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Introduction

Genomics is a field of biology that deals with the study of all the DNA of an organism, that is, its genome. It includes identification, characterization, functional elements, and how they interact, and the role of the environment affecting them.[1] Precision medicine or personalized medicine is an innovative approach for tailoring disease prevention and its management, giving due consideration to the differential genomics of individuals, environment, and lifestyle.[2] Genomics and precision medicine have many medicolegal, ethical, and social implications. Genomic medicines offer accurate, faster diagnosis and tailored treatment, especially in cancer patients and inherited diseases. It aims to understand how a person's genetics, lifestyle, and environment may help to determine the best approach for disease prevention and treatment. It facilitates the right treatment for the patient at the right time.[3]

There are many ethical and medicolegal implications of genomics and precision medicine, such as genetic data privacy, informed consent, confidentiality, beneficence, nonmaleficence, genetic discrimination, autonomy, justice, data interpretation, data quality, advancement in technology, expansion of new areas, clinical guidelines, clinical practice, research, regulatory framework, government policies, and regulatory compliance. Ongoing education of healthcare providers on the ethical use of genomics and precision medicine is a need of hour.[4]

Data sharing on phenotypic and genotypic information of communities is required to improve the genetic variant's disease causality assertions. The care of the individual with a genetic disease can be optimized by understanding the population-scale genetic variation. The patient care can be enhanced through improved diagnostic sensitivity using genome sequencing for precise therapeutic targeting.[5–7] Genomics strategies, such as DNA-sequencing technologies and analysis algorithms, need to be adapted in healthcare management for better outcomes.[8,9]

Genomics in Forensic Medicine

Genomics plays an important role in forensic medicine. It has a vital role in revolutionizing the field of crime scene investigation and human identification.[10] The main key applications of genomics in forensics are as follows:

1. Human Identification: Genomic analysis helps in human identification to resolve paternity disputes, determine ancestry, and predict physical characteristics.
2. DNA analysis: Genomic analysis of DNA evidence can help to reconstruct crime scenes and identify individuals.
3. DNA profiling: Next-generation sequencing (NGS) helps the analysis of multiple genetic markers, including short tandem repeats, mitochondrial DNA, and single-nucleotide polymorphisms.
4. Genetic genealogy: A search in a public genealogy database using genomic data can help to identify unknown individuals. Forensic DNA databases can be used to create and search for DNA profiles to help investigators match DNA evidence to suspects or victims.
5. Forensic Genetic Phenotyping: Genomic analysis from DNA evidence can predict physical characteristics such as height, hair color, and eye color.

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6. Predictive Genomics: Prediction of physical traits, such as facial features, and geographic ancestry can be done using genomic data.
7. Age Prediction: An individual's age can be predicted using genomic analysis. It may help investigators to narrow down suspect lists.
8. Missing Person Identification: Genomic analysis will be useful to identify human remains and reunite families with loved ones.
9. Cold Case Investigation: NGS technology can re-analyze DNA evidence from cold cases. It will help investigators find new leads and convictions.
10. Biological Fluid Identification: Body fluids at crime scenes, such as blood or saliva, can be identified using DNA methylation analysis.

The Benefits of Genomics in Forensic Medicine

1. Improved Accuracy: DNA analysis of evidence using genomic analysis helps in precise identification.
2. Improved Efficiency: NGS technology facilitates quicker and more efficient DNA analysis from trace evidence.
3. Enhanced Investigative Power: Genomic data help investigators to generate new leads for solving complex cases.

Challenges in Forensic Genomics[11]

1. Standardization: There is a need for appropriate guidelines and training to develop standardized protocols for genomic analysis applications in forensic investigations.
2. Interpretation: Highly efficient expertise is needed for interpreting complex genomic data and ensuring its relevance to forensic investigations.
3. Data quality and integrity: Contamination, degradation, or other quality issues lead to damage to genomic data.
4. Data privacy and data protection: Appropriate security measures to be taken to restrict unauthorized access to confidential information and the genomic data
5. Ethical Considerations: There is a need to address ethical concerns about consent, genetic privacy, and potential biases.
6. Regulatory frameworks: There is no clear regulatory framework at present to regulate the use of genomic data in forensic medicine.

Precision Medicine in Forensic Medicine

1. Personalized medicine: It involves applying individualized medical approaches for improving forensic investigations and legal proceedings. Precision medicine helps provide accurate medical treatment to an individual's specific genetic profile. This data can be helpful in forensic cases.[12]
2. Genetic predisposition: Genetic predispositions to certain diseases or conditions can be identified by precision medicine. This information may help to solve forensic cases involving injury or death.
3. Pharmacogenomics: Genomic analysis facilitates the prediction of an individual's response to certain treatments. This is particularly helpful in forensic toxicology case investigations.
4. Toxicogenomics: Genetic responses analysis to drugs, toxins, and substances will help to improve forensic toxicology.
5. Forensic Psychiatry: Personalized medicine approaches can be applied to understand an individual's mental health and behavior.

Resources for Learning More About Genomics in Forensic Medicine

1. Journal of Forensic Sciences: This journal publishes various original research articles related to the application of genomics in forensic medicine.
2. International Society for Forensic Genetics: It is a professional organization that helps to promote the advancement of forensic genetics and its application.
3. National Institute of Justice: It provides resources and funding for research on genomics applications in forensic medicine.

Future Directions[11,12]

1. Integration with other technologies: Genomics and precision medicine will increasingly be integrated with different technologies, such as artificial intelligence and machine learning, to yield useful results.[13]
2. Expansion to new areas: Genomics and precision medicine will be applied to new areas, such as forensic psychology and forensic anthropology.[14]
3. Increased focus on ethics and policy: There will be an increased focus on the ethical and policy implications of using genomics and precision medicine in forensic medicine.

Conclusion and Recommendations

With technological advancement and emerging discoveries, genomics and precision medicine are evolving rapidly. The genomic data are complex. Considering data complexity, a specialized expertise is required to apply genomic data for its accurate interpretation.

Accurate genotypic and phenotypic data sharing in the global domain will facilitate accelerating the causality determination for novel genes or variants. A deeper understanding

of disease through genomics will allow much better therapeutic precision.

There are various unique ethical considerations related to genomics and precision medicine. It involves the main ethical issues such as informed consent, genetic privacy, and genetic discrimination. There is a need for standard uniform guidelines for handling ethical concerns of genomic data use and applications. Healthcare professionals should keep themselves up-to-date on the latest advanced knowledge on clinical and forensic applications of genomics.

Declaration of Conflicting Interests

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Exhumation Pattern and Its Medicolegal Importance: A Twenty-year Retrospective Descriptive Study

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Abstract

Exhumation, the process of retrieving buried remains, is critical in medicolegal investigations, particularly in cases of suspicious or unnatural death. In India, exhumations are conducted under strict legal protocols to determine the cause of death and to collect essential forensic evidence. This retrospective descriptive study analyzed 20 exhumation cases from June 2003 to August 2023 at a tertiary care hospital and teaching institution. Data were collected from police requisitions, postmortem reports, and inquest papers focusing on demographic details, burial conditions, postmortem changes, and the cause of death. Among the 20 cases, 65% involved male victims; predominantly those aged 15–55 years. Most of the cases (65%) were homicides. The retrieved dead body showed various decomposition changes depending upon the time interval between burial and exhumation and the depth of the burial site. The cause of death was determined in 70% of cases, with early decomposition yielding better forensic outcomes compared to advanced stages of decomposition or skeletonization. Exhumation provides invaluable medicolegal evidence, though challenges arise with prolonged burial. Improved forensic protocols and technology can enhance the accuracy of findings.

Keywords

Exhumation, medicolegal autopsy, decomposition, cause of death, burial practices

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Introduction

Exhumation, derived from the Latin terms *ex* (out of) and *humus* (ground), refers to the process of retrieving a body from its burial site, primarily for legal or medical investigations.[1] In forensic practice, exhumations are vital for uncovering new evidence in cases where suspicions of unnatural death arise after burial or when additional clarification on the cause or manner of death is required. This procedure allows for post-mortem analysis long after burial, presenting a critical opportunity to assess factors such as trauma, poisoning, or diseases that may have gone undetected previously. However, the process is complex and must be meticulously managed to ensure the integrity of both the remains and the investigation. It is often complicated by factors such as body decomposition, environmental conditions, and burial durations, which can make forensic examinations particularly challenging.[2,3] In many countries, including France, Germany, and Scotland, specific time limits regulate exhumations; however, in India, there is no fixed period within which exhumation must be performed.[4,5] In India, the procedure is governed by strict legal protocols, with the Criminal Procedure Code (Section 176) mandating that an executive magistrate be present to oversee the process.[6] Furthermore, exhumation from consecrated grounds requires special authorization from appropriate religious or civil authorities.[6] Despite these challenges, a properly conducted exhumation can yield crucial insights that are essential for medicolegal justice, establishing identity, and addressing unresolved questions. This study on exhumation cases examines the various factors that can complicate forensic investigations, particularly in addressing medicolegal questions associated with such cases. This highlights the significant challenges that forensic experts face, including the effects of prolonged burial on the body and the complexities of interpreting postmortem findings.

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Materials and Methods

This retrospective descriptive study was conducted in the Department of Forensic Medicine and Toxicology at the Pondicherry Institute of Medical Sciences, Puducherry, India. The study spans a period from June 2003 to August 2023 and includes 20 exhumation cases from Tamil Nadu and Puducherry.

For each case, a detailed examination was carried out, including the collection of basic demographic data such as age, gender, and burial conditions. The following factors were collected and documented for each case from the postmortem reports and inquest papers submitted:

- Socio-demographic profile of victims such as age, sex, and religion.
- Primary intention of exhumation and relevant legal sections under which the case was registered.
- Time interval between the time of interment (burial) and exhumation, soil type, and dimension of the burial site.
- Body condition at the time of exhumation includes the degree of decomposition and postmortem changes.
- The cause of death, as well as any injuries noted.

All cases exhumed by our institute followed standard operating procedures throughout the exhumation process. A dedicated team, consisting of two forensic experts, two trained diggers, a mortician, a photographer, and an investigating police officer, conducted each exhumation. Graves were identified and opened in the presence of a magistrate, and measurements of the burial site were recorded. The area around the grave was marked, and any additional circumstantial evidence was photographed, tagged, and documented.

Once the body or coffin was located, care was taken to remove it from the grave without disturbing the potential forensic evidence. In most cases, the body was placed on a clean mat beside the grave; however, in certain instances, it was transported to the morgue in a body bag. A thorough autopsy was conducted using Ghon's technique for organ evisceration. Routine histo-pathological and toxicological samples were collected and sent to a regional forensic science laboratory for further analysis. All procedures were photographed and documented using identification tags.

Results

Demographic Profile of Victims

This study examined 20 exhumation cases conducted between June 2003 and August 2023. The age of the deceased ranged from 3 days to 70 years, with a median age of 32 years. Among the cases, 65% (13) were male, and 35% (7) were female. Regarding religion, 17 cases were Hindu, one was Muslim, and two were of unidentified faith.

Investigation Procedure

All exhumations were conducted under legal requisition from magistrates, as per Indian law. Fourteen cases involved suspected homicides investigated under Sections 302 and 201 IPC (Indian Penal Code), with burial intended to conceal evidence. Two cases were investigated due to death due to rash and negligent act under Section 304 (A) IPC and Section 176 CrPC (Criminal Procedure Code), and both these cases involved traditional burial practices. Four cases had allegations of suspicious or unnatural death, including poisoning and smothering, leading to investigations under Criminal Procedure Code Sections 176 (Table 1).

Burial Practices and Locations

Of the 20 cases, 17 involved clandestine burials to hide crimes, while three cases were traditional burials. Traditional burials used porous wooden coffin box in one case and in other two cases the body was wrapped in ritual white cloth (Figure 1) and buried in their respective graveyards, while clandestine graves were primarily shallow and in isolated locations such as sea shore, riverbanks, dried river beds, isolated farmlands, in between rock crevices, rocky cave, and at places in old abandoned grave yards. None of the bodies was embalmed.

