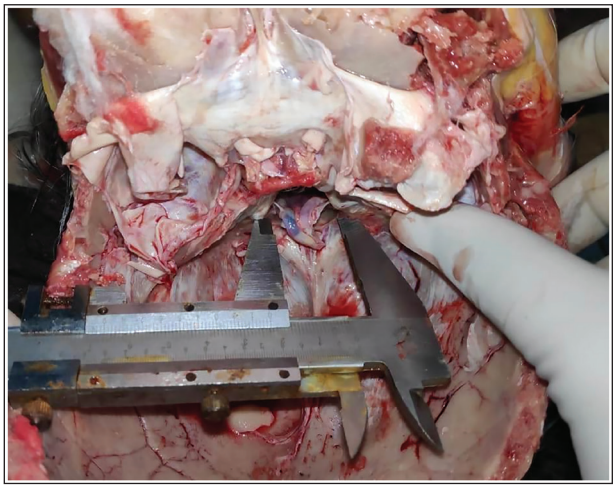

Figure 3. Showing Measurement for TL of Foramen Magnum.

Observation and Results

The present study was carried out in the Department of Forensic Medicine and Toxicology, a tertiary care hospital in western India. Total of 106 cases were studied for the estimation of stature from the dimensions of FM. Out of the total cases, 76 (71.7%) cases were of males, while 30 (28.3%) cases were of females.

The maximum number of cases was between ages 26 and 40 years in males and females, while the lowest numbers of cases were in age groups older than 70 years.

Descriptive statistical analysis of the Dimensions of FM in cadavers in relation to stature in females is as follows:

Stature in females ranged from 147 cm to 172 cm, with a mean (±SD) was 155.93 cm (±7.99 cm), and a 95% confidence interval of the mean was ±2.982. The mean APL of FM was 3.17 cm and (±SD) was (±0.37), ranging from 2.8 cm to 3.9 cm, while the 95% confidence interval of the mean was ±0.139. The mean TL of FM was 2.75 cm and (±SD) was (±0.26), ranging from 2.5 cm to 3.4 cm, while the 95% confidence interval of the mean was ±0.098.

Descriptive statistical analysis of the Dimensions of FM in cadavers in relation to stature in males. It is as follows:

Cadaveric length (stature) in males ranged from 147 cm to 180 cm, with a mean (±SD) was 164.24 cm (±7.66 cm) and a 95% confidence interval of the mean was ±1.750. The mean APL of FM was 3.39 cm and (±SD) was (±0.42), ranging from 2.8 cm to 4.2 cm, while the 95% confidence interval of the mean was ±0.095. The mean TL of FM was 2.91 cm and (±SD) was (±0.22), ranging from 2.5 cm to 3.3 cm, while the 95% confidence interval of the mean was ±0.051.

A simple regression formula was obtained to estimate stature from the dimensions of FM in males and females (Table 1). Strength of correlation for the dimensions of FM with Stature varies between males and females. The strength of correlation varies from moderate positive correlation to very strong positive correlation. Correlation coefficient or Pearson coefficient value (*R*) for Females was 0.84 and 0.75 for AP length and TL of FM, while it was 0.91 and 0.64 for AP length.

Similarly, the *R* value in males was 0.89 and 0.91 for APL and TL of FM, while it was 0.89 and 0.75 for APL.

Overall, the strength of correlation was better in males compared to females.

In males, a very strong positive correlation was observed with TL of FM, while the other three dimensions showed a strong positive correlation.

Both the dimensions of FM showed a strong positive correlation with the cadaveric length. The standard error of estimate for females was 4.47 and 5.42 for AP length and TL of FM.

Similarly, the *R* value in males was 3.57 and 3.14 for AP length and TL of FM.

Discussion

The number of cases in the present study was almost similar to Gruber et al. (2009) (03), Radhakrishna et al.[14] and Ukoha et al.,[15] while the method, that is, on medicolegal autopsy, was similar to Babu et al.[16]

Distribution of the Stature of Male and Female

As per Table 2, Stature in females ranged from 147 cm to 172 cm, with a mean (±SD) was 155.93 cm (±7.99 cm) and a 95% confidence interval of the mean was ±2.982. As per Table 3, Stature in males ranged from 147 cm to 180 cm, with a mean (±SD) was 164.24 cm (±7.66 cm), and a 95% confidence interval of the mean was ±1.750.

The above findings were almost similar to Cui and Zang's[1] study in China, which showed the mean stature of the cadaver was 165.22 cm in North Chinese males and 161.01 cm in South Chinese males. Babu et al.[16] stated the mean stature of the population of Mangalore as 166.66 cm in males, which is almost similar to the present study.

Distribution of APL and TL of FM of Males

The mean APL of FM was 3.39 cm and (±SD) was (±0.42), ranging from 2.8 cm to 4.2 cm, while the 95% confidence interval of the mean was ±0.095. The mean TL of FM was 2.91 cm and (±SD) was (±0.22), ranging from 2.5 cm to 3.3 cm, while the 95% confidence interval of the mean was ±0.051 as given in Table 3.

Table 1. Detailed Regression Statistics Showing Correlation of Dimensions of Foramen Magnum in Males and Females.

Group	Parameter	Length	Regression Formula	*R*	*R*2	Adjusted *R*	Standard Error
Females	Foramen Magnum	APL	$y = 17.69\times + 99.82$	0.84	0.70	0.69	4.47
		TL	$y = 22.39\times + 94.31$	0.75	0.56	0.55	5.42
Males	Foramen Magnum	APL	$y = 16.34\times + 108.8$	0.89	0.79	0.79	3.57
		TL	$y = 31.21\times + 73.43$	0.91	0.84	0.83	3.14

Table 2. Comparison of APL and TL of Foramen Magnum with Other Studies in Males.

Sr. No.	Study	Sample Size	Population	Method	Mean APL (CM)FM and *R* Value	Mean TL (CM) FM and *R* Value
1	Cui and Zang[1]	276	Chinese	Dry skulls, Skeletons	3.57	3.03
					R = 0.328	*R* = 0.124
2	Gruber et al.[3]	111	Central European	Dry skulls, Skeletons	3.66	3.11
					R = 0.28	*R* = 0.25
3	Babu et al.[16]	51	Mangalore, Karnataka	Medicolegal autopsy	3.894	3.317
					R = 0.136	*R* = 0.956
4	Deshmukh et al.[17]	40	Nanded, Maharashtra	Anatomy dept, Dry skulls	3.4	2.9
5	Shepur et al.[18]	100	Davangere, Karnataka	Dry skulls	3.34	2.85
		15		CT images (living subjects)	3.85	2.91
6	Kumar et al.[19]	19	Sohar, Oman	Dry skulls	3.678	3.005
7	Jain et al.[20]	38	North India	Dry skulls	3.69	3.15
8	Radhakrishna et al.[14]	55	Mangalore, Karnataka	Dry skulls	3.404	2.863
9	Ukoha et al.[15]	90	Nigeria	Dry skulls	3.626	3.439
10	Shaikh et al.[21]	77	Maharashtra, Andhra Pradesh, Chhatisgarh, Karnataka	Dry skulls	3.515	2.938
11	Gilbe et al.[22]	81	Central India	Medicolegal autopsy	3.1*R* = 0.69	2.9*R* = 0.7
12	Karthi et al.[23]	57	New Delhi	PM CT images	3.95*R* = 0.69	3.36*R* = 0.61
11	Present study	76	Mumbai region (Coastal Maharashtra)	Medicolegal autopsy	3.39	2.91
					R = 0.89	*R* = 0.91

Table 3. Comparison of APL and TL of Foramen Magnum with Other Studies in Females.

Sr. No.	Study	Sample Size	Population	Method	Mean APL (CM) FM	Mean TL (CM) FM
1	Deshmukh et al.[17]	34	Nanded, Maharashtra	Anatomy dept, Dry skulls	3.4	2.8
2	Shepur et al.[18]	50	Davangere, Karnataka	Dry skulls	3.31	2.73
		15		CT images (living subjects)	3.52	2.76
3	Kumar et al.[19]	17	Sohar, Oman	Dry skulls	3.322	2.949
4	Jain et al.[20]	30	North India	Dry skulls	3.29	2.95
5	Radhakrishna et al.[14]	45	Mangalore, Karnataka	Dry skulls	3.172	2.659
6	Ukoha et al.[15]	10	Nigeria	Dry skulls	3.439	2.816
7	Shaikh et al.[21]	34	Maharashtra, Andhra Pradesh, Chhattisgarh, Karnataka	Dry skulls	3.49	2.89
8	Gilbe et al.[22]	55	Central India	Medicolegal autopsy	2.7 $R = 0.45$	2.6 $R = 0.65$
9	Karthi et al.[23]	43	New Delhi	PM CT images	3.4 $R = 0.62$	2.91 $R = 0.6$
8	Present study	30	Mumbai region (Coastal Maharashtra)	Medicolegal autopsy	3.17	2.75

Mean APL of FM in males in the present study were in accordance with studies of Deshmukh et al.,[17] Shepur et al.,[18] (dry skulls study) and Radhakrishna et al.[14] While it was slightly on the lower side as compared to the findings of Shaikh et al.[21]

Similarly, findings obtained in the present study of mean APL of FM in males were not consistent with the studies of Gruber et al.,[3] Babu et al.,[16] Shepur et al.[18] (CT Images Living subjects), Kumar et al.,[19] Jain et al.,[20] Cui and Zang,[1] Gilbe et al.,[22] Karthi et al.,[23] and Ukoha et al.[15]

Differences in the findings of various studies could be due to environmental variations, genetic differences and nutritional factors, as the study conducted by Gruber et al. was done in central Europe, Cui and Zang[1] in China, Babu et al.[16] in Mangalore, Karnataka, Kumar et al.[19] in Oman, Jain et al.[20] in North India and Ukoha et al.[15] in Nigeria. A study conducted by Shepur et al.[18] was done on Living subjects by Computed Tomography examination could be a factor responsible for the difference in findings, as in the same study conducted on dry skulls, findings obtained match with the findings in the present study.

Mean TL of FM in males in the present study were in accordance with studies of Deshmukh et al.,[17] Gilbe et al.[22] and Shepur et al.[18] (CT images study). While it was more or less similar to findings of Radhakrishna et al.,[14] Shepur et al.[18] (dry skulls), and Shaikh et al.[21]

Similarly, findings obtained in present study of mean TL of FM in males were not consistent with the studies of Cui and Zang,[1] Gruber et al.,[3] YP Raghavendra Babu et al.,[16] Kumar et al.,[19] Jain et al.,[20] Karthi et al.,[23] and Ukoha et al.[15] Difference in the findings with various studies could be due variations in environmental conditions, genetic, nutritional factors and difference in sample size.

In the current study *R* value in Males for APL and TL of FM was 0.89 and 0.91. Both the dimensions had having strong positive correlation with stature, but the TL had having more strong positive correlation with stature as compared to the APL. In a study done by Gruber et al.,[3] sagittal ($R = 0.28$) and transverse diameters ($R = 0.25$) and in a study performed by Cui and Zang,[1] with *R* values for APL and TL is 0.328 and 0.124, showed weak correlation with stature. Both the dimensions in both the studies had having very weak positive correlation, which is inconsistent with the present study. Also, the sagittal diameter had having slightly better correlation than the transverse diameter, which is also not consistent with the present study.

Similarly, in the YP Raghavendra Babu et al.[16] study, R value for APL and TL of FM was 0.136 and 0.956. TL was showing a strong positive correlation, while APL was showing a very weak positive correlation with stature. This shows that only TL of FM can be used as a reliable indicator for stature estimation, which is partly compatible with our study, where both dimensions were strongly positive. A study done by Gilbe et al.[22] showed a moderately positive correlation, where TL had having better correlation compared to AP length, which is opposite to the study done by Karthi et al.[23]

The mean APL of FM was 3.17 cm and (±SD) was (±0.37), ranging from 2.8 cm to 3.9 cm, while the 95% confidence interval of the mean was ±0.139. The mean TL of FM was 2.75 cm and (±SD) was (±0.26), ranging from 2.5 cm to

3.4 cm, while the 95% confidence interval of the mean was ±0.098 as given in Table 3.

Mean APL of FM in females in the present study were exactly similar to the study of Radhakrishna et al.[14] While it does not match with the rest of the studies. Differences in the findings of various studies could be due to environmental variations, genetic differences and nutritional factors and differences in sample size.

Mean TL of FM in females in the current study were in agreement with studies of Shepur et al.[18] While it was slightly less compared to findings of Deshmukh et al.[17] and Ukoha et al.[15]

Similarly, findings obtained in present study of mean TL of FM in females were inconsistent with the studies of Cui and Zang[1] Gruber et al.,[3] Babu et al.,[16] Kumar et al.,[19] Jain et al.,[20] Radhakrishna et al.,[14] Gilbe et al.,[22] Karthi et al.,[23] and Shaikh et al.[21] Difference in the findings with various studies could be due variations in environmental conditions, genetic, nutritional factors and difference in sample size.

Limitations of the Study

In the current study, the sample size was restricted, especially in the case of females. Therefore, stature estimation from FM dimensions to be carried out with vigilance. The current study will be applicable for stature estimation from FM dimensions in the population of coastal Maharashtra and cannot be loosely used for the pan-India population. The utility of the current study for stature estimation is constrained to mutilated remains for autopsy and to be used with skeletal remains with caution.

Conclusion

Although the appendicular skeleton is conventionally used for stature estimation, forensic situations often present only fragmented remains. The FM, owing to its anatomical protection and high survival rate even in mutilating trauma, offers a robust parameter. However, its potential remains underexplored in the Indian context, particularly in the Western coastal population. "This study demonstrates that the FM, especially its transverse diameter, can be a reliable parameter for stature estimation in forensic cases where traditional bones may be unavailable." The strong correlation, particularly in males, supports its use in medicolegal identification in Western Indian populations. Further studies with larger, more diverse populations and advanced imaging can help refine these findings for broader forensic application.

Abbreviations

APL: Anteroposterior length
TL: Transverse length
FM: Foramen magnum

Authors Undertaking

We confirm that the information provided above is correct. I/We confirm that I/we have contributed sufficiently as per the ICMJE guidelines to be eligible for authorship in the submission made to IJME, and state that I/each of us am/is equally responsible and accountable for the entire content of the submission. We also state that the submission is our original work and is free of plagiarism of any kind.

Declaration of Conflicting Interests

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Ethics Approval and Informed Consent

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ORCID iD

Ravindra B Deokar https://orcid.org/0000-0003-1539-1035

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Determination of Sexual Dimorphism from Fingerprint Ridge Density Among Indian Tamil Ethnic Group: A Forensic Perspective

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Priyanka R[1], Swethaa S[2] and Srimitha RS[2]

Abstract

Fingerprint evidence is one of the most reliable biometric tools in forensic identification due to its uniqueness and permanence. Fingerprints are frequently encountered at crime scenes in both partial and complete forms. An emerging morphological feature of interest is fingerprint ridge density, defined as the number of ridges within a specified area of the fingerprint. The present study aimed to evaluate sex-based differences in fingerprint ridge density across three anatomical regions of the fingerprint: Radial (R), ulnar (U), and lower (L) in the Indian Tamil population. The study was conducted on 274 individuals (137 males and 137 females) aged between 18 to 60 years. Fingerprints were collected from all 10 fingers of each participant. Ridge density was measured in three defined regions of the fingerprint: R, U, and L areas. Statistical analysis was carried out using the independent *t*-test to compare ridge density values between males and females in each region. The findings revealed that females exhibited significantly higher ridge density than males across all three regions of the fingerprint. Among the studied regions, the L area demonstrated the highest mean ridge density, followed by the R and U regions. These differences were consistent across both hands and all fingers, although slight variations were observed in a few anatomical areas. Overall, the results strongly indicated the presence of sexual dimorphism in fingerprint ridge density. The study concludes that fingerprint ridge density is a reliable morphological parameter for sex differentiation in the Indian Tamil population, with females consistently showing higher ridge density than males. The L region of the fingerprint was found to be the most dependable area for distinguishing sex.

Keywords

Fingerprint ridge density, sex determination, forensic identification, sexual dimorphism, fingerprints

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Introduction

Dermatoglyphics has been used for a very long time as an important morphological trait for the purpose of individual identification. It is based on the study of the patterns on our hands and feet, which are unique, hereditary, and stable throughout life, making them extremely useful for both forensic and medical fields.[1] Fingerprints are formed by ridges and furrows during the intrauterine period of fetal development. Fingerprints are unique in nature for each individual and are permanent throughout human life. They are considered the most potent evidence encountered in all types of crimes.[2] Dactyloscopy is the study of fingerprint ridges, types, and patterns to identify an individual.[3] Law enforcement has been utilizing fingerprints as conclusive evidence for individual recognition for more than a century. Ridge counting and ridge characteristics are usually studied by fingerprint examiners during the comparison of fingerprints obtained from suspects with questioned prints recovered from crime scenes. Therefore, these characteristics of fingerprints have been widely studied by researchers and analysts for personal identification. The ridges of the fingerprint also play a vital role in the identification of gender based on ridge density.[4]

[1]Division of Forensic Science, Faculty of Allied Health Sciences, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India
[2]Division of Forensic Science, Department of Allied Health Sciences, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India

Corresponding author:
Priyanka R, Division of Forensic Science, Faculty of Allied Health Sciences, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu 600116, India.
E-mail: priyanka@sriramachandra.edu.in

Ridge density, or the number of ridges occurring in a specific area, is the most predominant constituent of epidermal ridge detail in the fingerprint.[5] The ridge density of fingerprints can be influenced by two factors: The width of the ridges and the distance between them.[6,7] Sex determination plays a vital role during crime investigation, so ridge density from fingerprints aids in possible identification.[8,9] A unique aspect of ridge density analysis is that investigators can determine an individual's sex even from partial fingerprints, which are the most frequently encountered at crime scenes.[10–12] The variations between genders are primarily attributed to genetic influences on ridge formation during embryonic development.[13] The width of ridges determines the number of ridges that can be present within a specific area of a fingerprint.[14] The present study focused on determining whether the ridge density of a single fingerprint can be used to identify the gender of an individual, and to assess the variation in ridge count across different fingers, between the left and right hands, and among the designated areas (lower [L], radial [R], and ulnar [U]) within a single fingerprint. This study will be valuable in forensic investigations, as it demonstrates that even a single fingerprint, commonly encountered at crime scenes, can provide reliable clues for gender identification.

Methodology

This cross-sectional study was conducted at Sri Ramachandra Institute of Higher Education and Research. The ethical clearance was obtained from the Institutional Ethics Committee (IEC-NI/24/DEC/99/175). A total of 274 adult participants (137 females and 137 males), aged 18–60 years, and belonging to the Indian Tamil ethnic group, were enrolled. Rolled impressions from all 10 fingers of each participant were collected on a fingerprint sheet using the inking method. Ridge counts were performed diagonally within a 5 mm × 5 mm square, focusing on the R and U regions of the central core, as well as the L area adjacent to the flexion crease of the terminal phalanx on each fingerprint obtained from both hands, following the procedures outlined by Gutiérrez-Redomero et al.[15] Ridge density was calculated for each area across all 10 fingers separately for males and females. Statistical analyses were conducted to determine significant differences between genders.

Criteria for Sample Selection

Inclusion Criteria

The study includes only adult participants aged between 18 to 60 years who can provide complete rolled patent fingerprints showing both the core and delta clearly. To maintain cultural and genetic homogeneity, only individuals from the Indian Tamil population will be included, as this can influence fingerprint ridge density. Participants must be free from skin diseases or conditions, such as eczema or psoriasis, that could affect the quality of fingerprints and introduce confounding variables. Both male and female participants will be clearly defined to facilitate an accurate analysis of sexual dimorphism in fingerprint ridge density.

Exclusion Criteria

Participants with plain, partial, smudged, or unclear fingerprints will be excluded, as these may not provide reliable data. Individuals with skin conditions, diseases, or injuries affecting the fingers or hands that could compromise fingerprint quality will also be excluded. Furthermore, participants who do not belong to the Indian Tamil population will be excluded to maintain cultural and genetic homogeneity in the study.

Result

Statistical Analysis

Data were analyzed using R version 4.4.1. The dataset consisted of ridge density values measured on the R, U, and L areas of each finger of both hands. Descriptive statistics, including the mean and standard deviation, were calculated for fingerprint ridge density across each specified area for all 10 fingers, segmented by sex, presented in Tables 1–4, along with the corresponding p values obtained from independent sample t-tests (Table 5). Significant gender differences ($p < .05$) were observed in 27 out of 30 variables after confirming approximate normality through visual inspection of histograms. No correction for multiple comparisons was applied, given the exploratory nature of the analysis. However, highly significant p values (<.001) were observed in the majority of variables, supporting robustness of the findings.

Descriptive Statistics

As shown in Tables 1–4, the data indicate that mean ridge density is higher and more consistent in the lower area across all fingers in females (left and right hands) than in males.

Independent Sample t-tests

As shown in Table 5, the results of independent sample t-tests comparing male and female ridge density measurements across all 10 digits (thumb to little finger) of the right and left hands. Ridge density was significantly higher in females for most finger segments, especially in the left and right thumb, index, and little fingers, as evidenced by extremely small p values. A few segments did not show statistically significant differences.

Discussion

In the present study, fingerprint ridge density measurements covering R, U, and L areas of all fingers on both hands were

Table 1. Ridge Density Distribution in Three Anatomical Areas of the Left Hand Fingers of Females.

Variable	Max	Mean	Median	Min	*SD*
Thumb_L	17	15.37	15	14	0.71
Thumb_R	12	10.69	11	9	1.04
Thumb_U	12	10.68	11	8	1.12
Index_L	17	15.12	15	14	0.77
Index_R	13	11.13	11	8	1.02
Index_U	14	10.77	11	9	1.22
Middle_L	17	14.99	15	14	0.69
Middle_R	12	10.79	11	9	0.95
Middle_U	12	10.58	11	8	0.87
Ring_L	17	15.19	15	14	0.52
Ring_R	13	11.04	11	8	1.28
Little_L	17	15.51	15	14	0.58
Little_R	13	10.86	11	9	1.08
Little_U	12	10.38	11	8	0.99

Table 2. Ridge Density Distribution in Three Anatomical Areas of the Right Hand Fingers of Females.

Variable	Max	Mean	Median	Min	*SD*
Thumb_L	17	15.18	15	14	0.9
Thumb_R	13	11.06	11	9	1.07
Thumb_U	13	11.09	11	9	1.16
Index_L	17	15.07	15	12	0.68
Index_R	13	10.86	11	8	0.89
Index_U	15	10.99	10	9	1.64
Middle_L	17	15.04	16	9	1.45
Middle_R	13	10.39	10	9	1.09
Middle_U	12	10.55	11	10	0.53
Ring_L	17	14.93	15	13	0.89
Ring_R	12	10.19	10	9	0.7
Ring_U	15	10.62	10	9	1.28
Little_L	17	14.94	15	12	1.25
Little_R	13	11.13	11	9	1.05
Little_U	15	10.85	11	9	1.25

analyzed for 274 participants (137 males and 137 females) to explore sexual dimorphism. The results indicate that females consistently exhibit higher ridge density than males across most fingers and regions. This finding is consistent with Gutiérrez-Redomero et al.[16] who reported that female fingerprints were characterized by finer ridges and greater ridge counts within the same unit area compared to males. The current study findings further reveal that the L area showed the most pronounced differences. Specifically, the mean ridge density in females' L (proximal) areas ranged between 14 and 17 ridges/25 mm² on the left hand and 9–17 ridges/25 mm² on the right hand, whereas males exhibited a L and slightly more variable range of 8–16 ridges/25 mm² on the left hand and 9–17 ridges/25 mm² on the right hand. In the R region, females showed densities of 8–13 ridges/25 mm² on the left hand and 8–13 ridges/25 mm² on the right hand, whereas males ranged between 7–17 ridges/25 mm² on the left hand and 6–14 ridges/25 mm² on the right hand. In the U region, females exhibited densities of 8–14 ridges/25 mm² on the left hand and 9–15 ridges/25 mm² on the right hand, while males showed 7–14 ridges/25 mm² on the left hand and 6–14 ridges/25 mm² on the right hand. Similar patterns were noted in the R and U regions, where females exhibited narrower but consistently higher ridge densities than males. These results are in agreement with previous studies, which consistently reported finer ridge structures and greater ridge density in

Table 3. Ridge Density Distribution in Three Anatomical Areas of Left Hand Fingers of Males.

Variable	Max	Mean	Median	Min	*SD*
Thumb_L	110	14.07	14	9	8.44
Thumb_R	14	9.86	10	7	1.53
Thumb_U	13	9.55	10	7	1.6
Index_L	16	12.78	13	9	1.55
Index_R	15	9.71	10	8	1.54
Index_U	14	10.12	10	7	1.66
Middle_L	15	12.69	13	8	1.9
Middle_R	17	9.74	10	7	1.94
Middle_U	14	10.34	10	8	1.61
Ring_L	16	12.54	13	8	2.09
Ring_R	12	9.55	10	7	1.11
Ring_U	13	9.94	9	8	1.35
Little_L	16	12.9	13	10	1.55
Little_R	12	10.23	10	8	1.17
Little_U	12	10.03	10	8	0.97

Table 4. Ridge Density Distribution in Three Anatomical Areas of Right Hand Fingers of Males.

Variable	Max	Mean	Median	Min	*SD*
THUMB_L	16	13.34	13.5	10	1.38
THUMB_R	12	9.8	10	6	1.34
THUMB_U	13	9.79	10	6	1.27
Index_L	17	13.12	13	9	1.39
Index_R	14	10.04	10	8	1.73
Index_U	12	9.78	10	8	1.15
Middle_L	17	13.33	14	9	1.61
Middle_R	14	10.16	10	6	1.95
Middle_U	14	10.04	10	7	1.51
Ring_L	16	12.98	13	9	1.71
Ring_R	13	10.23	10	6	1.46
Ring_U	13	9.47	9	7	1.28
Little_L	15	12.82	13	9	1.49
Little_R	14	10.15	10	6	1.86
Little_U	13	9.79	10	7	1.55

females across diverse populations.[17–19] These quantitative differences reinforce the observation that female fingerprints are generally finer, with a higher number of ridges per unit area, particularly in the L regions, compared to males. The variation observed in males, especially in the R and U areas, indicates a coarser and more heterogeneous ridge pattern, consistent with previously reported sexual dimorphism in fingerprint ridge density.[20,21]

The sexual dimorphism observed in ridge density in the present study can be explained by anatomical differences in finger size and ridge spacing. Males generally possess larger finger pads, which accommodate broader ridge breadths and consequently result in fewer ridges per unit area. In contrast, females tend to have smaller fingers with finer, more closely spaced ridges, thereby producing higher ridge density values. Our findings are consistent with previous studies,[22–25] which similarly reported that ridge density differences between sexes are largely attributable to variations in ridge width and finger pad dimensions rather than differences in ridge formation processes. This supports the notion that ridge density is an indirect reflection of sexual dimorphism in finger morphology and is therefore a reliable criterion for sex estimation across populations.

Our findings also align with a Sudanese study,[26] which reported higher ridge density in females and emphasized the L areas as most reliable for sex estimation. However, unlike

Table 5. Gender Based Comparison of Fingerprint Ridge Density (mean ± *SD*) Across Digits of the Right and Left Hands.

Variable	Mean Male	Mean Female	*p* Value
Right_THUMB_U	9.79	11.09	<.001
Right_THUMB_R	9.8	11.06	<.001
Right_THUMB_L	13.34	15.18	<.001
Right_Index_U	9.78	10.99	<.001
Right_Index_R	10.04	10.86	<.001
Right_Index_L	13.12	15.07	<.001
Right_Middle_U	10.04	10.55	<.001
Right_Middle_R	10.16	10.39	.235
Right_Middle_L	13.33	15.04	<.001
Right_Ring_U	9.47	10.62	<.001
Right_Ring_R	10.23	10.19	.792
Right_Ring_L	12.98	14.93	<.001
Right_Little_U	9.79	10.85	<.001
Right_Little_R	10.15	11.13	<.001
Right_Little_L	12.82	14.94	<.001
Left_THUMB_U	9.55	10.68	<.001
Left_THUMB_R	9.86	10.69	<.001
Left_THUMB_L	14.07	15.37	.077
Left_Index_U	10.12	10.77	<.001
Left_Index_R	9.71	11.13	<.001
Left_Index_L	12.78	15.12	<.001
Left_Middle_U	10.34	10.58	.123
Left_Middle_R	9.74	10.79	<.001
Left_Middle_L	12.69	14.99	<.001
Left_Ring_U	9.94	10.21	.072
Left_Ring_R	9.55	11.04	<.001
Left_Ring_L	12.54	15.19	<.001
Left_Little_U	10.03	10.38	.003
Left_Little_R	10.23	10.86	<.001
Left_Little_L	12.9	15.51	<.001

Note: A *p* value less than .05 is considered statistically significant.

their observation of consistently higher densities in the left hand and some regions lacking significant sex differences, our results showed more uniform dimorphism across both hands and regions, suggesting possible population-specific variability.

When compared with previous studies, several similarities and differences emerge. Gutiérrez-Redomero et al.[27] observed differences in ridge density across U, R, and lateral regions, consistent with the current study showing the highest densities in the L areas. Krishan et al.[28] reported that in the North Indian population, R and U regions had higher ridge density than L areas, whereas in the Indian Tamil population, the present study shows that the L areas consistently exhibit higher ridge density, indicating population-specific variation. Similarly, Nayak et al.[29] reported that females generally have ridge density greater than 13 ridges/25 mm² while males have fewer than 12 ridges/25 mm². The current study corroborates this trend with mean values in females ranging from 14 to 17 ridges/25 mm² and males showing L ranges, highlighting a consistent gender difference. Unlike prior studies on European and sub-Saharan populations, where right-hand ridges were coarser, the Indian Tamil participants displayed higher ridge density in the left hand, suggesting potential genetic or developmental influences unique to this population. Additionally, recent studies[30,31] emphasize the forensic utility of establishing population-specific thresholds, as ridge density values can vary not only between genders but also across ethnic and regional groups. Incorporating such standards could greatly improve the accuracy of forensic applications in diverse populations.

Female fingerprints are finer and show higher ridge density primarily because of smaller finger size, and the thinner epidermis compresses the ridges per unit area. Additionally, sex-specific hormonal influences during fetal development, such as L testosterone and higher estrogen exposure in females, lead to more closely spaced ridges, whereas males develop coarser, more widely spaced ridges. Overall, the study confirms that fingerprint ridge density is sexually dimorphic in the Indian Tamil population, with females showing finer and denser ridges than males, particularly in the L areas. The quantitative data provided strengthen the basis for using ridge density as a reliable parameter for gender determination in forensic investigations, highlighting specific anatomical regions that are most informative.

Conclusion

The present findings affirm the utility of fingerprint ridge density as a reliable, non-invasive, and cost-effective indicator for gender estimation. The strong statistical differentiation in 27 of 30 areas across multiple fingers and fingerprint regions underscores its forensic value. Moreover, the study emphasizes the importance of standardized, area-specific sampling and bilateral data acquisition to enhance the robustness of ridge density-based identification. This study is particularly useful in the case of partial or distorted fingerprints collected from the crime scene. The inclusion of data from the Indian Tamil population also helps bridge a critical gap in population-specific forensic research. Future research should further investigate the role of genetic, environmental, and age-related factors in influencing ridge density and explore machine learning integration for automated gender classification using ridge-based parameters.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

Ethical clearance was obtained from the Institutional Ethics Committee (Ref: IEC-NI/24/DEC/99/175).

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Informed Consent

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ORCID iD

Priyanka R https://orcid.org/0009-0006-5151-9082

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Original Research Article

FGA Locus DNA Sequence Testing as Personal Identification

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Aditya Rahman Ernanto[1], Dinda Amaliatul Khasanah[2], Yunita Aldirahayu[2], Rizki Setiyaningrum[2] and Aprilia Indra Kartika[1]

Abstract

Short tandem repeat (STR) DNA, one of which is the FGA locus, can be used as a profiling tool for personal identification analysis in the forensic field because it has many allelic combinations based on the complex repetitive pattern of DNA sequences. The FGA locus was reported to have the highest discrimination power in the Indonesian population. The aim of this study was to understand the ability of personal discrimination from the FGA locus sequences in a DNA forensics testing scenario of Indonesian subjects. The specimens were used towels (T), toothbrushes (TB), and hair ties (HT) from certain people and buccal swabs (BS) from the same people and two others as controls whose identities were analyzed. DNA extraction using the Phenol CIAA (*chloroform isoamyl-alcohol*) method followed amplification of the DNA of FGA loci that targeted repetitive sequences, agarose gel electrophoresis, and Sanger sequencing of FGA loci. The amplification showed the DNA bands from the FGA loci were around 350 bp. The sequencing results showed that the number of repetitions of the FGA allele from samples T, TB, and HT was identical to BS1, which was 19 repetitions, while BS2 and BS3 were 22 and 21 repetitions, respectively. Thus, the sample items T, TB, and HT are owned by individual BS1. The FGA gene sequenced by the Sanger method can be used in a limited way, only detecting repetitive sequences on the longest allele as a differentiator between one individual and another.