Time Interval Between Interment and Exhumation

The time interval between interment and exhumation ranged from 3 days to 128 days. Of the 20 cases, eight were exhumed within one week, with 50% (four cases) displaying early decomposition changes and the other 50% showing advanced putrefaction (Figure 2). For exhumations conducted between one week and four weeks post-burial (seven cases), early decomposition was observed in 42.9% (3 cases), partial skeletonization in 42.9% (three cases) (Figure 3), and advanced putrefaction in 14.3% (one case). When exhumation occurred after one month (five cases), the majority exhibited partial skeletonization (two cases), complete skeletonization (two cases), and adipocere formation (one case) (Table 2).

Figure 1. Exhumed Body Covered with White Cloth After Digging the Burial Site.

Figure 2. Exhumed Body in the Advanced Stage of Putrefaction.

Figure 3. Exhumed Body in the Stage of Partial Skeletonization.

Figure 4. Exhumed Body Showing Ligature Material Around the Neck.

Depth of Burial Site and the State of the Body

Table 3 shows the relationship between the depth of burial and the state of decomposition. Of the nine bodies buried at depths less than four feet, five cases showed early decomposition changes, while the remaining cases exhibited advanced putrefaction (one case), partial skeletonization (11.1%), complete skeletonization (11.1%), and adipocere formation (11.1%). In burials between four and eight feet (nine cases), only 22.2% showed early decomposition changes, while advanced putrefaction and partial skeletonization each accounted for 33.3% of the cases. Additionally, complete skeletonization was observed in 11.1% of cases, with one case (11.1%) showing adipocere formation. For the two cases buried deeper than eight feet, one exhibited advanced putrefaction, and the other was partially skeletonized.

State of the Dead Body and Cause of Death Determination

Out of the 20 exhumed cases, the cause of death was determined in 14 cases (70%). Among the seven cases in the early decomposition category, six (85.7%) had a clear cause of death. These included cranial and cerebral injuries (three cases), thoracic injuries (one case), manual strangulation (one case), and smothering combined with traumatic asphyxia (one case). One case in this category remained inconclusive. In the advanced putrefaction category (five cases), the cause of death was established in three cases. These included poisoning (one case), cranial and cerebral injuries (one case), and smothering (one case), while two cases could not be determined due to the extent of decomposition. For cases with partial skeletonization (five cases), three had a clear cause of death: cranial injuries due to blunt trauma (one case), spinal cord transection (one case), and ligature strangulation (one case). The remaining two cases were inconclusive. In the complete skeletonization category (two cases), the cause of death was determined in one case as ligature strangulation (Figure 4), while the other case remained undetermined. The single case of adipocere formation was attributed to ligature strangulation due to the preserved condition of the body in a water-saturated burial environment.

Discussion

Exhumation cases are relatively uncommon in the literature but are critical in cases involving unnatural death, including homicides, suspicious deaths, poisoning, and criminal abortions.[7,8] The forensic examination following exhumation serves as the final resort for diagnosing deaths that have not been adequately investigated or examined.[9] The success of any exhumation depends on the technical equipment available for the task, as well as the preservation conditions of the body (including the

duration of burial, the condition of the corpse at the time of burial, and other environmental factors).[7]

Socio-demographic Profile of the Victims

The socio-demographic profile of the victims of this study is similar to that of the other studies conducted on exhumed bodies,[8–11] whereas older victims of the age group of 41–55 years were predominant in the study conducted by Ingale et al.[12] Regarding religion, there were 17 Hindus, one was Muslim, and two were not determined in our study. This is consistent with the findings of Gitanjali[8] (14 cases of Hindu, 73.68%) and Ingale et al.[12] (16 cases of Hindu, 88.88%).

Reasons for Exhumation

In our study, most of the cases (18 out of 20) were interred for unlawful burial, and two cases were buried before completion of legal formalities. It is similar to the study by Kremer Sauvageau.[11] In 60% of cases, the most common indication for exhumation is primary suspicion of homicide (302 IPC), which is similar to studies conducted in Germany over 155 cases of exhumation in 30 years.[15] The other indications for exhumation in their study were (a) primary suspicion of intoxication, (b) possible medical malpractice, (c) accidents, including traffic accidents, and (d) clarification of cause of death, circumstances, or identity. In another study, the primary reason for exhumation was related to the grading and effects of pneumoconiosis in connection with the cause of death.[16]

Time Interval Between Interment and Exhumation

The interval between time of interment and exhumation in our study ranged from 3 days to 4 months, whereas in other studies it ranged from 5 days to 20.5 years.[8–15] The data shows a clear relationship between the time elapsed between burial and exhumation and the condition of the body. This trend indicates that as the time since burial increases, the degree of decomposition becomes more pronounced, with bodies transitioning from early decomposition to skeletonization and adipocere formation. These findings were similar to the study conducted by Stachetzki et al. and Karger et al.[15,16]

Depth of Burial Site and State of Bodily Remains

The percentage of cases with early decomposition changes reduced from 55.6% in burial sites less than four feet to 22.7% in burial sites with depth between four and eight feet, to zero in cases of burial sites with more than eight feet. The relationship between the depth of burial and the state of decomposition also shows that shallower graves (<4 feet) tended to exhibit more early decomposition, while deeper graves (>4 feet) showed more advanced stages of decomposition, including skeletonization and adipocere formation, though the data set is too small for statistical significance.

Cause of Death and State of the Dead Body at Exhumation

In our study we were able to determine the cause of death 14 cases out of 20 cases (70%) whereas it varied in other studies by Grellner and Glenewinkel (78%),[10] Karger et al. (63%),[15] Gitanjali (42.10%),[8] However, in nearly 30% of cases, the exact cause of death remained uncertain, reflecting the inherent difficulties in post-exhumation forensic analysis, especially in environments where forensic infrastructure may be limited.

Determination of Cause of Death

The determination of the cause of death relied on detailed autopsy procedures, which included external and internal examinations, as well as supplementary investigative methods.

- External Examinations: These focused on identifying visible injuries, such as abrasions, ligature marks, and other signs of trauma. For suspected strangulation, key findings included neck abrasions, fractures of the hyoid bone, and damage to the thyroid cartilage.
- Internal Examinations: The internal assessment involved analyzing the cranial, thoracic, and abdominal cavities to identify trauma or hemorrhages indicative of blunt force injuries.
- Smothering Cases: In smothering cases, specific autopsy findings, such as tears in the frenulum, contusions on the buccal mucosa, or fractured teeth, were critical. Adhesive tape or cloth found over the mouth or nose provided circumstantial evidence. Toxicological analysis was used to exclude other causes of death, and the absence of systemic findings further supported the diagnosis.
- Ancillary Investigations: Histopathological examination of tissues revealed microscopic evidence of trauma or pathological changes. Toxicological analysis of viscera provided key findings in poisoning cases. Diatom analysis was particularly useful in drowning cases, confirming the presence of aquatic organisms consistent with drowning environments.
- Integration of Findings: The combined use of autopsy findings, ancillary tests, investigative reports, and circumstantial evidence was vital for establishing the cause of death. This comprehensive approach was particularly crucial in advanced decomposition and skeletonization cases, where traditional autopsy techniques often faced limitations.

The present study determined that mechanical asphyxia (smothering–two cases, ligature strangulation–three cases, manual strangulation–one case) was determined as the cause of death based on the external visible injuries, presence of ligature material around the neck, presence of adhesive tape

around the mouth and nostrils, along with internal frenulum tears and rib fractures in these cases. The details of these findings were described against each case in Table 1. Also in the present study, the cause of death was attributed to cranio-cerebral trauma (five cases), thoracic traumatic injuries (one case), and spinal cord transection (one case) based on the external and internal injuries, which were described against respective cases in Table 1. A single case of poisoning was determined based on the hospital investigations during antemortem stay and toxicological analysis of viscera.

Table 1. Exhumation Cases with Autopsy Findings.

Age and Sex	Autopsy Findings Based on Which Cause of Death was Determined	Alleged Allegation	Traditional/ Clandestine Burial	Investigation	Cause of Death	Time Interval Between Burial and Exhumation	State of Body
21/M	Multiple linear abrasions on both sides of the neck, along with an inward fracture of the hyoid bone	The victim was assaulted and buried by a group of known friends	A clandestine burial to hide the crime at a graveyard	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Asphyxia due to manual strangulation	5 days	Early decomposition changes (rigor mortis and post-mortem lividity disappeared, marbling, and greenish discoloration of skin at places)
40/M	Comminuted fracture and diastatic fracture of the frontoparietal bone	Victim assaulted and buried by an intimate partner (to whom the victim is not legally married)	A clandestine burial to hide the crime at a graveyard	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Cranio-cerebral injuries sustained	6 days	Early decomposition changes (rigor mortis and post-mortem lividity disappeared, marbling, and greenish discoloration of skin at places)
28/F	Based on the hospital investigations during antemortem stay and the toxicological analysis of the viscera	The body was buried without informing the investigating officer in a medicolegal case	Traditional burial in a graveyard with no coffin box	Section 174 subsection (iii) (investigation of unnatural death) of the Criminal Procedure Code, Section 176 (omission to give notice or information to a public servant by someone who is legally required to do so) of the Indian Penal Code	Organophosphorus Poisoning	7–8 days	Advanced decomposition changes (skin slippage, scalp hair, and nails pluckable, distended, decolored, and disfigured body parts)
25/M	No external and internal significant findings were noted, as the body showed advanced decomposition changes	A mentally challenged victim was assaulted by her stepmother and biological father and buried	Clandestine burial to hide the crime at an agricultural sugarcane farm land	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Cause of death could not be ascertained due to advanced decomposition changes	7–8 days	Advanced decomposition changes (skin slippage, scalp hair, and nails pluckable, distended, decolored, and disfigured body parts)

(Table 1 continued)

(Table 1 continued)

Age and Sex	Autopsy Findings Based on Which Cause of Death was Determined	Alleged Allegation	Traditional/ Clandestine Burial	Investigation	Cause of Death	Time Interval Between Burial and Exhumation	State of Body
32/M	Partially skeletonized body with a diatom of a similar species found in a drowned water body	The victim was made to take alcohol and drowned by his friend	Clandestine burial, the body was recovered from a seashore close to a wall made of hollow bricks	Section 174 subsection (iii) (investigation of unnatural death) of the Criminal Procedure Code, 302 (homicide amounting to murder) of the Indian Penal Code	Death due to drowning cannot be ruled out	30 days	Partially skeletonized body
48/F	Fracture over the skull with multiple lacerations and contusions over the scalp	The victim was assaulted and buried by a gang of friends	Clandestine burial to hide the crime at the banks of a dried river bed	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Cranio-cerebral damage consequent to blunt force trauma to the head	14 days	Partially skeletonized body
70/M	Neck muscle contusion, Fracture of thyroid and hyoid bone noted	The victim was kidnapped, strangled for monetary extortion, and buried by a gang of friends	A clandestine burial to hide the crime at the riverbed	Section 365 (kidnapping or abduction of a person with the intention of secretly and wrongfully confining them), Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Asphyxia due to ligature strangulation	56 days	The body with adipocere formation was buried near the riverbed
34/F	No significant external and internal findings. Toxicological analysis of the viscera is negative	The patient had abdominal pain and was admitted to the hospital, where they died. Relatives alleged medical negligence after the burial of the body	Traditional burial. The body was wrapped in a white cloth and buried inside a porous wooden box in a graveyard	Section 174 subsection (i) (investigation of suspicious death) of the Criminal Procedure Code, Section 304A of the Indian Penal Code	Cause of death could not be ascertained due to advanced decomposition changes	14 days	Early decomposition changes (rigor mortis and post-mortem lividity disappeared, marbling, and greenish discoloration of skin at places)
19/F	Ligature material was present, entangled around the neck tissue and scalp hair by a knot, along with complete skeletonization of limbs	The victim was strangled and buried by her group of friends	A clandestine burial to hide the crime at the riverbed	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Asphyxia due to ligature strangulation cannot be ruled out	63 days	The body was completely skeletonized

(Table 1 continued)

(Table 1 continued)

Age and Sex	Autopsy Findings Based on Which Cause of Death was Determined	Alleged Allegation	Traditional/ Clandestine Burial	Investigation	Cause of Death	Time Interval Between Burial and Exhumation	State of Body
27/M	Naked body with mouth and nose closed with adhesive tape, with an internal femoral tear, and multiple rib fractures on both sides	The victim was kidnapped, assaulted for monetary extortion, and buried by a group of his friends	Clandestine burial to hide the crime at a dried river bed	Section 365 (kidnapping or abduction of a person with the intention of secretly and wrongfully confining them), Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Asphyxia due to Smothering and Traumatic asphyxia	4 days	Early decomposition changes (rigor mortis and post-mortem lividity disappeared, marbling, and greenish discoloration of skin at places)
55/M	Naked body with mouth and nose closed with adhesive tape and cloth. Multiple contusions over the buccal mucosa of the inner lip with a fracture of a tooth	The victim was smothered by a friend in an interpersonal clash	Clandestine burial to hide the crime in agricultural land	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Asphyxia due to smothering cannot be ruled out.	20 days	Advanced decomposition changes (skin slippage, scalp hair, and nails pluckable, distended, decolored, disfigured body
43/F	First and second cervical bone fracture dislocation	The victim was assaulted and buried by the son due to a property dispute	Clandestine grave burial to hide the crime in crevices between rocks	Section 302 (homicide amounting to murder) of the Indian Penal Code	Transection of the spinal cord.	8 days	The body was partially skeletonized
30/F	No significant external and internal findings, as the body was completely skeletonized	The victim was killed by an intimate partner to whom she was not legally married (adultery)	Clandestine grave burial to hide the crime in the rocky cave	Section 302 (homicide amounting to murder) of the Indian Penal Code	Death could not be ascertained due to the advanced stage of putrefaction	128 days	The body was completely skeletonized
45/M	Oblique, incomplete ligature mark above the thyroid cartilage in the neck	The victim committed suicide by hanging, and relatives buried the body without notifying the wife or the investigating officer. Wife later intimated to the police and initiated an investigation, as she was suspicious of relatives	Traditional burial with a wooden coffin box at a graveyard	Section 174 subsection (i) (investigation of suspicious death) of the Criminal Procedure Code,	Asphyxia due to hanging	20 days	Early decomposition changes (rigor mortis and post-mortem lividity disappeared, marbling, and greenish discoloration of skin at places)

(Table 1 continued)

(Table 1 continued)

Age and Sex	Autopsy Findings Based on Which Cause of Death was Determined	Alleged Allegation	Traditional/ Clandestine Burial	Investigation	Cause of Death	Time Interval Between Burial and Exhumation	State of Body
5/F	Contusion in the right cheek and Fracture in the maxillary bone extending to the middle cranial fossa	The victim was assaulted and buried by neighbors	Clandestine burial to hide the crime at agricultural farm land	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Cranio-cerebral injuries sustained	7 days	Advanced decomposition changes (skin slippage, scalp hair, and nails pluckable, distended, decolored, disfigured body
13/M	The body was found with Ligature material entangled with a fixed knot around the neck, along with a thyroid bone fracture, and with partial skeletonization of body parts	The victim was strangulated and buried by a friend	A clandestine burial to hide the crime at the graveyard	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Asphyxia due to ligature strangulation	12 days	Partially skeletonized body
1month/M	No significant external and internal findings, as the body showed an advanced stage of putrefaction	Mother has buried her three-day-old baby, who died suddenly, without informing the investigating officer	Traditional burial with the body wrapped in white cloth at the graveyard	Section 174 subsection (i) (investigation of suspicious death) of the Criminal Procedure Code,	Death could not be ascertained due to the advanced stage of putrefaction	3 days	Advanced decomposition changes (skin slippage, scalp hair, and nails pluckable, distended, decolored, disfigured body
25/M	Fracture over the skull with multiple blunt force injuries associated with brain hemorrhage	The victim was assaulted by friends and buried due to an interpersonal dispute	Clandestine burial to hide the crime at a dried river bed	Section 201 (man missing), 302 (homicide amounting to murder) of the Indian Penal Code	Cranio-cerebral damage consequent to blunt force trauma to the head and face	3 days	Early decomposition changes (rigor mortis and post-mortem lividity disappeared, marbling, and greenish discoloration of skin at places)
37/M	No significant external and internal findings, as the body was partially skeletonized	The victim was admitted to the hospital by relatives and died due to natural causes. He was buried by relatives without informing his wife (living away). Since my wife had a suspicion, she initiated an investigation	Traditional burial with the body wrapped in white cloth at the graveyard	Section 174 subsection (i) (investigation of suspicious death) of the Criminal Procedure Code,	Death could not be ascertained due to the advanced stage of putrefaction	66 days	Partially skeletonized body

(Table 1 continued)

(Table 1 continued)

Age and Sex	Autopsy Findings Based on Which Cause of Death was Determined	Alleged Allegation	Traditional/ Clandestine Burial	Investigation	Cause of Death	Time Interval Between Burial and Exhumation	State of Body
70/M	Fracture over the skull with multiple blunt force injuries associated with brain hemorrhage	The victim was hit by the accused, driving his vehicle negligently, and the accused buried the victim	A clandestine burial to hide the crime in a graveyard	Section 201 (man missing), 304 (A), (causing death due to negligent act)	Cranio-cerebral damage consequent to blunt force trauma to the head	10 days	Early decomposition changes (rigor mortis and post-mortem lividity disappeared, marbling, and greenish discoloration of skin at places)

Table 2. Time Interval Between Burial and Exhumation Compared with the State of the Body.

Time Interval Between Burial and Exhumation	No. of Cases	State of the Dead Body				
		Early Decomposition Changes	Advanced Stage of Putrefaction	Partial Skeletonized	Complete Skeletonized	Adipocere Formation
≤1 Week	08	04	04	–	–	–
1 week–≤4 weeks	07	03	01	03	–	–
>1 month	05	–	–	02	02	01
Total	20	07	05	05	02	01

Table 3. Depth of Burial Site Compared with the State of the Dead Body.

Depth of the Burial Site	No. of Cases	State of the Dead Body				
		Early Decomposition Changes	Advanced Stage of Putrefaction	Partial Skeletonized	Complete Skeletonized	Adipocere Formation
<4 feet	09	5	1	1	1	1
4 feet–<8 feet	09	2	3	3	1	–
>8 feet	02	–	1	1	–	–
Total	20	7	5	5	2	1

Conclusion

This 20-year retrospective study of exhumation cases highlights the critical role exhumations play in forensic investigations, particularly in cases of unnatural deaths such as homicides and suspicious deaths. The findings emphasize the significant impact of environmental factors, burial depth, and the duration of burial on the state of the body, which directly affects the ability to determine the cause of death. Early exhumations often provided more useful forensic evidence, while advanced decomposition and skeletonization presented greater challenges in determining the cause of death. Ultimately, while exhumation presents various difficulties, it continues to offer families closure and provides essential evidence in legal and medicolegal contexts. Future improvements in forensic technology and protocols could enhance the accuracy and success of exhumation-based investigations, especially in cases with prolonged burial intervals.

Authors' Contribution

All authors contributed equally to the preparation of this article.

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

All the data gathered from the exhumation and postmortem documents. Confidentiality of the deceased was maintained throughout this study at various stages. Ethical approval from the Institutional Ethical Committee was obtained.

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Informed Consent

As this is a retrospective, record based study, and all the identifiable information have been de-linked from the study data, we requested and obtained a wavier of informed consent for this study.

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Exploring Digit Lengths and Ratios in Haryanvi Population to Unravelling Sexual Dimorphism: A Pilot Study

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Abstract

Sexual dimorphism is crucial in forensic anthropology, differentiating between males and females. The potential role of digit ratios, especially 2D:4D, has been proposed in predicting sexual dimorphism due to hormonal influences during fetal development, but many studies also contradict its universal acceptability. This study aims to find the reliability of both digit lengths and ratios in sex estimation in the Haryanvi population. The digit lengths of 215 participants (M = 113; F = 102) aged 18–50 years were measured using a digital vernier calliper, and digit ratios were calculated using it. Significant sexual dimorphism was found in digit length, but digit ratios demonstrated relatively poor results. The single best variable for percentage sexing accuracy in digit lengths was found for 2DL(L) (79.5%), and the best combination was given by 2DL(L), 1DL(L), and 4DL(L) (83.7%). However, none of the ratios showed good classification accuracy for sex estimation for this population. The research underscores the need for caution in relying solely on digit ratios for sex estimation in forensic investigations. Instead, a multifactorial approach considering ethnic diversity should be used. The findings contribute to the discussion regarding the reliability of digit ratios as a universal indicator of sexual dimorphism.

Keywords

Digit ratio, forensic anthropology, sex estimation, sexual dimorphism

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Introduction

Sexual dimorphism, the differentiation of male and female physical characteristics, has been of interest in forensic anthropology.[1] Several fields, such as forensic investigation, medical diagnosis, and genetic studies, can benefit from the use of biological markers to determine gender.[2] The digit ratio (2D:4D) refers to the relative lengths of the index (2nd digit) and ring (4th digit) fingers, typically measured from the bottom crease where the finger joins the hand to the tip. This ratio is believed to exhibit sexual dimorphism in humans, with males generally having a lower 2D:4D digit ratio than females; that is, in men, the ring finger is typically longer relative to the index finger compared to women.[3] This characteristic is believed to be established due to distinct exposures to sex hormones during early development.[4] But lately, many studies have been done in various regions of the world stating that digit ratio, particularly 2D:4D, is an inappropriate universal forensic marker to check sexual dimorphism in the population.[5–8] Mclyntyre and associates (2005) observed that 2D:4D decreased between ages 6 and 8 in a longitudinal sample and was a far more inconsistent sexually dimorphic indicator than 3D:4D among ethnic groups, indicating that 3D:4D could serve as a better predictor of prenatal sex differences.[9] The sexual dimorphic trait of the finger ratios is governed by HOX genes and influenced by oestrogen and testosterone concentrations in utero.[3,10–12] HOX genes are a family of genes that play a crucial role in development and are responsible for the regulation of the body plan during embryonic development. determining the anterior-posterior (head-tail) patterning of the developing embryo, segmentation identity and developmental timing in the embryo.[13]

Therefore, the inspiration for this study came from these two facts: First, the high popularity of the digit ratio for sex determination[6,14–17] and second, the recently strengthened

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opposition to the use of these digit ratios as sexual dimorphic markers.[3,5,10,18–20]

Hence, this study aims to explore the forensic applicability of digit lengths and ratios as sexually dimorphic indicators in the Haryanvi population, potentially highlighting variations across ethnic groups and contributing to the broader literature on digit ratios, addressing the uncertainties surrounding their reliability and validity among different populations.

Materials and Methods

Participants

This study was a cross-sectional study conducted in the Haryana state of India. 215 individuals (113 males and 102 females) were randomly selected for the study within the age range of 18–50 years, and informed consent was taken from each individual. Participants with any deformity in the hand, disease or injury were excluded from the research study.

Procedure

The measurements of the left and right hands were taken by the first author. The palms of the participants' hands were made to face upward on a horizontal flat surface, and the forearms were aligned with the middle finger. Fingers should be maximally extended and close together (Figure 1). Digit length is defined as the measure of the distance between the finger's respective tip and the proximal flexion crease.[14] Using Weiner and Lourie's[21] standardised technique, the participant's digit length was measured (in mm) directly using a standard digital vernier calliper (least count of 0.01 mm) on both hands. Sex, age, and height were also recorded for each individual.