Keywords

Forensic DNA, short tandem repeat, FGA, Sanger sequencing

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Introduction

In the human genome, there are many sequences with varying repetitive patterns, one of which is short tandem repeat (STR) DNA. Recently, the standard method of forensic DNA profiling has been STR analysis.[1] STR DNA can be used as a profiling tool for personal identification analysis in the forensic field because it has many allelic combinations based on the length of the complex repetitive DNA sequences being analyzed.[2] STR DNA identification from biological specimens using Polymerase Chain Reaction (PCR) has been proven to be a simple method, but very accurate and sensitive in analyzing or differentiating each individual.[3]

DNA profiling is used to determine an individual's unique genetic characteristics. It involves analyzing specific regions of the DNA that exhibit variations among individuals. These regions, known as genetic markers (biomarkers), include STR loci like FGA.[4] The combined DNA index system (CODIS) is a DNA database system used in the United States for the storage and comparison of DNA profiles obtained from crime scene evidence, convicted offenders, and missing persons. It was developed by the Federal Bureau of

[1]Molecular Biology Laboratory, Department of Medical Laboratory Technology, Faculty of Nursing and Health Science, Universitas Muhammadiyah Semarang, Jawa Tengah, Indonesia
[2]Department of Medical Laboratory Technology, Universitas Muhammadiyah Semarang, Jawa Tengah, Indonesia

Corresponding author:
Aditya Rahman Ernanto, Molecular Biology Laboratory, Department of Medical Laboratory Technology, Faculty of Nursing and Health Science, Universitas Muhammadiyah Semarang, Jl. Kedungmundu Raya No. 18, Semarang, Jawa Tengah, Indonesia.
E-mail: ernanto.aditya@gmail.com

Investigation (FBI) and is widely utilized by federal, state, and local forensic laboratories. From the beginning of its appearance in October 1998 until December 31, 2016, there were 13 STR locus cores, then updated effective January 1, 2017, to 20 STR locus cores. The most recent version of CODIS as of now is CODIS 20, which refers to the number of 20 core STR loci included in the system.[5,6]

The STR locus on the combined DNA index system 13 (CODIS13), which has the highest discrimination power in the Indonesian population, was the FGA locus.[7] The FGA locus contains mixed tetranucleotide repeats found in the third intron of the Human Alpha Fibrinogen gene on the long arm of chromosome 4 (4q28). FGA, also known as FIBRA or HUMFIBRA, has a high mean exclusion chance compared to other common STR loci, making it an effective paternity test and forensic identification tool.[4]

The FGA locus has a complex tetranucleotide repeat motif called core repeat and total repeat; the consensus sequences are $[TTTC]_3[TTTT][TTCT][CTTT]_n[CTCC][TTCC]_2$.[8] Total repeats range from 13 to 29 times, with a core repeat pattern CTTT of 5–21 times.[2] FGA loci have a size range of 308-465bp.[9] According to the size total repeat pattern, FGA alleles can be divided into two groups, those in the allele size ranges of 16–34.2 and 42.2–51.2. Although we have not yet found any alleles between 34.2 and 42.2, it is possible that some people will carry these alleles.[10] Repetition allele ranged between 16–31.2 and 40.2–44.2 reported in the South African population.[11]

STR analysis involves amplifying and analyzing the number of repetition sequence units at certain loci. By comparing the number of repeats at a certain locus between a known sample (e.g., crime scene evidence) and a reference sample (e.g., DNA from a suspect or a DNA database), it is possible to determine if the samples originate from the same individual. This research, therefore, aims to find out how effective FGA locus sequences are for personal identification in DNA forensics testing of Indonesian subjects.

Material and Methods

Study Design

The design of this study was an experimental design. Personal items used as a source of DNA were used towel (T), a toothbrush (TB), and a hair tie (HT) from one female student of the Universitas Muhammadiyah Semarang, while buccal swabs (BS) were taken from BS from the same female student and two other students as a comparison control. This research was conducted at the Molecular Biology Laboratory at Universitas Muhammadiyah Semarang.

Sample Collection

Sample collection was done on a used towel without being washed by cutting the fibers suspected of having attached skin epithelium. TB and HT were cut at the suspected epithelial spots.[12] The buccal area was swabbed by rotating and rubbing the buccal area 20 times.

DNA Extraction

DNA extraction using the Phenol CIAA (Chloroform Isoamyl-Alcohol) method. Each specimen was put into a 1,5 ml tube and added 1:1 with lysis buffer (100 mM Tris HCl, pH 8; 100 mM NaCl; 50 mM EDTA; 2% SDS). 20 µl of Proteinase-K (10 mg/ml) was added and incubated in a dry bath at 55°C for 5 hours. Cotton swabs and towel fibers in the microtube were taken using sterile tweezers. Add Phenol CIAA (25:24:1) 1:1 and vortex for 10 seconds. The suspension was centrifuged at 8.000 rpm for 5 minutes. The aqueous phase supernatant was taken and transferred to a new 1,5 microtube. Cold ethanol (96%) was added 1:2 to the microtube and centrifuged at 13.000 rpm for 5 minutes at 4°C. Remove the supernatant. 70% ethanol was added as much as 500 µl into the microtube containing the DNA and then centrifuged at 13.000 rpm for 5 minutes at 4°C. The supernatant was discarded, and this process was repeated three times. After that, the supernatant was discarded, and the pellet was air-dried. The final step was dissolving the DNA isolate with 25 µl of Tris-EDTA (TE buffer) and storing it at −20°C. The concentration and purity of DNA were measured using the MN-913A MaestroNano Pro (MAESTROGEN) spectrophotometer.

FGA Locus Amplification

DNA was amplified by PCR using the T-Personal Thermocycler (BIOMETRA) using a pair of primers at the FGA locus (forward 5'-GGCTGCAGGGCATAACATTA-3' and reverse 5'-ATTCTATGACTTTGCGCTTCAGGA-3').[13] Amplification of all samples used FGA loci by PCR T-Personal Thermocycler (BIOMETRA). The setting was as follows: 95ºC for 3 min, then 95ºC for 30 sec, 58ºC for 30 sec, 72ºC for 30 sec, for 35 cycles. DNA polymerized template continued with typing while stored at 4ºC.

Electrophoretic Reaction

The result shows that PCR products were electrophoresed on MUPID-exU submarine electrophoresis under 3% agarose with DNA ladder DM1100 ExcelBand™ 50bp (SMOBIO) to analyze the size of DNA bands.

DNA Sequencing and Analysis

PCR products from samples that show well-amplified band results will be carried out using the DNA sequencing method of Sanger Sequencing by 1st Base through PT. Genetics Science Indonesia. DNA sequence results were analyzed using assembly contig sequence with DNA Baser Assembler version 5.20 software and nucleotide similarity alignment using BLAST from https://blast.ncbi.nlm.nih.gov/.

Results

The PCR product, as a result of FGA amplification, was visualized on a 3% agarose gel, with visible DNA bands measuring around 350 bp (Figure 1). The result shows clearly visible DNA bands, which have a size of around 350 bp. The gel also shows double bands from the sample.

Simulation results from running Primer-BLAST NCBI using the FGA primer obtained the target product with a size of 346 bp (Figure 2) and used it as a reference. In the

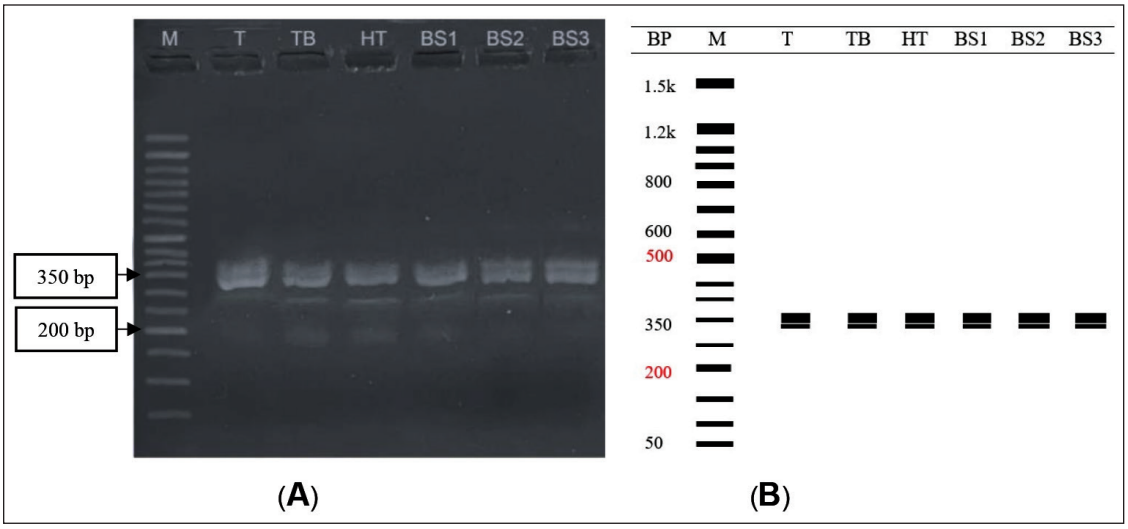


Figure 1. The Electrophoresis of the Samples Visualized on a 3% Agarose Gel Showed the FGA Gene Bands. (A) Electrophoresis of Agarose Gel; (B) Diagrammatic Representative.

Note: BP = Base Pair, M = Marker, T = Towel, TB = Tooth Brush, HT = Hair Tie, BS1 = Buccal Swab-1, BS2 = Buccal Swab-2, BS3 = Buccal Swab-3.

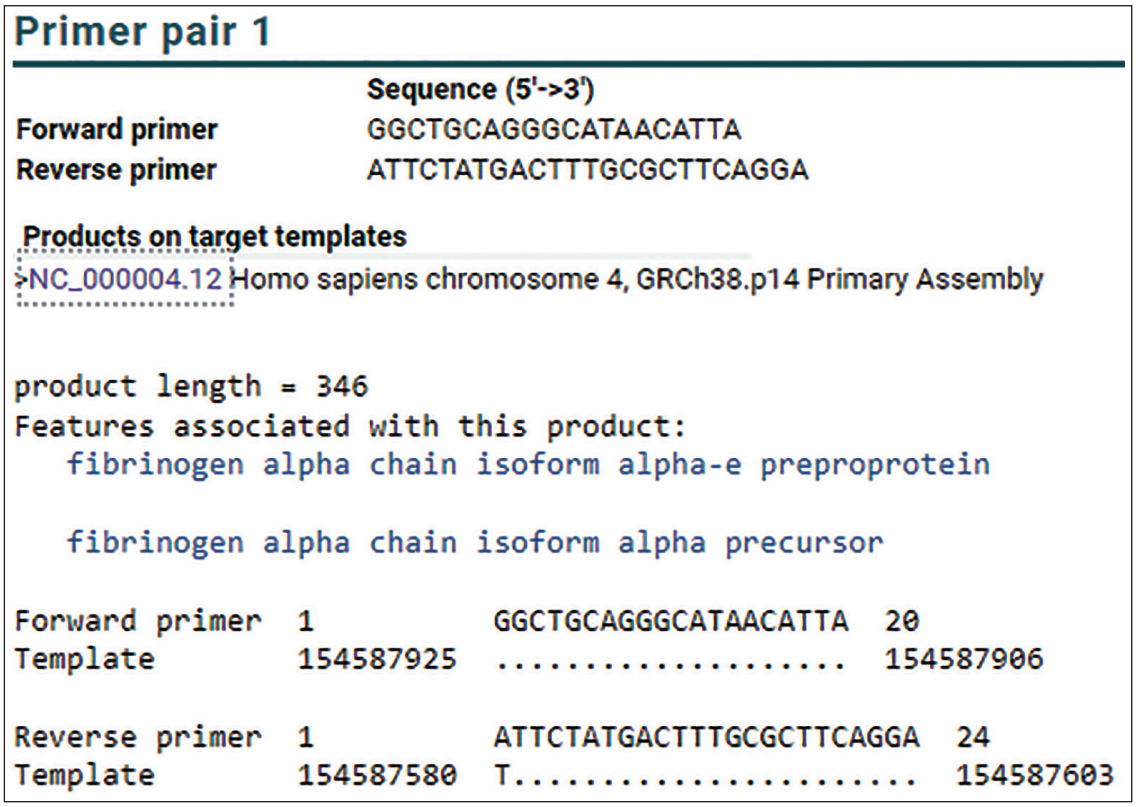
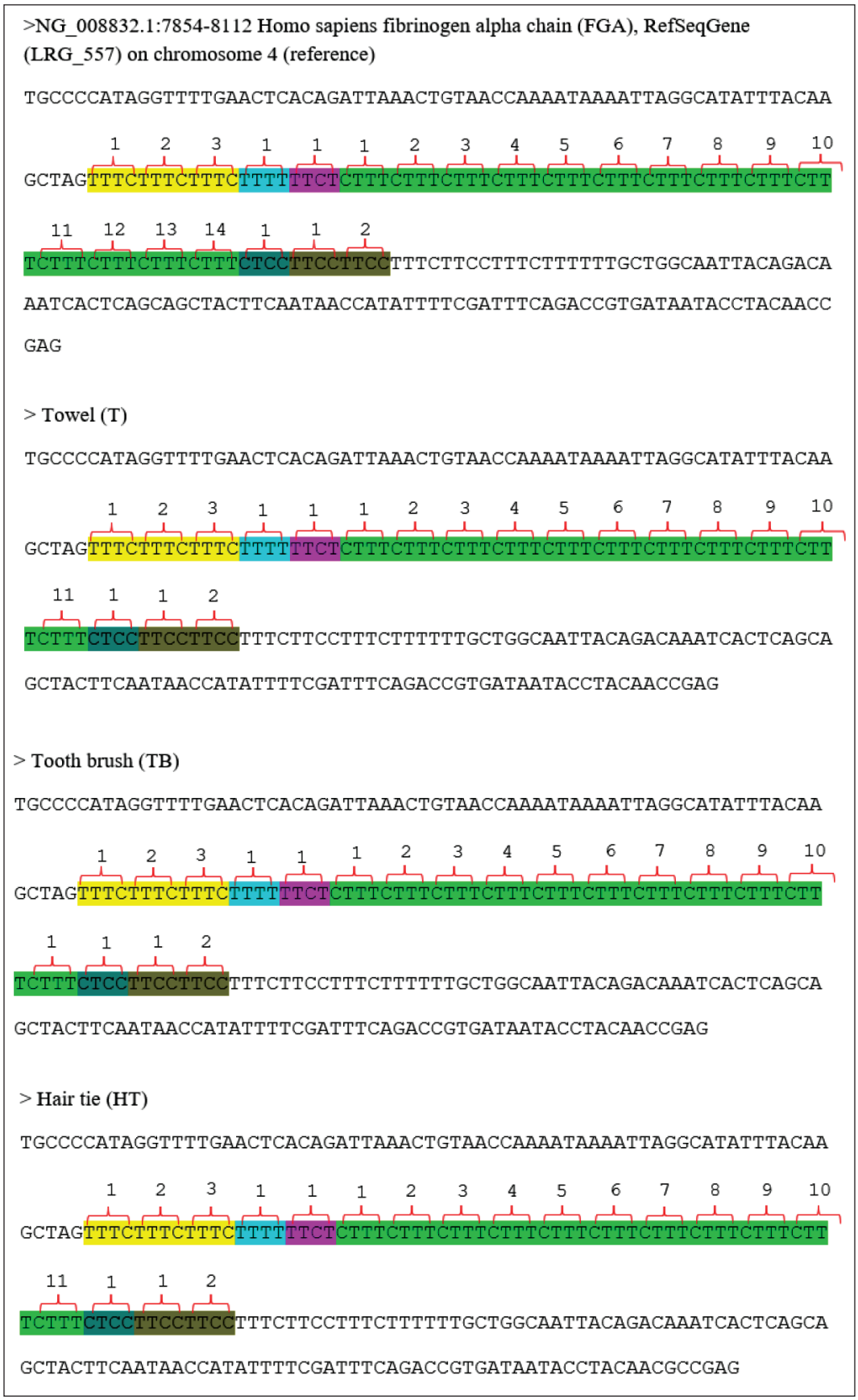


Figure 2. Modified Figure of Running Primer-BLAST Using FGA Primers.



(Figure 3 continued)

(Figure 3 continued)

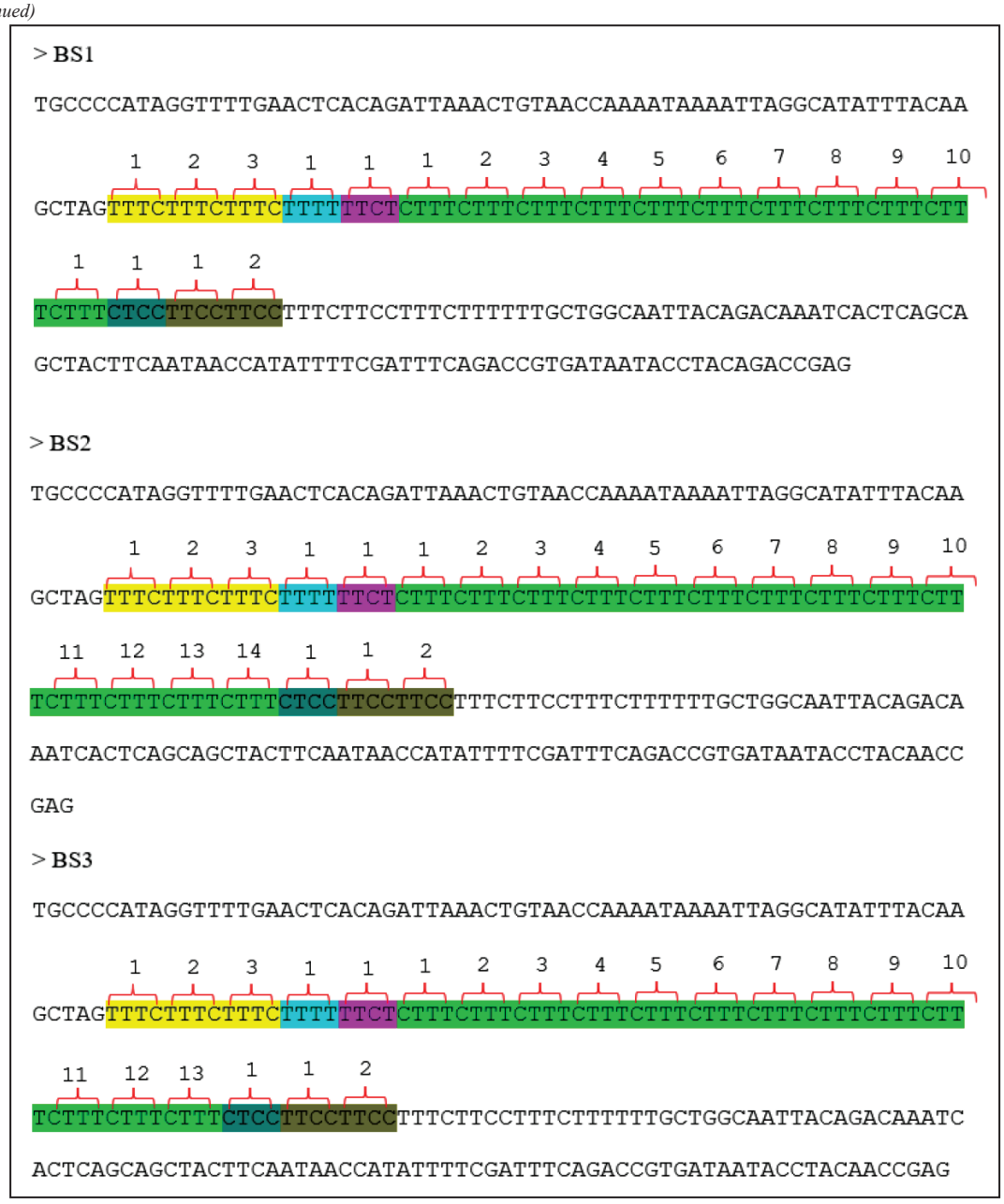


Figure 3. FGA Sequences Result in the Form of Complex Repetition Motives from the Database Reference with Accession Number NG_008832.1 and the Samples: Towel, Toothbrush, Hair Tie, Buccal Swab 1 (BS1), Buccal Swab 2 (BS2), and Buccal Swab 3 (BS3).

reference sequence, we can see that there are 14 repetitions of the core sequence $[CTTT]_{14}$ (Figure 3). The target DNA sequence is on the negative strand, based on the Genbank database.

During the assembly process, the DNA sequences from Sanger sequencing were trimmed at the beginning and at the ends of the DNA segments so that the contig DNA sequences were shortened. The contig was then subjected to alignment on BLAST and showed the highest similarity to Homo sapiens fibrinogen alpha chain (FGA), RefSeqGene (LRG_557) on chromosome 4 with accession number NG_008832.1 and will be used as a reference gene.

Multiple sequence alignment analysis from the DNA sequencing results was performed using Clustal Omega software (https://www.ebi.ac.uk/Tools/msa/). The sequences were aligned, and then the number of core repetition patterns $[CTTT]_n$ was counted. Every human has a total number of repeat patterns as a result of different allele variations.

The STR allele polymorphism of the FGA locus in the samples was the number of repetitions of the $[CTTT]_n$ core

Table 1. Description of Sequenced FGA Alleles from Personal Items (T, TB, HT) and People to Be Identified (BS1, BS2, BS3).

Samples	Allele	Core Repeat	Repetition Pattern					
Consensus		n	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_n$	CTCC	$[TTCC]_2$
NG_0088321	22	14	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_{14}$	CTCC	$[TTCC]_2$
T	19	11	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_{11}$	CTCC	$[TTCC]_2$
TB	19	11	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_{11}$	CTCC	$[TTCC]_2$
HT	19	11	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_{11}$	CTCC	$[TTCC]_2$
BS1	19	11	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_{11}$	CTCC	$[TTCC]_2$
BS2	22	14	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_{14}$	CTCC	$[TTCC]_2$
BS3	21	13	$[TTTC]_3$	TTTT	TTCT	$[CTTT]_{13}$	CTCC	$[TTCC]_2$

pattern, which was different for each human in this research scenario. This can be used as a difference between one individual and another. The total repetition pattern $[CTTT]_n$ in the samples showed variation results (Table 1).

Discussion

STR loci have various types based on repetitive patterns, including simple, compound, and complex types. Simple types have repetition units that are identical in repetitive sequence, along with the length. Compound repetition is made up of two or more contiguous simple repeats, while complex repetition has several repeat units with varied unit lengths as well as variable intervening sequences and a large number of variant alleles. FGA is a complex type of STR.[2] The basis for determining alleles from a STR locus is based on the length of DNA fragments, especially those that have certain repeating patterns in them. The standard method for analyzing alleles in STR DNA is capillary electrophoresis.[14] In this study, we try to perform the Sanger sequencing method to analyze STR DNA in the FGA locus. The results of this study were a DNA band from a 3% agarose gel and a Sanger sequencing result.

Electrophoresis band results may show the size of the target DNA fragment (Figure 1). However, the agarose gel electrophoresis method cannot show accurate measurement results; therefore, we followed it with the Sanger sequencing method, which can analyze the sequences of the target DNA. The result from a 3% agarose gel was around 350 bp and showed double bands. It means that the DNA fragment has a different length for each allele in diploid chromosomes; the more repetitive units, the longer the DNA band detected in an allele, and this finding is in line with.[15]

The sequencing results at the FGA target locus clearly show the repetition pattern sequence (Figure 3) and the number of repetition units (Table 1). However, the repetition unit that was read in the sequence was only the longest allele, so this is a weakness of STR analysis by Sanger sequencing analysis; this finding is supported by.[16] Sanger STR sequencing cannot be performed routinely because loci cannot be multiplexed and heterozygous alleles must be separated manually before sequencing.[17] This method can be used as an alternative to STR DNA analysis for personal testing, although it has limitations. This limitation can be reduced by using more than one STR locus to strengthen the analytical results.

Based on the scenario of our research, using non-living material as a sample to determine the identity of the owner of the sample, DNA extraction has been successfully carried out. We matched the longest repetition alleles so we could get a match with the owner of the DNA in the sample. The sample used towels, tooth brushes, and HT was identical to BS1, which was 19 total repetitions with 11 core repetitions [CTTT] of allele variations. BS2 has a total of 22 repetitions with 14 core repetitions [CTTT] of allele variations. BS3 has a total of 21 repetitions, with 13 core repetitions [CTTT] of allele variations (Table 1). The results of the used towels, toothbrush, and HT sample match BS1, an indication that the three samples have the same number of repetitions as BS1. It can be concluded that the sample belongs to BS1.

Conclusions

A personal identification test using the FGA locus can be done, but with limitations, only detecting repetitive sequences on the longest allele. The use of more than one STR locus may increase the accuracy of the discrimination analysis. From the research scenario, we can find out who owns the DNA in the sample being examined.

Abbreviations

CODIS: Combined DNA index system
DNA: Deoxyribonucleic acid
Phenol CIAA: Phenol chloroform isoamyl-alcohol
PCR: Polymerase chain reaction
STR: Short tandem repeat

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Authors' Contributions

ARE was responsible for the conception and design of the study (lead) and formal analysis (lead). DAK, YA, and RS contributed to the sample collection. DAK performed an investigation in the laboratory experiment. YA and RS helped in the laboratory experiment. RS is responsible for operating the software and the visualization of study results. YA contributed to the analysis of data and interpretation. AIK was responsible for conception (supporting), writing review, and editing. ARE wrote the original draft (lead). DAK wrote the original draft (supporting). All authors read and approved the final manuscript.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

Ethical approval to carry out this research was obtained through ethical clearance number 209/VI/2022/KomisiBioetik issued by the Institutional Review Board and Bioethics Committee of the Faculty of Medicine, Universitas Islam Sultan Agung.

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Informed Consent

All individuals who participated in this research provided informed consent and permitted the dissemination and publication of the results. Privacy and participant confidentiality were strictly maintained throughout the study.

ORCID iD

Aditya Rahman Ernanto https://orcid.org/0000-0003-0806-5784

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A Need-based Approach to PBL: Conventional Problem-based Learning Versus Modified Problem-based Learning—A Comparative Study

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Sudhir Ninave[1], Jayant Vagha[2], A J Anjankar[1], A N Keoliya[1], Sanjot Ninave[3] and Tileshkumar B. Turankar[1]

Abstract

Problem-based learning (PBL), introduced in the 1960s, is a vital and often debated aspect of medical education. PBL is a highly effective educational method, often expressing a preference for it over traditional lecture formats. We aim to implement modified PBL in Forensic Medicine and compare the performance of II MBBS students using both traditional and modified approaches to enhance learning outcomes. A survey was conducted among 2nd MBBS students in their 5th semester to assess the effectiveness of a modified PBL approach. Utilizing a five-point Likert scale for data analysis, the findings revealed that a significant majority of students in batches C1 (45%), C2 (50%), and C3 (55.56%) believe that modified PBL is more effective than traditional learning methods. Furthermore, 60% of C1 students, 66.67% of C2 students, and 61.11% of C3 students reported improved communication skills resulting from this approach. Additionally, a notable percentage of students acknowledged an enhanced understanding of course material, with 52.50% from C1, 61.11% from C2, and 66.67% from C3 expressing this viewpoint. Modified PBL is an effective approach to enhancing student engagement and enriching education in preclinical and paraclinical sciences. It promotes interactive learning and develops essential problem-solving skills. Implementing modified PBL requires a spacious demonstration hall and a round table to foster discussions and interactions among students.

Keywords

Problem-based learning, modified problem-based learning, learning styles, questionnaire

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Introduction

Learning is the unique journey through which each person perceives, processes, and retains new information, shaping their understanding of the world.[1] Problem-based learning (PBL), introduced in the 1960s, is a vital and often debated aspect of medical education.[1] While discussions about its effectiveness continue, what is undeniable is the need for adaptability; no system can be perfect without modifications tailored to the unique dynamics of each student cohort and their learning environment. Challenges often stem from various constraints, such as limited resources, inadequate infrastructure, and a shortage of qualified teaching staff, particularly in specialized areas like Forensic Medicine. An article published by the World Health Organization regarding the reorientation of medical education underscores the value of PBL as a dynamic educational approach. This method involves presenting learners with real patient cases, fostering active engagement and critical thinking. It is imperative to thoughtfully select relevant issues for learning, as this selection process plays a significant role in enhancing the educational experience and effectively preparing students for future healthcare challenges.[2] Various studies have demonstrated that students perceive PBL as a highly effective educational

[1]Department of FMT, Jawaharlal Nehru Medical College, Sawangi (Meghe), Wardha, Maharashtra, India
[2]Department of Pediatrics, Jawaharlal Nehru Medical College, Sawangi (Meghe), Wardha, Maharashtra, India
[3]Department of Anaesthesia, Jawaharlal Nehru Medical College, Sawangi (Meghe), Wardha, Maharashtra, India

Corresponding author:
Sudhir Ninave, Department of FMT, Jawaharlal Nehru Medical College, Sawangi (Meghe), Wardha, Maharashtra 442107, India.
E-mail: sudhirninave@yahoo.in

method, often expressing a preference for it over traditional lecture formats.[3] This preference underscores the value of engaging and interactive learning experiences that promote deeper understanding and retention of knowledge. Addressing these issues is essential for maximizing the potential benefits of PBL and ensuring its success in preparing future healthcare professionals. Students engaged in PBL demonstrate a stronger emphasis on comprehension rather than rote memorization. They effectively utilize journals and online databases for information and select their own reading materials. This approach fosters greater confidence in their information-seeking skills and encourages a more thorough and analytical learning process. Furthermore, these students apply a "backward-directed" hypothetico-deductive method of reasoning.[4] They also show enhanced interpersonal skills, a deeper understanding of psychosocial concepts, and a positive attitude toward patient care.

Aims and Objective

The primary objectives of our study are established within three distinct timeframes: short term, intermediate term, and long term. The outlined goals are as follows:

Short term: We aim to implement modified PBL as an effective teaching tool in Forensic Medicine. By comparing the performance of II MBBS students using both conventional and modified PBL, we can demonstrate the benefits and improvements in learning outcomes that this innovative approach can provide.

Intermediate term: To utilize modified PBL as an effective evaluation tool for second-year MBBS students, enhancing their analytical and problem-solving skills.

Long term: To incorporate modified PBL as a foundational evaluation method in Forensic Medicine and Toxicology (FMT) as well as other paraclinical disciplines at DMIMS (DU), thereby contributing to the advancement of educational quality and patient care.

Material and Methods

Study site and population: This research was conducted at Jawaharlal Nehru Medical College, Wardha. Participants were second-year MBBS 5th-semester students. Three batches of a total number of 76 students were formed: batch C1, $n = 40$, C2, $n = 18$, C3, $n = 18$. All three batches were considered for our study. In the practical class, the modified PBL exercise case scenario of injury examination was given to all three groups. One faculty member as a facilitator, one professor as observer, was appointed. The participants were observed while solving the exercise in small groups and in a large group in three different practical classes. Each batch was given 40 minutes, and then participants were given a feedback form questionnaire containing 15 questions in the form of 5 Likert scale. Twenty minutes were given to the students to fill out the feedback form, and feedback was collected and data analyzed.

Data Collection Method

At the conclusion of the session, we requested that students complete a survey to assess their satisfaction with the modified PBL approach. This valuable feedback will aid us in evaluating the effectiveness of the method and identifying areas for enhancement.

Date Recording

Participants, who had firsthand experience with PBL and modified PBL, were briefed on the study's objectives to understand their perceptions of both approaches. They were assured of voluntary participation, anonymity, and confidentiality. To encourage student responses, participants were instructed to answer freely, without hesitation. The survey questionnaire consists of 15 questions, consensus agreed upon by peers, covering key aspects of modified PBL. Participants selected one of four response options for each question: Strongly agree, Agree, Disagree, Neutral. This questionnaire aimed to elicit participants' genuine feedback on their experiences.

Data Analysis

The data collected from students were thoughtfully analyzed using a five-point Likert scale, providing valuable insights for enhancing our programs and strategies.