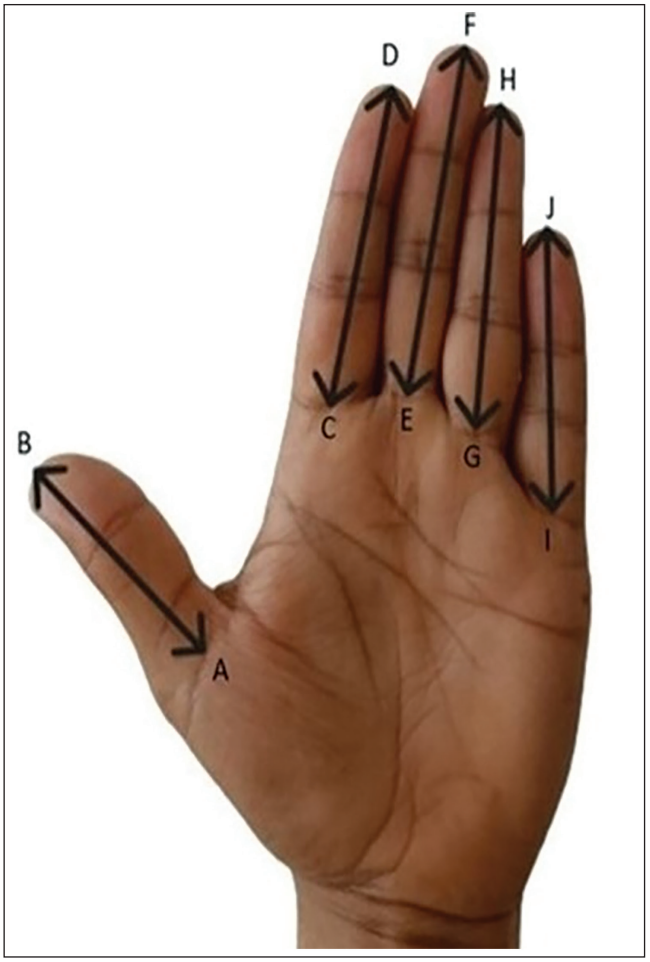

Figure 1. Length of Thumb 1D (A to B); Length of Index Finger 2D (C to D); Length of Middle Finger 3D (E to F); Length of Ring Finger 4D (G to H); Length of Little Finger 5D (I to J).

Measures

Morphometric Measurements

The measurements recorded were:

1. Thumb length (1DL): It is the distance between the tip of the thumb and the palm's border crease (A to B).
2. Index finger length (2DL): It is the distance between the tip of the index finger and the palm's border crease (C to D).
3. Middle finger length (3DL): It is the distance between the tip of the middle finger and the palm's border crease (E to F).
4. Ring finger length (4DL): It is the distance between the tip of the ring finger and the palm's border crease (G to H).
5. Little finger length (5DL): It is the distance between the tip of the ring finger and the palm's border crease (I to J).

Digit Ratio

This ratio was calculated by taking the ratio of the length of the fingers.

Sectioning Point

It is defined as the average of the respective digit ratio for both left and right hands for both sexes. Based on this sectioning point for the digit ratios, the percentage accuracy for sex determination was determined on the study population.

Cohen's d Value

It is to calculate the effect size of two independent populations by subtracting the means of the populations and dividing by the pooled standard deviation. In the context of sexual dimorphism in digit ratios, Cohen's d can be used to quantify the difference in digit ratios.[22]

Formula for Cohen's d:

$$d = \frac{M_2 - M_1}{\sqrt{\frac{SD_1^2 + SD_2^2}{2}}}$$

Where, M_1 = Mean (Group 1); M_2 = Mean (Group 2); SD_1 = Pooled standard deviation (Group 1); SD_2 = Pooled standard deviation (Group 2); Interpreting Cohen's d: Small effect size = 0.2; Medium effect size = 0.5; Large effect size = ≥0.8.[23]

Statistical Analysis

For statistical analysis of the data, SPSS 21.00 was used. Descriptive statistics for 2D and 4D lengths were calculated. Student's *t*-test was used for studying male-female differences for the variables (at $p < .05$). Discriminant analysis for percentage classification accuracy was also performed.

Results

Digit Length

The descriptive statistics for all the digit lengths of both hands for the entire population are represented in Table 1. The differences between the mean digit lengths were found to be statistically larger in males ($p < .001$). Except for 1DL being larger on the right side in females, all left-side digit lengths were larger in both sexes. The digit length in both sexes and in respective hands followed the order:

3D>4DL>2DL>1DL>5DL

The discriminant function analysis for the digit lengths to calculate classification accuracies and Cohen's d value to study effect size is reported in Table 2. Maximum sexing accuracy for the left and right hands was shown by 2DL and 1DL, respectively. 3DL (left) and 1DL (right) variables showed the highest Cohen's d value. Therefore, for the right hand, variable 1DL excelled in both accuracy and Cohen's d value. But left-hand values differ, as the Cohen's d value focuses on the magnitude of the difference between group means, whereas classification accuracy does not consider the size of the effect but rather the overall correctness of predictions. Therefore, considering both the methods, variables 1DL and 3DL performed well to study correctness in predictions and differences between groups.

The stepwise discriminant function analysis is tabulated in Table 3. In stepwise analysis, 3DL and 1DL (F1) together classified sex up to 80.9% accuracy. 2DL(L) (F2) performed best in direct analysis with 79.5% accuracy. Better accuracy was given by 2DL(L) and 1DL(L) (F3), with 82.8% and finally, in F4, adding 4DL(L) with F3 showed the best accuracy of 83.7%. But a combination of all variables did not perform better than F3 and F4, suggesting F4 as the best combination for sex estimation.

Digit Ratio

Table 4 represents descriptive statistics, the standard deviation of all the digit ratios derived from the digit lengths, percentage classification accuracies and Cohen's d value for both hands and for both sexes. The digit ratios showing significant sexual dimorphism are 1D:2D L, 1D:2D R, 1D:3D L, 1D:3D R, 1D:4D L, 1D:4D R, 1D:5D L, 1D:5D R, 2D:1D L, 2D:1D R, 3D:1D L, 3D:1D R, 4D:1D L, 4D:1D R, 5D:1D L, and 5D:1D R, with the highest being 1D:2D R with 61.9%. But none of the digit ratios showed good classification accuracy, which can be used for sex estimation for this population. All the ratios also showed low values of magnitude to study the effect size. In addition to this, the sex-wise distribution based on the 2D:4D digit ratio of the participants is depicted in Figures 2 and 3.

Table 5 represents the descriptive statistics and Cohen's d values of adult males and females in six population groups. In the present population, minimal sex differences were observed, similar to Manning et al. and Apicella et al.[8–19] Contrarily, Dey and Kapoor (2016) reported sex classification in the range of 84%–93% using digit ratios and a considerable sex effect size (d= −1.81).[14] Kanchan et al. also found

Table 1. Descriptive Statistics of Digit Lengths (in mm) Among Males and Females of the Haryanvi Population.

Males (*n* = 113)										
	Left Hand					**Right Hand**				
Variables (mm)	**1DL**	**2DL**	**3DL**	**4DL**	**5DL**	**1DL**	**2DL**	**3DL**	**4DL**	**5DL**
Mean	65.91*	74.38*	82.11*	76.14*	61.53*	65.70*	73.93*	81.52*	75.86*	61.10*
SD	4.31	4.40	4.74	4.65	4.20	4.44	4.34	4.51	4.26	4.41
Females (n = 102)										
Mean	58.97*	68.48*	75.32*	70.22*	56.53*	59.14*	67.95*	74.54*	69.82*	56.05*
SD	4.41	3.39	4.01	4.10	3.21	3.87	3.47	3.55	4.07	3.22

Notes: *n* = No. of samples, 1DL = Thumb digit length; 2DL = Index digit length; 3DL = Middle digit length; 4DL = Ring digit length; 5DL = Little digit length; *SD* = Standard deviation.
*p value < .001

Table 2. Percentage of Correct Classifications for the Discriminant Functions of Different Hand Variables for the Left and Right Hand and Cohen's d Value.

	Left				Right			
Variables	**Males %**	**Females %**	**Average Accuracy %**	**Cohen's d Value**	**Males %**	**Females %**	**Average Accuracy %**	**Cohen's d Value**
1DL	77.9	79.4	78.6	1.58	78.8	80.4	79.5	1.59
2DL	76.1	83.3	79.5	1.52	71.7	77.5	74.4	1.50
3DL	80.5	77.5	79.1	1.72	77.9	79.4	78.6	1.55
4DL	63.7	77.5	70.2	1.45	73.5	79.4	76.3	1.35
5DL	70.8	80.4	75.3	1.31	73.5	77.5	75.3	1.33

Table 3. Standardised and Unstandardised Discriminant Function Coefficients, Structure Matrix, and Sectioning Points in (Stepwise Discriminant Analysis) Original Samples.

Functions and Variables	**Raw Coefficients**	**Standardised Coefficient**	**Structure Coefficient**	**Centroids**	**Sectioning Points**	**Average Accuracy**	
						O	**C**
Stepwise Analysis							
F1 3DL(R)	0.116	0.637	0.903	M = 0.898	−0.0485	80.9	80.9
1DL(L)	0.156	0.506	0.84	F = −0.995			
(constant)	−19.459						
Direct Analysis							
F2 2DL(L)	0.253	1	1	M = 0.707		79.5	79.1
(constant)	−18.08			F = −0.783			
F3 2DL(L)	0.124	0.493	0.916	M = 0.825		82.8	81.4
1DL(L)	0.145	0.631	0.857	F = −0.914			
(constant)	−17.973						
F4 2DL(L)	0.098	0.387	0.913	M = 0.827		83.7	82.8
1DL(L)	0.142	0.620	0.854	F = −0.916			
4DL(L)	0.031	0.134	0.771				
(constant)	−18.139						
All variables	–	–	–	–	–	80.5	76.7

pronounced sex differences and high effect sizes.[15] Whereas Marczak et al. (2017) in their study found varying statistical differences between sexes for digit ratios and the effect sizes.[20] The findings collectively underscore the complexity and variability of the digit ratios across various populations and the importance of considering both mean group size and effect size for analysis.

Discussion

In forensic investigations, the most important task of the investigator is the identification of the body. There are several cases where mutilated bodies are found, and biological profiling has to be done. For this purpose, sex estimation plays a pivotal role, being one of the 'big four' of anthropology.[24] Hence, the present study also aims to estimate the sexing accuracy for digit lengths and ratios.

The digit lengths performed better than the digit ratios in the present study. Several kinds of research have been done lately to find which hand dimensions perform better for sex estimation. Hafez and Shahin (2020) found that hand dimensions could predict sex with better accuracy than using digit ratios in the Egyptian and Malaysian populations.[25] Similar results, where the performance of digit lengths was more accurate than the ratios, were encountered by Banyeh et al. (2022) and partially by Sarkodie et al. (2023).[26,27] The possible reason for the sexing accuracy of the digit ratio performing extremely poorly could be that small sexual dimorphism in one variable and correspondingly greater sexual dimorphism in the second variable may have higher prediction accuracies of the ratios. Contrarily, equal values of sexual dimorphism in both values of the ratio would result in ineffective sex estimation and therefore imply that it should not be used for the predictions.

One of the digit ratios, 2D:4D ratio, is considered by a few researchers to be sexually dimorphic. Few studies favoured the use of 2D:4D ratio as a forensic marker for sexual dimorphism,[6,14–17] while others (including the present study) contradicted the use of this indicator.[3,5,10,18–20] The interpretations are done from Cohen's d effect size values instead of *p* values (Table 5).

Table 4. Descriptive Statistics of all the Digit Ratios Among Males and Females of the Haryanvi Population, Their Percentage Classification Accuracy and Cohen's d Value.