Observations and Results

Our research shows that many students appreciate the seating arrangement for large groups. In fact, 55% of students in the C1 batch, 72.22% in the C2 batch, and 61.11% in the C3 batch find it to be a pleasant experience. An impressive majority of students from batches C1 (60%), C2 (72.22%), and C3 (66.67%) expressed their satisfaction with the level of interaction among group members, highlighting its adequacy as shown in Figure 1. This positive feedback underscores the value of collaborative engagement in enhancing the learning experience. Research showcases that larger group interactions significantly enhance the likelihood of achieving desired outcomes, as noted by half of the C2 and C3 batches. The undeniable advantages of modified PBL are evident, with C1 (45%), C2 (50%), and C3 (55.56%) asserting its superiority over traditional learning methods. The data further emphasizes that every group member can effectively communicate with the facilitator, highlighted by C1 (60%), C2 (61.11%), and C3 (66.67%) as shown in Figure 2. Additionally, a substantial majority—C1 (60%), C2 (66.67%), and C3 (72.22%) agreed that large group discussions lead to well-rounded conclusions. Importantly, participants also noted

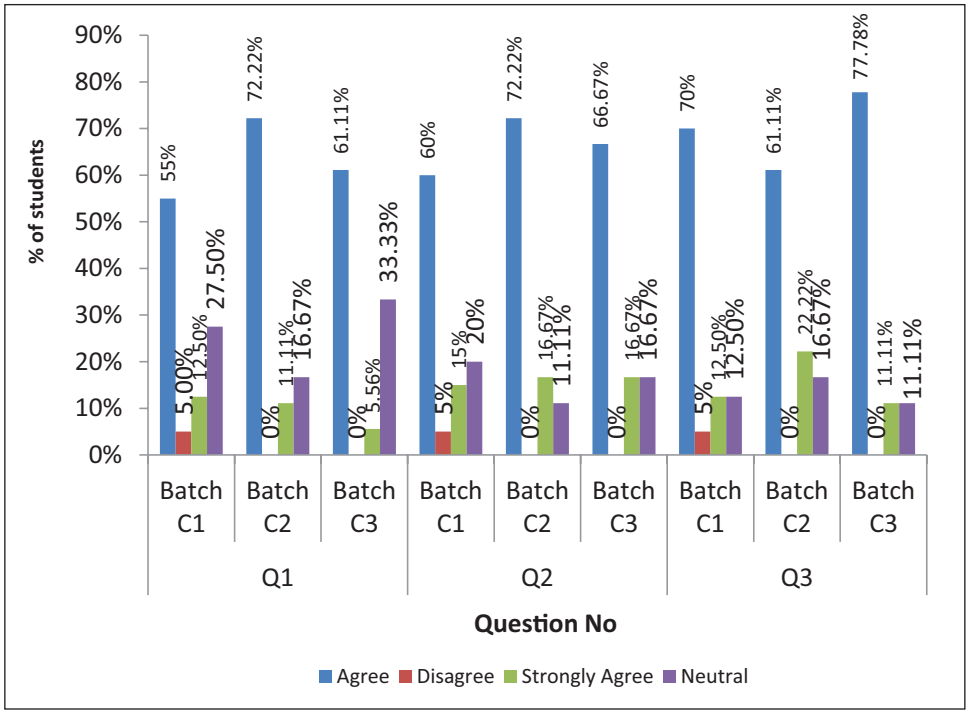

Figure 1. Showing the Response to Questions 1, 2, and 3.

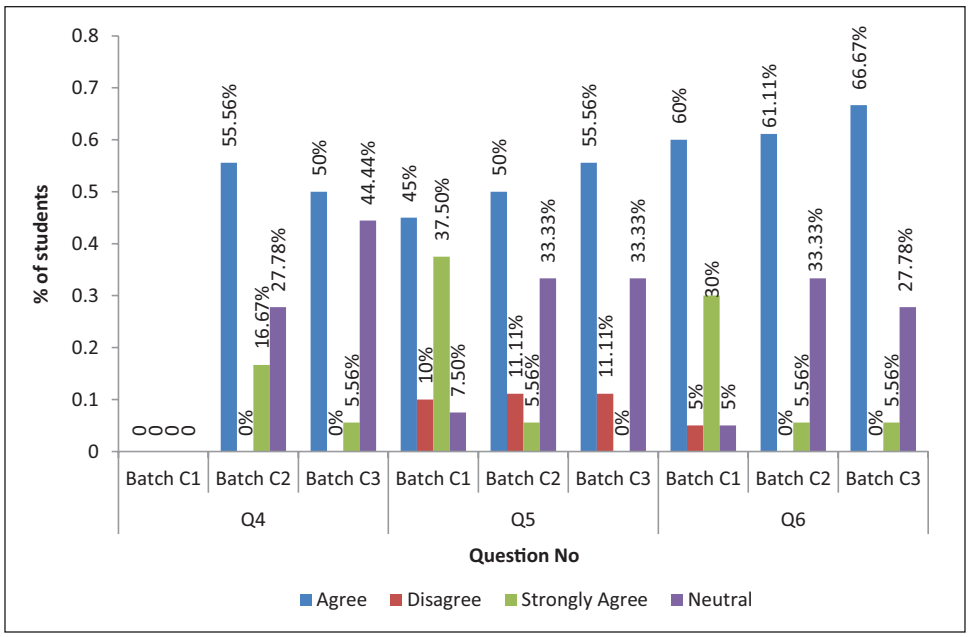

Figure 2. Showing the Response to Questions 4, 5, and 6.

that modified PBL significantly enhances their communication skills, as supported by C1 (60%), C2 (66.67%), and C3 (61.11%), as shown in Figure 3. Adopting this approach can transform educational experiences for all.C1 (52.50%), C2 (61.11%), and C3 (66.67%) all affirmed that modified PBL significantly enhanced their understanding of the course material. Furthermore, the majority of students felt that this approach increased their comfort level in group work, with responses indicating C1 at 62.50%, C2 at 72.22%, and C3 at 77.78% as shown in Figure 4. This clearly demonstrates the positive impact of modified PBL on both learning and collaboration. C1 (75%), C2 (83.33%), and C3 (88.89%) all enthusiastically agree that modified PBL cultivates a meaningful, constructive thinking process. Furthermore, a notable majority of students—C1 (52.50%), C2 (66.67%), and

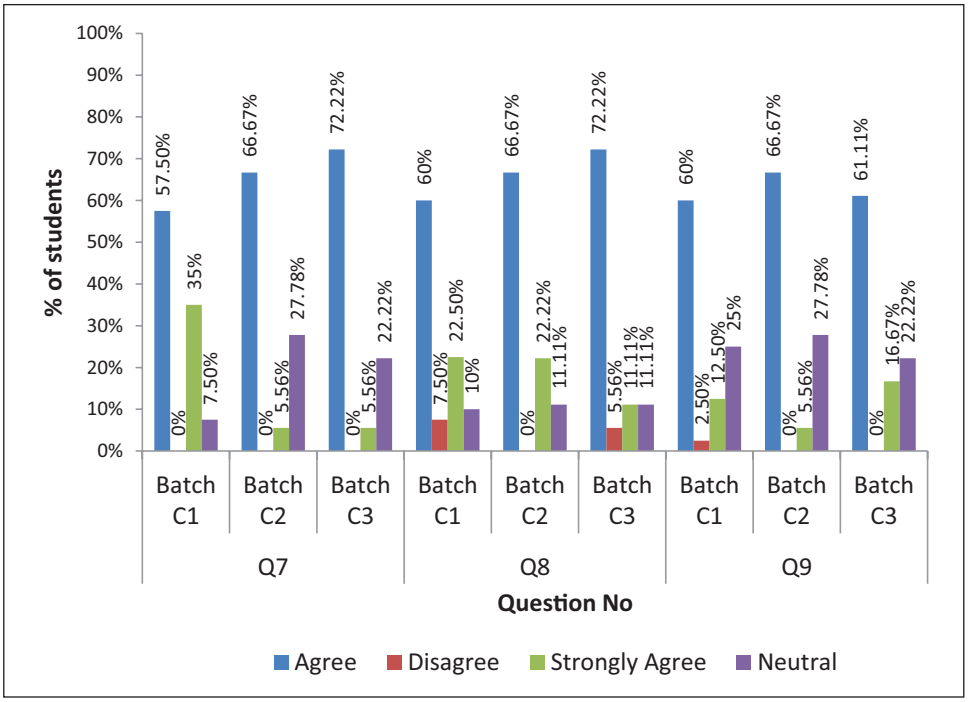

Figure 3. Showing the Response to Questions 7, 8, and 9.

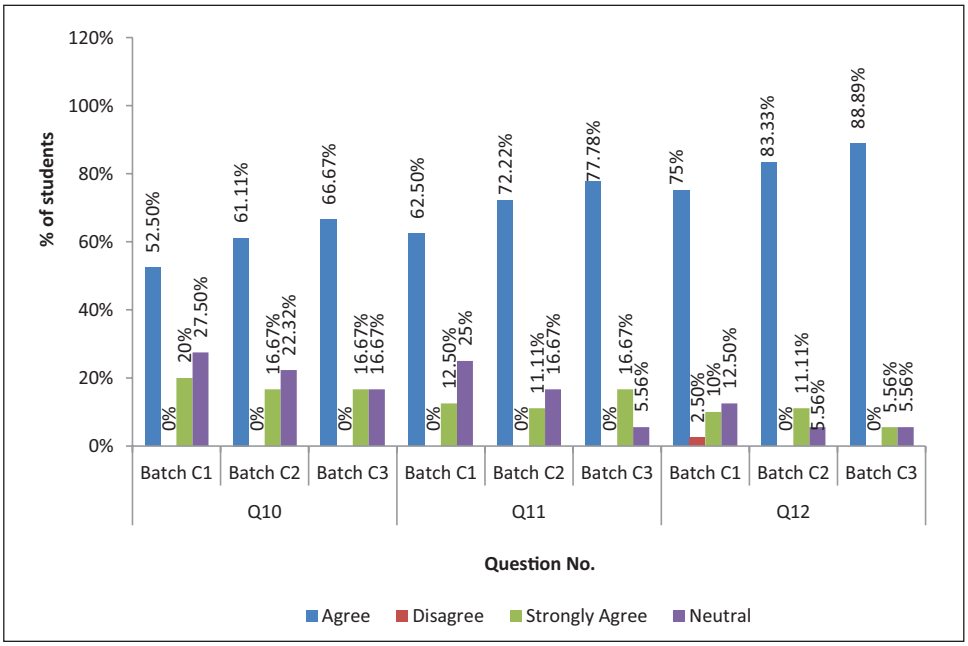

Figure 4. Showing the Response to Questions 10, 11, and 12.

C3 (55.56%)—clearly believe that PBL teaching surpasses traditional classroom instruction, highlighting its effectiveness in enhancing learning outcomes. C1 (60%), C2 (66.67%), and C3 (72.27%), as shown in Figure 5, found inspiration in the belief that additional trigger materials—such as photographs, video clips, and articles from scientific journals—can transform PBL into a more impactful experience.

Discussion

A study conducted by E. Arruzza found that PBL yields statistically significant enhancements in preparedness and attitudes among medical students.[5] Globally, medical radiation students exhibit a positive reception toward PBL. However, we observed that a few areas need to be improved, such as

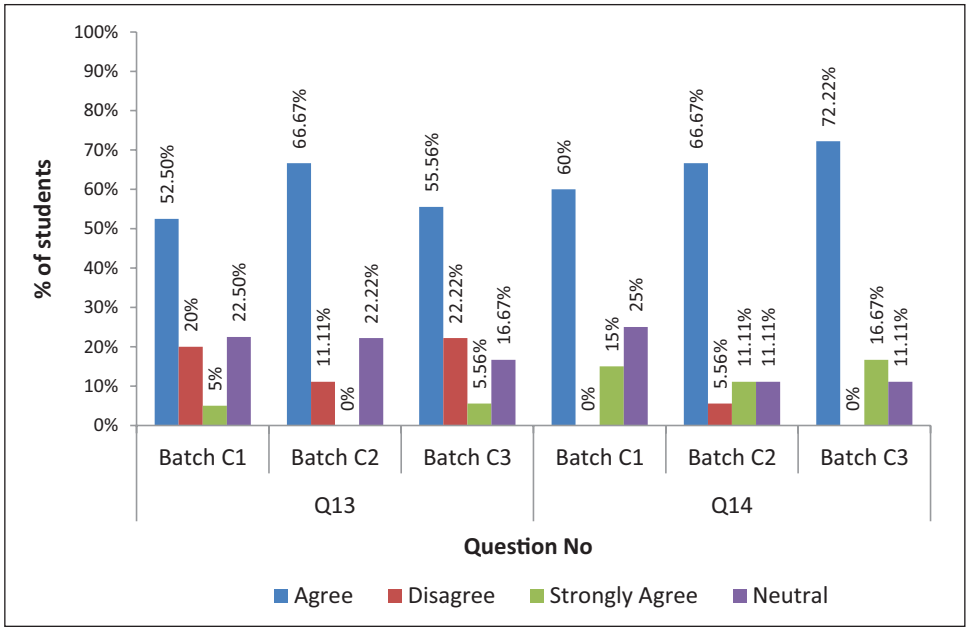

Figure 5. Showing the Response to Questions 13 and 14.

insufficient resources, limited simulation realism, and challenges arising from group dynamics. A study by R. Hudec suggests that adopting a modified PBL approach could potentially enhance outcomes compared to traditional PBL, offering valuable insights for educational improvement.[6] These findings underscore the efficacy of PBL while highlighting opportunities for refinement.[7] The research conducted by K. A. J. Al Khaja emphasizes notable limitations in the PBL approach. Specifically, it indicates that during the pre-clerkship phase, students acquire prescribing skills to only a limited extent.[8] This finding underscores the need for further evaluation of the PBL curriculum to enhance student competencies in essential clinical skills. A study conducted by Virendar Pal Singh emphasizes the importance of incorporating PBL into the medical curriculum, particularly within the context of practical training in autopsy.[9] This method is proposed to enhance the students' analytical skills and better prepare them for the complexities of their future medical practices. Our study indicates that PBL has the potential to strengthen students' cognitive abilities, improve knowledge acquisition, and enhance satisfaction. Nevertheless, conducting additional research will help us better understand its full impact and effectiveness.

Conclusion

Modified PBL offers a promising approach to enhance student interaction and enrich the learning experience in preclinical and paraclinical sciences. Implementing modified PBL has the potential to greatly benefit undergraduate students, providing them with valuable skills and insights for their future studies and careers.

Challenges Faced

The implementation of modified PBL necessitates a spacious demonstration hall, complemented by a round table to facilitate discussions and promote interaction among students. This arrangement is vital for creating an inclusive and engaging learning environment.

Suggestion for Participants

To enhance the comparison of the PBL classes, it would be beneficial to schedule them on different days, focusing on the same topic. This arrangement will allow for a more thorough analysis and understanding of the differences in approach and outcomes.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval and Informed Consent

The study commenced following the approval of the Institutional Ethics Committee (ethical approval letter no. DMIMS(DU)/IEC/2013-14/302). Participants who met the eligibility criteria were thoroughly informed about the study and included after granting verbally informed consent. We prioritized their privacy by assuring them that their data would remain confidential.

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Questionnaire

1. Seating arrangement in the classroom for larger group was comfortable?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
2. Whether interaction among the group members was satisfactory?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
3. Whether the facilitator was approachable to every member of group?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
4. Is it true that interaction in a larger group made it easier for you to arrive at expected outcome?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
5. Do you like modified PBL as compare to conventional?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
6. Was it is possible for interaction with the facilitator for each member at the group?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
7. How you find it to discuss the topic among the group members?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
8. Could You come to proper conclusion at the end of discussion with large group?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
9. Do you think that modified PBL enhanced the communication skill?
   Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
10. Modified PBL enhanced the relation of course content?
    Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
11. Whether modified PBL increases comfort level in working group?
    Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
12. Whether it demonstrates constructive thinking process?
    Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
13. PBL teaching is better than classroom teaching?
    Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
14. Additional trigger material can be included for PBL scenarios like photo graph , video clips , articles from scientific journal a real or simulated patient
    Agree ☐ disagree ☐ strongly agree ☐ neutral ☐
15. Suggestions if any

Opioid Toxicity Crisis: A View Into the Challenges and Opportunities Ahead—A Narrative Review

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Dipayan Deb Barman[1] and M. Mukesh[1]

Abstract

This narrative review examines the escalating opioid crisis, particularly focusing on the role of fentanyl and its analogues in opioid-related overdose deaths in the United States and Asia. Data indicates a significant increase in fatalities linked to opioid misuse, with fentanyl being 50–100 times more potent than morphine, and a staggering 82.3% of opioid-related deaths in 2020 were attributable to overdoses. The article analyzes contributing factors to opioid toxicity, including dosage, tolerance, combination with other substances, administration routes, individual physiological responses, and polydrug use. It highlights the epidemiology of opioid toxicity across the USA and various Asian countries, identifying similarities and differences in prevalence, risk factors, and governmental responses. The review discusses the efficacy of current prevention strategies, such as the Prescription Drug Monitoring Programs (PDMPs), opioid substitution therapy (OST), and harm reduction initiatives, while emphasizing the need for improved public education and awareness. Furthermore, it addresses the challenges in managing opioid toxicity, such as rapid onset of action, risk of co-ingestion, and the importance of naloxone administration. The article advocates for a coordinated, multi-faceted approach that includes data sharing, policy harmonization, international collaboration, and technological innovations, particularly artificial intelligence, to mitigate the opioid crisis and enhance patient safety. Ultimately, it underscores the necessity for a balanced approach to opioid regulation that considers both legitimate medical use and the complexities of misuse and addiction.

Keywords

Artificial Intelligence, CDC, Fentanyl, opioid, opioid abuse, opioid toxicity

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Introduction

Opioids are strong pain-relieving medications that can lead to evident physical dependency and craving. The CDC (Center for Disease Control) has stated a triphasic crisis in the USA, with opioids causing deaths in the 1990s, 2010 and 2013, with fentanyl accounting for the majority of overdose deaths in 2020.[1] About 82.3% of deaths remained associated with opioid overdose cases.[2] Most overdose-caused deaths remained related to fentanyl and its equivalents, such as carfentanyl, furanyl fentanyl, acetyl fentanyl, 4-fluoroisobutyryl fentanyl (or para-fluoroisobutyryl fentanyl), then cyclopropyl fentanyl.[3]

The misapplication of carfentanyl in humans, formerly permitted for strict use in animals, has led to an astounding jump up to 45% of overdose-related deaths due to misuse of fentanyl and its analogues, organized with tramadol among 2016 and 2017.[3,4] The use of fentanyl unlawfully by illegal drug producers has further compounded the condition due to widespread use of over-the-counter or nonprescription opioids.[5] The Drug Enforcement Administration (DEA) promotes for more state-of-the-art advanced technology for the recognition of non-pharmaceutical fentanyl (NPF) in pain medication drug combinations.[6,7]

[1]Department of Forensic Medicine and Toxicology, Shri Sathya Medical College and Research Institute, Chennai, Tamil Nadu, India

Corresponding author:
M. Mukesh, Department of Forensic Medicine and Toxicology, Shri Sathya Medical College and Research Institute, Chennai, Tamil Nadu 603108, India.
E-mail: mukeshmathen220@gmail.com

Methods

Literature Search

The literature exploration for writing this narrative review has been completed using literature exploration engines such as Google Scholar, PubMed, and Scopus. Related articles were searched, and at first, the titles and abstracts of the articles were screened. Thereafter, articles related to opioid overdose deaths have been chosen. For running the search, keywords such as opioids, fentanyl, opioid analogues, management strategies, and overdose have been used. Articles which focused on opioid abuse, overdose crisis, opioid management, opioid substitution therapy (OST), harm reduction programs, and governmental strategies on opioid abuse mitigation were included in the search. Around 104 relevant articles have been shortlisted for drafting this narrative review article.

Epidemiology of Opioid Toxicity in the USA and Asia

It is a serious concern for the world. In the USA, about 2.1 million people are impacted by the opioid crisis, while globally, around 16 million people have been adversely impacted.[8] Opioid use disorders in the USA, defined by the American Psychiatric Association DSM-5, involve a strong urge to abuse opioids, leading to dependence and addiction.[9]

In Canada, opioid abuse became a big problem, with opioids being the 10 most common substances detected by Canada's Drug Analysis Service (DAS).[10,11] In Canada, since the 1980s, there has been a growing rate in sales of prescription opioid medication to patients, ranking second after the USA in terms of prescription opioids.[12] From 2016 and 2017, states such as West Virginia, Ohio, New Hampshire, Pennsylvania, then the District of Columbia documented the peak mortality rates in terms of drug overdose-related deaths.[13,14]

Asian nations represent one of the key cases of the world's unlawful opioid misuse, with India unaided accountancy for the world's 1/3rd part of the opioid ill-treating populace.[15] Bangkok fentanyl was traded as heroin, on behalf of a major threat.[16]

This write-up compares opioid toxicity epidemiology in the USA and Asian countries, explores prevalence, use designs, risk factors, and overdose-related morbidity and mortality.

Factors Contribute to Opioid Toxicity

Opioid toxicity, activated by extreme or misused opioid drugs, is prejudiced by numerous aspects, which are critical for stopping and handling contrary actions. Some important features are

1. Dose and potency: The severity of opioid toxicity is typically determined by the quantity and efficiency of the drug consumed, with high quantities increasing the risk of overdose and toxicity.[17,18] Superabundance of opioids is due to additional unbarred inducement of the opiate pathway. This can lead to death due to problems such as failure of the nervous system and respiratory apparatus.[19–21]
2. Tolerance and sensitivity: Chronic opioid use can lead to tolerance, increasing sensitivity to opioid effects and toxicity. Morphine, the most commonly used pain medicine, has been related to amplified adverse effects.[22,23]
3. Combination with other substances: Collaboration of opioids with benzodiazepines or alcohol, or other CNS depressant substances, is possible. Uniting opioids with these constituents can potentiate their properties, leading to respiratory depression and overdose.

Features inducing opioid usage comprise combination with other substances, direction of route, individual factors, and formulation. Combining opioids can lead to respiratory depression and overdose, as seen in the USA.[24,25]

1. Route of administration: The administration method of opioids, including intravenous or intranasal use, can significantly impact their onset, intensity, and duration of action, increasing the risk of toxicity.[26]
2. Individual factors such as age, weight, liver and kidney function, and pre-existing medical conditions can influence an individual's response to opioids, potentially increasing toxicity risk.
3. Opiod Formulation: Long-acting opioids require less frequent dosing, better pain management, and reduced risk of overdose and adverse effects.[27–30]
4. Accidental ingestion: Opioid medications by children, especially when kept at home, are a cause of accidental toxicity.[31] A study of 960 medical case reports from 12 pediatric hospitals found that over half of adverse drug events were caused by opioid use.[32,33]
5. Drug Interactions between opioids and other medications pose a significant risk due to their potential to affect metabolism, elevate opioid levels, and impact drug transport, absorption, and cytochrome P-450 enzymes.[34,35]
6. Polydrug use, where individuals combine multiple substances for recreational purposes, can increase the risk of opioid toxicity significantly.[36,37] In France, 67% of patients had a history of benzodiazepine use in their life, while in Spain, at least 45% were regularly taking benzodiazepines.[38–42]
7. Lack of attentiveness about opioid toxicity, signs of overdose, and the importance of seeking prompt medical attention can postpone the treatment and worsen the illness.[43] A study by Binswanger in the

USA found some blocks, counting nonappearance of awareness about opioid overdose,[44] concerns about legal liability,[45] and nonappearance of information about the use of naloxone.[46]

8. Illicit drugs and contaminants can also surge the risk of toxicity in cases of opioid usage. Research on the general population showed that in the USA, there had been at least 90% of opioid usage had occurred.[47–50] These persons used more than two other materials along with opioids within the same year, and another 25% had used at least two ingredients while having opioid use disorder.[51]

Averting opioid toxicity requires accountable prescribing, patient education, awareness of misuse risks, and access to addiction treatment and naloxone, a medication that reverses opioid overdoses.

Prescription Opioids and Opioid Analogues

Prescription opioids and opioid analogues are both types of opioid drugs, but have some key changes in their origins and legal status:

Prescription Opioids

Prescription opioids are a class of medicines that are lawfully prescribed by healthcare specialists to manage pain. These drugs are resulting from opium or synthesized in laboratories to mimic the effects of natural opiates. Common prescription opioids include:

1. Codeine: A comparatively mild opioid frequently used in combination with added medications to treat pain or suppress coughing.
2. Morphine: A potent opioid used in hospitals for mitigation of intermediate to severe grade pain.
3. Oxycodone: A strong opioid available to handle reasonable to severe pain and is reachable in both at once release and extended-release forms.
4. Hydrocodone: Hydrocodone is typically used in combination with NSAIDS, such as Ibuprofen or Acetaminophen, to alleviate modest to critical pain.
5. Hydromorphone: A very strong opioid used in some situations to handle critical pain.
6. Fentanyl: An enormously potent synthetic opioid used for managing severe pain, often in the form of coverings or lozenges.

Prescription opioids can be effective in treating pain when used appropriately beneath the guidance of a healthcare professional. However, they also carry a risk of dependence and overdose if misused or taken deprived of a prescription.

Opioid Analogues

Opioids, together with prescription and synthetic, can efficiently treat pain under healthcare guidance, but misuse or overdose can lead to misuse, requirement, and mimic the effects of natural opioids like morphine or heroin.[52]

Fentanyl, a strong painkiller, is regularly prescribed in medical practice for severe pain,[53,54] predominantly in cancer patients, and its short-acting analogues, alfentanil, sufentanil, and remifentanil, are frequently used in anesthesia events.[55,56]

Opioids should be used carefully and according to medical guidance to avoid abuse, addiction, and overdose. Seeking qualified help is crucial for recovery.

Opioid Regulation and Strategies

The opioid epidemic in the USA is inclined by cultural attitudes, healthcare systems, drug abuse rates, and political considerations, resulting in state-specific laws then policies.[57] such as monitoring the prescription drugs,[58] management of naloxone dispersal mechanisms,[59,60] and remark of pain treatment centers.[61–63]

Common Aspects of Opioid Regulation and Policies

Prescription regulations, controlled substance scheduling, and opioid overdose prescription: Most countries regulate opioid prescription and dispersal, demanding that health care workers follow particular strategies. In 2015, the USA issued an attention cautionary about fentanyl and its connections.[64] In 1996, Chinese policymakers applied legal restrictions on fentanyl and registered it in the collection of narcotic resources.[65]

Controlled substance scheduling contains needful primary care workers to form a reliable team capable of responding to opioid crises and decisive the most effective naloxone administration method.

Opioid Overdose Prescription

In the United States, 50,000 people remained experts between 1996 and 2010 under the OEND program, saving about 10,000 lives in cases of overdose through the management of naloxone.[66–68]

China is applying numerous programs to prevent opioid overdose deaths, with identification and inhibition, detoxification, and peer education training.[69] Naloxone kits are used in hospitals and emergency ambulance amenities, with the first community-based organization of naloxone launched in 2008 on a restricted scale.[70]

Prescription Drug Monitoring Programs (PDMPs) are real pools of electronic accounts that serve as a method of prescribing and providing controlled substances, including opioids.[71,72]

Opioid Substitution Therapy

OST reduces HIV transmission risk and health hazards in parental abusers, falling abscesses, contagions, septicemia, and endocarditis, purifying life quality and health.[73–75]

Harm minimization programs and Drug misuse control programs aim to mitigate harmful effects, deprived of strict bans, counting harmless needle sharing, checked consumption sites, education on harmless drug use means, and bloodborne contagion testing.[76,] The CDC advocates for cautious opioid use in chronic pain patients to stop overdoses and long-term side effects, and needful initial non-opioid use beforehand transitioning to opioids.[77–79]

Criminalization and Law Enforcement are additional vital aspects of speaking opioid toxicity. Some nations have required strict laws and penalties on owning and use of drugs, asserting them as criminal offenses.[80] For example, Singapore has a zero-tolerance policy to illicit drug transporting and prescribes the death penalty to persons and imprisoned with charges of unlawful drug trafficking. Other nations such as Myanmar, Laos, Thailand, Brunei, and Vietnam have alike punitive actions in place.[81,82]

Public education and awareness are significant strategies to minimize the growth rates of opioid misuse and addiction. Plans such as new policy development, population education, and social campaigns can be very effective[83,84] in spreading alertness about the dangers linked with opioid abuse and minimizing the problem of stigmatization of opioid misusers in society.[85,86] It is critical to strike a stability among the legitimate medical use of opioid medications and the complexities of opioid misuse and addiction.[87–89]

Challenges in addressing opioid toxicity include rapid onset of action, risk of co-ingestion, administration of naloxone, prescribing guidelines and practices, and long-term management. In the USA, irrational prescription practices have been attributed as a major contributor to the opioid crisis.[90–92] The CDC guidelines require healthcare givers to prescribe opioid medications judiciously and keep them reserved for management of severe intractable pain in cancer patients and avoid use as far as possible in patients with chronic pain due to non-cancer etiology.[93,94]

Long-term opioid management is crucial, addressing root causes and providing follow-up care.[95] In China, trained human resources are desired for methadone rehabilitation clinics, though in the USA, therapy is essential.[96,97]

The opioid crisis demands considerable government care and financial assistance for suitable treatment and upkeep programs, including increased subsidies for Methadone Maintenance Therapy clinics in China.[98]

Treatment strategies include developing a model across nations and states, identifying cases of opioid toxicity, and treating overdose with prompt administration of naloxone.[99] Naloxone is used as an initial defense in prehospital situations, reversing nervous system and respiratory depression, while Medication Assisted Treatment (MAT) is implemented, involving methadone and Buprenorphine for maintenance therapy.[100]

Naltrexone, its extended-release form, has been available for deep muscle injection since 2017 and is active in opioid maintenance therapy.[101] Buprenorphine, in an implantable method, was permitted by the US FDA in 2016 and is now obtainable as Probuphine.[102]

Prevention and Education Initiatives

1. Education and awareness agendas are vital for raising awareness about the health hazards and risks of opioid misuse, including public awareness in schools and health care provider-moderated meetings on pain minimization alternatives.[103,104]
2. Enhance treatment accessibility by providing validation-based procedures like MAT and making counseling and behavioral treatment centers easily reachable in hospitals, clinics, and mobile opioid treatment centers.

The global opioid crisis, aggravated by synthetic opioids and misuse in pain management, dictates coordination among agencies, organizations, and governmental organizations to develop tailored plans and policies. This contains data distribution, policy coordination, and supply chain rules. Association among international organizations like the World Health Organization, UNODC, and Interpol is vital.

Artificial Intelligence-aided support and management programs

1. Emerging predictive analysis algorithms using demographic records, medical records, and prescription data.
2. Prescription monitoring schemes driven by AI can track patients on opioid medications and send alerts to physicians about overdose or misuse.
3. Smart wearable AI-enabled devices used for improved tracking and monitoring of opioid patients.
4. AI for early intervention events using virtual assistants and chatbots, providing patients with data about pain management and informed policymaking.
5. AI can also improve treatment by providing better data about patients based on patient records and side effects.
6. Genetic research using AI to identify an individual's genetic predisposition toward opioid addiction.
7. Data exploration based on patterns can help health agencies and organizations understand the pattern of opioid abuse and toxicity in society, enabling effective intervention measures and resource allocation.

Conclusion

Opioid abuse and toxicity are a major challenge in today's world. The development of synthetic opioids and their application in pain management, followed by their irrational use and prescription, has caused a serious health crisis. There is a need for systematic collaboration among governments and organizations to develop policies and regulations aimed at the

effective control of opioid production, marketing, distribution, and prescription. There is a need for educating and training healthcare givers about opioid medications.

There is a need for providing training to healthcare personnel on opioid medication, pain management guidelines and safe opioid prescription practice. Robust mechanisms to monitor opioid dependent patients, opioid addicts, and illicit users should be developed through cooperation of the healthcare sector, government and social organizations, Artificial intelligence should also be used to ensure patient support, patient education, proper surveillance and monitoring and as well as data mining to continuously monitor the epidemiology and magnitude of opioid problem in society. This will enable organization and governmental bodies to create opioid reduction and opioid abuse, and toxicity management policies based on the specific requirements of the patient and healthcare community.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval and Informed Consent

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ORCID iD

M. Mukesh https://orcid.org/0009-0006-5687-8033

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Review Article

Significance of Reconstructing Road Traffic Accident Scenes and the Role of Forensic Engineering in Determining the Manner of Death

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Ashok Kumar Rastogi[1]

Abstract

Road traffic accidents are becoming increasingly common due to rising economic status, a growing number of vehicles, and the pressures of modern life. Autopsy surgeons determine the cause of death through post-mortem examinations; however, they are often unaware of findings from the accident scene. In India, road traffic accident reconstruction is rarely performed. In some instances, homicides are staged as road accidents to conceal the crime. The examination and reconstruction of accident scenes play a crucial role in distinguishing between accidental deaths and those resulting from foul play.

The study is based on an extensive review of research articles, books, and online resources. The article was searched on Google Scholar, PubMed, and the Google search engine, and the Medical Subject Headings (MeSH) terms used were road traffic accidents (RTA), crime scene, and forensic engineering. Incident site analysis, when correlated with autopsy findings, can help determine whether a death was caused by an accident or was homicidal. Proper preservation of evidentiary material at the scene aids in identifying the vehicle, driver, victim, and the exact location of impact. The study's main objective is to know how crime scene reconstruction and forensic engineering play a vital role in determining the manner of death.

Keywords

Road traffic accident, reconstruction, forensic engineering, evidence, homicide

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Introduction

Forensic engineering is the application of engineering principles and methodologies in legal investigations. This rapidly evolving field spans multiple engineering disciplines, including electrical, chemical, civil, metallurgical, and environmental engineering, all applied within a legal framework.[1]

Forensic engineers play a crucial role in resolving accident cases and criminal matters involving death or serious injury. While forensic science primarily focuses on biological and chemical analyses, forensic engineering extends its methodologies to understanding the response of human tissues to traumatic forces caused by impacts, falls, stabbings, bullet wounds, and explosions. Currently, most forensic engineering investigations occur within civil litigation; however, some cases, such as those involving criminal activities, also fall under its domain.

For example, consider an aviation disaster. The cause of a plane crash could stem from defective design, structural failure, or pilot errors, which are typically addressed in civil litigation. However, it could also result from terrorist activities, such as a bomb explosion or hijacking, which are criminal matters. The cause of such a disaster is initially unknown, and only through detailed forensic investigations can the true cause be determined. The explosion of Pan Am Flight 103 over Lockerbie, Scotland, on 21 December 1988, is a prime example.[2] Forensic engineers determined that the explosion was caused by a small terrorist bomb strategically placed in a baggage container adjacent to the fuselage, rather than by a design defect, mechanical malfunction, structural failure, or pilot error. The meticulous recovery and analysis of debris, partial aircraft reconstruction, study of its structural breakup, and examination of passenger injuries are landmark cases in forensic investigations.

[1]Department of Forensic Medicine and Toxicology, All India Institute of Medical Science (AIIMS), Patna, Bihar, India

Corresponding author:
Ashok Kumar Rastogi, Department of Forensic Medicine and Toxicology, All India Institute of Medical Science (AIIMS), Patna, Bihar 801507, India.
E-mail: ashokaiimspatna@gmail.com

Forensic engineering primarily analyzes property loss and injuries resulting from failures in materials, components, design, and construction. In cases involving property damage, economic loss, personal injury, or death, forensic evidence—along with expert testimony—is presented in court, arbitration, or other legal proceedings. These investigations are critical in prosecuting and defending civil and criminal claims. The primary objective is to determine whether an incident resulted from equipment design flaws, improper installation, human error, or a combination of these factors.

A significant aspect of forensic engineering involves road traffic accident reconstruction. By applying principles from mechanical, chemical, civil, and electrical engineering, forensic engineers help reconstruct accidents and identify their causes. Newton's laws of motion, which consider mass, velocity, and force, are particularly useful in these reconstructions. The force exerted in a collision directly correlates with the severity of injuries sustained, making forensic engineering essential in understanding accident dynamics and distinguishing between accidental and intentional acts.[3]

Methods

This study is based on an extensive review of research articles, books, and online resources. The article was searched on Google Scholar, PubMed, and the Google search engine, and the MeSH terms used were road traffic accidents, crime scene, and forensic engineering. Additionally, insights were gathered from forensic medicine departments, including autopsy examinations, crime scene analyses, and interactions with law enforcement personnel.

Discussion

Intrusion of engineering knowledge in the forensic field for the reconstruction of the crime scene in cases of road traffic accidents, which tells about the real story of the accident. Road traffic accidents are very common. India is a highly populated country, and very easy availability of facilities to obtain a vehicle with the help of a loan provider. Many accidents are staged to conceal the crime; thorough examination of the body and reconstruction of the crime scene can throw light on whether the road traffic accident was an accident or any foul play. In the Indian scenario, if a person dies due to an accident, the dead body is sent for autopsy examination. In almost all cases, by observation, the autopsy surgeon is unable to opine whether the death was due to a road traffic accident or homicide by vehicle. Forensic pathological evidence and scientific evidence would both be taken into consideration to decide the cause of death and the manner of death.[4] The cause of the accident can be analyzed in two ways: failure analysis and root cause analysis (RCA).[5] Eyewitness testimony is generally more reliable and accurate than assumptions and speculation. Eyewitnesses can be cross-examined to determine the accuracy and facts, but in many cases, eyewitnesses are not available to discuss the real cause of the accident.

Many road traffic accidents are staged intentionally to disguise homicide. Therefore, every death attributed to an road traffic accidents (RTA) should undergo a thorough autopsy and detailed scene reconstruction to determine whether the death was accidental or the result of foul play. Key aspects of reconstruction include assessing the road conditions, vehicle status, the driver's skill level, and potential substance use or addiction. Expert evaluation of these factors is essential in forming an accurate opinion during the forensic investigation.

Forensic mechanical evaluation provides insights into the force applied during a road traffic accident by assessing the vehicle's speed and brake condition. The state of the brakes indicates how much force was reduced upon braking, which in turn helps estimate the extent of damage. Evaluating both the speed and braking efficiency contributes to understanding the severity of the impact.

Injury patterns observed on the body also provide important clues. The location and height of injuries related to the ground can indicate whether they are consistent with a vehicular impact. The presence of braking at the time of the accident, along with injury patterns, helps determine if the death was accidental or the result of foul play. When injuries align with typical accident scenarios and mechanical findings, the possibility of foul play can often be ruled out.[6] The site of primary impact injuries observed in the pedestrian during the accident suggests the accident or foul play.

Forensic Engineering in Autopsy Examination and Crime Scene Examination

Various Branches of Forensic Engineering

1. Forensic physics
2. Forensic Chemistry
3. Electrical engineering
4. Civil engineering
5. Mechanical engineering and related fields.

Various Uses of Forensic Engineering

1. Train accidents
2. Plane crash
3. Factory accidents
4. Electrical short circuit fire
5. Reconstruction of the crime scene
6. Reconstruction of road traffic accident
7. Solving various crimes and many more.

History of Forensic Engineering

Considered the father of criminalistics, Edmond Locard made significant contributions to forensic science. In 1910, he established the world's first forensic laboratory in France and formulated the fundamental principle of forensic science: "Every contact leaves a trace," now known as Locard's Exchange Principle.[7] Forensic engineering, an essential branch of forensic science, has played a crucial role in solving numerous accident cases by applying engineering principles to investigations. By integrating knowledge from various engineering fields, forensic experts have successfully determined accident causes, identified responsible parties, and prevented future incidents. In some cases, meticulous forensic engineering investigations have saved lives, such as those of American pilots, by identifying and addressing mechanical failures before further crashes could occur.[1,4,8]

Examples include forensic engineering and the reconstruction of the incident scene of road traffic accidents.

1. A dead body was found on the roadside with only a head injury. The autopsy report confirmed that the cause of death was due to the head injury, raising suspicion that the death might be homicidal in nature. Forensic experts conducted a scene investigation and accident reconstruction to clarify the circumstances. After a thorough examination of the road conditions and the recovered motorcycle, it was determined that the death resulted from an accident rather than foul play.[8,9]
2. Based on the crime scene examination and analysis of physical evidence, an accidental death case was later classified as murder under Section 103 of the Bhartiya Nyaya Sanhita. The deceased's family members alleged that the victim was murdered and then dragged by a vehicle in an attempt to dispose of the body and destroy evidence. To verify these claims, crime scene reconstruction was conducted. Investigators analyzed the scene's appearance, the locations and positions of physical evidence, and the injuries sustained by the deceased. This forensic examination played a crucial role in determining the actual cause and manner of death.[10]

Methods of Road Traffic Accident Scene Reconstruction[11]

Empirical Methods

1. It contains testing of materials in the laboratory.

Theoretical Methods

1. RCA
2. Event and causal factor charting
3. Management oversight and risk tree
4. System Safety Accident Investigation

Source of Physical Evidence in the Investigation of A Road Traffic Accident:

The Crime Scene Examination

1. The vehicle may be one or more, its type, directions, and positions.
2. Track marks such as tire impressions of wheels, which are found either at sharp turns or where the vehicle has been reversed.
3. Broken or damaged part of the vehicle.
4. Grease and lubricants, glass pieces of various shapes and sizes.
5. Paint chips or smears.
6. Dust, dirt, or other debris, pieces intact, or otherwise fallen from the suspect vehicle at the time of impact.
7. Personal or vehicular articles left at the scene.
8. Drag marks of the loaded material (such as wood, concrete, and pieces of stone).

The Vehicle Examination

1. Look out for paint chips or smears.
2. Dust, dirt, or other debris, pieces intact, or otherwise fallen from the suspect vehicle at the time of impact.
3. Personal or vehicular articles left at the scene.
4. Drag marks of the loaded material (such as wood, concrete, and pieces of stone).
5. Mechanical fault in the vehicle.
6. Evidence related to changes in paint and the number of registration plates, serial numbers on the engine and chassis.
7. Evidence related to the overloading of vehicles.
8. The load on a vehicle may leave a characteristic smell on the way through which it has moved.

The Victim Examination

1. Paint, glass pieces, grease, and lubricants tier mark may be present on the cloth of the victim.
2. Injuries
3. Blood, fibers, hairs, and skin for the control sample
4. Alcohol and narcotics in the body, if the victim had shown the same signs of disease from the post-mortem report.

Collection of Evidence

Photograph and Sketch the Scene Immediately

1. Capture images and create sketches as soon as possible before collecting evidence.

2. Ensure that key landmarks are included in the photographs to establish the location.
3. Take close-up shots showing identifying details of the vehicle, such as the type and number plate.

Document Vehicle-specific Details

1. Record the speedometer reading and note the vehicle's temperature, atmosphere, and radiator water before moving it.

Preserve and Collect Evidence

1. Gather loose trace evidence (e.g., paint chips and broken glass) that could be lost during transportation.
2. Conduct a thorough examination of the vehicle for any additional physical evidence.
3. Collect various forms of forensic evidence, including:
    - Skid marks and broken machinery parts
    - Bloodstains, fibers, and hair
    - Alcohol traces, glass fragments, paint samples, and soil
    - Dust, debris, grease, and lubricants
4. Collect control samples where necessary for comparison.

Documentation and Reporting

1. Maintain detailed records of all collected evidence.
2. Ensure that photographic findings and other documentation support the investigation.

Evaluation of Physical Evidence

1. Is the vehicle itself a cause of the accident?
2. Speed
    - The ability of the driver.
    - The performance of the vehicle.
    - The condition of the road.
3. The following methods can calculate speed.
    - From the length of the skid marks.
    - From the radius of the curved scuff mark.
    - From the extent of vehicle damage.
    - The speed and the nature of the surface of the road result in the distance taken by the vehicle to come to a halt.
    - The coefficient of friction (μ') between the tire and the road surface can be a reliable estimate of speed (V), which can be calculated from the length of the tire mark.

Conclusion

Accident scene reconstruction should be conducted in a road traffic accident case to determine whether the incident was genuinely an accident or involved foul play. An autopsy report alone cannot always establish whether injuries are homicidal or accidental. Scene examination, evidence collection, and forensic engineering assessments are essential in drawing accurate conclusions. Reconstructing the accident scene provides valuable insights into whether the death was accidental or homicidal. Regardless of discipline, forensic engineers play a crucial role in solving such cases, driven by their investigative curiosity and problem-solving expertise. Curiosity is a trait shared by all forensic engineers. Regardless of discipline, all forensic engineers must be able to solve issues. Reconstruction of crime scenes with the help of technology and engineering is a growing field.

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ORCID iD

Ashok Kumar Rastogi https://orcid.org/0000-0002-6207-860X

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Examining Egg Donor Rights in the Surrogacy (Regulation) Act, 2021 of India: A Medico-legal Study

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Pyali Chatterjee[1,2]

Abstract

The eagerly awaited Surrogacy (Regulation) Act of 2021, following extensive deliberations and amendments during its legislative journey, disappointingly neglects the essential rights of egg donors, notably in terms of health insurance coverage and safeguarding their well-being throughout and after the egg retrieval process. The Act lacks provisions for addressing reported instances of medical complications and, tragically, even the unfortunate demise of egg donors. This significant oversight not only infringes upon the fundamental rights of these contributors but also underscores a disproportionate emphasis on the rights of surrogate mothers within the framework of the Surrogacy (Regulation) Act, 2021. This research endeavor seeks to illuminate the deficiencies within the Act as it pertains to the rights of egg donors and, in response, proposes viable remedies for consideration.

Keywords

Egg donor, surrogacy, artificial hormone, egg removal, IVF, oocyte

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Introduction

In 2021, at last, the Surrogacy Act was passed. Many amendments and discussions were made before passing this act. One of the important amendments that were done before passing it was the banning of commercial surrogacy[1] for the protection of surrogate mothers from being trafficked. Now, only altruistic surrogacy is allowed. As per Section 2(b) of the Surrogacy (Regulation) Act, 2021,

> [A]ltruistic surrogacy means surrogacy in which no charges, expenses, fees, remuneration, or monetary incentive of whatever nature, except the medical expenses incurred by the surrogate mother and the insurance coverage for the surrogate mother, is given to the surrogate mother, her dependents, or her representative.[2]

Thus, altruistic surrogacy means that the surrogate mother does not receive any monetary support from the intending couple except for the medical expenses of renting her womb.[3]

From time to time, the government has taken various measures for the protection of surrogate mothers in surrogate industries. On July 15, 2019, before the passing of the act, when the Surrogacy (Regulation) Bill, 2019 was presented before the Lok Sabha by Dr. Harsh Vardhan, Minister of Health and Family Welfare, he said that the main objective behind the bill was that

> *The bill is aimed at ending the exploitation of women who are lending their wombs for surrogacy and protecting the rights of children born through this. The bill will also look after the interests of the couple that opts for surrogacy, ensuring that there are laws protecting them against exploitation by clinics that are carrying this out as a business. There are very few countries in the world that allow commercial surrogacy, with experts arguing that this is an exploitation and abuse of human dignity. We cannot allow women in our country to be exploited without their understanding what is happening to them. The government has a duty to protect the interests of these women.*[4]

[1]Faculty of Law, ICFAI University, Raipur, Chhattisgarh, India
[2]Tashkent State University of Law, Tashkent, Uzbekistan

Corresponding author:
Pyali Chatterjee, Faculty of Law, ICFAI University, Raipur, Chhattisgarh 490042, India.
E-mail: pyali.chatterjee@gmail.com

This clearly shows that the government was concerned more about the surrogate mother's rights as well as their health.

If we talk about the surrogacy process, most of us generally think that surrogacy consists of three parties, that is, the surrogate mother, the intended couple, and the hospitals. But there is one more party that plays an important role in the surrogacy process, that is, the egg donor. Egg donors are equally important as surrogate mothers. They also played an important role in the surrogacy process, especially in cases where the egg could not be retrieved from couples because of infertility issues.

Egg Donor

The surrogacy process is of two types: (a) gestational surrogacy and (b) traditional surrogacy.

Gestational surrogacy[5]: Gestational surrogacy is a type of surrogacy where the surrogate mother is not genetically related to the fetus. In this kind of surrogacy, either the intended parent's egg or a donor egg is used for fertilization. Once the fertilization process is done, it is inserted into the womb of the surrogate mother through IVF. The pregnancy is carried out by the surrogate mother, who gives birth to the child. Here in gestational surrogacy, the surrogate mother is not genetically linked to the child, as she only rents her womb for carrying the child. The egg donor is needed here if gametes are not possible to retrieve from the couple in case of gestational surrogacy. In India, only gestational surrogacy is allowed for the surrogacy process. Actually, for many, there is a misconception that surrogacy means only intended couples and a surrogate mother. But the truth is that when the gametes from any of the couples cannot possible retrieved due to any medical conditions, then this sperm donor and egg donor are required for the surrogacy process.

Pic- Compiled by the author to show that in the surrogacy process, apart from the intended couples and surrogate mother, egg donor and sperm donor are also required to complete the surrogacy process in some cases (Figures 1 and 2).

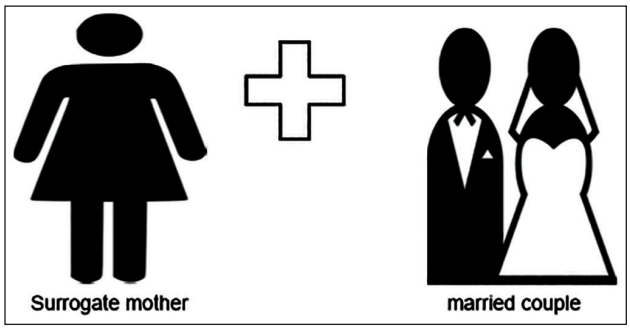

Figure 1. When Gametes Are Taken From the Intended Couple. Then the Parties for the Surrogacy Process Will Be Surrogate Mother and the Intended Couples.

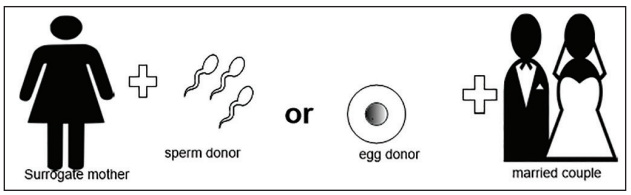

Figure 2. When Gametes Are Taken From Any Donor (Egg or Sperm) Due to Medical Issues Related to the Fertility of Either Member of the Intended Couple. In This Case Sperm Donor or Egg Donor Is Required to Complete the Surrogacy Process.

Traditional surrogacy[5]: Traditional surrogacy, on the other hand, is the opposite of gestational surrogacy. In traditional surrogacy, the child will be genetically attached to the surrogate mother. Surrogate mother gametes are used here for fertilization. No egg donor is required here in this process. In India, it is not allowed.

Thus, from the above discussion, it is clear that in gestational surrogacy cases, an egg donor can also be a party to the surrogacy process when gametes are not possible to retrieve from the intended couples due to any medical reason.

Law Relating to Egg Donor

Criteria

The legislature has kept the same criteria for becoming a surrogate mother and egg donor in the Surrogacy Act. Section 4(iii)(b)(I) of the act states that

> [N]o woman, other than an ever-married woman having a child of her own and between the ages of 25 and 35 years on the day of implantation, shall be a surrogate mother or help in surrogacy by donating her egg or oocyte or otherwise.[2]

It is also mentioned that the surrogate mother cannot use her gametes for surrogacy and that only married women who are closely related to couples can become surrogate mothers, as well as these women can become surrogate mothers once in their lifetime. Here in surrogacy, it is mentioned that for surrogacy egg donor must be married and must have one child.

But if we go through the Assisted Reproductive Technology (Regulation) Act, 2021 (hereinafter referred to as the ART Act), we will find that the bank registered under the ART Act can obtain oocytes from "females between twenty-three years of age and thirty-five years of age, and an oocyte donor shall donate oocytes only once in her life, and not more than seven oocytes shall be retrieved from the oocyte donor."[6] It is not necessary here in ART that the egg donor be closely related to the intended couple. Anyone here can donate eggs.

Medical Insurance

The definition given by the Surrogacy Act regarding altruistic surrogacy says that in altruistic surrogacy

> [N]o charges, expenses, fees, remuneration, or monetary incentive of whatever nature, except the medical expenses and such other prescribed expenses incurred by the surrogate mother and the insurance coverage for the surrogate mother, is given to the surrogate mother, her dependents, or her representative.[2]

Regarding insurance, it is defined as

> [A]n arrangement by which a company, individual, or intending couple undertakes to provide a guarantee of compensation for medical expenses, health issues, specified loss, damage, illness, or death of a surrogate mother, and such other prescribed expenses incurred on such a surrogate mother during the process of surrogacy.[2]

Section 4. (iii)(a)(III) of the same says that

> [I]nsurance coverage of such an amount and in such a manner as may be prescribed in favour of the surrogate mother for thirty-six months covering postpartum delivery complications from an insurance company or an agent recognized by the Insurance Regulatory and Development Authority established under the Insurance Regulatory and Development Authority Act.[2]

Surprisingly, the Surrogacy Act mentions the criteria for the egg donor. But nothing has been mentioned about the medical insurance for an egg donor. The act is silent about the insurance for an egg donor for a surrogacy process. Regarding insurance, one can see the Assisted Reproductive Technology (Regulation) Act, 2021. Section 22(1) of the ART Act says that

> [T]he clinic shall not perform any treatment or procedure without insurance coverage of such amount as may be prescribed for a period of twelve months in favor of the oocyte donor by the commissioning couple or woman from an insurance company or an agent recognized by the Insurance Regulatory and Development Authority established under the provisions of the Insurance Regulatory and Development Authority Act, 1999.[6]

Section 22(4)(ii) speaks about insurance, which "means an arrangement by which a company, individual, or commissioning couple undertakes to provide a guarantee of compensation for specified loss, damage, complication, or death of an oocyte donor during the process of oocyte retrieval."[6] Even regarding oocyte donation, it is mentioned in the ART Act that an oocyte donor shall donate oocytes only once in her life and that no more than seven oocytes shall be retrieved from the oocyte donor. Though it is mentioned here in the ART Act that insurance should be provided to the egg donor, in actual cases, the situation is different. In cases of the death of the egg donor, the family members have to run here and there for the compensation amount.[7]

Punishment

The Surrogacy Act has made it clear that

> [N]o person, organization, surrogacy clinic, laboratory, or clinical establishment of any kind shall sell human embryos or gametes for the purpose of surrogacy; run an agency, a racket, or an organization for selling, purchasing, or trading in human embryos or gametes for the purpose of surrogacy; or import, or shall help in getting imported, in whatever manner, human embryos or human gametes for surrogacy or for surrogacy procedures.[2]

Selling and purchasing of gametes are punishable offenses under the Surrogacy Act as well as under the ART Act. But what about the right to get compensation amount for the loss of wages suffered by the egg donor during the egg retrieval process? Nothing has been mentioned about the economic loss suffered by the egg donor under the ART Act, as well as under the Surrogacy Act.

Drawbacks of the Surrogacy and ART Act

One of the conflicts that arises here in the ART is whether seven plus seven oocytes from both ovaries can be removed or whether, in total, seven oocytes can be removed from both ovaries. This is not addressed here in the Act. Another conflict is that for surrogacy, it is specifically written that an egg donor should be married, but for ART, marriage is not a condition for an oocyte donor. Marriage is a condition only for the intended couples. Because nowhere in the ART Act except for intended couples' marriage been used as criteria. Now it becomes a question for egg donors: which law will be followed?

Violation of Egg Donor Rights

Now, from the above discussion, we have seen that the egg donor is also one of the parties to the surrogacy agreement, depending upon the intended couple's health conditions. Although nothing has been mentioned in the Surrogacy Act about the insurance benefit for the egg donor, reference can be taken from the ART Act, as surrogacy cannot be done without the support of ART. But there are many instances where it can be seen that egg donor rights have been violated. The following are some major areas where egg donor rights are violated-

Synthetic Hormone

There is no uniform law or guideline regarding the dosage of Gonadotropin injection, which is a synthetic hormone used in the process of egg removal. The number of oocytes that can be removed from the donor has been mentioned in the ART Act, but there is no mechanism to check in actuality how many oocytes have been removed.[8] Even because of the use of the synthetic hormone, many short-term and long-term health issues are associated with it. Short-term risk associated with it is ovarian hyperstimulation syndrome (OHSS), ruptured cysts, ovarian torsion, bleeding, pelvic pain, mood swings, infection, premature menopause, kidney failure, stroke, and even death. Other most serious long-term risks are future infertility and cancer, most commonly ovarian, breast, and endometrial. But if we check the insurance provider of the ART Act there, we will find that insurance covers only short-term risk; nothing has been mentioned about long-term risk. Here at ART Act, the insurance has been provided only for 12 months and not more than that, and from past research, it has been proven that long-term health risk is associated with the egg donation process. This is a violation of the egg donor's right to health, as most of the time it has been noticed that egg donors were not aware of the risk associated with the egg removal process.[9] Even if we go through Section 21 of the ART Act, then we can find that the ART clinic has to provide professional counseling to the commissioning couple and woman regarding all potential outcomes and the likelihood of success of assisted reproductive technology procedures in the clinic. The clinic will inform the commissioning couple and woman regarding the costs, benefits, and risks associated with the procedures, including the possibility of multiple pregnancies; also, it will help the commissioning couple or woman to reach an informed decision on matters that would be important to them. But nothing has been mentioned about providing professional counseling to egg donors about the risks associated with the egg retrieval process. This is the drawback of the law because poor, innocent women become victims of these ART and Surrogacy clinics.[10]

Number of Eggs Removal

Recently, an unidentified 23-year-old lady from Delhi died suddenly during the egg retrieval process. The woman was married with a child, and she was healthy when she went to the hospital for the egg-donate procedure. Upon her death, a post-mortem report revealed that she died from OHSS, a complication that affects one in three women undergoing IVF.[11] In general, the oocyte donation process starts with ovarian stimulation, the first step in IVF, which involves taking synthetic hormones to boost the number of eggs produced by the ovaries. This is done so that doctors can collect as many eggs as possible to fertilize, which increases the choice of embryos that can be implanted.[11] This is another violation of the rights of the egg donor. Even in many past research, it has been found that women donate eggs more than once in their lives. Even if they become a surrogate mother more than once in their life. This is a way for them to earn huge money[10] in a short duration.

Right to Remuneration

Before 2016, both the Assisted Reproductive Technology (Regulation) Bill and the Surrogacy (Regulation) Bill were considered to be consolidated laws that sat on a wall like "Humpty Dumpty."[12] It was later, when commercial surrogacy was banned in India, Humpty Dumpty had a great fall, leaving the Surrogacy Regulation and Assisted Reproductive Technology Bill as two different laws. But even though they have been separated, these two have to run simultaneously. As surrogacy is not possible without ART. Here, it is important to mention that commercial surrogacy is strictly prohibited as per the Surrogacy Act 2021, and it is also a punishable offense; the surrogate mother will not receive any remuneration from the surrogacy agreement. Recently, a writ petition has been filed by Aniruddha Narayan Malpani Versus UOI and others | W.P. (Civil) No. 1129 of 2022 before the honorable Supreme Court regarding the violation of egg donor rights in IVF industries.

> This petition specifically deals with the rights of egg donors. IVF through third-party donor eggs constitutes 40 percent of all IVF procedures and the Act completely overlooks their rights to compensation for the time and effort of going through the surgical procedure of going through egg retrieval and other expenses like food, travel, and accommodation, which is unjust and unreasonable leading to an extreme shortage of egg donors in the country. While surrogacy consists of three to five percent of assisted reproduction, IVF makes up 97 to 98 percent of it. Therefore, the number of people affected by it is very large. The provision of allowing only one oocyte donation in the lifetime of a donor and other ancillary provisions are not just unscientific and unreasonable but against international best practices. These issues have not been dealt with, in the surrogacy PIL.[13]

Now, the IVF industry, which runs with the help of egg donors, violates the economic rights of the egg donor due to a lack of provisions in the ART Act related to remuneration benefits for an egg donor. Even if it may raise the issues of human trafficking in the surrogacy and IVF industries.[8]

Conclusion and Suggestion

1. The insurance coverage for egg donors should be increased from 12 to 36 months, like that of the Surrogacy Act of 2021.
2. Remuneration should be fixed nationwide for egg donors, just like the government has fixed costs for

knee replacement surgery in India.[14] By doing this, egg donors' rights will be protected from loss of wages during the egg retrieval process, as well as their economic rights, which will not be violated. In most cases, it is the poor lady who approaches the ART clinic for egg donation. It is a kind of source of income that they can earn through this process.

3. Proper professional, as well as legal, counseling, should be provided to the egg donor to ensure that she has received all kinds of information related to the risks associated with the egg retrieval process, as well as about their rights and benefits from this process. After having professional counseling, the egg donor should sign the consent form along with the two witnesses. One witness must be from the family of the egg donor and one from the ART clinic.
4. There must be a mechanism to check the number of eggs that are retrieved during the egg retrieval process. A camera recording should be done for every egg retrieval process. That should be kept in the records of the ART clinic.
5. The National Board of the ART Act can create an All India System software for recording the details of an egg donor, which will be accessible only by the ART clinics registered under the ART Act. It will be linked with the Aadhaar card so that every single detail and history of the egg donor will be available in the portal for verification to check the number of times they have gone for the egg donation. An Aadhar card should be mandatory for egg donation to ensure that a woman does not donate her egg more than once during her life. Through the Aadhar card, it will be easy to track the record of the egg donor. Even by performing this insignificant act, a poor lady can be saved from human trafficking.
6. Guidelines must be framed for the usage and dosage of synthetic hormones in ART clinics for the egg retrieval process.
7. More research is needed to find the drawbacks of the ART Act and the Surrogacy Act. So that no one's rights should be violated.

There is no doubt that surrogacy is a wonderful process for those who want to have their baby. It is an achievement for medical science to provide a ray of hope to infertile couples who hope to have their baby through this ART process. But on the other hand, this process has many drawbacks. This is a complex and costly process in which, directly or indirectly, many people are involved. The benefits of this process can be enjoyed by couples who are financially stable, and this process can provide a short-term earning opportunity to the egg donor, as they are one of such parties in the process of surrogacy. It has been seen in the past that the right to health and the economic rights of the egg donor have been violated most of the time in surrogacy cases. The lawmakers must check and provide a remedy to the egg donor, as they are an important part of the surrogacy process, and their rights should not be violated. Even so, it is the government's responsibility to ensure that egg donor rights are not violated.

Declaration of Conflicting Interests

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ORCID iD

Pyali Chatterjee https://orcid.org/0000-0002-3307-0465

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Review Article

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Uttam Singh[1], Rajvinder Singh[1] and Sandeep Singh Sahota[2]

Abstract

Forensic ballistics involves the examination of firearms and related evidence and their interpretation for judicial procedures. When reconstructing a crime scene, forensic ballistics can help determine the shooter, the weapon used, the range, and the approximate time of the incident. In spite of its contemporary literary connotations, forensic ballistics has been practiced for decades. Black powder and gunpowder predate forensic ballistics. Forensic ballistics is a combination of various scientific disciplines such as physics, mathematics, statistics, computers, photography, forensics, and medico-legal. This is a unique and practical field that is used in the scientific and judicial investigation of offenses related to weaponry. Its contributions to legal and medico-legal studies are widely recognized. Although there is a wealth of information available about the development of forensic ballistics worldwide, there is a dearth of information and substantial gaps in the literature. To describe the development and dissemination of forensic ballistics throughout India, this review study consults outdated but useful literature. This review may be helpful to criminal investigators, prosecutors, and anyone interested in comprehending firearm evidence and legal investigation, since forensic ballistics is of importance to the legal, social, and scientific sectors. Researchers and students who are interested in the subject can learn more about the development and dissemination of forensic ballistics in India from this review.

Keywords

Forensic sciences, forensic ballistics, evolution of forensic ballistics, ballistics in India, integrated ballistics identification system (IBIS), automatic firearm identification system (AFIS)

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Introduction

Justice is as old as civilized society, and crime is as old as humanity. To help the judicial system fully illuminate a crime scene, forensic experts systematically collect and examine the visible evidence. To determine if a crime is true or not, forensic science is essential to legal investigations since it manages and retrieves evidence from crime scenes using the right scientific methods. Consequently, it would be true to state that the use of forensic science has changed the general public's trust in the criminal justice system. One of the many subfields of forensic science is forensic ballistics. It relates to using the principles of physics and ballistics to aid legal matters. The term "ballistics" originates from the Greek word "ballista," also known as "ballein" or "ballo," which described a type of ancient military siege engine used to launch stones. Ballistics understands the laws that apply to all projectiles, regardless of their type. Ballistics is the study of projectile behavior in relation to weapons, including in the air, inside a gun, and at the moment of contact. Physics and ballistics are closely related scientific disciplines since ballistics is a naturally occurring subset of engineering physics. Ballisticians design and develop new kinds of weaponry using a multidisciplinary approach and physics principles. Applying knowledge of firearms, ammo, and bullets to legal matters is known as forensic ballistics.[1]

[1]Department of Forensic Science, Maharshi Dayanand University, Rohtak, Haryana, India
[2]Forensic Science Laboratory, Mohali, Punjab, India

Corresponding author:
Uttam Singh, Department of Forensic Science, Maharshi Dayanand University, Rohtak, Haryana 124001, India.
E-mail: ud.singh528@gmail.com

Forensic ballistics combines two meanings to provide the judicial system with practical knowledge.[2] The Oxford Advanced Learner's Dictionary defines the terms "forensic" and "ballistics" respectively as "the scientific study of things that are shot or fired through the air, such as bullets and missiles," and "connected with the scientific tests used by the police when trying to solve a crime."