Variable		Male Mean (n = 113)	Female Mean (n = 102)	p Value	% Classification Accuracy	Cohen's d Value
1D:2D	L	0.8869 ± 0.045	0.8618 ± 0.059	.001*	58.1	0.48
	R	0.8895 ± 0.049	0.8706 ± 0.042	.003*	61.9	0.41
1D:3D	L	0.8036 ± 0.047	0.7838 ± 0.054	.005*	54.9	0.39
	R	0.8067 ± 0.046	0.7940 ± 0.048	.049*	56.3	0.27
1D:4D	L	0.8667 ± 0.0478	0.8412 ± 0.062	.001*	56.3	0.46
	R	0.8669 ± 0.050	0.8482 ± 0.051	.007*	56.3	0.37
1D:5D	L	1.0730 ± 0.0611	1.0449 ± 0.077	.003*	55.3	0.40
	R	1.0778 ± 0.069	1.0568 ± 0.069	.027*	55.3	0.30
2D:1D	L	1.1304 ± 0.057	1.1660 ± 0.084	.000*	58.1	0.06
	R	1.1276 ± 0.063	1.1513 ± 0.057	.004*	60.5	0.39
2D:3D	L	0.9064 ± 0.033	0.9098 ± 0.027	.401	54.0	0.11
	R	0.9072 ± 0.030	0.9120 ± 0.032	.267	52.1	0.15
2D:4D	L	0.9776 ± 0.035	0.9762 ± 0.033	.769	48.4	0.04
	R	0.9751 ± 0.036	0.9746 ± 0.046	.928	52.1	0.01
2D:5D	L	1.2108 ± 0.056	1.2129 ± 0.049	.765	50.7	0.04
	R	1.2123 ± 0.058	1.2141 ± 0.060	.823	53.5	0.03
3D:1D	L	1.2485 ± 0.072	1.2821 ± 0.092	.003*	54.9	0.41
	R	1.2437 ± 0.072	1.2639 ± 0.075	.046*	55.3	0.27
3D:2D	L	1.1047 ± 0.038	1.1001 ± 0.033	.348	54.4	0.13
	R	1.1034 ± 0.037	1.0978 ± 0.036	.256	53.0	0.15
3D:4D	L	1.0790 ± 0.032	1.0733 ± 0.031	.178	53.5	0.18
	R	1.0751 ± 0.030	1.0688 ± 0.036	.165	52.6	0.19
3D:5D	L	1.3370 ± 0.067	1.3338 ± 0.056	.709	55.8	0.05
	R	1.3371 ± 0.065	1.3319 ± 0.061	.547	50.7	0.08
4D:1D	L	1.1574 ± 0.065	1.1955 ± 0.092	.000*	57.7	0.48
	R	1.1573 ± 0.067	1.1833 ± 0.072	.007*	56.3	0.37
4D:2D	L	1.0242 ± 0.037	1.0255 ± 0.035	.787	48.8	0.04
	R	1.0269 ± 0.038	1.0281 ± 0.045	.831	53.0	0.03
4D:3D	L	0.9275 ± 0.028	0.9325 ± 0.027	.188	53.0	0.18
	R	0.9309 ± 0.026	0.93676 ± 0.031	.136	52.6	0.20
4D:5D	L	1.2389 ± 0.048	1.2429 ± 0.044	.520	50.7	0.09
	R	1.2439 ± 0.054	1.2472 ± 0.062	.681	53.0	0.06
5D:1D	L	0.9349 ± 0.054	0.9625 ± 0.075	.002*	54.9	0.42
	R	0.9316 ± 0.061	0.9502 ± 0.061	.027*	55.8	0.30
5D:2D	L	0.8258 ± 0.033	0.8258 ± 0.033	.705	50.2	0
	R	0.8267 ± 0.039	0.8255 ± 0.039	.827	54.4	0.03
5D:3D	L	0.7499 ± 0.038	0.7510 ± 0.031	.807	56.3	0.03
	R	0.7496 ± 0.036	0.7523 ± 0.034	.574	50.7	0.08
5D:4D	L	0.8083 ± 0.301	0.8055 ± 0.028	.489	51.2	0.01
	R	0.8054 ± 0.035	0.8038 ± 0.041	.760	53.5	0.04

Note: If the p-value < 0.05, then statistical differences are present; hence, these "*" marked values show significant sexual dimorphism.

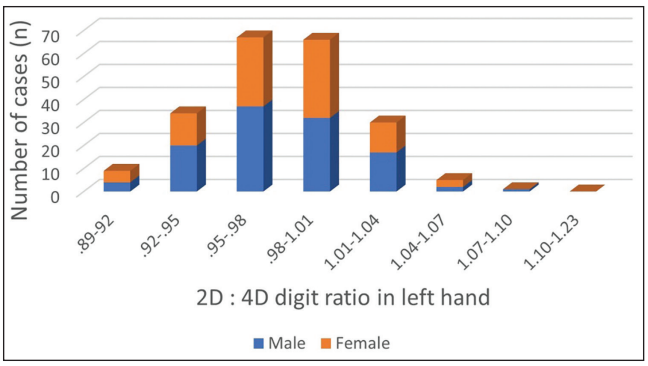

Figure 2. Left-hand 2D:4D Digit Ratio Distribution of Participants Across Sexes.

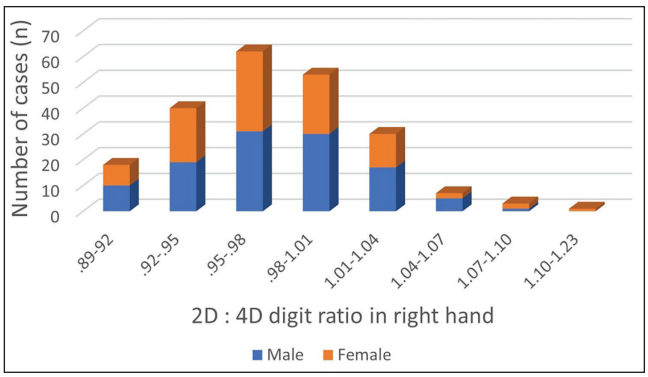

Figure 3. Right-hand 2D:4D Digit Ratio Distribution of Participants Across Sexes.

Table 5. Descriptive Statistics, Cohen's d Effect Size and Mean Group Difference of 2D:4D Digit Ratio in Different Population Groups.

		Male			Female				
Study	**Hand**	***n***	**Mean**	***SD***	***n***	**Mean**	***SD***	**D**	**Mean Group Difference**
Present study, Haryana, India	Left	113	0.9776	0.035	102	0.9762	0.033	0.04	0.0014
	Right		0.9751	0.036		0.9746	0.046	0.04	0.0005
Kanchan et al.,[15] India	Left	150	0.9546	0.021	150	0.9904	0.023	−1.63	0.0358
	Right		0.9557	0.022		0.9867	0.025	−1.32	0.031
Dey & Kapoor,[14] New Delhi, India	Left	141	0.9689	0.026	159	1.0142	0.030	−1.62	0.0453
	Right		0.9678	0.022		1.0145	0.029	−1.81	0.0467
Manning et al.,[18] India, English and S.Africa	Mean	80	0.96	0.04	80	0.97	0.04	−0.38	0.01
Marczak et al.,[20] Papua	Left	47	0.97	0.067	32	0.95	0.047	0.34	0.02
	Right		0.95	0.047		0.94	0.039	0.23	0.01
Apicella et al.,[19] Hadza	Left	116	0.983	0.04	133	0.988	0.05	−0.11	0.005
	Right		0.984	0.04		0.975	0.04	0.23	0.009

Note: *n* = No. of samples, *SD* = Standard deviation, d = Cohen's d effect size.

In previous studies, Kanchan et al.[15] and Dey and Kapoor[14] found large group differences in the means of 2D:4D between sexes and a low standard deviation, whereas other studies (including the present study) showed very low values of group differences and larger *SD*, suggesting no overlap.[18–20] When the mean group difference is large, and *SD* is low, higher values of d are obtained, and vice versa yield lower values of d. On comparing Cohen's d value for group comparisons, the values between 0 and 0.20, around 0.50, and around 0.80 or larger show small, medium, and large effects, respectively. This fairly shows the reason why the values obtained by these two studies[14,15] show a larger size effect, and the other four studies[18–20] show a small or negligible effect.

In the present study, the sex differences in 2D:4D hover around 0.5 d values corresponding to a small to medium-sized sex effect, suggesting distributional nonoverlap of 2D:4D between sexes, resulting in poor performance of the 2D:4D digit ratio. Moreover, the digit ratios on the left and right hands were not sexually dimorphic in the Haryanvi population and did not depict the typical human digit formula where 2D>4D.[14] The exact reasons for this anomalous trend cannot be pinpointed; it could be due to a large sample size (low standard deviation), overlap between sexes, within sex variability due to age,[28] ethnicity, hormonal fluctuations,[29] postnatal factor influences,[30] different methodology of measurement, etc.[6]

Voracek employed logistic regression analysis and the receiver operating characteristic (ROC) technique in an Austrian population; however, neither produced striking findings.[5] This study was conducted using discriminant function analysis and Cohen's d value, which produced unsatisfactory findings and further contradicted the use of digit ratios for sex determination. In an Austrian population, Voracek used logistic regression analysis and the ROC approach, but could not obtain impressive results either (Voracek, 2009). This study was done based on discriminant function analysis and Cohen's d value, yielding unsatisfactory results, which further contradicts the use of digit ratios for sex determination.

There are several reasons why this may not be an appropriate method for sex determination in medico-legal investigations. First, the method for measuring digit ratio is not standardised and can vary substantially among researchers,

impacting the precision of sex determination. Second, while there is a correlation between digit ratio and gender, there is a substantial overlap between male and female ratios. This indicates that a substantial proportion of individuals may be misclassified if the digit ratio is used as a sex indicator. In addition, the digit ratio can be affected by a variety of factors, such as race, age, and hormonal imbalances. In some cases, conditions such as polycystic ovary syndrome can alter the digit ratio, resulting in masculinisation of the female digit ratio.[31] Considering these concerns, it is evident that the digit ratio alone should not be used as a sex determination indicator in medico-legal investigations; rather, other established methods, such as digit lengths, morphological examination and DNA analysis, can be used.[5,32,33]

Conclusion

Digit lengths can serve as a tool for individual sexing with reasonable accuracy in the Haryanvi population, but understanding the discrepancies of using digit ratios for sex determination is pivotal in forensic investigation. The digit lengths over the ratios predicted better, as evident from our study. While the method using ratios shows its use due to the hypothesised link to prenatal hormone exposure, its applicability in medico-legal investigations is constrained. Ultimately, the most accurate method for determining sex is likely to be a multifactorial approach that considers a variety of biological and environmental markers.

Declaration of Conflicting Interests

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Ethical Approval

None.

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Informed Consent

The informed consent has been obtained from the participants for the study.

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Postmortem Evaluation of Pattern of Skull Fractures and Its Correlation in Cases of Head Injury at a Tertiary Care Hospital

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Abstract

Head injuries, resulting from mechanical forces impacting the scalp, skull, and brain, are a major cause of morbidity and mortality, particularly in road traffic accidents (RTA). While skull fractures alone may not be fatal, they often lead to significant haemorrhage and brain damage. This study aims to analyse the patterns of head injuries in postmortem cases, focusing on the type, site, and extent of skull fractures, and correlating these with scalp, facial, and brain injuries, especially in RTA cases. A cross-sectional descriptive study was conducted over a span of 12 months at a tertiary healthcare teaching hospital in western India. A total of 350 postmortem cases of fatal head injuries were examined, following ethical approval. Inclusion criteria encompassed individuals who died due to head trauma, while decomposed bodies, natural deaths, and cases with unknown histories were excluded. Data on injury mechanisms, demographics, and postmortem findings, including skull fractures and associated injuries, were collected and analysed using descriptive statistics. Among the 350 cases, 52.57% of skull fractures were linear, 33.71% comminuted, and 21.14% depressed. The most frequent external injuries included scalp lacerations (90.84%) and abrasions (42.25%). RTAs accounted for 40.85% of skull fractures, with a notable incidence in the 21–40 age group (44.86%). Intracranial injuries were common, with subarachnoid haemorrhage (88.29%), cerebral contusion (65.43%), and subdural hematoma (66.29%) as the most prevalent. The presence of skull fractures correlated significantly with both scalp injuries and intracranial haemorrhages. This study reveals that skull fractures, particularly linear and comminuted, are prevalent in fatal head injuries, especially due to RTAs. Significant intracranial damage, such as subarachnoid haemorrhage and cerebral contusion, was frequently observed. The findings emphasise the need for targeted preventive measures and improved management strategies for head trauma, particularly in young adults.