The word "firearms forensic examination," a 20th-century scientific term, was utilized early on in both Europe and the United States as well. Still, based on technical considerations, "forensic ballistics" has gained more traction.[3] Ballistics research is still undervalued since non-specialists prefer to enjoy and use firearms in the ways they are familiar with, blissfully ignorant of the specifics. However, those who are interested, particularly academics, may find it incredibly intriguing to learn about firearms' development, operation, and forensics. People of different academic levels have studied ballistics and its history for centuries. Literature advocates that medieval China developed guns first. The Chinese blacksmiths then constructed a tube robust enough to withstand explosions caused by gunpowder. Early constructed guns used a ramrod-powered muzzle-loading method to operate. Weapons technology's rapid and progressive growth reached a turning point in the 19th century. By creating a far better ignition system known as the percussion cap in 1807, Alexander John Forsyth (1768–1843) eliminated the drawbacks of the flintlock mechanism. The change from flintlocks to percussion cap guns in armament was made possible by technical advances in firearm and ammunition design. The percussion cap included mercury fulminate as a primer to burst the primary charge loaded and filled at the breech end. The projectile, a round lead ball, began to assume beautiful cylindrical geometries and was occasionally spitzer and jacketed. This significant development in weapon technology improved the accuracy of gunfire. It paved the way for the current breech-loading guns and self-contained metallic cartridges.

Additionally, the 20th century saw a similar progression in gun propellants. In the weapon cartridges, nitro-based single and double powders replaced the traditional black powder and cordite. Computer and digital technologies added another creative twist to forensic ballistics by creating cutting-edge automated software and computational ballistics.[1,4]

Development of Forensic Ballistics in India

The literature on Indian forensic ballistics is scanty, but it was initiated during the British Empire. No thorough coverage has been done since the subject's inception in India. Therefore, the present article has included the birth and extension of forensic ballistics in India. India has always put sincere efforts into the advancement of science and technology. In the late 1950s, India focused on "experimental sciences" under its National Science Policy to conquer scientific self-reliance for industrial development.[5] Forensic science is an array of several scientific fields. Ever-changing and advancing scientific tools and techniques keep providing forensic science with new working wings. Forensic experts also monitor these scientific developments and try to deliver their reliable and robust knowledge in laboratories and judicial proceedings.[6]

The Government of India has also been diligent in ensuring the establishment and development of forensic science. It started in 1952 with the establishment of the first state forensic science laboratory in Kolkata (then Calcutta) and is still going on with the establishment of the world's first National Forensic Science University (NFSU) in Gandhinagar, Gujarat, in the year 2020. India has, to date, established seven Central Forensic Science Laboratories (CFSLs), 32 State Forensic Science Laboratories (SFSLs), and a large number of Regional Forensic Science Laboratories (RFSLs). All these scientific set-ups and a few other investigative agencies, including the National Investigation Agency (NIA), Central Bureau of Investigation (CBI), and Intelligence Bureau (IB), have been working day and night to help law enforcement agencies tackle and solve crime cases. All forensic domains have been constantly progressing over time. Forensic ballistics has also shown great promise in combating firearm-related crime in India.

1. Indian Gun Laws and Initial Introduction of Forensic Ballistics: It might be an unblemished portrayal of the technological facilities for bolstering forensic ballistics-based R&D work in India. How far today's India is from such scientific expansion comes to our minds with the requirement of a swift address. However, if someone wants to understand the forensic ballistic strategies involved in solving crimes in Europe and the USA, a basic understanding of ballistics advancements and their comparison with practices employed in India becomes a vital topic. It is evident from the literature that Mughal and British artillery in India used different types of firearms, especially the muzzleloader. In the mid-1800s, the British colonial government was more attentive to trends and legal regulations on firearms for some important reasons.[7] Martial, hunting, and self-defense were legal grounds for keeping and using firearms, but criminal conduct was never far away. These malicious activities pushed the creation of modern police forces and a stringent Arms Act. The Indian Arms Act 1878, during the headship of Lord Lytton, Viceroy of British India, made the act of holding an unlicensed gun a punishable act with a fine and imprisonment for a given period. There were several such cases and movements involving illegal weapons when the fight for freedom was on the rise in the British Raj. The Arms Act, enacted in 1878 during the British Raj and later post-independence, was replaced by the Arms Act 1959 of the Parliament of India. It was an attempt to curb illegal weapons and violence

in India. It followed the enactment of the Arms Rules 1962, which banned unauthorized or illegal manufacturing, selling, possessing, acquisition, import-export, and transport of firearms and ammunition in India. The Arms Act (1959) saw several amendments in the past. The last Arms (Amendment) Act, 2019, was published by the Legislative Department, Ministry of Law and Justice, vide Gazette of India (E) Part-II Section-I No. 72 on 13 December 2019. Literature also reveals a strong bond between medico-legal and forensic science in India. On the recommendation of the William Bentinck committee in 1833, the first medical college, known as "Medical College Kolkata," was established on January 28, 1835.[8,9] Observing the 1857 revolt, the British in India established the Indian Police Act in 1861 to regulate the police departments in the country. However, again, socio-political chaos forced the British administration to establish a ballistic laboratory under the Calcutta Police Department in 1930 to examine firearms. In the mid-1930s, different states' Criminal Investigation Departments also established scientific sections and minor ballistics laboratories to assist the police in criminal investigation.[10] However, the scientific analysis of legal evidence had already commenced in the British Empire. Keeping in view the medico-legal problem of poisoning cases, the first Chemical Examiner Laboratory (for examining commercial and civic articles sent by the state excise and prohibition department), under the Department of Health, was set up on October 30, 1849, at Madras (now Chennai) under the control of the Medical Board, Fort St. George, Department of Health. Later, in 1929, this laboratory became entitled to perform medico-legal and chemical-legal analysis. Ballistics and explosive divisions came into being for the first time in India. Literature also points to the initiative taken by Lieutenant Colonel C. Newcomb, Principal of Madras Medical College and Chemical Examiner, to the Government of Madras, to introduce a technique for identifying the fired cartridge cases and bullets.[11] Later, the British government established three other chemical examiner's laboratories at Kolkata (1853), Agra (1864), and Bombay (1870) that covered a similar scientific pattern of analysis.

2. Fundamental Ordinance and Ballistics Set-ups in India: India has several specialized Army Ordinance and ballistics laboratories that are mostly research-oriented. They are generally unaffiliated with central, state, or RFSLs. The ready availability of ammunition is a breath of fresh air in the Army's overall preparedness, particularly during wartime. Indian Ordnance Factories (IOF) are the oldest and largest industrial structures governed by the Ordnance Factory Board (OFB), primarily to achieve self-reliance in equipping the armed forces. The official beginning and administration of the Army Ordinance in India started during the British reign. The purpose of establishing ordnance factories was to aid in some military-related work. Therefore, to strengthen the military infrastructure, they accepted establishing a Board of Ordnance at Fort William, Kolkata, in 1775, and the first official foundation of the Army Ordnance originated in India. It followed the establishment of a Gunpowder factory (1787) and a Rifle Factory (1904) in Ishapore. The first industrial establishment of ordnance factories was established in 1801, and it is now known as the Gun and Shell Factory in Cossipore. In India, the Director General Ordnance Service at Army Headquarters is the apex authority for the overall procurement and management of ammunition in the Army. Most of the ammunition for the Army is procured from the OFB. Before 1950, India had only 19 ordnance factories. India now has 41 operational ordnance factories. In a breakthrough development, the Government of India has also decided to form a Directorate of Ordnance (Coordination and Services) under the Department of Defense Production (DDP) with effect from 1st October 2021, as a replacement for the current OFB (1979) Headquarters. OFB has been dissolved and converted into seven Defense Public Sector Undertakings (DPSUs) from 1st October 2021. The DPSUs include Munitions India Limited, Advanced Weapons and Equipment India Limited, among others, governing several ordnance factories in India.[12,13] The DDP deals with several matters related to defense production and the planning and control of departmental production units of the OFB and DPSUs. Another milestone in intensifying the Indian defense system was the establishment of the Department of Defense Research and Development Organization (DRDO) in 1958, following the amalgamation of the Technical Development Establishment of the Indian Army and the Directorate of Technical Development and Production with the Defense Science Organization (DSO). Initially, DRDO was a functional unit of 10 laboratories, but it has expanded to a network of more than 50 laboratories. DRDO is an internationally recognized and esteemed institute of R&D in various disciplines, including instrumentation and ballistic missile systems. DRDO focuses on scientific aspects of military equipment and logistics, and formulating R&D plans for defense equipment. Terminal Ballistics Research Laboratory (TBRL), as the name suggests, is an arsenal laboratory based on terminal ballistics. The DRDO took the initiative to establish its TBRL in Chandigarh in 1961. TBRL entered operation in 1967 but was officially introduced in 1968. Its center is in Chandigarh, and its experimental facilities, including

a shooting range, are located in Ramgarh (Haryana). The goals behind the opening of this laboratory were the development of specialized instrumentation, range technology, and advanced weapon systems.[14] The Standardized Testing and Quality Certification Service of the Government of India's Department of Information Technology certifies laboratories according to the international quality management system standard ISO 9001:2008 in 2014. Table 1 shows the overall progress of the Indian Defense and Ballistics Research Institute.

3. The Inception of Ballistics in Forensic Science Laboratories: One of the oldest cities in East India, Kolkata (formerly known as Calcutta), was the center of a colony developed by the British East India Company. Calcutta developed rapidly during the British Indian Empire in the 19th century. The British turned it into the capital of the British Indian Empire until 1911, as it was the center of India's trade and police administration. The establishment of similar departments had begun in the early 19th century. Still, after independence, the first forensic science laboratory was established (July 1, 1952), followed by the first central forensic science laboratory in Kolkata (then Calcutta) in 1957, as an outstation subordinate office of IB, Union Ministry of Home, Government of India. According to the literature, CFSL started operating with Ballistics, Biology, Chemistry, and Physics Divisions, while the scientific services of FSL Kolkata extended with the addition of the Ballistics Section in 1973.[10] The Bureau of Police Research and Development (1970) also regulated the CFSL until 2002. Later, in 2002, the Directorate of Forensic Science Services (DFSS) was set up by the Government of India on the recommendations of "The National Human Rights Commission" and "Padmanabhaiah Committee on Police Reforms" by the Ministry of Home Affairs vide its Order No. 25011/41/2001-GPA.II/PM-II on December 31, 2002. DFSS was established exclusively to administer CFSLs, except CFSL Delhi, which was then under the CBI, the foremost investigating agency of India. The Ballistic Division is an integral segment of CFSLs and State SFSLs in India, but seldom operates conjointly under the Physics Division in India. It will not be long before the RFSLs have a full-fledged ballistics section/division.
4. Legendary Indian Forensic Experts/Ballisticians: Since developing forensic laboratories, India has produced some recognized pioneers in forensic ballistics. Despite their good native contributions, the international literature does not have considerable written records of their impact. B.R. Sharma, former Director of CFSL, Chandigarh, and one of the great Indian forensic scientists. He is an ever-spoken and respected Indian forensic expert. He has written several books on the fundamentals of forensic science. His book, "Firearms in Criminal Investigation and Trials" (1990), contains beneficial forensic information about firearms, ammunition, and court proceedings. J.K. Sinha (former Deputy Director of CFSL, Chandigarh) wrote a book entitled "Forensic Investigation of unusual firearms." The late Mohan Jauhari, Head of the Ballistics Division of CFSL, Calcutta, made a few good research contributions mainly in the field of velocity and estimation of the range of firing in wound ballistics. His manual entitled Identification of Firearms, Ammunition and Firearm Injuries, Bureau of Police Research and Development. The Government of India (1980) contains beneficial forensic ballistic information. It is also pertinent to mention the contributions of Dr. Narayan Pandurang Waghmare (currently working as a Director of the Forensic Science Laboratory, Panaji, Goa). His primary field of expertise is forensic ballistics. He has also published several research papers on ballistics studies in journals of international repute. J.K. Modi, former Deputy Director (Ballistics), National Institute of Criminology and Forensic Science, Delhi (now known as NFSU, Delhi Campus), and Mr. K.C. Varsheny, Deputy Director (Ballistics, FSL, Government of NCT, Delhi), have made great efforts in the infrastructural developments of forensic ballistics in India.
5. Hi-Tech Developments in Forensic Ballistics in India: The Ballistics and Forensic Institute holds the mandate for R&D work. These laboratories occasionally conduct projects based on testing bulletproof vests, helmets, and armored vehicle equipment. Indian academic institutions are also starting to take an interest in developing a forensic ballistics facility internationally. NSFU, Gandhinagar, has a fully functional BRCTR. The establishment of the BRCTR in 2016 is one of the new initiatives in the research and development field of forensic ballistics by the NFSU of Gujarat. BRCTR is focused on the application and advancement of cutting-edge technology in forensic ballistics for beneficial purposes, including studying terminal ballistics and creating cutting-edge procedures for criminal investigations involving firearms. BRCTR of the School of Forensic Science, NFSU provides services and R&D developments on ballistics material testing services to the defense, police, other security agencies, and industries dealing with security-related materials. The area of terminal ballistics, which is utilized in a variety of weapons, ammo, and materials, has a broader scope as far as research in this field is concerned.[15] The US-based engineering conglomerate DuPont recently unveiled its first integrated ballistics center in Hyderabad in 2012. DuPont has state-of-the-art ballistic

testing facilities to support the development of body armor, helmets, vehicle armor, and tactical plates for law enforcement and the military. The center is dedicated to developing local ammunition solutions tailored to India's security needs.

6. Status of Automated Ballistic Systems in India: The CFSL, under the administration of the DFSS, has made many advances in analysis and research. In 2002, as one of the earliest advancements, the DFS, Ministry of Home Affairs, Government of India, labeled the CFSL Chandigarh Center of Excellence in Physical Sciences. Of course, the Ballistics and Physics Divisions were significant working units in achieving this honor. The first installation of the Integrated Ballistic Identification System (IBIS) was at CFSL in Chandigarh in 2003–2004. It was an IBIS Trax-3D workstation consisting of separate Bullet Trax3D and Brass Trax3D workstations for hit point analysis and a data concentrator for comparing bullets and cases, respectively. Similarly, CFSL Kolkata's Ballistics Division was upgraded in 2010 with an IBIS Trax-3D workstation consisting of Bullet Trax3D and Brass Trax3D workstations for match point analysis and a data concentrator. As per official records, the remaining five CFSLs (Delhi, Hyderabad, Pune, Guwahati, and Bhopal) do not have any such facility. The Ballistics Division (occasionally conjoined with the Physics Division) is integral to SFSL/DFS in India. There are fewer automated installations of IBIS/Balscan in Indian SFSLs, as only a few have been updated. Table 2 shows the overall establishment of Ballistics Divisions and automated Ballistics facilities in Indian CFSLs, whereas Table 3 presents automated ballistics identification facilities in Indian SFSLs.
7. Hurdles Associated with Automated Ballistic Identification System (ABIS), Especially in India: Gun-related crime in India seems to continue despite gun control laws being portrayed as very strict. Firearms crime, in general, remains slightly higher in India. Law heavily regulates the possession and issuance of firearms, so criminals are developing alternatives using homemade or improvised guns. Illegal use of domestically manufactured weapons is severe in some parts of India. The joint responsibility of state and central authorities is to seriously consider this matter, which is a grave security concern. Additionally, forensic analysis of improvised firearms can be more complex than that of standard firearms. Like other criminal cases, firearms-related cases are reported to the local police station and processed and investigated by the Indian Forensic Laboratories. Today, IBIS has become a tool for law enforcement and forensic laboratories, especially for quickly matching cases and bullets to other firearms or specific firearms. Several factors have hampered the movement of Indian forensic institutions toward ABIS over the years. Let's examine such factors:

    a. Exiguous databases: The AFIS system lacks an extensive firearms signature database. Regardless of phase, such signatures must be entered into a national database accessible to all forensic and law enforcement agencies. Functional integration between different forensic laboratories is required. Lack of cooperation between different forensic laboratories can lead to poor forensic performance within a country. The Indian legal trend to record and share signatures on firearms at every step is a significant obstacle to the effective operation of the ABIS in India. The ballistics evidence database generated through IBIS is installed on the central server hub in Canada. The server integrations of such databases could be complex to access when the technical fault is so minor.
    b. The problem of improvised firearms: India has stringent laws on issuing standard weapons and ammunition. Nonetheless, the use of firearms is one of the preferred methods of crime. Domestically produced, cheap firearms generally have smooth bores rather than rifle bores. According to the National Crime Record Bureau (2021), 45,847 cases were registered during 2021. Of these, 45,492 (99%) arms belong to the category of unlicensed, crude, or country-made improvised. Several localities of Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, Haryana, West Bengal, and Delhi carry a considerable burden of cases registered under the Arms Act.[16] If such firearms continue at the same rate across the country, the implementation and maximum benefit of advanced ballistic systems such as ABIS can encounter matching problems.
    c. Cost and maintenance issues: Installation and annual subscription fees for integrated ballistic information systems commonly cost hundreds of millions. Since these systems are imported, several factors contribute to the higher initial cost. Additionally, grants allocated to forensic laboratories vary according to state policy. Therefore, its affordability can be uncertain everywhere. States with high firearm crime rates should pay special attention to installing advanced forensic ballistic facilities. The information obtained reveals that CFSL's AFIS/IBIS hub is not yet operational. Such services are operational on multiple SFSLs. Also, the recurring cost is a massive burden in the maintenance of such systems.

8. Suggestions For Improving the Usage of Automated Ballistics Identification Systems in India: India spends most of its budget on modernizing its defense sector. Budgets were freed up in the name of police modernization to develop the criminal justice system and police enforcement. The forensic institute will receive part of this funding for modernization. Recently, the Indian government initiated a forensic improvement process focused on crimes against women under the "Nirbhaya Fund" and declared 2010

the Year of Forensic Science. Many FSLs and CFSLs in India have yet to be upgraded to high-tech automatic firearms identification facilities. Forensic laboratories already using this feature face technical challenges despite proper implementation. Available set-ups still do not meet national and international standards, especially regarding collaboration and integration. Therefore, to strengthen the field of forensic ballistics, the afollowing points should be addressed:

a. Reassessment of the Arms Act can help in tightening the criminal nexus more rigorously. For example, governments must implement a mandatory database of all standard or licensed firearms in the country.
b. States with high shooting incidents should be given priority and additional funding for further development of ABIS technology.
c. Several ABIS systems (IBIS, Evofinder, Balscan, Aresenal, Drugfire, etc.) are available worldwide, but they are not compatible with each other. Therefore, a common platform should be provided for interconnection. Mandatory technical integration at the state, federal, and international levels by forensic and other law enforcement agencies could be a significant achievement for AFIS.
d. Establishing a single regulatory body in the country for the ABIS hub, such as the National Crime Records Bureau (NCRB), can store all the data. In addition, the data should be comparable within countries. Even NCRB can act like a company by expanding its services, especially in data security management.
e. Data security issues and issues related to such systems should be addressed immediately and kept in audit mode. These systems with software and hardware need to be updated regularly. Therefore, better Automated Match Candidates (AMCs) and Congruent Matching Cell (CMCs) must be designed so that such systems can operate for a long time at a low cost. Recruitment and regular training of experts to operate ABIS should be the responsibility of relevant laboratories and authorities.
f. National laboratories should work together to conduct interdisciplinary research in forensic ballistics. Prioritizing ABIS's research and development work will ensure that such systems remain operational and enable us to solve future analytical problems based on firearm identification. Hiring research-oriented staff helps. Governments should encourage research and development activities in forensic ballistics by funding researchers.
g. Academic institutes collaborating with FSLs and defense agencies should establish specialized research facilities and make firing ranges readily available to researchers interested in forensic ballistics.
h. Relevant subjects' curricula should be updated with the topic of forensics. Academic institutes should also establish a forensic ballistics museum.
i. Researchers should ensure that high-quality forensic ballistics research is published only in top-quality journals with a reputation for using valid and error-free methods.

Table 1. Origin of Indian Defense, Ordinance, and Ballistic Laboratories.

Type	Name	When and Where
Ordinance and ammunition boards and factories	First gunpowder factory (Dutch Ostend Company) in India	1712, Ichhapur
	Board of Ordnance	1775, Kolkata
	Gunpowder factory Ishapore	1787, Ishapore, Kolkata
	Gun Carriage Agency (presently known as Gun and Shell Factory), the first ordnance factory	1801, Cossipore, Kolkata
	Ammunition Factory Khadki	1869, Pune
	Rifle Factory Ishapore	1904, Ishapore, Kolkata
	IOF came under a separate charge as the "IG of Ordnance Factories"	1906
	Changed to the "Director of Ordnance Factories"	1933
	OFB	1979,
	Directorate of Ordnance (Coordination and Services)	1st October, 2021
Ballistics R&D laboratories	Department of DRDO	1958, Delhi (headquarters)
	Armament Research and Development Establishment (under DRDO)	1958, Pune
	TBRL	1968, Chandigarh and Ramgarh (Haryana)
Other related agencies and laboratories	CBI	1963, New Delhi
	NIA	2008, New Delhi
	Ballistic Research Center and Testing Range (BRCTR)	(ISO 9001:2015 Certified), NFSU (then GFSU) Gandhinagar
	DuPont provides state-of-the-art ballistic testing laboratories	2012, Hyderabad

Notes: IG, inspector general; GFSU, Gujarat Forensic Sciences University.

Table 2. Overall Establishment of Ballistics Divisions and Automated Ballistics Facilities in CFSLs.

CFSL (Establishment Year)	Establishment of Ballistic Division	Automated Ballistic System and Year of Installation
CFSL Chandigarh (1978)	1978	IBIS Trax-3D station with Bullet-Trax3 and Brass Trax3D (2003–2004)
CFSL Kolkata (1957)	1957	IBIS Trax-3D station with Bullet-Trax3 and Brass Trax3D (2010)
CFSL Hyderabad (1967)	1994	Facility not Available
CFSL New Delhi (1968)	1968	Facility not Available
CFSL Kamrup (Assam) (2011)	2016	Facility not available
CFSL Bhopal (2011)	No	Facility not available
CFSL Pune (2011)	2021	Facility not available

Table 3. Automated Ballistic Identification Facility in Indian SFSLs.

SFSL	Automated System	Year of Installation
DFS Gandhinagar	IBIS	2007
FSL Hyderabad	Balscan LIM	2019
FSL, Mohali	Balscan LIM	2020
SFSL, Junga	Balscan LIM	2021
DFS, Bangalore	Balscan LIM	2022
FSL Raipur	Balscan LIM	2023
DFS Mumbai	IBIS	2009
RFSL Nagpur	IBIS	2013

Conclusion

The evolution of forensic ballistics in India is a compelling narrative of scientific perseverance, institutional development, and legal reform. From the foundational efforts during the British era to the modern advancements exemplified by high-tech installations such as IBIS and the establishment of institutions such as the NFSU, India's journey reflects its dedication to enhancing scientific methodologies in crime investigation. While significant strides have been made through the expansion of forensic laboratories, the formulation of firearm regulations, and the contributions of pioneering experts, challenges persist—particularly in terms of automation, infrastructure, integration, and analysis of improvised firearms. Despite these hurdles, India's forensic ballistics system has shown remarkable potential. Addressing the gaps in automated systems, standardizing national databases, ensuring inter-agency cooperation, and fostering research and academic integration are the next crucial steps. With focused investment, technological modernization, and strategic policy reforms, India is well-positioned to not only strengthen its forensic ballistic capabilities but also emerge as a global leader in the domain of forensic science.

Limitations of the Study

It is important to note that forensic ballistics or forensic identification of firearms is a broader scientific field, but given the length of this article, the reviewed literature is limited to India. To make such an article a complete compendium of forensic information on ballistics and firearms research, the remaining relevant and useful literature across the world needs further assessment.

List of Abbreviations

ABIS: Automated Ballistic Identification System
AFIS: Automatic firearm identification system
AFK: Ammunition Factory Khadki
AHQ: Army Headquarters
AWEIL: Advanced Weapons and Equipment India Limited
BRCTR: Ballistic Research Center and Testing Range
CBI: Central Bureau of Investigation
CFSL: Central Forensic Science Laboratory
CMC: Congruent Matching Cell
DDP: Department of Defense Production
DFSS: Directorate of Forensic Science Services
DGOS: Director General Ordnance Service
DIT: Department of Information Technology

DPSUs: Defense Public Sector Undertakings
DRDO: Defense Research and Development Organization
DSO: Defense Science Organization
DTDP: Directorate of Technical Development and Production
FDR: Firearm Discharge Residue
GSR: Gunshot Residue
IB: Intelligence Bureau
IBIS: Integrated Ballistic Identification System
IBIS: Integrated Ballistics Identification System
IOF: Indian Ordnance Factories
IPA: Indian Police Act
MIL: Munitions India Limited
NFSU: National Forensic Science University
NIA: National Investigation Agency
OFB: Ordnance Factory Board
RFSL: Regional Forensic Science Laboratory
SEM: Scanning Electron Microscopy
SEM-EDX: Scanning Electron Microscopy-Energy Dispersive X-rays
SFSL: State Forensic Science Laboratory
SFS-NFSU: School of Forensic Science-National Forensic Sciences University
STQC: Standardized Testing and Quality Certification Service
TBRL: Terminal Ballistics Research Laboratory
TDE: Technical Development Establishment

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Authors' Contribution

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Availability of Data and Material

The data was collected through questionnaires, personal interviews, research articles, and through the web.

Consent for Publication

The publisher is hereby provided with the rights to publish our review article. It is also stated that this review article has not been published anywhere else or has not been sent to any other publisher.

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ORCID iD

Uttam Singh https://orcid.org/0000-0002-7911-3619

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Medical Termination of Pregnancy Act in India: Legal Progress, Ethical Gaps, and Social Realities

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Madhusudan R. Petkar[1], Rahul M. Band[1] and Ashwinikumar B. Sapate[1]

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The right to abortion is one of the most important aspects of reproductive freedom and justice. From time immemorial, religious beliefs have been against abortion as it was seen as taking a life given by God. In recent times, two contrasting ideologies have existed in the world, pro-life and pro-choice, clashing in political, legislative, and medical domains. Even as developed nations are struggling on this front, India chose to take the pro-right and pro-choice path five decades back by enacting legislation.[1] In India, estimates are that about six million abortions happen every year, of which four million are through the process of medical termination of pregnancy (MTP) and two million are spontaneous.[2] Before the enactment of the MTP Act, 1971, the law dealt with only criminal abortion under sections 312–316 of the Indian Penal Code, 1860. MTP Act 1971, later amended in 2021, is a significant step in favor of reproductive rights. The latest amendments are a positive step that enhances access to safe abortion procedures by raising the gestational restriction to 24 weeks for specific groups of women. Nevertheless, despite these encouraging developments, major legal, ethical, and social issues still need to be addressed to ensure the Act fully reaches and protects the reproductive health of every woman.

Legally, while the Act allows abortion in cases where there are risks to maternal health or fetal abnormalities, the requirement for medical approval continues to restrict access. In practice, this means the procedure is not available on request, even in the first trimester, and ultimately places the decision in the hands of healthcare providers. For women living in rural or underserved areas, where medical professionals are often scarce, this legal framework can delay care and limit their options. In addition, even if it is medically prudent, requiring the clearance of more than one doctor for terminations beyond 20 weeks may cause needless delays and obstacles to prompt care.[3] The Prevention of Children from Sexual Offenses (POCSO) Act, 2012, is putting some barriers to universally implementing the MTP Act 1971. The POCSO Act makes it mandatory for doctors treating pregnant minors to report such cases to law enforcement authorities. Though it might serve the purpose of bringing offenses to light and protecting victims, in some cases, it creates significant challenges for victims seeking help from registered medical practitioners and carrying out abortions in an unsafe manner. Doctors also hesitate to provide abortion services to young girls for fear of persecution. It brings the right to privacy guaranteed under the MTP Act to a crossroads with the POCSO Act. Therefore, it is crucial to promote access to safe induced abortion services to reduce morbidity and death associated with unsafe abortion and increase public awareness of abortion law, safe MTP procedures, and licensed service providers.[4]

As we compare Indian laws of MTP with other countries, the Indian MTP Act is applicable throughout the nation, while the United States of America has delegated powers to individual states for the enactment of MTP laws. The maximum gestational limit for MTP varies globally; most countries provide it up to 12 weeks, but it is extended to 18 weeks (Sweden), 20 weeks (Netherlands), and 24 weeks (United Kingdom and India). The indications for MTP, globally, are to preserve a woman's life, physical health, and mental health, in case of rape or incest, in cases of fetal anomaly, for economic or social reasons, and on request.[5]

From an ethical perspective, concerns regarding women's liberty to make decisions regarding their bodies are raised by the Act's continued prioritization of fetal rights over mother

[1]Department of Forensic Medicine and Toxicology, Dr. D. Y. Patil Medical College, Hospital and Research Center, Dr. D. Y. Patil Vidyapeeth, Pimpri, Pune, Maharashtra, India

Corresponding author:
Rahul M. Band, Department of Forensic Medicine and Toxicology, Dr. D. Y. Patil Medical College, Hospital and Research Center, Dr. D. Y. Patil Vidyapeeth, Pimpri, Pune, Maharashtra 411018, India.
E-mail: rahul.m.band@gmail.com

autonomy. While the 2021 amendments to the Act enable abortion in cases of fetal abnormalities, the demand for medical explanation still causes delays and challenges, especially for women who have gone through sexual assault or those dealing with unintended and unplanned pregnancies.[6]

The social stigma associated with abortion continues to be a significant barrier. Even though abortion is legal, many women nevertheless experience stigma, prejudice, and even violence when they want one, particularly if they are single or come from marginalized communities. Because of this stigma and a lack of awareness of the Act's provisions, women often seek unsafe and illegal abortions, putting their health and lives in danger.[7]

The Supreme Court of India's judgment on September 29, 2022, held that unmarried women have the same right to abortion as married women. The MTP Act, 1971, most recently amended in 2021 (Amendment Act), governs the circumstances under which abortions are legally permitted in India.[8] The Supreme Court, while delivering a landmark judgment, emphasized that in a gender-equal society, interpretation of the MTP Act and Rules must consider current social realities. Speaking for the bench, Justice Chandrachud noted,[9] "a changed social context demands a readjustment of our laws. Law must not remain static, and its interpretation should keep in mind the changing social context and advance the cause of social justice."

To effectively implement the MTP Act and empower women, the law must be reframed to prioritize women's reproductive rights and informed consent. Public awareness programs should educate women about their legal rights and available services. Additionally, training medical professionals can help ensure respectful, unbiased, and timely abortion care.

Authors' Contribution

Dr. Madhusudan R. Petkar: Design and concept
Dr. Rahul M. Band: Manuscript writing and correspondence
Dr. Ashwinikumar B. Sapate: Proofreading of manuscript

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ORCID iD

Madhusudan R. Petkar https://orcid.org/0000-0002-4488-7438

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Signature of the Weapon: A Rare Case of Flash Suppressor Burn

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Fathima Harsha[1], Renjini Johnson[1], Anup Kumar Raipuria[1], Shiuli[1], Sangeeta Kumari[1], Mousami Singh[1] and Anoop Kumar Verma[1]

Abstract

Firearms are dangerous weapons and are often used to commit homicides as well as suicides. Every case of a firearm is unique, and its wound pattern provides insights into the type of weapon used, range of firing and direction of shot. The demise of a 25-year-old male police constable during his duty hours under suspicious circumstances raised the question of whether it was a homicide or suicide. The most important findings were the signature imprint created by the flash suppressor around the entry wound resembling a flower petal pattern, and the trigger position of the right-hand index finger. Injuries produced by flash suppressors are less reported in the literature, so forensic experts should be aware of these patterns of firearm wounds, as they can even mimic multiple entry wounds.

Keywords

Burns, wounds, firearms, forensic pathology, weaponry

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Introduction

Firearms are dangerous weapons, and fatalities resulting from firearms have increased recently. Each case of a firearm is unique, and the pattern and characteristics of the wound greatly describe the type of weapon used and the direction and range of the firing. Flash suppressors are devices that are affixed to the muzzle end of the firearm, and they are a modification of the firearm.[1] Nowadays, flash suppressors are part of the weaponry attached to almost all modern rifles and many civilian rifles as well. The pattern of the wound produced by a flash suppressor gives a characteristic pattern around the entry wound, which marks the signature of the weapon. When a firearm attached to a flash suppressor is fired, the fire and gases that escape from the muzzle end get expelled through the slits or rows of vents situated in the flash suppressor in specific directions.[1] This will produce a peculiar petal-like pattern of burning and singeing around the wound of entry. The number of petals that are produced on the flower pattern depends upon the number of slits present in the flash suppressor, providing clues about the specific firearm used. Also, this burn and searing pattern gives an idea regarding the range of firing as well as the direction of firing.[2,3] However, determining the manner of death in firearm cases presents a significant challenge, requiring thorough evaluation and analysis by forensic experts.[4] This is a rarely documented case of suicidal death by firearm involving a flash suppressor. It has produced a characteristic pattern around the wound of entry, which left the signature of the weapon. Also, the positioning of the trigger finger provided further insight into the manner of the death.

Case Report

The dead body of a 25-year-old male was brought for medico-legal autopsy to the KGMU mortuary. According to the inquest report, the deceased was a Provincial Armed Constabulary (PAC) Jawan who was found dead lying in a significant pool of blood in the rear seat of a car. He was found in a sitting position. His service rifle, the INSAS 5.56 mm, was recovered from his body in a half-holding

[1]Department of Forensic Medicine and Toxicology, King George's Medical University, Lucknow, Uttar Pradesh, India

Corresponding author:
Fathima Harsha, Department of Forensic Medicine and Toxicology, King George's Medical University, Lucknow, Uttar Pradesh 226003, India.
E-mail: fathimaharshapm586@gmail.com

Figure 1. Dried Blood Stains Present Over the Right Hand.

position from his hand. This happened during his duty hours, which raised a suspicion of whether the incident was a suicide or homicide. An X-ray of the entire body confirmed that there was no lodged bullet inside. At autopsy, dried blood stains were present around the mouth, nostrils, and both ears. Dried blood stains were present over his right hand (Figure 1), and his right index finger was in trigger position (Figure 2).

On external examination, a firearm entry wound 2 cm × 1.5 cm × cavity deep was noted at the submental region, 4 cm below the chin, oval-shaped, with inverted and irregular margins. Around the entry wound, four dermo-epidermal burn marks measuring 4 cm × 1 cm were seen resembling flower petals (Figure 3), which were symmetric and had soot deposition over them. Blackening and abrasion of the collar were present around the entry wound. A firearm exit wound of 14 cm × 10 cm is present on top of the head, extending to the forehead (Figure 4) with irregular, everted, and reddish margins.

Discussion

Firearm injuries create patterns of wounds that vary from case to case. The pattern of wounds produced by flash suppressors is particularly unique and characteristic. It consists of a cylinder in which there are multiple longitudinal slits running lengthwise or rows of openings or vents.[5] On firing, the fire and gases emerging from the muzzle end of the weapon will create a distinctive pattern of burning and fouling around the entrance wound that will leave the signature of the weapon. The number of slits in the flash suppressor will decide the number of 'petals' in the flower around the entry wound and

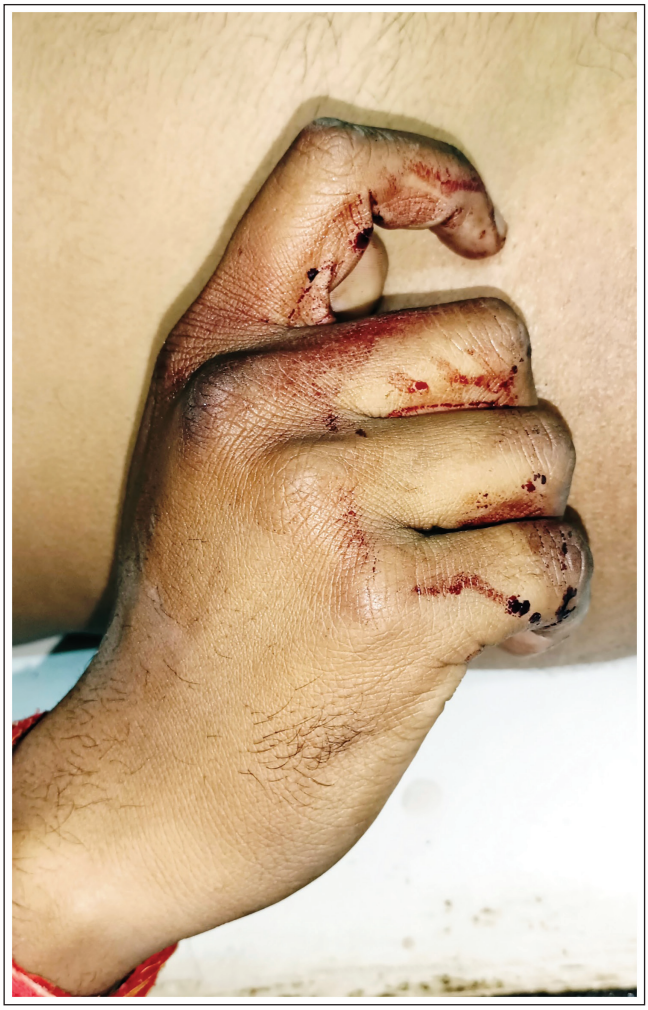

Figure 2. Right Hand Showing the Index Finger in Trigger Position, Consistent with Self-inflicted Firearm Injury.

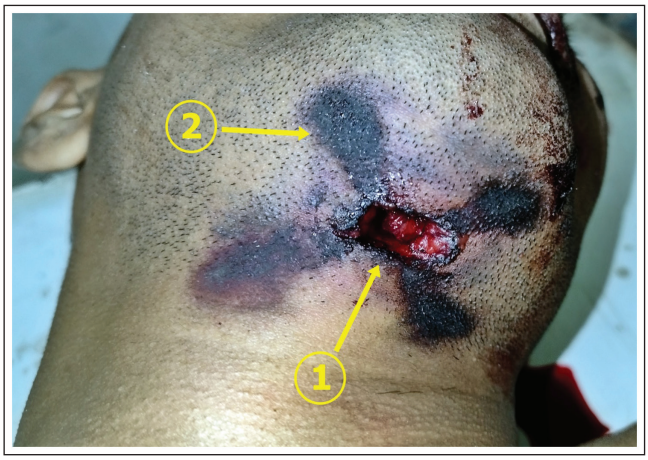

Figure 3. Firearm Entry Wound Located Below the Chin (Marked as 1), Surrounded by Four Petal-shaped Burn Marks Caused by the Hot Gases from the Flash Suppressor (Marked as 2), Characteristic of Close-range Discharge.

Figure 4. Firearm Exit Wound Over Forehead and Vertex, Measuring Approximately of Size 14 cm × 10 cm Extending into Skull Cavity Deep.

Figure 5. Flash Suppressor of the INSAS 5.56 mm Rifle, Showing Four Rows of Slits, as Observed in the Present Case.

may give one an idea of the type of flash suppressor and model of the weapon used.[6] There are different varieties of flash suppressors, such as cone-shaped and basket-type with several slits, etc., which may vary according to manufacturers and models of firearms.[7]

The INSAS 5.56mm rifle in this case has a flash suppressor with rows of slits over four sides. Each row has three circular openings (Figure 5). This has created a characteristic four-petal, flower-like searing and blackening of skin around the entry wound in this case. Because all petals were almost symmetric with similar size, this also confirms that the barrel was perpendicular to the body. The range of firing must have been contact or near contact one.[3]

In firearm deaths, another challenge is determining the manner of death. It is not always straightforward. The presence of a trigger finger (the finger resting on or near the trigger at the time of death), along with blood splashes on the hands, is important. If the weapon is firmly grasped in the victim's hand due to the instantaneous rigor effect (the immediate stiffening of muscles after death), it strongly suggests suicide.[2–4] In this case, the trigger finger position of the index finger with the weapon naturally gripped in the right hand, along with the bloodstain over the right hand, points toward suicide, making staged weapon placement unlikely. This confirms the manner of death as well.

Tatiya et al. reported a firearm case of patterned injury due to a flash suppressor in which there were three oval-shaped dermo-epidermal burns present around the entry wound, and they concluded that this pattern of searing and blackening was produced with a flash suppressor SLR rifle that had three symmetrical slits.[6]

Naik SK et al. reported a case report of medico-legal aspects of atypical firearm injuries in which a 20-year-old man was injured by a G3 infantry rifle during his military duty hours. The flash suppressor of the same produced an atypical firearm entry wound with six irregular skin burn wounds around the entry wound, which emphasizes entry wound needs to be examined with caution.[8]

Koutsaftis S et al. reported a case from Greece that detailed the unusual suicide of a 29-year-old man who used a military-issued G3 automatic rifle. Forensic examination revealed a distinctive injury pattern around the gunshot wound, characterized by soot deposits and seared skin. These marks were arranged in a flower-like configuration, attributed to the close-range discharge of the rifle with a flash suppressor. The burn patterns were consistent with gas and soot expelled through the device's slits, reinforcing the role of muzzle attachments in altering wound morphology. This case highlights the importance of recognizing atypical features in contact firearm injuries during forensic investigations.[9]

Conclusion

The injuries created by the flash suppressor are characteristic "flower petal patterns" that leave the signature of the weapon. We should deal with every case of firearms as unique. Injuries produced by flash suppressors are less reported in the literature, so forensic experts should be aware of these patterns of firearm wounds, as they can even mimic multiple entry wounds.

These unusual features can be misinterpreted in court as evidence of deliberate close-range firing, use of an unusual weapon, or even fabrication of injuries. Such misinterpretations may mislead the judicial process if the forensic basis of these patterns is not properly explained. Hence, awareness of the characteristic effects of flash suppressors is crucial for accurate medico-legal evaluation and testimony.

In the courtroom, such findings serve as objective, scientifically grounded evidence, strengthening the expert's testimony regarding weapon characteristics and firing distance. When the weapon is fired at close range, these dispersed hot gases may produce a patterned burn around the entry wound, which can mimic tattooing or stippling but is distinguished by its regular, petal-like configuration. These patterns serve as important diagnostic aids in forensic examination, but they are not the sole determinants of the manner of death.

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ORCID iDs

Fathima Harsha https://orcid.org/0000-0003-3154-525X
Sangeeta Kumari https://orcid.org/0000-0002-5869-4987

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Reducing Occupational Hazards in Forensic Autopsy: A Novel Approach to Brain Removal via Craniotomy

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Murali G[1], Dilip Vaishnav[2], Pulkit Girdhar[1] and YS Bansal[1]

Abstract

The COVID-19 pandemic, like other highly contagious outbreaks, has forced us to rethink and adjust many aspects of daily life. In the medical world, most fields have quickly developed new methods or adapted existing ones to reduce the risks posed by the virus. Forensic pathology, which often involves high-risk aerosol-generating procedures (AGPs) during autopsies to investigate deaths from unknown causes, faces the same challenge. The need to protect healthcare workers in this area has become more critical than ever.

In light of this, the authors present an alternative method for removing the brain during autopsies in post-craniotomy cases, eliminating the need for the traditional approach of sawing through the skull. This technique reduces the risk of generating aerosols, which are a primary mode of transmission for airborne infections. Importantly, the method can be applied to all cases, regardless of whether the deceased is suspected of carrying an infectious disease, making it a versatile and safer option. This innovative approach shows how forensic pathology can evolve to meet the safety demands of the pandemic without sacrificing the quality of the investigation. By reducing the risk of exposure to infectious agents, forensic pathologists and other professionals involved in post-mortem procedures are protected. In a time when infection control is a top priority, such changes to traditional practices help ensure that crucial medical examinations can continue safely.

Keywords

COVID-19, autopsy, craniotomy, sawing, aerosol-generating procedure (AGP), minimally invasive technique

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Introduction

It is not advisable to perform an autopsy on the COVID-19 case, even for diagnosis, let alone the academic interest.[1–4] However, this recommendation may not be feasible in all circumstances in the practice of forensic pathology, as one gets to see unexpected sudden deaths, suicides, custodial deaths, homicides, and other high-profile cases with either a confirmed or suspected COVID-19 diagnosis. Here, it becomes an obligation for the pathologist to perform a complete medicolegal autopsy. Still, there remains a potential risk that the virus could persist on the bodies of the deceased, as viable SARS-CoV-2 has been shown to survive on surfaces for several days.[5,6] A complete autopsy on a COVID-19 body needs a team of highly trained forensic pathologists and infrastructures such as a negative-pressure Biosafety Level 3 autopsy suite, which is not available at many autopsy centers, especially in resource-constrained nations.[3,7] Hence, minimal invasive autopsy techniques have been recommended in all such cases to minimize unnecessary hazardous procedures.[8,9]

Skull vault opening using an electric saw is one such aerosol-generating procedure (AGP) that increases the possibility of transmission of COVID-19.[10] Even though the electric saws are complemented with vacuum units, they are still considered unsafe because of their inefficiency to completely collect the bone dust and other tissue fragments emanating from high-speed sawing.[11] Though these AGPs are inevitable

[1]Department of Forensic Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh, India
[2]Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, Rishikesh, Uttarakhand, India

Corresponding author:
YS Bansal, Department of Forensic Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh 160012, India.
E-mail: yogendrabansal@hotmail.com

in cases where the brain is the organ of interest, the authors still believe that there should be some workaround for brain removal, at least in autopsies where surgical craniotomies have already been done. Many methods are being tried to overcome the negative effects of conventional autopsies in these COVID times.[12] It is in the same context; a new method has been developed and adopted by the authors and discussed in this case study.

Craniotomy, Types, and Indications

Craniotomy, a procedure involving the temporary removal of a section of the skull to access the brain, has a long and evolving history. Its earliest forms can be traced to prehistoric times, where it was believed to serve ritualistic or spiritual purposes, such as releasing malevolent spirits. Ancient Egyptians adapted the fire-making bow drill for cranial procedures as early as 1400 BCE, and the earliest known writings on craniotomy are attributed to Imhotep, around 2900 BCE. By the 5th century BCE, Hippocrates introduced its therapeutic use for treating skull fractures. The technique and associated instruments were further documented in the early 16th century by Berengario in his work "De Fractura Calvae." The Renaissance period saw an increase in craniotomies due to injuries from firearms and explosives. Significant advancements in antiseptic techniques and the introduction of general anesthesia in the 19th century contributed to the widespread adoption and refinement of the procedure. Today, craniotomy remains a vital neurosurgical intervention, supported by coordinated care from interprofessional medical teams to ensure optimal patient outcomes.[13–15]

A craniotomy is the surgical removal of part of the calvarium (skull) to expose the brain. This removed portion of the bone is called the bone flap. The bone flap may be temporarily removed and replaced after the neurosurgical intervention. The bone flap, after removal, may be stored in the abdominal wall or a bone bank.[16,17] In cases of compound fractures, where the bone is fragmented, multiple pieces may need to be discarded during the procedure, as they cannot be effectively replaced.

Craniotomy surgeries are performed for a variety of traumatic and non-traumatic skull and brain pathologies, including brain tumors; clipping or repairing an aneurysm; removing arteriovenous malformations; evacuating blood or blood clots from a leaking blood vessel; addressing arteriovenous fistulas; draining brain abscesses; repairing skull fractures or tears in the dura mater; relieving intracranial pressure (ICP) by removing damaged or swollen areas of the brain due to traumatic injury or stroke; treating epilepsy; and implanting stimulator devices to manage movement disorders such as Parkinson's disease.[16,18,19]

There are several types of craniotomies, categorized based on factors such as the location of the pathology, ease of access, maximum safety, and minimal damage to surrounding organs and tissues. In neurosurgical and forensic practice, various craniotomy techniques—commonly referred to as surgical "corridors"—are selected based on clinical indications, lesion location, and required exposure. The following sections briefly outline several key approaches commonly employed in both therapeutic and postmortem settings.

1. Frontotemporoparietal (FTP) craniotomy: The FTP approach is frequently utilized in cases of traumatic brain injury, particularly when prompt decompression is essential. This technique involves the removal of a bone flap that spans the frontal, temporal, and parietal regions, allowing wide exposure of the cerebral cortex. In resource-limited environments, a modified version with liberal duroplasty and bone replacement during the same procedure can offer an effective, single-stage intervention without compromising outcomes.[20]
2. Decompressive craniectomy: Decompressive craniectomy is typically employed in patients with elevated ICP that is unresponsive to medical therapy. By removing a substantial portion of the skull, this approach allows the swollen brain to herniate outward, thereby reducing ICP and minimizing further neurological damage. It remains a cornerstone procedure in the management of malignant cerebral edema.[21]
3. Pterional craniotomy: One of the most established neurosurgical corridors, the pterional craniotomy grants access to the anterior and middle cranial fossae. It is especially useful in managing aneurysms, skull base tumors, and arteriovenous malformations. The technique offers excellent exposure of the Sylvian fissure and related neurovascular structures, with minimal cortical disruption.[22]
4. Frontotemporal craniotomy: The frontotemporal craniotomy provides targeted access to the frontal and temporal lobes. It is frequently employed for lesion resections, hematoma evacuation, and vascular interventions, offering surgeons a direct route to the lateral fissure and deeper basal structures.[23]
5. Bifrontal craniotomy: This bilateral approach enables comprehensive visualization of the anterior cranial fossa and is ideal for managing midline pathologies or diffuse frontal contusions. It is often used in decompressive surgeries where symmetrical cerebral decompression is required.[24]
6. Minimally invasive supra-orbital keyhole craniotomy: This technique, accessed through an eyebrow incision, allows for less invasive entry to the anterior cranial base. It is well-suited for the resection of small tumors and aneurysms, particularly in cosmetically sensitive areas. The reduced operative footprint often translates into faster recovery and reduced complications.[25]
7. Retro-sigmoid craniotomy: Primarily utilized for posterior fossa surgeries, the retro-sigmoid approach is favored in the management of cerebellopontine angle lesions such as vestibular schwannomas. It provides

sufficient exposure while preserving important neurovascular structures.[26]

8. Orbitozygomatic craniotomy: This extended approach involves removing portions of the orbital rim and zygomatic arch to improve access to deep-seated tumors and vascular lesions. It minimizes brain retraction while optimizing visibility of the skull base and surrounding anatomy.[27]
9. Translabyrinthine craniotomy: This skull base technique provides access to the cerebellopontine angle while intentionally sacrificing residual hearing. It is most commonly indicated in patients with non-serviceable hearing undergoing resection of vestibular schwannomas.[28]
10. Suboccipital craniotomy: The suboccipital approach is traditionally employed to access the posterior cranial fossa, particularly for resection of cerebellar tumors or decompression in Chiari malformations. It allows for safe entry to the brainstem and fourth ventricle while preserving critical posterior circulation structures. Among these, FTP craniotomy is the most commonly performed in traumatic cases, which are frequently encountered in medicolegal autopsies.[16,18,19,29]

Surgical FTP Craniotomy Procedure

The surgical FTP (frontotemporal parietal) craniotomy procedure typically begins with a C-shaped or question mark-shaped incision made on either side of the scalp. The upper anterior portion of the incision is usually positioned above the corresponding eyebrow, while the lower posterior end is placed near the upper attachment of the corresponding ear. Once the scalp has been incised, the next step involves removing the bone over the skull vault at the site of interest. This is achieved by creating burr holes at the margins of the area, followed by sawing to connect these burr holes, thereby freeing the bone flap. The excised bone flap is often temporarily stored in the patient's anterior abdominal wall, thigh, or in a bone bank, and it is typically replaced once the surgery is complete and the patient has sufficiently recovered.[20,30]

The Procedure of Skull Opening and Delivery of Brain in Conventional Autopsy

During a conventional autopsy, the procedure of skull opening and brain removal follows a systematic approach. Initially, a bimastoid incision is made through the full thickness of the scalp. The scalp flaps are then reflected anteriorly to the level of the supra-orbital ridges and posteriorly to the occipital protuberance using a combination of sharp and blunt dissection techniques. The temporalis muscles are carefully dissected away from their origins on both sides. The cranium is subsequently opened using either a mechanical or electrical saw, with the sawing line extending above the superciliary ridges in the front and through the occiput at the back. It is important to note that the use of an electrical saw in this step generates significant aerosols. The skullcap is then removed by gently inserting and twisting a chisel along the cut line, which facilitates the opening of the skull.

Once the skullcap is removed, the external surface of the dura mater is inspected. The dura is then cut along the sawing line and gently pulled back after the anterior attachment of the falx cerebri has been detached. The frontal lobes of the brain are carefully lifted from the anterior cranial fossa while basal attachments are severed. With continued lifting and slight traction applied to the undersurface of the cerebral lobes, the tentorium cerebelli is incised along the superior border of the petrous bone bilaterally. This allows the tentorium to be reflected posteriorly, exposing the cerebellum and brainstem.

At this point, the cervical cord and its attachments are severed as far inferiorly as possible through the foramen magnum. The cerebellar lobes are then digitally scooped from their respective fossae, enabling the delivery of the brain, including the brainstem, in its entirety. Final, the dura mater can be stripped from the inner surface of the skull, allowing the base of the skull to be examined for fractures or other abnormalities.[31–35]

Proposed Modified/Minimal Invasive Approach

The proposed modified, minimally invasive approach for brain removal during autopsy has been applied in three cases at the Department of Forensic Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh. All of these cases involved roadside accidents and had undergone FTP craniotomy as part of their surgical management. This approach aims to deliver the brain in clearly defined parts through the pre-existing FTP craniotomy defect, thereby minimizing procedural artifacts and avoiding the use of electric sawing, which is considered an AGP.

Autopsy Technique

The initial steps, such as placing the body, positioning the head, and documenting external findings, remain consistent with conventional autopsy procedures.[31–33] Upon examining the head in post-craniotomy cases, one may observe the craniotomy wound margins either fully healed or in various stages of healing. In cases with minimal healing, the wound margins can be manually separated without the use of instruments, and the scalp is reflected away from the wound margins (Figure 1). To facilitate the process, an incision is made from the contralateral mastoid process, intersecting the craniotomy wound perpendicularly. The scalp flaps thus created are reflected anteriorly and posteriorly (Figure 2). If the craniotomy margins are completely or nearly healed, a regular bimastoid incision may be used.

Figure 1. Downward Reflection of the Dura Mater to Expose the Underlying Cerebral Hemisphere.

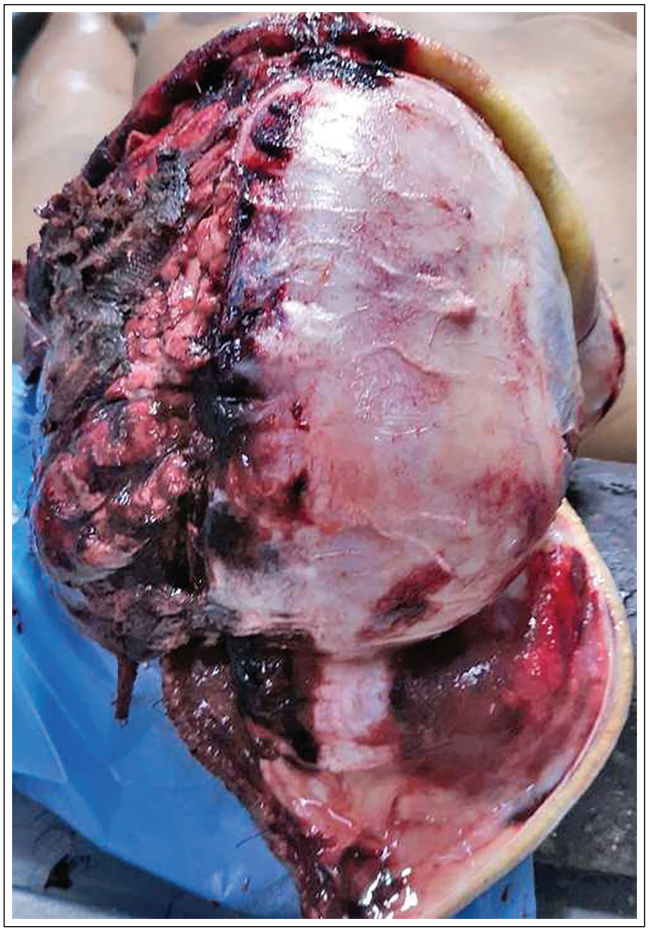

Figure 2. Scalp Flaps Reflected Anteriorly and Posteriorly at the Midsagittal Region.

After reflecting the scalp, the skull vault, craniotomy defect, and the undersurface of the scalp are exposed. Special care should be taken during this step, as craniotomy involves the removal of a section of cranial bone, and a deep incision may inadvertently injure the brain. Furthermore, when removing staples from the craniotomy wound, attention should be paid to prevent the sharp ends of the staples from injuring gloved fingers.

Through the craniotomy defect, the dura mater is examined. If the dura mater remains intact and covers the brain, it is carefully incised along the craniotomy wound margins, except at its inferior border, and gently reflected downward. The cerebral convexity is exposed, and the ipsilateral half of the brain is retracted outward at the sagittal fissure using a brain retractor. The falx cerebri and corpus callosum are then identified (Figure 3). The corpus callosum is incised along its length and depth in the midline, following the plane of the falx cerebri (Figure 4). A complete axial incision is made anterior to the concave notch of the tentorium cerebelli through the third ventricle, separating the cerebrum from the rest of the brain (Figure 5). This step can be facilitated by lifting the cerebral hemisphere with a spatula or retractor. The ipsilateral half of the brain is then carefully delivered by severing its attachments, such as cranial nerves.

The next step involves incising the anterior and posterior attachments of the falx cerebri, reflecting it toward the now-vacant side, to allow for further examination of the contralateral brain. Additional incisions are made in the falx cerebri to release tension and facilitate the removal of the other half of the brain (Figure 6). With the previous axial incision having separated the cerebrum from the brainstem and cerebellum, the remaining half of the brain is easily delivered by severing any basal attachments (cranial nerves) with blunt-ended scissors. This is aided by tilting the head to the contralateral side and digitally manipulating the brain by inserting gloved fingers into the subdural space.

Once both cerebral hemispheres are removed, the tentorial attachment is incised along the petrous edges bilaterally to expose the cerebellum and brainstem (Figure 7). The spinal cord is transected as deeply as possible, and the brainstem–cerebellar complex is removed using conventional methods. The dura can then be stripped as usual, exposing the inner surface of the skull (Figure 8). Use of an external light source may assist in a more detailed examination.

In this modified approach, the brain is removed in three distinct parts: (a) The right half of the cerebrum, (b) the left half of the cerebrum, and (c) the brainstem–cerebellar complex, all without the need for additional sawing. These parts can then be examined in a manner consistent with conventional autopsy methods (Figure 9).

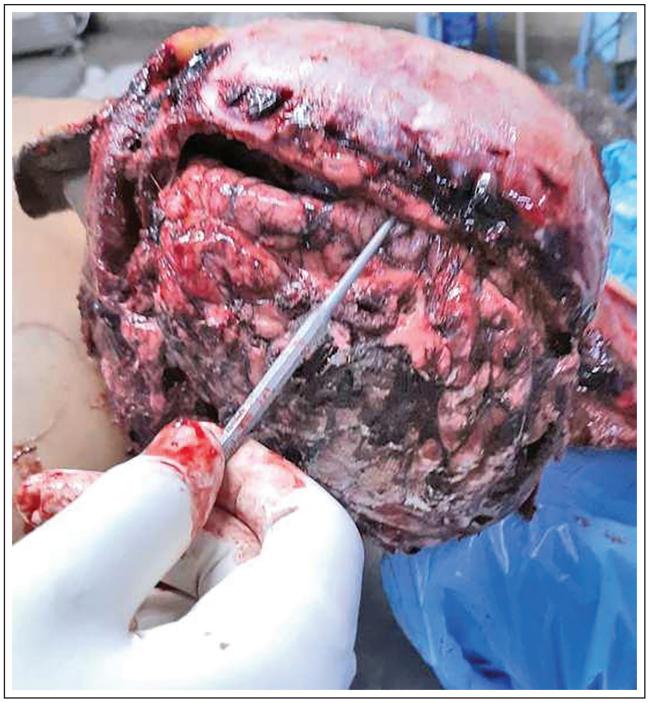

Figure 3. Ipsilateral Half of the Brain Retracted Outward at the Sagittal Fissure to Visualize the Falx Cerebri and Corpus Callosum.

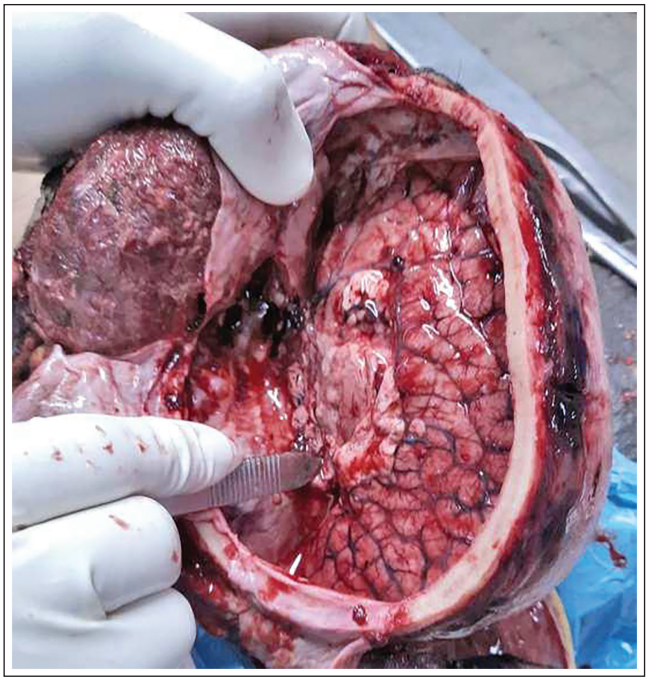

Figure 5. An Axial Incision made Anterosuperior to the Concave Notch of the Tentorium Cerebelli Through the Third Ventricle to Separate the Second Half of the Cerebrum from the Brainstem and Cerebellum.

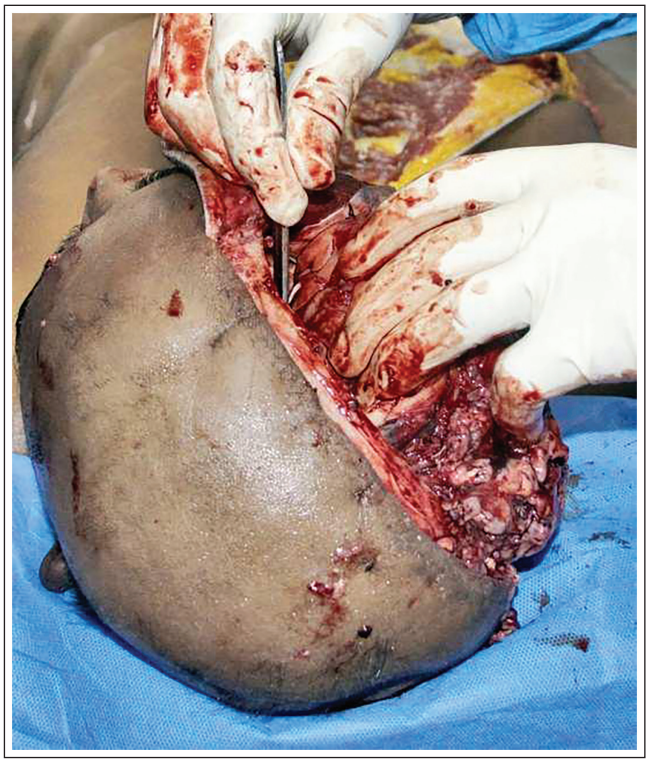

Figure 4. The Corpus Callosum Incised Along its Length and Depth in the Midline, Following the Plane of the Falx Cerebri.

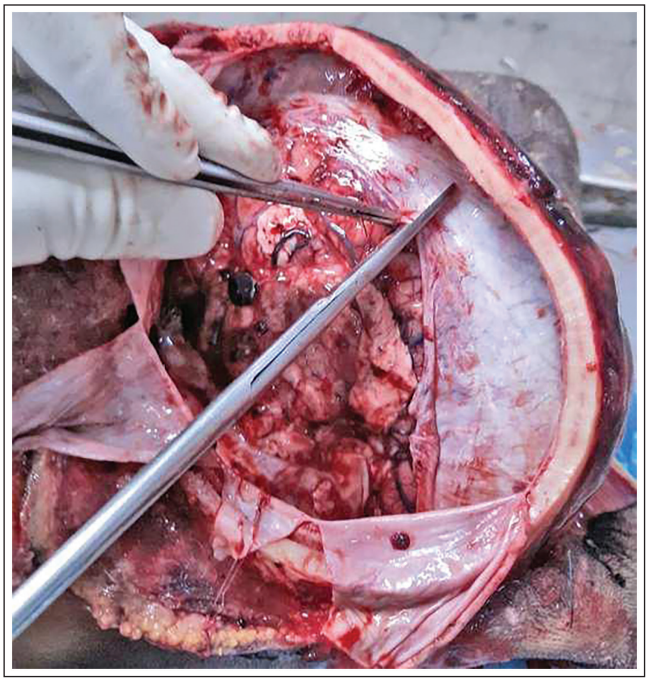

Figure 6. Reflection of the Falx Cerebri Away from the Remaining Half of the Cerebrum by Incising it at Multiple Points to Release Tension.