Keywords

Head injury, skull fracture, road traffic accidents, intracranial haemorrhage, forensic autopsy
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Introduction

A head injury occurs when mechanical forces cause significant or minor structural alterations to the scalp, skull, and/or skull contents.[1] Being the most exposed portion of the body, the head is frequently involved in occurrences and plays a significant role in road traffic accident (RTA) morbidity and death.[2] The scalp has a robust blood supply; therefore, injuries can range from minor abrasions to extensive lacerations, frequently resulting in substantial bleeding.[3–5] Linear, compression, or comminuted fractures are the possible forms of skull fractures that can happen at the base or vault of the skull. The classification of these fractures as open or closed depends on the skin's integrity.[3,5] Although single skull fractures seldom result in death or severe morbidity from head injuries, these injuries typically involve haemorrhage and brain tissue damage.[3,4] RTA, fall from height or on level ground, occupational injuries, and assault are the usual causes of trauma with geographical variation. The World Health Organization

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(WHO) predicts that by 2030, RTA will rank as the fifth most common cause of death globally.[6,7] Since the mean age of trauma victims typically falls within the highly productive middle age group, head injuries are especially alarming.[8,9]

In light of this, the purpose of this study was to examine head injury patterns in postmortem cases, with a particular emphasis on the type, site, size, and extension of skull fractures. The study sought to correlate the occurrence and characteristics of skull fractures with associated injuries to the scalp, face, and brain. Additionally, it aimed to explore the circumstances leading to these injuries, particularly in RTA cases, and analyse how these factors relate to the patterns of skull fractures observed.

Methodology

This cross-sectional descriptive study was conducted over a period of 12 months in the Forensic Medicine department at a tertiary care teaching hospital in western India. The consecutive sampling method was deployed for this study, where special emphasis was given to individuals who died from fatal head injuries and were brought for medico-legal autopsies, with a sample size of 350 cases, based on an estimated monthly load of 30–35 cases. Inclusion criteria involved deceased individuals with fatal head injuries, while cases of decomposed bodies, unknown histories, extensive burns, or deaths from natural diseases were excluded. Data collection involved gathering personal details from police inquest papers, hospital records, and interviews with relatives. Information on the head injury, mechanisms like RTA, fall from height, fall of heavy object, assault, railway accident, and the victim's profile in RTA were documented. A detailed postmortem examination was conducted, with a focus on head injuries, including skull fractures and sub-scalp injuries. A standardised proforma was used to collect data on injury characteristics, demographics, and contextual information. Descriptive statistics, such as frequencies, percentages, and distributions, were employed for data analysis, and the findings were compared with existing literature to draw relevant conclusions.

Results

Out of the forensic autopsies conducted during the study period, 350 cases of head injury were analysed. Following noteworthy and pertinent findings from the current study are shown in a table and figure format.

Discussion

As per our observations depicted in Figure 1, males made up 295 cases (84.29%) of the 350 head injury cases because they were more likely to be involved in outdoor activities like driving and working outside, making them more likely to be involved in accidents. In contrast, females made up 52 cases (14.86%), and they died primarily from RTA or unintentional falls at home. The study by Pathak Akhilesh et al. showed a similar outcome, with a 5:1 male-to-female head injury case ratio.[10] According to the study by Sachin Chourasia and Abhijit Rudra, of the 50 cases of traumatic head injury caused by blunt force trauma, 40 (80%) were male, while only 10 (20%) were female. The male victim to female victim ratio in this study was 4:1.[11] Out of 350 cases in the current study, the age group of 21–30 years old had the highest incidence of head injuries, as shown in Figure 2. comprising of 84 cases (24.00%) followed by age group of 31–40 years (21.71%) comprising of 76 cases. The obvious explanation is that people between the ages of 21 and 40 make up most of the workforce and spend most of their time outside due to a variety of work-related, educational, and athletic activities that require frequent travel. As a result, they are more likely to sustain injuries from falls, assaults, and other traffic incidents. Since kids and elderly individuals are typically indoors, which comprises the dependent population of society, the age range of 1–10 and over 80 years had the lowest number of instances. Similar findings were observed in the study by Kamble NP, Chavan GS, and Deokar RB, which found that the frequently affected age range was 21–30 years old (29%), then 31–40 years old (19%).[12] This study contrasted with that of Raja Rupani, Anoop Verma, and Shiuli Rathore (2013), who found that the age group most at risk was 41–50 years old, followed by 11–20 and 21–30 years old.[13]

Table 1 shows the pattern of scalp injury according to the type of injury and site of scalp. Out of 350 cases, 208 cases (59.43%) did not show any kind of external injury to scalp, whereas remaining 142 cases (40.57%) showed presence of

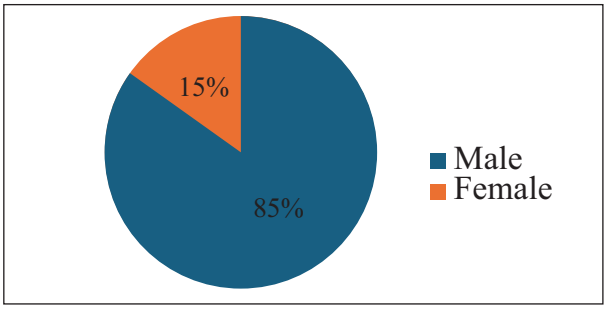

Figure 1. Sex-wise Distribution of Cases.

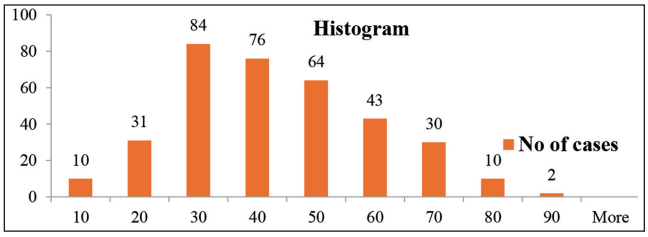

Figure 2. Age-wise Distribution of Cases.

external injury to scalp. In 85 cases (59.85%), the parietal area was where these scalp injuries were most frequently observed, whereas least common site was occipital region in 48 cases (33.80%). Laceration was observed most frequently among all external injury over scalp which was seen in 129 cases (90.84%) with most common site being parietal region in 47 cases (36.43%) and least common site was temporal region in 22 cases (17.05%) followed by abrasion in 60 cases (42.25%), most common site of abrasion was frontal region in 22 cases (36.67%). The least common type of scalp injury was sharp force injuries, that was incised wounds and chop wounds, which accounted for three cases (2.11%) out of 142 cases showing presence of external injury to scalp. There was no case of firearm injury in the study. This study supports the result of a study carried out by Shivendra Jha et al., which showed that the most common type of scalp injury was laceration, which accounts for 46 cases (59.7%) of head injury due to RTA out of a total of 77 cases, followed by contusion, 21 cases (27.3%).[14] Similar trend was seen in a study by S.B. Bhatt, J.A. Tanna, who studied distribution of superficial injuries in vehicular accidents, where laceration was the most common injury over region of head and face in 30 cases (50%), followed by abrasion in 27 cases (45%).[15]

As shown in Table 2, out of 350 cases, only 107 cases (30.57%) did not show presence of any kind of facial injury, whereas remaining 253 cases (69.43%) showed presence of external injury over face. Among these, abrasion was commonest injury type encountered, which accounted for 163 in number (46.57%), then laceration, which accounted for 80 cases (22.86%). There was only one case of an incised wound, and no case of a firearm wound over the face. This study contrasts with the research conducted by Amit Kumar et al., according to which most common type of soft tissue injury over face was laceration, amounting to 79 cases (43.89%) out of 180 fatal accidents sustaining facial injury.[16] As per Table 3, only 22 cases (6.29%) did not show presence of any kind of under scalp injury, whereas remaining 328 cases (93.71%) showed presence of under scalp injury. Among which maximum number of cases were of sub-scalp contusion, which comprises 236 cases (67.43%), whereas least number of cases were of scalp laceration, that is, 53 cases (15.14%). Contusion of temporalis muscle was seen in 92 cases out of 350 (26.29%). According to a study by Sunil Nail, Dr Rupesh Naik, laceration was linked to skull fractures in 60 cases (61.86%) and scalp contusions in 104 cases (1.04%).[17]

Figure 3 shows that out of 350 cases, 53 cases (15.14%) did not show presence of any skull fracture. The maximum number of cases of head injury showed presence of vault fracture in 114 cases (32.57%), followed by combined vault + base fracture in 72 cases (20.57%). The minimum number of cases was of facial fracture in 14 cases (4.0%), followed by combined fracture of facial + base in eight cases (2.29%). A

Table 2. Pattern of Facial Injury According to Type of Injury.

Type of Injury Over Face	No. of Cases (*N* = 350)	%
No injury	107	30.57
Abrasion	163	46.57
Contusion	64	18.29
Laceration	80	22.86
Crush injury	14	4.00
Incised wound	1	0.29
Firearm wound	0	0.00
Surgically sutured wound	28	8.00

Table 3. Pattern of Under-scalp Injury.

	No. of Cases (*n* = 350)	%
No injury	22	6.29
Sub-scalp contusion	236	67.43
Extracranial haematoma	199	56.86
Scalp laceration	53	15.14
Temporalis m/s contusion	92	26.29

Table 1. Pattern of Scalp Injury.

	Site of Injury to the Scalp					
Type of Scalp Injury	Frontal	Parietal	Temporal	Occipital	Total	%
Abrasion	22 (36.67%)	16 (26.67%)	17 (28.33%)	5 (8.33%)	60	42.25
Contusion	4 (15.38%)	9 (34.62%)	7 (26.92%)	6 (23.08%)	26	18.30
Laceration	31 (24.03%)	47 (36.43%)	22 (17.05%)	29 (22.48%)	129	90.84
Crush injury	14 (35%)	12 (30%)	9 (22.5%)	5 (12.5%)	40	28.16
Incised wound	0 (0%)	0 (0%)	1 (33.33%)	2 (66.67%)	3	2.11
Chop wound	1 (33.33%)	1 (33.33%)	0 (0%)	1 (33.33%)	3	2.11
Firearm wound	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0	0
No injury	–	–	–	–	208	59.43
Total	72 (50.70%)	85 (59.85%)	56 (39.43)	48 (33.80)	–	–

similar trend was seen in a study conducted by Sachin Chaurasia et al., where out of 50 incidents in total, in 18 (46.15%) victims, the combination of vault and base fracture of skull was reported. In 19 cases (48.72%), skull vault alone was fractured, and in two cases (5.13%), the skull base was fractured.[11] This study contrasts with another by Raja Rupani et al. that found that, of 40 cases with skull fractures, 22 cases (55%) had a vault fracture, while 35% of cases involved both a base and a vault.[13]

In our study, as depicted in Figure 4, among skull vault fractures, fissured/linear fracture was most common with 125 cases (35.71%), then comminuted and depressed fracture in 60 cases (17.14%) and 43 cases (12.29%) respectively. Crush fracture was least common in 16 cases (4.57%). A bone defect of craniotomy was seen in 30 cases (8.57%). This supports the findings of a research by Sunil Naik and Rupeshkumar Naik, in which the majority of 51 patients (52.6%) had linear or fissure fractures, 20 cases (20.6%) had comminuted fractures, 10 cases (10.3%) had both comminuted and depressed fractures, and others had various fractures.[17] This is also

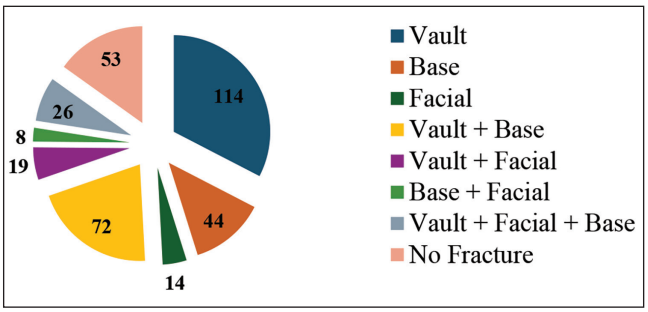

Figure 3. Pattern of Skull Fracture.