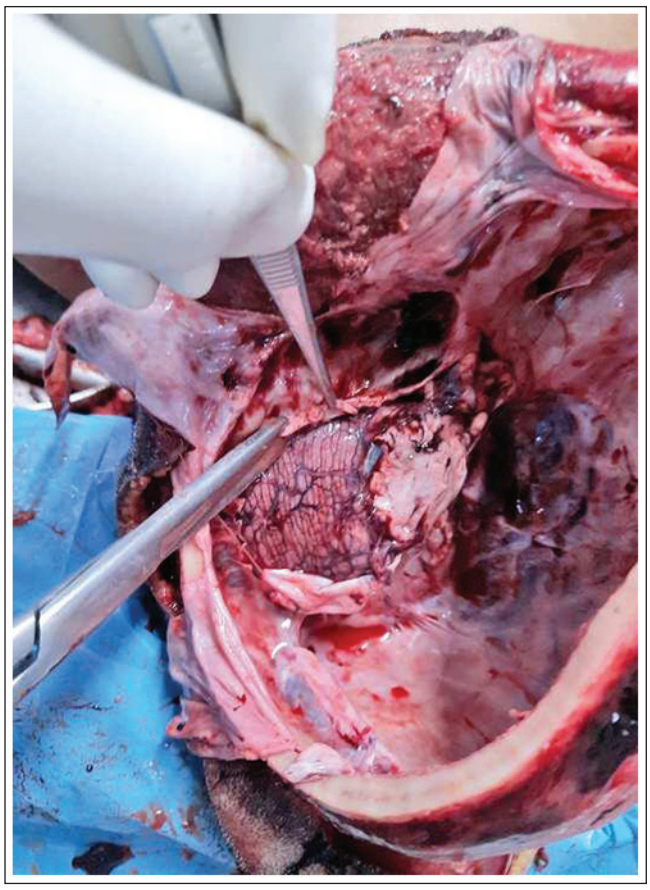

Figure 7. Incision of the Tentorial Cerebelli Along the Petrous Edges Bilaterally to Expose the Cerebellum.

Figure 8. Exposure of the Inner Surface of the Skull by Stripping the Dura Mater.

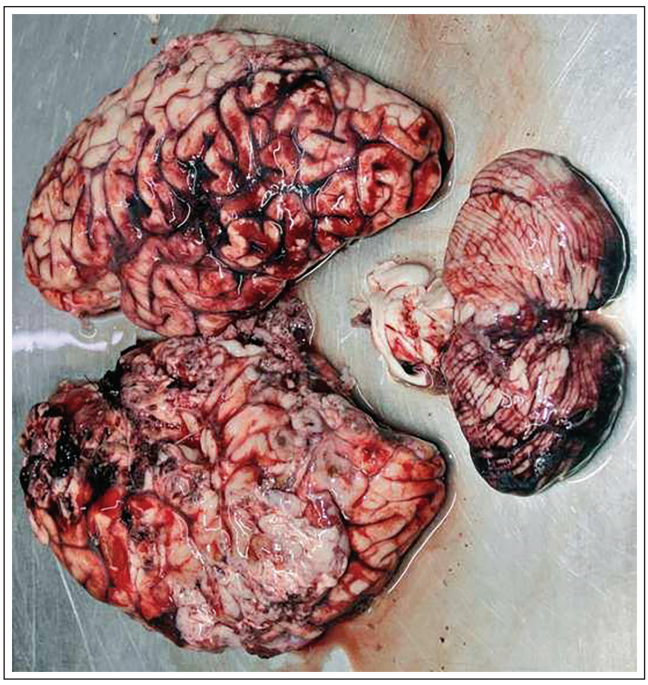

Figure 9. The Whole Brain Removed in Three Distinctive Parts.

Limitations

Suitability for certain cases: This procedure is feasible only in cases where the brain's firmness permits digital manipulation. In cases where the brain has already begun to putrefy, handling and removing the brain becomes significantly more challenging.

Risk of transecting the posterior aspect of the circle of Willis: During the separation of the cerebrum from other structures, there is a possibility of transecting the posterior aspect of the circle of Willis. However, in such cases, antemortem radiological investigations are usually available, which mitigates the impact of this limitation.[36–41] Even if these structures are transected, they remain available for gross and histopathological examination.

Size of craniotomy defect: In some instances, the craniotomy defect may be too small to allow for the brain's easy delivery. In such cases, greater digital manipulation or mechanical nibbling of the craniotomy wound margins may be required to complete the procedure.

Conclusion

The proposed method is particularly beneficial during situations involving highly infectious cases, where the spread of hazardous agents through aerosols poses a significant threat to the health of personnel working in mortuaries. In cases where a complete examination of the brain is essential, such as in highly sensitive autopsies, this technique offers a safer alternative. The novel procedure for brain removal through

the craniotomy defect, without sawing the skull, minimizes the risk of aerosolization and potential exposure to infectious agents.

Given its utility, this method can be adopted not only in confirmed cases of highly infectious diseases but also in non-infectious autopsies. The rationale for broader application stems from the high number of asymptomatic cases of infectious diseases, which may go undetected during routine procedures. By incorporating this technique universally, forensic pathologists can ensure a higher level of safety, reducing the risk of inadvertent exposure to undiagnosed infections. Therefore, this method has the potential to become a standard practice in autopsy procedures, contributing to the overall safety of forensic pathology professionals while maintaining the integrity of the examination process.

Data Availability Statement

Not available publicly.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval and Informed Consent

Not applicable.

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ORCID iDs

Pulkit Girdhar https://orcid.org/0000-0003-3669-5310
Yogender S Bansal https://orcid.org/0000-0002-5752-7968

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Fatal Projectile Injury from an Unsecured Metal Rim During Tire Inflation: A Case Report and Safety Insights

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Bajrang K. Singh[1], Sunil K. Soni[1], Jai P. Verma[1], Mohit Chauhan[2] and Ashok K Rastogi[3]

Abstract

Tire service stations present serious hazards, especially during high-pressure air inflation. While tire bursts are known to cause fatal injuries, metal rim ejections due to improper disk locking are underreported. This case highlights the risks associated with unsecured metal disks and underscores the need for safety measures in the form of a daily check-up of the machine before starting the work. Here a 40-year-old mechanic sustained fatal injuries when a loosely fitted metal rim was propelled by high tire pressure during air inflation. With the remolding machine door left open, rising pressure dislodged the poorly locked disk, sending the rim six feet, striking his head and face. The injuries matched the distorted rim found at the scene. He was hospitalized, unconscious, and died five hours later. This case highlights the dangers of improper locking during tire inflation, emphasizing the need for strict safety protocols. Secure disk fittings, protective barriers, and adherence to guidelines are crucial. Raising awareness, proper training, and enforcing safety regulations can help prevent fatal injuries in tire service stations.

Keywords

Trauma, blast injuries, tire injuries, metal rim, missile, patterned injuries

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Introduction

Exploding tires during inflation pose hazards, including direct injuries from metal rim fragments and barotrauma from high-pressure. Secondary injuries can result from falls or impacts caused by the explosion's force. Most tire explosions occur at service stations or during maintenance.[1] Various factors, such as the size of the tire, the amount of pressurized air, and the distance between the tire and the victim, determine the severity of trauma.[2] Secondary explosion injuries occur when tire fragments or wheel components, accelerated by the initial detonation or high-pressure loads, strike the body.[3,4]

Case Report

A 40-year-old mechanic suffered fatal injuries while working at a tire service facility. He left the retreading machine door open during truck tire maintenance and inflation. Due to improper locking, the metal rim separated from the tire under high-pressure and was propelled as a missile, striking the right side of his head and face from about six feet away. The impact caused him to fall, hitting the back of his head. He was hospitalized, unconscious, and died five hours later. The autopsy revealed a 5 cm stitched wound on the lower right face, 0.8 cm lateral to the right angle of the mouth (Figure 1). On suture removal, the wound margins were irregular and contused. The underlying mandible and teeth of both jaws were fractured (Figure 2). Another 18 cm stitched wound was present obliquely across the right neck, face, and forehead,

[1]Department of Forensic Medicine and Toxicology, MGM Medical College, Indore, Madhya Pradesh, India
[2]Department of Forensic Medicine and Toxicology, Lady Hardinge Medical College, New Delhi, India
[3]Department of Forensic Medicine and Toxicology, All India Institute of Medical Science (AIIMS), Patna, Bihar, India

Corresponding author:
Ashok K Rastogi, Department of Forensic Medicine and Toxicology, All India Institute of Medical Science (AIIMS), Patna, Bihar 801507, India.
E-mails: drashokr@aiimspatna.org; ashokaiimspatna@gmail.com

Figure 1. Two Linear Stitched Wounds on the Right Side of the Face Were Caused by the Impact of the Metal Rim's Edge (Blue Arrow).

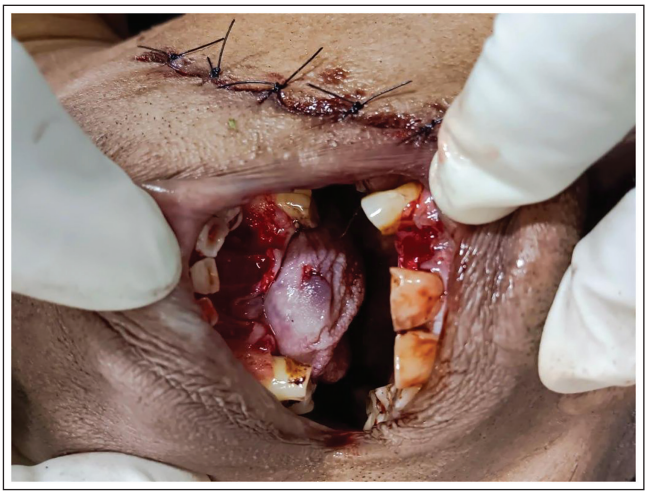

Figure 2. Broken Teeth in Both Upper and Lower Jaws (Blue Arrow).

starting 1 cm below the mandibular angle, crossing the lateral end of the right eyebrow, and ending 1 cm above it (Figure 1). A linear skull fracture of length 6 cm was found in the upper part of this injury at the right frontal bone and extended to the left parietal region. A lacerated wound was seen over the right

Figure 3. Depressed Skull Fracture with Scalp Laceration Resulting from a Fall onto the Edge of Another Metal Disk at the Tire Service Station (Blue Arrow).

frontoparietal region of the scalp with an underlying depressed fracture of dimension 08 cm x 02 cm (Figure 3). Subarachnoid hemorrhage was found over the right frontal, right parietal, and both occipital regions; subdural hemorrhage was seen over the right occipital region of the brain (Figure 4). Craniocerebral damage because of blunt force trauma to the head and face regions was opined as the cause of death.

Discussion

Tire remolding, or retreading, replaces worn tread with a new one, offering a cost-effective and sustainable alternative to new tires. The process involves placing an old tire on a metal disk with outer and inner parts secured by two locks (Figure 5). Metal rims (Figure 5) will be placed over both sides of the tire over the metal disk, and these rims will be kept in place due to the properly fitted and locked metal disk. After that, the tire is placed in the remolding machine (Figure 6). During air inflation, the rising tire pressure pushes the metal rims outward, but the secured disk locks prevent displacement. A truck tire explosion at 90 psi releases 63,000 ft-lb of energy—enough to lift a 3,000 lb car 21 feet, with an estimated force of 2000 g.[5] During inflation, high tyre pressure caused the sudden release of improperly secured metal locks, propelling the outer rim as a missile. The mechanic, standing and bending forward in front of the open remolding machine, was struck. A deformed metal rim was found at the scene due to the impact. (Figure 7). All machines may be installed in strict accordance with the standards of the Occupational Safety and Health Administration, the Bureau of Indian Standard Act,

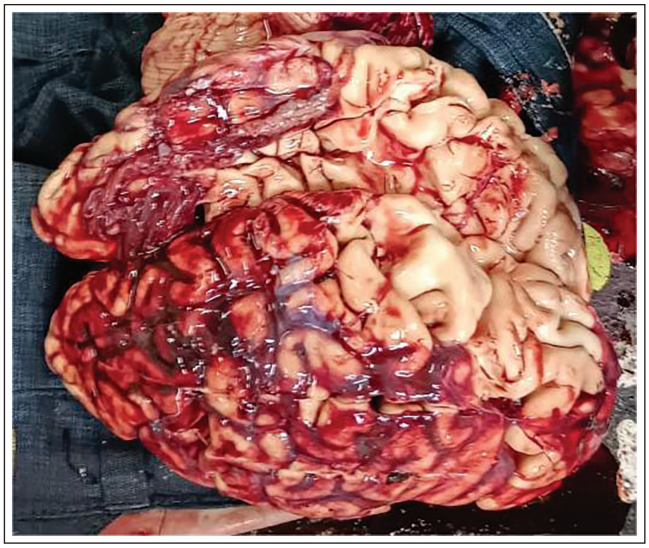

Figure 4. Subarachnoid Hemorrhage Over the Right Frontal, Right Parietal, and Both Occipital Lobes of the Brain, Along with Patches of Subdural Hemorrhage Over the Right Occipital Lobe (Blue Arrow).

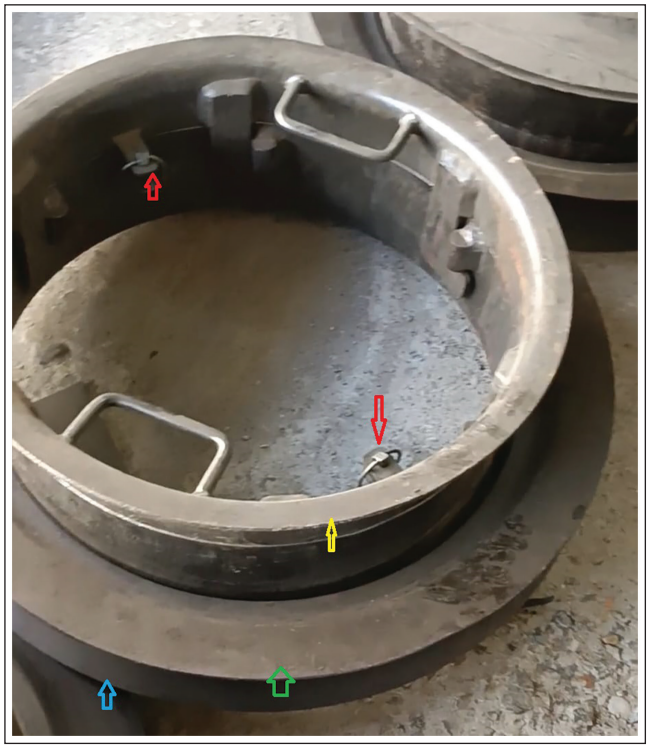

Figure 5. Metal Disk Used to Support the Tire During Inflation, Along with Both Metal Rims that Encase the Tire. Blue Arrows Indicate the Outer and Inner Metallic Rims; Yellow Arrows Point to the Metal Disk; Red Arrows Highlight the Metal Locks Securing the Metallic Disk Components Together.

Figure 6. Remolding Machine with an Open Door. The Red Arrow Indicates the Door Component.

2016, and the Occupational Safety, Health, and Working Conditions Code, 2020.[6,7]

The metal rim first struck obliquely near the right angle of the mouth, causing a fracture, broken teeth, and a laceration. Due to the facial contour, the rim's movement led to a second impact on the right face and forehead, causing another fracture and laceration. The high-impact strike caused the mechanic to fall onto another metal disk, resulting in secondary injuries, including a laceration and depressed fracture. Both facial lacerations were linear, consistent with a high-velocity impact from the metal rim. Pneumatically induced injuries from tire inflation are rare.[8] Most reported cases involve tire/tube explosions, but this case is unique as no explosion occurred. Instead, improper disk locking and an open remolding machine door led to a fatal injury.

Interesting Facts About the Manuscript

1. It is the unique case in which a metal rim acted as a missile during mechanical air inflation without the explosion of a tire/tube. No similar case has been found even after extensive searches using various search engines, including PubMed, Google Scholar, and ResearchGate.
2. The deceased was working on another tire at approximately six feet distance at the time of impact; this fact is also unique about this case.
3. Secondary injuries due to the fall of the deceased over the edge of another metal disk kept at a tire service station caused a depressed fracture corresponding to the edge of the disk.
4. The mechanic in this case failed to lock the disk properly and left the remolding machine's gate open after placing the tire. These facts highlight a number of risk concerns at the tire servicing station that could have dangerous repercussions.

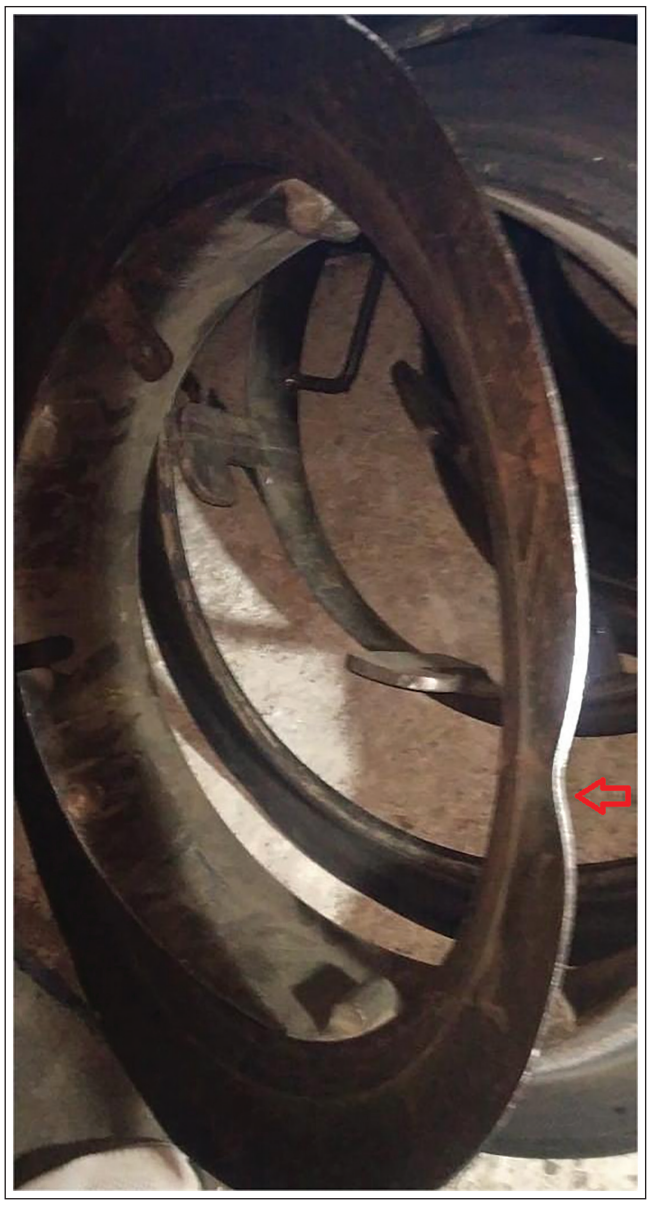

Figure 7. Deformed Metallic Rim that Struck the Deceased's Face. The Red Arrow Marks the Deformed Portion of the Rim.

Conclusion

Tire inflation carries significant occupational risks, including explosions due to overpressure or hidden structural flaws in the tire. Improper disc locking mechanisms can also result in fatal injuries. Ensuring that the remolding machine's door is securely locked during the inflation process is critical for worker safety. This case highlights the occupational hazards faced in tire service centers and emphasizes the importance of strict safety protocols, including the installation of certified standard machines, adherence to manufacturer guidelines, and regular daily inspection and maintenance of equipment.

Author's Contribution

All authors have contributed to this manuscript.

Availability of Data and Material

Data sharing is not applicable.

Consent for Publication

The authors declare their consent for publication.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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ORCID iD

Ashok K Rastogi https://orcid.org/0000-0002-6207-860X

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Cornelia de Lange Syndrome: A Recipe for Gastrointestinal Disaster? A Case Report

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Pranav A[1], Pratima R Bhat[1] and Deepak Nayak M[2]

Abstract

Cornelia de Lange syndrome (CdLS) is a rare genetic disorder (1 in 10,000–30,000 births) often linked to gastrointestinal (GI) complications such as perforation. The most common GI complication in CdLS is gastroesophageal reflux, caused by improper valve function between the stomach and esophagus, allowing stomach acid to flow back. Mutations are usually sporadic and not inherited. Forensic awareness is vital to avoid misinterpretation as abuse, account for intellectual disability and consent issues, and recognize risks of sudden death from undiagnosed malformations such as intestinal obstruction. At autopsy, features such as facial anomalies, limb defects, and GI pathology can indicate CdLS as a factor in unexplained deaths or related conditions. Given its genetic complexity and potential mosaicism, careful evaluation, even postmortem, is essential for accurate cause of death determination. We describe a case of a 25-year-old female with genetically confirmed lifelong intellectual disability who presented with sudden abdominal pain, vomiting, and melena, followed by unconsciousness. She was declared dead at a tertiary care hospital. Autopsy findings revealed ileal dilatation with perforation. CdLS is a rare genetic disorder with drastic involvement in the GI system. Thus, prompt inquiry of case details and investigations, coupled with a thorough post mortem examination is of paramount importance in such cases.

Keywords

Cornelia de Lange syndrome (CdLS), gastrointestinal (GI) complications, autopsy, abdominal pain

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Introduction

Growth retardation, characteristic facial dysmorphism, primordial short stature, psychomotor delay, behavioral issues, hirsutism, and upper limb reduction defects ranging from mild phalangeal abnormalities to oligodactyly are the hallmarks of Cornelia De Lange syndrome (CdLS), a multisystem developmental disorder.[1] This disorder was also known as Amsterdam dwarfism or Brachymann syndrome.[2] DNA testing is helpful for confirmation of the clinical diagnosis, but the sensitivity is only 50% for mutations associated with the Nipped B-like protein (NIPBL) gene.[3] Its incidence has been estimated to be at 1 in 10,000 to 30,000.

Case Details

A 25-year-old female, mentally disabled since birth with autistic features, had a history of behavioral disturbances from the age of 12 years, for which she received treatment in Bengaluru. She was officially certified by the Government of Karnataka as having a severe intellectual disability with 90% impairment. In 2016, she was diagnosed with hypothyroidism, paralytic ileus, and ascites. Genetic testing later confirmed CdLS.

In early 2024, she was admitted as an inpatient to a rehabilitation home, where she remained for two months. On the evening before her death, she had dinner around 8:30 pm. The following morning, she suddenly developed abdominal pain accompanied by vomiting and melena, followed by loss of consciousness. She was rushed to the emergency medicine department, where doctors declared her dead.

[1]Department of Forensic Medicine and Toxicology, Kasturba Medical College, Manipal, Manipal Academy of Higher Education, Manipal, Karnataka, India
[2]Department of Pathology, Kasturba Medical College, Manipal, Manipal Academy of Higher Education, Manipal, Karnataka, India
Corresponding author:
Pranav A, Department of Forensic Medicine and Toxicology, Kasturba Medical College, Manipal, Manipal Academy of Higher Education, Manipal, Karnataka 576104, India.
E-mail: apranav96@hotmail.com

Ethical Consideration

Ethical approval for this case report was not required as per the guidelines of our institution for individual case studies and was waived by the Institutional Review Board. Written informed consent was obtained from the patient's next-of-kin for the publication of this case report and any accompanying images or data. All identifying information has been removed from the case report to protect the patient's privacy.

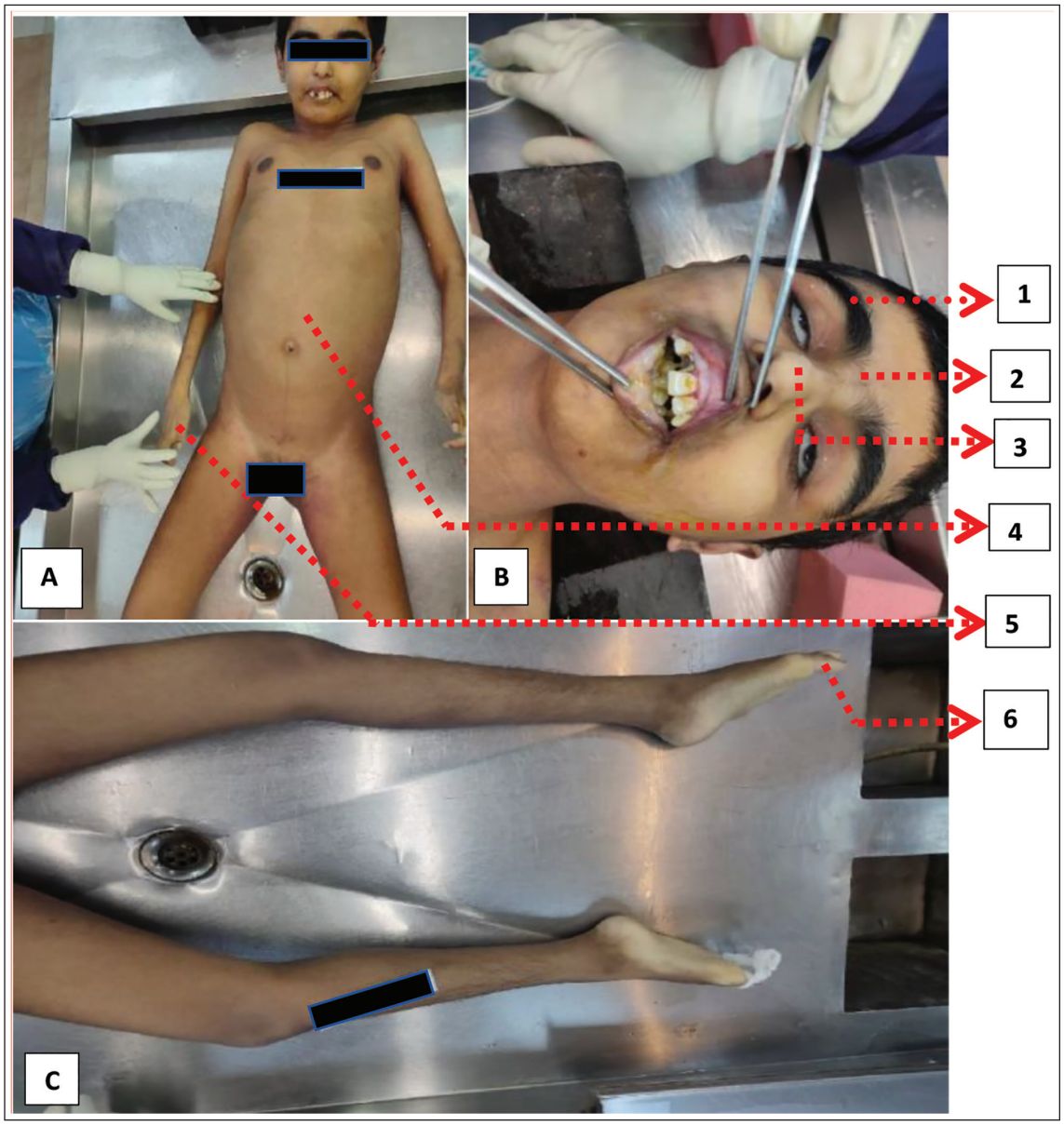

Figure 1. (A, B, and C). External Features of the Patient.

Images A and B show the following external features:

1. Thick eyelashes
2. Synophrys
3. Short, upturned nose
4. Abdominal distension
5. Small hands (micromelia)

Image C shows:

6. Hallux valgus

External Examination

On examination, thick eyelashes, synophrys, a short upturned nose, abdominal distension, small hands (micromelia), and hallux valgus were observed over the body, which was suggestive of features of CdLS (Figure 1).

Internal Examination

The crucial positive findings noted in the internal examination involving the small intestinal mucosa (Ileum) were ileal distension, ischemic enteritis, and ileal perforation (Figures 2, 3, and 4, respectively).

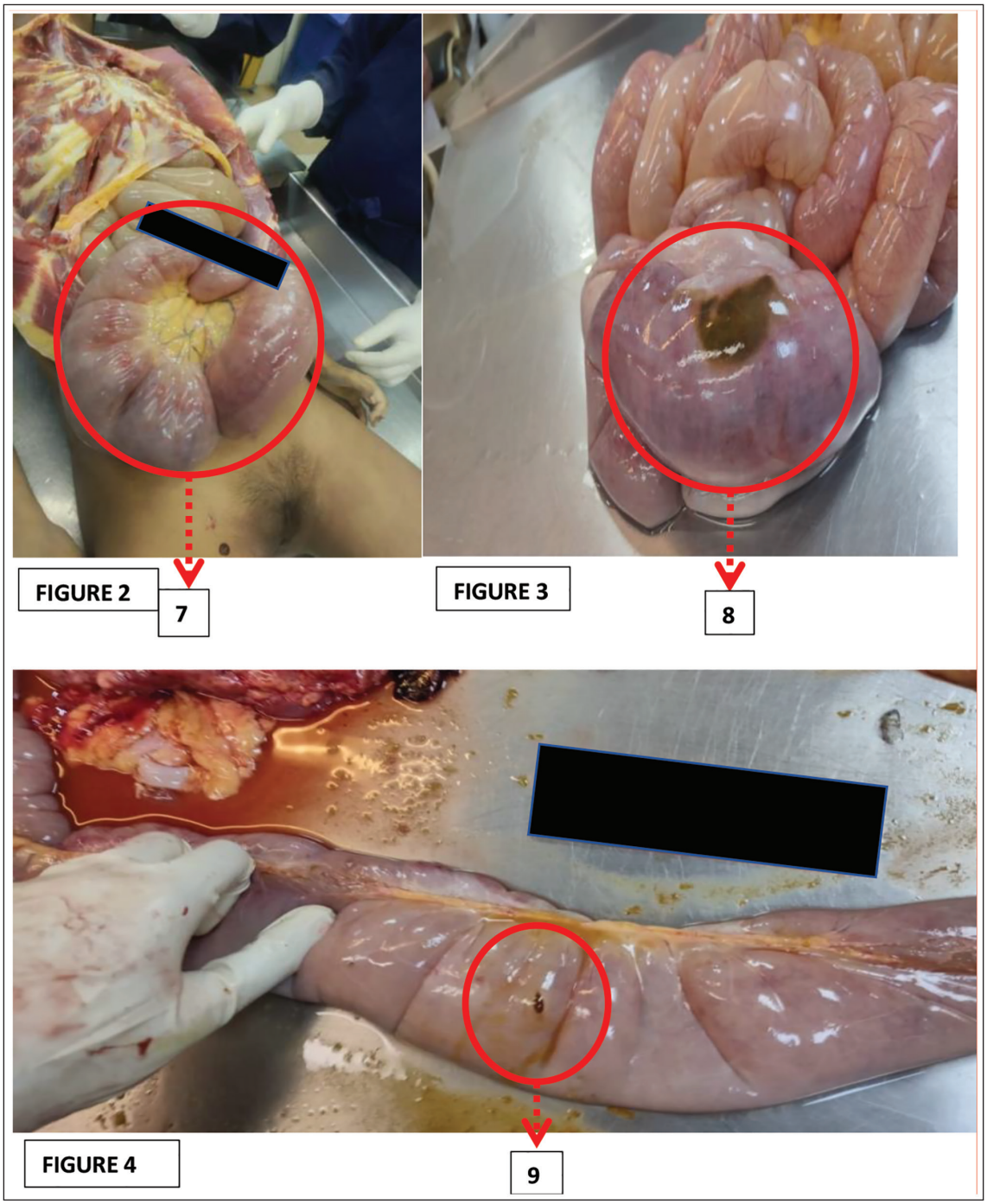

Figure 2. Ileal Distension; **Figure 3.** Ischemic Enteritis; **Figure 4.** Ileal Perforation.

There was a presence of an ileal perforation, measuring 3.5 × 1.5 cm, situated at a point 90 cm from the appendix.

7. Ileal Distension
8. Ischemic Enteritis
9. Ileal perforation

Histopathological Examination (Figures 5 and 6)

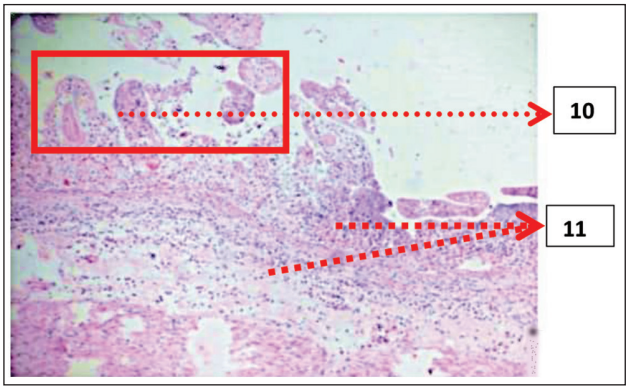

Figure 5. Histological Examination of the Entire Ileum.

10. Aerated epithelium
11. Coagulative necrosis extending up to the submucosa

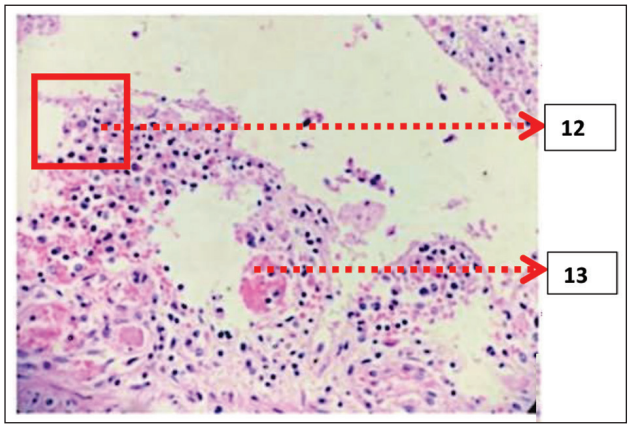

Figure 6. Histological Examination of the Entire Ileum.

12. Necrosis
13. Thrombosed vessel

Cause of Death

The cause of death was ischemic enteritis secondary to peritonitis.

The postmortem examination of individuals with CdLS must be conducted with the utmost respect for the dignity of the deceased and sensitivity toward the family. Recognizing that CdLS is a rare genetic disorder associated with distinctive physical and medical complications, forensic and pathological evaluation should balance the pursuit of scientific and medicolegal clarity with compassion.

Discussion

The scoring system of CdLS is as follows.[4]

The cardinal features mainly include the head and neck features:

Eye manifestations such as synophrys (meeting of the medial eyebrows in the midline) and thick eyebrows, a short nose, concave nasal ridge, upturned nasal tip, and downturned corners of the mouth.

The suggestive features include short fifth finger, small hands and feet, microcephaly, abnormally increased hair growth, prenatal and postnatal growth retardation (<2 standard deviations), hirsutism, global developmental delay, and intellectual disability.

Classic CdLS: >11 points (at least three cardinal features).

Non-classic CdLS: 9 or 10 points (at least two cardinal features).

Molecular testing: 4–8 points (at least one cardinal feature).

Insufficient molecular testing: <4 points.

In the above case, from the aforementioned features, a score of 19 points suggests classic CdLS.

Unique facial dysmorphism, primordial short height, hirsutism, upper limb reduction deficits, unique craniofacial traits, and low Intelligence quotient ranges are the hallmarks of CdLS.[5]

A mutation in the NIPBL gene is typical of traditional CdLS.[6]

Short stature, microcephaly, low frontal hairline, thick eyebrows, synophrys, long eyelashes, concave nasal root, shallow fossa, thin upper lip, lowered corners of the mouth, widely spaced teeth, micrognathia, small hands, short fifth toe, tiny feet, hirsutism, or intellectual disability are the following.[7]

Facial dysmorphic characteristics include hirsutism, intellectual impairment, small hands, clinodactyly, tiny feet, synophrys, thick eyebrows, long eyelashes, shallow fossa, thin upper lip, and lower corners of the mouth.[8]

Among the gastrointestinal (GI) malformations in association with this syndrome, a recent study showed that, although sigmoid volvulus is well-known in adults, it is a rare but potentially fatal illness in children. Sigmoid volvulus may therefore be an under-recognized cause of intestinal blockage and digestive perforation that results in death in patients with CdLS, despite the fact that it is difficult to identify.[8]

The importance of recognizing the syndromic condition in forensic autopsy is that since this disorder has distinctive dysmorphic features, it may guide the investigators to check missing persons reports for individuals with CdLS. Many of these deaths are related to natural complications. Without recognizing the syndrome, these deaths could be misinterpreted as neglect, abuse, or accidental choking. This helps the forensic experts to correctly attribute the death to natural disease processes, avoiding wrongful legal conclusions.

Confirming CdLS at autopsy allows genetic counseling for surviving family members and any identification of recurrence risks. The relevance of CdLS in forensic medicine lies in the distinct physical features and developmental delays associated with the condition, which can aid in differentiating

individuals, estimating age, and identifying victims. Forensic experts may consider these traits as supportive evidence in establishing identity and assessing injuries within the broader context of an investigation. Forensic recognition of CdLS contributes to medical knowledge by documenting natural histories and complications. This helps the public health and research bodies understand mortality trends in rare diseases, which may improve medical care.[8]

Conclusion

The autopsy can serve as a confirmatory tool because it allows systematic documentation of external dysmorphic features, internal malformations, and histopathological or genetic findings that match the syndrome. The importance of documenting this rare syndrome in forensic practices is that it clarifies the cause and manner of death by preventing wrongful allegations of neglect, homicide, or abuse. Documented CdLS cases highlight the vulnerability of affected individuals, and they help to establish standards of care for the institutions and caregivers. Since this is an autosomal dominant disorder, the genes affected can be passed on to the next generation. The family members must be counseled. The most common genetic mutation involved is NIPBL (60%). Because of its effects on a person's health, development, and general well-being, CdLS has medicolegal significance and may give rise to intricate legal issues. The characteristics of the syndrome, such as intellectual disability, developmental delays, and a variety of physical deformities, might affect choices about genetic counseling, healthcare, and disability rights.

Recommendations

In the following pregnancy, parents should receive prenatal diagnosis counseling. Samples from chorionic villous sampling, amniocentesis, or embryonic cells obtained by in vitro fertilization can all be used for prenatal molecular testing.

For areas without access to full gene panels or sophisticated sequencing techniques, targeted single-gene testing of frequently implicated genes, such as NIPBL, is nevertheless useful.

Abbreviations

CdLS: Cornelia De Lange syndrome.
BRD 4: Bromodomain-containing protein 4.
HDAC8: Histone deacetylase 8.
NIPBL gene: Nipped B-Like protein gene.
IQ: Intelligence quotient.
SMC1A: Structural maintenance of chromosomes 1A.
RAD21: RAD21 homolog, double-strand break repair protein.
ANKRD11: Ankyrin repeat domain 11.
SMC3: Structural maintenance of chromosomes 3.
STAG: Cohesion complex component.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

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Patient Consent

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ORCID iD

Pranav A https://orcid.org/0009-0002-1794-2427

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Homicidal Death Due to Blunt Force Trauma Disguised as Burn: A Case Report

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Surya Prakash L R A[1], Pawan Kumar Maurya[2], Bajrang K Singh[1], Tapan S Pendro[1], Jitendra S Tomar[1], Sunil K Soni[1] and Ankit Pandey Jain[1]

Abstract

We report the case of a 37-year-old male whose burned body was discovered under suspicious circumstances in an abandoned location. Postmortem examination revealed the body in a pugilistic attitude with extensive burns, sparing the upper half of the face, portions of the scalp, and parts of the back. The absence of a line of redness at the junction of burnt and unburnt areas indicated that the burns were sustained in the postmortem period. Multiple lacerated wounds and fractures of the facial bones with ecchymosis of surrounding structures were noted, confirming antemortem blunt force trauma. The tracheal mucosa was unremarkable, with no evidence of soot deposition, thereby ruling out antemortem inhalation of smoke. Internal examination revealed subarachnoid and subdural hemorrhages over the left cerebral hemisphere and at the base of the brain, findings consistent with fatal cranio-cerebral injury resulting from blunt force trauma. Correlation of external and internal findings established that death resulted from cranio-cerebral damage due to multiple blunt force injuries, with postmortem burning inflicted to conceal the homicidal nature of the death.

Keywords

Homicide, blunt force trauma, soot particles, postmortem burn

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Introduction

One of the most challenging tasks in forensic medicine is determining the cause of death in cases involving burnt bodies under suspicious circumstances. Such investigations often require careful consideration of several critical aspects. The foremost concern is whether the individual was alive at the time the fire began or whether the burns were sustained postmortem. Establishing whether death resulted directly from burn injuries or whether another cause of death preceded the fire is equally important. In situations where burns are not the primary cause of death, it must be assessed whether they contributed in any way to the fatal outcome.[1]

The manner of death also plays a crucial role in medicolegal evaluation. Differentiating between accidental burns, suicidal self-immolation, and homicidal burns is central to reconstructing the sequence of events. In some instances, the possibility of fire being used to conceal a crime must also be considered. Furthermore, investigations frequently extend to understanding how the fire originated, which may provide insights into intent or accidentality.[1]

Another significant challenge lies in the identification of the victim, particularly when the body is extensively charred. This becomes even more complex in cases of mass fatalities, where forensic experts must also attempt to establish the order of death among multiple victims.[1]

Case Report

On January 11, 2023, the burnt body of a 37-year-old male was brought to the mortuary of our institute. According to police records, the deceased was found in an abandoned place under suspicious circumstances. Subsequent investigation

[1]Department of Forensic Medicine & Toxicology, MGM Medical College, Indore, Madhya Pradesh, India
[2]Department of Pharmacology, SSMC, Rewa, Madhya Pradesh, India

Corresponding author:
Surya Prakash L R A, Department of Forensic Medicine & Toxicology, MGM Medical College, Indore, Madhya Pradesh 452001, India.
E-mail: stanlean2012@gmail.com

Figure 1. Pugilistic Attitude of the Deceased.

established the personal identity of the deceased, revealing that he was a businessman by occupation.

Observation

The extremities were observed to be in a semi-flexed posture, consistent with a pugilistic attitude due to heat stiffening (Figure 1). A piece of burnt cloth, emitting a distinct odor of petrol, was found adherent to the neck region of the deceased. Scalp and facial hair were singed. Superficial-to-deep burns were present over the bilateral temporal and occipital regions of the scalp, lower part of the face, anterior and posterior aspects of the neck, right upper limb, both sides of the chest, abdomen, both lower limbs, genital region, and gluteal regions bilaterally. A loop of intestine was noted protruding through the right side of the abdomen.

The left hand and the distal to middle one-third of the left forearm were absent; the remaining portion of the left upper limb was charred, with exposed bone showing burn effects. The burned tissues were indistinguishable by type and appeared blackened. The posterior aspect of the body, bilateral frontoparietal regions of the scalp, and the upper half of the face were unburnt. No line of redness was observed at the junction of burnt and unburnt areas.

The nose was depressed and deformed; an underlying nasal bone fracture was present, with surrounding soft tissue showing reddish ecchymosis (Figure 2). A lacerated wound measuring 5.0 × 1.0 cm × bone deep was present over the right frontal region; another lacerated wound measuring 4.5 × 1.0 cm × bone deep was present over the right parietal region; and a lacerated wound measuring 3.0 × 1.5 cm × bone deep was present over the left frontal region. The margins of all injuries were irregular, and the edges were contused (Figure 3). The mandible and maxilla were fractured at multiple sites, with reddish ecchymosis noted in the surrounding soft tissues. The tongue was unburnt and found within the oral cavity. Multiple teeth were missing, and the respective sockets showed reddish ecchymosis (Figure 4).

Upon opening the skull, reddish ecchymosis was present over multiple areas of the scalp. The dura was intact.

Figure 2. Depressed Nose with Fracture of the Underneath Nasal Bone.

Figure 3. Lacerations With Underneath Reddish Ecchymosis

Figure 4. Socket of Teeth Showing Reddish Ecchymosis.

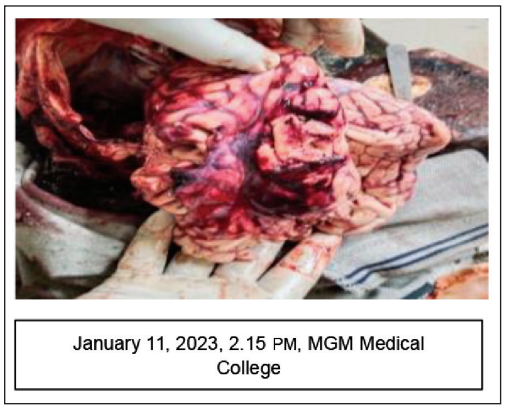

Figure 5. Subdural Hemorrhage and Subarachnoid Hemorrhage Over the Brain.

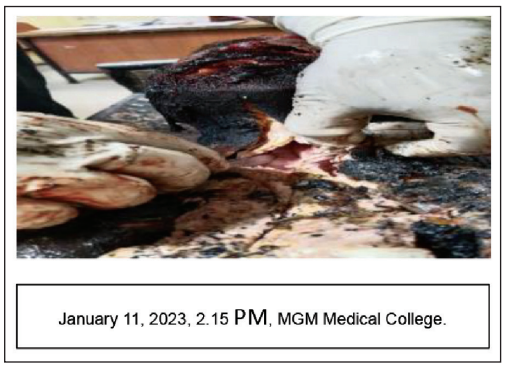

Figure 6. Trachea Without Evident Soot Particles.

Subarachnoid and subdural hemorrhages were present over the left cerebral hemisphere and at the base of the brain (Figure 5).

All visceral organs were grossly normal and appeared pale on cut section. The heart was empty. The tracheal mucosa was unremarkable, with no evidence of carbon soot deposition (Figure 6). No fluid blood was found in the pleural or peritoneal cavities. The stomach contained approximately 200 mL of brownish fluid; the gastric mucosa appeared pale. Histopathological examination of tissues and carbon monoxide estimation were not performed.

Discussion

Examination revealed multiple fractures involving the facial bones, accompanied by marked ecchymosis of the surrounding soft tissues. The distribution and pattern of injuries over the scalp were consistent with antemortem infliction and indicated a homicidal manner of causation. The injury characteristics suggested the use of a hard, blunt object capable of producing fatal injuries in the ordinary course of nature. These findings are consistent with those reported in the textbooks authored by Saukko and Knight[2], Aggrawal[3], Dikshit and Behera[4], Vij[5].

The pugilistic attitude observed in this case occurs because intense heat causes the muscles to coagulate and contract, leading to flexion of the arms and legs. As a result, the upper limbs rise as though the individual were holding a defensive posture. Importantly, this position develops solely due to heat and is not an indicator of whether the person was alive or dead before the fire. This finding is consistent with those reported in the textbooks authored by Aggrawal[3], Dikshit and Behera[4], Vij[5], DiMaio and Molina[6].

Notably, there was an absence of burns over the posterior aspect of the body, no soot particles were detected within the trachea, and no distinguishable line of redness was observed at the junction of burnt and unburnt skin. These findings were indicative of burns sustained in the postmortem period. These findings are consistent with those reported in the textbooks authored by Saukko and Knight[2], Aggrawal[3], Dikshit and Behera[4], Vij[5].

Based on the correlation of external and internal findings, the cause of death was determined to be cranio-cerebral damage resulting from multiple blunt force injuries to the head and facial region. Differentiation between blunt force trauma and heat-related artifacts was achieved through assessment of tissue vitality; the presence of ecchymosis and vital reactions surrounding the scalp injuries confirmed their traumatic and antemortem nature, thereby excluding heat ruptures.

These findings are consistent with those reported in the textbooks authored by Aggrawal[3], Dikshit and Behera[4]. Although histopathological and toxicological analyses could have provided further corroboration, the gross autopsy findings were deemed sufficient to establish both the cause and manner of death.

Conclusion

Determining the cause of death in charred bodies demands a high level of expertise and a systematic approach. The destructive effects of burns, along with heat-induced artifacts, often obscure critical autopsy findings, making the process highly challenging. In certain cases, burns may be present despite the victim having died from an unrelated cause, further complicating interpretation. A meticulous evaluation that integrates a well-documented case history, scene evidence, and relevant laboratory investigations is essential to arrive at a scientifically valid conclusion. Such an approach not only strengthens the medico-legal opinion but also helps prevent wrongful conviction of the innocent and acquittal of the guilty.

Authors' Contributions

All authors have contributed to this manuscript.

Availability of Data and Materials

Data sharing is not applicable.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

Not applicable as a Medico-legal autopsy does not require consent.

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Informed Consent

Authors declare consent for publication.

ORCID iD

L R A Surya Prakash https://orcid.org/0009-0004-8574-446X

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Body Packer Death Due to Accidental Drug Overdose in Delhi, India: A Case Report

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Naresh Jeengar[1] and U. Kishore[1]

Abstract

The authors reported a case of a body packer death due to heroin leakage in the stomach from a leaked package. The body packer was trying to transport the drug by hiding it in his gastrointestinal (GI) tract. The body was recovered after 6–7 days of the incident. A total of 50 egg-shaped packages were found in the body: 48 similar egg-shaped packages were found in the stomach, out of which one was leaked, one egg-shaped package was in the jejunum and one egg-shaped package was in the descending colon. The total weight of 50 capsules was 468 g. Toxicological analysis of the powder samples from the damaged package and the other 49 packages was performed and found positive for diacetyl morphine (heroin), monoacetyl morphine, caffeine, dextromethorphan and acetyl codeine. This case shows the difficulties during examination of a narcotic deceased postmortem and the importance of the history of the victim before the autopsy, a proper postmortem examination, the findings of toxicological tests and forensic photography. The cause of death was 'acute drug overdose due to rupture of filled capsule in stomach', which makes this case special. It indicates that body packing is an existing problem in India.

Keywords

Body packing, heroin toxicity, forensic autopsy, drug overdose, narcotic smuggling, autopsy findings

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Introduction

Body packing is one of the most important mechanisms of cross-border drug trafficking and it is associated with significant financial gains. This illegal activity is the concealment of illegal substances such as cocaine, heroin, hashish, amphetamines, ecstasy and others inside the digestive tract for the purpose of smuggling. Body packing was first reported in 1973.[1,2] Body packers, also known as mules, hide drugs in capsules, balloons, condoms, plastic bags or latex gloves in different parts of their body. These can include the mouth, rectum, gastrointestinal (GI) tract, ear, vagina or foreskin.[3]

After swallowing drugs, laxatives or enemas are used to remove them from the body. A 'body packer' usually carries about one kilogram of drugs divided into small multiple packets weighing between eight and 10 grams each and measuring 2–8 centimetres.[4] Each packet contains a lethal amount of narcotic drugs.[5–7] Customs officials find it challenging to identify suspects at airports or national borders.[8–10]

The appearance of intoxication, a person's demeanour, their travel itinerary, their destination, any suspicious information regarding their trip or their contacts in the area might all raise suspicions. Interpol occasionally provides pertinent information before the arrival of a suspect. Suspicious circumstances need a physical examination, an enzyme immunoassay urine test and a subsequent abdominal X-ray.[8]

The body packers are particularly vulnerable to packet rupture and subsequent toxicity. Additionally, GI blockage may develop and there have been reports of upper GI haemorrhage brought on by the packets' prolonged pressure on the gastric mucosa.[11]

In circumstances where the cause of death is unknown, forensic pathologists may find hidden drug packages during autopsies.[8,11]

In the present article, a case of a heroin body packer is discussed whose decomposed body was found in a rented room in Lajpat Nagar, Delhi. Death was due to an acute drug

[1]Department of Forensic Medicine and Toxicology, Dr Baba Saheb Ambedkar Medical College, Delhi, India

Corresponding author:
Naresh Jeengar, Department of Forensic Medicine and Toxicology, Dr Baba Saheb Ambedkar Medical College, Delhi 110085, India.
E-mail: nj9958503938@gmail.com

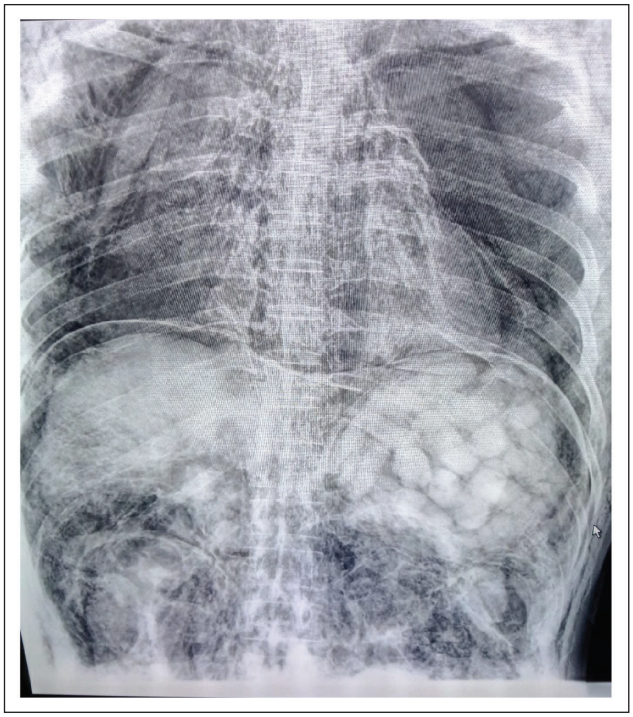

Figure 1. X-ray Abdomen Showing Multiple Egg-shaped Packages.

overdose due to rupture of a filled capsule in the stomach, which was detected at autopsy. Autopsy revealed that the body packer was carrying 50 heroin packages in the gastro intestinal tract (GIT), out of which one packet had leaked.

Case Report

Autopsy Finding

It was the dead body of an Afghan male aged about 33 years, which was found in a decomposed state in a rented room in Lajpat Nagar, Delhi. The body was examined by the authors. An X-ray of the abdomen was taken before autopsy due to a suspicious foreign body. In the abdominal X-ray, multiple egg-shaped packets were seen in the stomach (Figure 1 X-ray abdomen showing multiple egg-shaped packages). The body was emitting a foul smell. It was in an advanced stage of decomposition. No evidence of trauma was evident. There was marked congestion of cerebral vessels, but no intracranial haemorrhage. The brain's transverse and coronal regions showed no abnormalities. The stomach contained about 800 grams of semi digested food material with 48 egg-shaped packages among that one egg-shaped package was leaked (Figure 2 stomach containing egg-shaped packages) with yellow paste like material comes out.

No ulceration was present, but the stomach mucosa was congested. The jejunum contained one intact egg-shaped package and the descending colon also contained one

Figure 2. Stomach Containing Egg-shaped Packages.

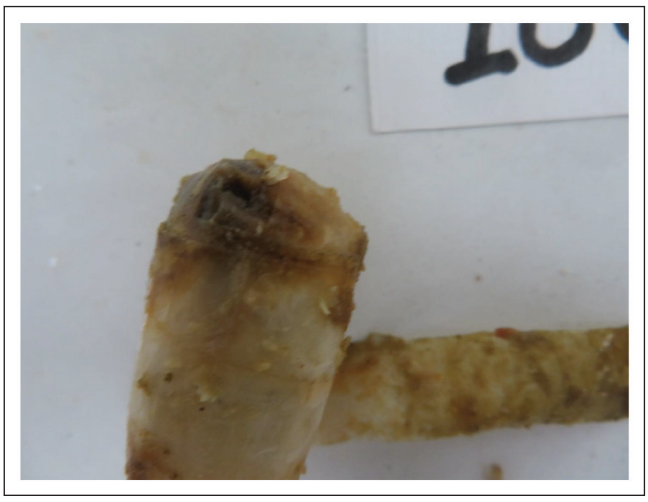

Figure 3. Leaked Egg-shaped Package.

egg-shaped package. The mucosa of the duodenum was congested. There was no evidence of intestinal obstruction.

The lungs were oedematous and softened. Liver, spleen and kidney were found congested. So, from internal examination, it was evident that 48 egg-shaped packages were present in the stomach, out of which one egg-shaped package leaked, one egg-shaped package was in the jejunum and one egg-shaped package was in the descending colon.

Toxicological Findings

The net weight of all packets (numbered 1–50) was 468 grams, out of which one egg-shaped package was damaged, having an individual weight of eight grams (Figure 3: leaked egg-shaped package). The weight of a single intact egg-shaped package was about 8–10 grams. Packages 1–50 were white in colour and wrapped in multiple layers of cellophane tape (Figure 4: 50 egg-shaped packages). The size of each egg-shaped package was about 4 cm × 1.5 cm.

Figure 4. Fifty Egg-shaped Packages.

Drugs were determined in packets and viscera samples using thin-layer chromatography (TLC) and gas chromatography coupled with gas chromatograph mass spectrometry (GC–MS). The (GC–MS system used-Agilent GC (6890N), an mass selective detection (MSD) (5977A) and an Hewlett-Packard (HP) ChemStation data analysis system, with injections performed using an auto sampler (7683 series).

In the TLC method, two developing solvent systems were used: System A, methanol–ammonia 100:1.5 v/v and system B, chloroform–methanol (9:1 v/v). Each suspected heroin sample (0.5 mg) was dissolved in one ml of methanol and centrifuged. The supernatant clear liquids were separated into clean vials. Five microliters of each sample was spotted on the TLC plates (precoated silica gel plates G 60 F, 20 × 10 cm, 0.2-mm thickness on aluminium from E-Merck). An ultraviolet lamp operating at lambda 254 nm and 366 nm (CAMAG, Switzerland) was used for the location of spots after development in a solvent system. Visualisation of separated spots was carried out after spraying with Dragendorff reagent, followed by acidified potassium iodoplatinate reagent.

Each packet contained diacetyl morphine (heroin), monoacetyl morphine, caffeine, dextromethorphan and acetyl codeine. Stomach, intestine, liver, spleen, kidney and blood contain diacetyl morphine (heroin), monoacetyl morphine, caffeine, dextromethorphan, acetyl codeine, codeine, morphine and fatty acid.

At the crime scene, police also found a yellow plastic bottle on which Mankind Kabz Churn was written and a bottle of lactulose solution.

Discussion

Body packing is more frequently linked to cocaine smuggling. Other drug instances, particularly those involving heroin, have also been documented.[12] A person who attempts to convey illegal substances from one nation to another by consuming condoms, balloons or wrapped bundles containing concentrated cocaine or heroin is known as a body packer or mule. Cathartics are self-administered and the packets are defecated out once they reach the destination. Rectal suppositories and single-use enemas are occasionally employed. Occasionally, the rupture of packets can cause significant poisoning.[13] Similarly, in our case, police found Mankind Kabz Churn and a lactulose bottle from the crime scene and a leakage of one egg-shaped package found from the stomach in the autopsy.

Our report agrees with the literature's conclusions that a young adult, generally male, in his or her mid-thirties, coming from a nation that produces drugs, fits the 'typical profile' of a body packer.[5,14,15] Similarly, in our case report, a 33-year-old Afghan male came from a foreign country one day ago in India. However, these days, youngsters, the elderly and even pregnant women are members of the network.[5]

If a foreign national is found dead in a hotel, the entire digestive tract should be opened to look for intact or burst drug packets. The vagina, anus and anal canal should all be thoroughly inspected.[10] In our case report, a foreign national was found in a friend's rented room.

Body packers are mostly identified by police, customs through suspicious behaviour. Typically, they are travellers who avoid eating or drinking anything on the plane, skip using the toilet and keep almost completely quiet the entire time.[16,17] Body stuffers typically succeed in passing the eaten packets with the aid of laxatives or enemas, but occasionally it is unsuccessful. Despite the fact that most body packers have no symptoms.[17] medical help is needed if the packages are not passed out or if intoxication occurs due to rupture of the packet inside the body.

In most cases of body packers, packets were found in the stomach. Large foreign bodies may encounter a meaningful barrier in the pylorus. Localised deposits may also be caused by anticholinergic overuse and intestinal paralysis brought on by excessive cocaine and heroin intoxication. The packages may be broken by mechanical movement or chemical digestion of the covering of the packets when they are inside the stomach.[3] In our case, we also found a total of 50 egg-shaped packets, out of which 48 packets were present in the stomach, in one packet had leaked into the stomach.

Ten fatalities and one survivor of attempts to transport cocaine inside the body were investigated by Wetli CV and Mittlemann RE. All the victims had recently taken flights from South America back to the United States. Eight victims had ingested balloons, condoms or plastic bags containing 3–6 g of cocaine, which were later discovered in their GI tracts. They recommended that the body packer condition should be in mind while doing a postmortem of a traveller who passes away unexpectedly, experiences seizures or exhibits any symptoms typical of cocaine toxicity.[18] In our case weight of the intact egg-shaped packet was 10 grams and similar to above above-cited case toxicological finding shows diacetyl morphine (heroin), monoacetyl morphine, caffeine, dextromethorphan and acetyl codeine in each packet.

In November 2000, Barnett JM and Codd G found a dead body associated with a cannabis body packer case. Two days

before his passing, the deceased had travelled to northern India. He had 55 cellophane-wrapped bags of cannabis resin discovered after his death in the large intestine. A subsequent police investigation of the apartment turned up the presence of an additional 133 similar parcels in the fridge, indicating that he may have concealed a total of 188 items. The distal large intestine was perforated due to consuming the packages, which led to peritonitis, which was listed as the cause of death.[19] Similarly, in our case, packets were wrapped in cellophane as mentioned in the above case.

Since not all body packers have been captured and only some of them show body packer syndrome signs, it is impossible to confirm the precise number of body packers. A thorough autopsy of a person suspected of being a body packer may disclose detailed information regarding the packaging techniques, precise quantity of packets, type of illicit drug delivered and placement of the packets in the body.

Conclusion

This article describes the body packer death due to accidental drug overdose in Delhi. Autopsy and toxicological analysis revealed 50 heroin-filled packets inside the deceased's GI tract, with one ruptured packet in the stomach, causing an acute drug overdose. This case highlights the ongoing issue of body packing in India and underscores the importance of thorough forensic examination in such cases.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Ethical Approval

Not required.

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Informed Consent

Informed consent was obtained from the relative of the deceased.

ORCID iD

Naresh Jeengar https://orcid.org/0009-0000-5056-8217

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Journal of Indian Academy of Forensic Medicine

Aims and Scope

Journal of Indian Academy of Forensic Medicine (JIAFM) is a quarterly peer-reviewed specialty medical journal which is the official publication of the Indian Academy of Forensic Medicine. The Journal covers all technical, medico-legal and clinical aspects of the Specialty including the Ethical and Social issues. JIAFM presents a comprehensive and meticulous exploration of the intricate facets within the realm of Forensic Medicine. It serves as a pivotal platform for scholarly investigations, discussions, and insights into ethical and social dimensions that intersect with Forensic Medicine.

Priority is accorded to Original Research Articles, Review Papers, and impactful Case Reports that significantly contribute to the field. By spotlighting these crucial areas, JIAFM endeavours to foster a deeper understanding of Forensic Medicine and promote best practices.

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***Journal of Indian Academy of Forensic Medicine* (JIAFM)** is a quarterly peer-reviewed specialty medical journal which is the official publication of the Indian Academy of Forensic Medicine. The basic ideology of publication of this journal is based on the objectives of Indian Academy of Forensic Medicine (IAFM). It is a quarterly published, multidisciplinary, Multispeciality, international, peer reviewed IAFM (society) journal published by SAGE as a medium for the advancement of scientific knowledge of Forensic Medicine, Medical Ethics, Medical Education, Law and allied sciences.

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From Editor's Desk

Dear All,

You have my sincere gratitude for believing in me and giving me this distinguished role as the Editor-in-Chief of Journal of Indian Academy of Forensic Medicine. Big thanks to all IAFM members and Esteemed voters. Words cannot describe how grateful I am. I am grateful to the former IAFM President - Dr Mukesh Yadav Sir and former IAFM Secretary- Dr Manish Kumath Sir for their kind blessings and continued support. With blessings and support from current IAFM President- Dr C B Jani Sir and IAFM Secretary- Dr Rajesh Dere Sir, I will prove myself with continued hard work, dedication and constant efforts towards upliftment of the journal status.

I am well aware of the obligations that you have placed on me. With your ongoing assistance, I hope that everyone will have a great time for their own academic upliftment, including upgradation of the journal quality and indexing status at par excellence. I will strive to improve the calibre and standard of JIAFM publications. Throughout the trip, I ask for your participation, understanding, and direction as needed. I would like to express my sincere gratitude to all of our past editors and co-editors who have distinguished this journal via their tireless efforts and dedication, which has allowed JIAFM to grow every year.

Being the Editor-in-Chief, on the behalf of my new editorial team including officially elected Joint Editor Dr Mohammed Ziyauddin G. Saiyed, I assure you a hassle-free and user friendly manuscript submission, handling and management system via SAGE platform for speedy process and final decision through editorial team. A few highly active national and international faculties with outstanding knowledge in a range of subspecialties have also been added as National, international editorial board and reviewer board panels, and they will be able to provide constructive criticism to help us get better.

Additionally, by including case series, research briefs, brief communications, book reviews, and letters to the editor, we intend to improve the publication sections. We genuinely anticipate our fraternity's academic advancement through high-calibre publications with your help.

Dr Ravindra B Deokar

MD (FM), LLB, LLM(HR), ACME, PGDFAO, FAIMER, EPGDHA (TISS), MBA (HAHCM)

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Email id: Jiafmeditor@gmail.com (M): +91-9423016325

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Professor (Additional), Forensic Medicine, Lokmanya Tilak Municipal Medical College & LTMG Hospital, Sion , Mumbai 400022 Maharashtra.
Senate Member, Maharashtra University of Health Sciences, Nashik, Maharashtra.

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