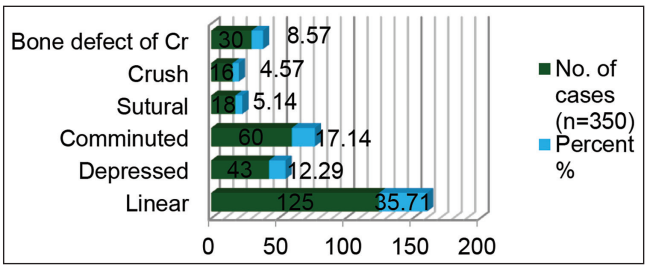

Figure 4. Pattern of Fracture of the Vault According to the Type of Vault Fracture.

consistent with research by Dinesh Kumar et al. that found that the most prevalent kind of skull fracture was linear, occurring in 132 instances (16.34%), followed by comminuted fracture vertex in 128 cases (15.84%) and depressed fracture vertex in 122 cases (15.10%). Basal fractures were the least frequent type of fracture, occurring in 121 cases (14.98%).[18] In contrast, research by Ashok Kumar Rajaput et al. found that 46 cases (48.93%) of skull fractures were comminuted, 38 cases (40.42%) had linear fractures, 8 cases (8.5%) had depressed fractures, and 1 (1.06%) case had sutural and gutter fracture.[19]

As mentioned in Table 4, we reported that, most common site of linear fracture was temporal bone in 60 victims (32.61%), followed by parietal bone in 51 cases (27.72%). Least common site for linear fracture was occipital bone in 31 cases (16.85%). Most common site for depressed fracture was frontal bone in 22 cases (29.73%), followed by parietal bone in 20 cases (27.03%). A comminuted fracture was noted maximum over frontal bone in 42 cases (35.59%). Crush fracture was noted maximum over temporal parietal region in 16 cases (30.77%). This can be explained by the fact that the lateral part of the frontal and occipital zones, as well as the temporo-parietal regions, are the most susceptible thin areas of the skull. The thin structure is primarily responsible for temporal bone involvement. The frequent involvement of parietal bone in crush and depressed fractures is mainly due to prominences and elevation of the bones of skull. According to a study by Yavuz M. Sunay et al., there were more depressed fractures in the frontal and parietal regions and linear fractures in the temporal and occipital regions ($p < .001$).[20] In research by Arvind Kumar et al., skull fractures were discovered in 1183 (69.63%) patients of head injuries, showing a similar pattern. The temporal bone 559 (47.25%) was the most often affected bone, followed by the parietal (45.47%), occipital (41.01%), and frontal (33.64%) bones.[21] A study by Shri Bhagwan et al. noticed a contrast result, with bony involvement being maximum at frontal bone (44.3%) followed by temporal bone (30.6%).[2]

As shown in Table 5, among fractures of base of skull, maximum number of cases were of hinge fracture in 85 cases (24.29%), among which hinge fracture type 1, which involves middle cranial fossa, was seen in majority of cases, 21 cases (15.71%). The least common site of basal fracture was seen in posterior cranial fossa and ring fracture, which is also seen in posterior cranial fossa in 14 cases (4%) and 16 cases (4.57%),

Table 4. Pattern of Fracture of the Vault According to the Site of Vault Fracture.

Type of Vault Fracture	Frontal	Parietal	Temporal	Occipital	Total
Linear	42 (22.83%)	51 (27.72%)	60 (32.61%)	31 (16.85%)	184
Depressed	22 (29.73%)	20 (27.03%)	19 (25.68%)	13 (17.57%)	74
Comminuted	42 (35.59%)	36 (30.51%)	30 (25.42%)	10 (8.47%)	118
Crush	15 (28.85%)	16 (30.77%)	15 (28.85%)	6 (11.54%)	52
Total	121 (34.57%)	123 (35.14%)	124 (35.42%)	60 (17.14%)	100%

Table 5. Pattern of Fracture of Base of Skull.

Base of Skull	No. of Cases (*n* = 350)	%
Incomplete	63	18.00
ACF	28	8.00
MCF	38	10.86
PCF	14	4.00
Hinge fracture	85	24.29
Hinge 1	55	15.71
Hinge 2	21	6.00
Hinge 3	39	11.14
Ring	16	4.57

Table 6. Pattern of Facial Bone Fracture According to Its Site.

Facial Fracture	No. of Cases	%
No fracture	283	80.86
Nasal	32	9.14
Mandible	33	9.43
Orbit	27	7.71
Z-M	38	10.86
Tooth	14	4.00

Table 7. Distribution of Cases According to Presence/Absence of Countercoup Injury.

Countercoup Y/N	No. of Cases (*N* = 350)	%
Yes	156	44.57
No	194	55.43
Total	350	100.00

Table 8. Pattern of Intracranial Injury.

Intracranial Injury	No. of Cases (*n* = 350)	%
SAH	309	88.29
SDH	232	66.29
IPH	36	10.29
EDH	21	6.00
IVH	21	6.00
Cerebral contusion	229	65.43
Cerebral oedema	108	30.86
Cerebral laceration	61	17.43

respectively. This is comparable to research by Saurabh Chattopadhyay and Chandrabhal Tripathi, in which only fatal cases (58.9%, n43) had a fracture of skull base. Posterior cranial fossa fracture was least frequent (4.1%); however, most vulnerable area to mechanical harm was middle cranial fossa. (38.35% n-28).[22]

Out of 350 cases, as shown in Table 6, no facial bone fracture was observed in 283 cases (80.86%). Among facial bone fractures, most common site was zygomatico-maxillary (Z-M) bone in 38 cases (10.86%), followed by mandible in 33 cases (9.43%). Amitkumar et al.'s study revealed that the mandible bone was the most frequently fractured facial bone, accounting for 5 (39.45%) of all cases. Four cases of nasal bone fracture (29.36%) and two cases of tooth fracture (17.43%) were documented. Zygomatico-maxillary complex fractures, amounting to only one, were the least frequent kind of fracture. Table 7 shows that 156 cases (44.57%) out of total of 350 cases of head injury showed presence of counter coup injury along with coup injury, which is suggestive of moving head in cases of RTA and Falls. According to a study conducted by Udaya Shankar et al. of a total of 181 cases, 28 cases had coup and contrecoup injuries.[23] According to research by Shivendra Jha et al., contrecoup injuries were most common in the frontal areas (62.5%), then in occipital (18.75%), right side lateral (2% or 22.5%), and left side lateral region (1% or 6.25%). Because of abundance of bony projections that originate from the base of the anterior cranial fossa, the frontal areas may have a higher prevalence of contrecoup lesions. It is reasonable to assume that the right lateral has a higher incidence of contrecoup lesions because the right side is more likely to be struck there.[14]

In the present study, as shown in Table 8, the maximum number of cases of subarachnoid haemorrhage (SAH) was present in 309 cases (88.29%), followed by subdural haemorrhage (SDH) in 232 cases (66.29%). Both Extradural haemorrhage (EDH) and Intraventricular haemorrhage (IVH) were seen in only 21 cases (6%). Brain contusion was the most common injury encountered in 229 cases (65.43%), then brain oedema in 108 cases (30.86%) and laceration of the brain in 61 cases (17.43%). In their study, Shreemantakumar Das and Asis Kumar Ray found that 182 cases—or 87.92% of the total of 207 head injuries—had intracerebral haemorrhage (ICH), either alone or in combination. The mixed kind of haemorrhage variety accounted for 74 cases, or 35.74%, of the 207 head injuries in the dataset. Subdural haemorrhage, however, was the largest when considered separately, accounting for 58 (28.01%), then extradural 20 (9.66%) and subarachnoid 17 (18.21%). Intracerebral haemorrhage 13 (6.28%) was the least common, and 25 cases (12.07%) had no visible haemorrhages.[24] Ganveer GB et al. observed a similar pattern in brain damage, indicating that cerebral contusion was the commonest, occurring in 41 cases (56.1%), then cerebral oedema in 24 instances (32.8%).[25]

In the current study, as depicted in Tables 9 and 10 age group mostly affected by skull fracture was 31–40 years with 105 cases, then 21–30 years with 101 cases, while there was only one case of skull fracture in 81–90 years. All three varieties of skull fracture, that is, fracture of vault, basilar fracture and facial bone fracture, showed dominance in the age group of 31–40 years. A study conducted by Anand Patil et al. observed that the most frequently affected age group of victims with skull fracture was 21–30 years, that is, 52 cases

Table 9. Correlation of the Distribution of Skull Fractures According to Age Group.

	Fracture				
Age Group in Years	**Vault**	**Base**	**Facial**	**Total**	**No Fracture**
1–10	6 (2.6%)	5 (3.3%)	4 (5.9%)	15	1
11–20	20 (8.7%)	11 (7.3%)	9 (13.4%)	40	6
21–30	51 (22.2%)	34 (22.7%)	16 (23.9%)	101	12
31–40	51 (22.2%)	35 (23.3%)	19 (28.4%)	105	12
41–50	47 (20.4%)	23 (15.3%)	10 (14.9%)	80	12
51–60	29 (12.6%)	23 (15.3%)	2 (2.9%)	54	6
61–70	20 (8.7%)	14 (9.4%)	4 (5.9%)	48	3
71–80	6 (2.6%)	4 (2.7%)	2 (2.9%)	12	1
81–90	1 (0.4%)	1 (0.7%)	1 (1.5%)	3	0
Total	230	150	67	458	53

Table 10. Correlation of the Distribution of Skull Fracture According to Gender.

	Fracture of the Skull			
Gender	**Vault**	**Base**	**Facial**	**No Fracture**
Male	199 (51.6%)	132 (34.3%)	54 (14%)	44
Female	31 (51.6%)	16 (26.7%)	13 (21.6%)	9
Total	230	148	67	53

Table 11. Correlation of Distribution of Skull Fracture According to Mechanism of Head Injury.

Mechanism of Injury	**No. of Vault #**	**%**	**No. of Base #**	**%**	**No. of Facial #**	**%**
Road traffic accident	143	40.85	100	28.57	45	12.85
Fall from height	40	11.42	53	15.14	12	3.42
Fall of a heavy object	16	4.57	12	3.42	5	1.42
Assault	12	3.42	11	3.14	2	2.99
Railway accident	14	6.06	7	4.67	15	6.48
Others	3	1.30	1	0.67	2	2.99
Total	231	100	150	100	67	100

(30%), then 31–40 years, that is, 51 cases (29%) and a single case in 61–70 years.[26] We observed that both fracture of vault and basilar fracture showed male preponderance, among which fracture of vault was present in 199 cases (51.6%), followed by basilar fracture in 132 cases (34.3%). Facial fracture showed female preponderance in 13 cases (21.6%). Percentage of females with vault fracture was equivalent to percentage of males with vault fracture. As shown in Table 11, fracture of vault was the dominant type of skull fracture in RTA (143 cases, 40.85%), fall of heavy object (16 cases, 4.57%), assault (12 cases, 3.42%), while basilar fractures were dominant in cases of fall from height in 53 cases (15.14%). Railway accidents show dominance of facial fractures in 15 cases (6.48%). A similar pattern was observed in research by Pathak Akhilesh et al., that basilar fractures are somewhat more common in cases of falls from height, linear fractures are more likely in situations of RTAS. Compared to falls from heights and assaults, RTAs are more likely to result in linear fractures that extend to the base of the skull. This is because head injuries caused by forceful contact with a broad resisting surface, such as the ground, are more likely to occur in these situations, especially when the victim is moving.[10] A study conducted by S.R. Saritha, C.S. Sreedevi observed that among all cases of fall from height, the skull was fractured in 36 cases (35.3%). Skull fractures with brain injury and intracranial haemorrhage were the most common combination of head injuries (25.5%).[27] Abhishekh Sangal et al. conducted a study to analyse the pattern of homicidal deaths, among which in over half (49.33%) of the homicide victims, the most vulnerable parts were the chest and abdomen combined, followed by the head in 18.06%.[28]

Table 12 shows that RTA shows dominance of linear fracture in 81 victims (65.6%), then comminuted fracture in 35 victims (58.3%). Victims of falls from height show

Table 12. Correlation of Distribution of Type of Vault Fracture According to Mechanism of Head Injury.

	Vault				
Mechanism of Injury	**Linear (%)**	**Depressed (%)**	**Comminuted (%)**	**Sutural (%)**	**Crush (%)**
Road traffic accident	81 (65.6)	18 (41.9)	35 (58.3)	10 (55.6)	6 (25.7)
Fall from height	24 (19.2)	14 (32.6)	15 (25)	5 (27.8)	2 (15.6)
Fall of a heavy object	3 (2.4)	1 (2.3)	2 (3.3)	1 (5.6)	1 (2.3)
Assault	9 (7.2)	5 (11.6)	0 (0)	1 (5.6)	0 (0)
Railway accident	5 (4)	5 (11.6)	6 (10)	0 (0)	5 (18.8)
Others	2 (1.6)	0 (0)	2 (3.3)	1 (5.6)	0 (0)
Total	124	43	60	18	14

Table 13. Correlation of Distribution of Type of Skull Fracture According to External Injury to Scalp and Face.

	Fracture			
External Injury to Scalp and Face	**Vault**	**Base**	**Facial**	**No Fracture**
Abrasion	32	15	20	10
Contusion	13	21	10	1
Laceration	58	16	18	11
Crush injury	14	19	7	1
Incised wound	2	0	1	1
Chop wound	2	0	0	0
Firearm wound	0	0	0	0

dominance of depressed fracture in 14 cases (32.6%), followed by sutural fracture in five cases (27.8%). The fall of a heavy object on the head shows maximum number of victims with sutural fracture in 8 (5.6%) cases, assault shows dominance of depressed fracture in five cases (11.6%), and railway accidents show exclusive presence of crush fracture in five cases (18.8%). In their study, Yavuz MS et al. demonstrated that the striking power, strike area, and physical characteristics of the skull at the point of impact are associated with the occurrence, degree of deformation, and extent of fracture. Compared to a linear fracture, the highest frequency of depressed fractures in homicide cases suggests that a significant amount of force was used. The force that causes harm to the underlying brain increases with the amount of force applied.[20] Table 13 shows a similar trend was observed in a study by Dr Sunil Kumar Soni et al., where in traffic accidents, fracture of skull was found in 57% victims and with commonest type of skull fracture being linear fracture alone (n = 64, 32%), then depressed (n = 19, 9.5%) and least common sutural fracture alone.[29] The study is in contrast to study by Dr Sunil Naik, where all cases of homicidal deaths with skull fracture show a majority of linear fracture in 51 cases (52.6%), then comminuted 20 (20.6%), while 10 (10.3%) victims sustained both comminuted and depressed fractures, followed by others.[17]

In this study, as mentioned in Table 13, majority of victims with fracture of vault had corresponding laceration type of external injury to scalp and face in 58 cases, followed by abrasion in 32 cases. Contusion was the most common external injury seen in victims with basilar fracture in 21 cases, whereas abrasion and laceration were dominant types of external injury in cases of facial fracture in 20 and 18 cases, respectively. The majority of victims without skull fracture showed dominance of laceration type of injury. Most scalp abrasions had associated fissured/linear fractures (59%) of the cranial vault and base of skull bones, then comminuted fractures (30.8%), as per a study by Udaya Shankar et al. The most frequent calvarial fractures associated with scalp lacerations were comminuted fractures (52.8%), then fissured/linear fractures (24.2%). However, there were no skull bone fractures because in 12 cases (15.7%), lacerations were only deep in the scalp tissue.[23]

Table 14 shows the fracture of the vault, which shows maximum incidence of corresponding scalp contusion in 168 cases, followed by extracranial hematoma in 147 cases; basilar fracture shows incidence of scalp contusion in 96 cases, whereas facial fracture shows corresponding scalp contusion in 48 cases. The analysis of Table 15, emphasising the type of skull fracture pertaining to type and presence of intracranial haemorrhage, reveals that skull fracture shows 100% presence in all cases of head injury with extradural haemorrhage and intraventricular haemorrhage, among which vault fracture shows dominance in 21 cases (6%) and 20 cases (5.7%) respectively. Subarachnoid haemorrhage was the least common among all intracranial haemorrhages with corresponding fracture in 90.9% cases. Most

Table 14. Correlation of Distribution of Skull Fractures According to Under-scalp Injury.

	Fracture			
Under-scalp Injury	**Vault**	**Base**	**Facial**	**No Fracture**
No injury	5	7	5	8
Scalp contusion	168	96	48	35
Extracranial haematoma	147	91	41	20
Scalp laceration	38	21	17	6
Temporalis muscle contusion	77	49	26	6

Table 15. Correlation of Distribution of Skull Fractures According to Intracranial Injury.

	Skull Fracture				
Intracranial Injury	**Vault (%)**	**Base (%)**	**Facial (%)**	**Total (%)**	**No Fracture (%)**
SAH	211 (47.7)	144 (47.7)	57 (16.3)	(90.9)	41
SDH	162 (36.6)	111 (36.9)	32 (9.1)	(91.6)	28
IPH	28 (6.3)	20 (6.6)	10 (2.9)	(95.1)	3
EDH	21 (4.8)	10 (3.3)	4 (1.4)	(100)	0
IVH	20 (4.5)	16 (5.3)	9 (2.6)	(100)	0
Cerebral contusion	154 (54.4)	86 (46.5)	39 (47.6)	279 (79.7)	31
Cerebral oedema	72 (25.4)	47 (29.7)	19 (23.7)	138 (39.4)	12
Cerebral laceration	57 (20.1)	25 (15.8)	24 (29.3)	106 (30.2)	2

of the cases with fracture of the vault lead to rupture of the epidural space's blood vessels, thus the incidence of extradural haemorrhage is maximum among cases with fracture of the vault, in 21 cases (4.8%). However, the force of impact was more in basilar fractures, which were transmitted to the deeper structures of the brain, leading to maximum incidence of intraparenchymal haemorrhage and intraventricular haemorrhage in 20 cases (6.6%) and 16 cases (5.3%), respectively. In the present study, the most common injury to brain encountered in fracture of vault is brain contusion in 154 cases (54.4%). Basilar fracture shows dominance of oedema of brain in 47 cases (29.7%), whereas facial fracture shows the presence of laceration of brain exclusively in 24 cases (29.3%). The fact that brain contusions and lacerations are more common in areas where the brain encounters projectile buttresses and ridges on the inner surface of the skull, such as the orbital surfaces of the frontal lobes and the inferior surface of the temporal poles, can help to explain the higher incidence of laceration-type brain injury in facial fractures and contusion in vault fractures.

Limitations

The study was limited to a single tertiary care centre in western India, which may affect the generalizability of its findings to broader populations or other regions. It included only fatal head injury cases brought for medico-legal autopsy, thus excluding non-fatal or treated cases that might show different patterns of skull fractures. Cases with decomposed bodies, unknown histories, or extensive burns were excluded, potentially omitting relevant data that could influence injury pattern analysis.

Conclusion

The study demonstrates a clear gender and age distribution in head injury cases, with males being predominantly affected (84.29%), especially in the active working age group of 21–40 years, which correlates with the increased outdoor and vehicular activities. The most common types of injuries observed were lacerations and contusions, primarily in the parietal and frontal regions of the scalp and face. Skull fractures were frequent, with the vault and basilar fractures being the most prevalent. RTAs were identified as the primary cause of injuries, followed by falls and assaults, with fracture patterns varying depending on the type of incident. Intracranial haemorrhages, such as subarachnoid haemorrhage and subdural haemorrhage, were the most common complications observed.

The findings of this study are consistent with previous research, but some variations were noted in the injury types and locations. The overall results underline the significance of trauma severity and impact direction on the type of injury sustained, as well as the role of age and gender in the vulnerability to head injuries.

Recommendations

Based on the findings, it is recommended to prioritise road safety measures, especially for males and individuals aged 21–40 years, who are more prone to head injuries due to accidents. Public awareness campaigns on safe driving, helmet use, and fall prevention should be implemented, with a focus on high-risk occupations and age groups. Further, better emergency medical protocols and early diagnosis should be promoted to manage scalp and brain injuries effectively. Additionally, efforts should be directed towards the prevention of falls in the elderly and children, as well as the management of fractures, particularly vault and basilar fractures, through improved trauma care and services for rehabilitation.

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

Institutional Ethics Committee's ethical permission was acquired by letter number IECBHR/131-2020 dated 4 December 2020.

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Informed Consent

This study was conducted on mandated forensic autopsies, as directed by the Police/Magistrate inquest. While consent is not required for the medico-legal autopsy itself, Ethical approval for the research was granted by the IEC of the Institute. All identifying information has been anonymized to protect the confidentiality and privacy of the deceased.

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Estimation of Age from Epiphyseal Fusion of Head of Humerus, Iliac Crest and Ischial Tuberosity in Southeast Region of Rajasthan by Digital Radiographs

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Abstract

Age estimation is vital in medico-legal and forensic contexts, particularly in developing countries like India, where reliable birth documentation is often lacking. Accurate age determination supports legal decisions in criminal responsibility, marriage eligibility, civil rights, and identity verification. This study aimed to assess skeletal maturity through radiological evaluation of epiphyseal fusion in the humeral head, iliac crest, and ischial tuberosity among individuals aged 16–21 years in south-east Rajasthan. An observational, cross-sectional study was conducted at Jhalawar Medical College's Department of Forensic Medicine, including 100 individuals (67 males, 33 females) aged 16–21 years. Participants underwent clinical and radiological examinations, with digital X-rays of the shoulder and pelvis analyzed for epiphyseal fusion by a blinded radiologist. Data were statistically analyzed using Microsoft Excel and relevant software tools; $p < .05$ was considered significant. Radiological findings demonstrated progressive fusion with age. In females, complete humeral head fusion was observed in all individuals aged 20–21, with an overall 60.61% showing complete fusion. The iliac crest and ischial tuberosity showed 30.30% and 21.21% complete fusion, respectively. In males, humeral head fusion was complete in 77.61% overall, including all those above 18. Iliac crest and ischial tuberosity fusion were complete in 47.76% and 37.31%, respectively. Fusion occurred earlier in females across all sites. The study confirms a consistent and age-progressive pattern of epiphyseal fusion, with earlier completion in females. Radiographic assessment of specific skeletal sites proves to be a reliable method for age estimation, particularly valuable in the 16–21-year age group in medico-legal investigations.

Keywords

Age estimation, epiphyseal fusion, humeral head, iliac crest, ischial tuberosity, south-east Rajasthan

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Introduction

Age estimation plays a pivotal role in personal identification in both civil and criminal proceedings, especially in developing countries like India, where birth records are often unreliable despite laws such as the Registration of Births and Deaths Act of 1969. Accurate age determination is essential in legal matters involving criminal responsibility, civil rights, and marital eligibility.[1]

Various methods are employed for age estimation, including general appearance, dental, and skeletal examinations. While general appearance and body measurements are unreliable due to individual variations, and dental data is limited after the eruption of most teeth by age 16, skeletal examination stands out as the most systematic and legally accepted approach. Radiological assessment of bone ossification, particularly epiphyseal union, is widely recognized for its accuracy.[2]

Key skeletal markers such as the ischial tuberosity and iliac crest are significant for determining the legal age for marriage in India—18 years for girls and 21 years for boys.

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These indicators are also valuable in resolving civil and criminal cases involving property disputes, passport verification, insurance claims, disputed identity or sex, and missing persons. For individuals above 16, radiographic analysis of the pelvis and shoulder bones becomes crucial.[3]

Ossification timing varies due to climate, heredity, race, nutrition, and socioeconomic factors, necessitating population-specific studies. earlier bone union in Indians than in Western populations, highlighting regional differences.[4] The ischial tuberosity, maturing post-18 years, serves as a reliable marker in legal assessments. The constancy in ossification age makes epiphyseal union a dependable legal standard, with faster fusion observed in females and in tropical regions.[5]

Modi's textbook emphasizes that regional differences within India complicate the establishment of uniform age standards. Reddy KSN noted earlier epiphyseal union in females, whereas skull sutures close more slowly. Radiology remains a reliable method for tracking ossification progression until full skeletal maturity.[6]

Materials and Methods

Study Overview

This observational, cross-sectional study was conducted at Jhalawar Medical College's Forensic Medicine Department with radiological support. After receiving ethical approvals, around 100 individuals aged 16–21 were enrolled. Participants included patients visiting the hospital for treatment or routine check-ups and students undergoing medical examinations. The study aimed to assess age-related parameters through radiological evaluation.

Inclusion Criteria

Only individuals aged between 16 and 21 years from southeast Rajasthan were included. Participants had to possess valid age proof, such as a birth certificate or matriculation certificate issued by a competent authority and must have given informed consent.

Exclusion Criteria

Subjects were excluded if they lacked valid age proof, were outside the 16–21 age range, or had severe malnutrition, chronic illness, endocrine disorders, or deformities in limbs or pelvis.

Data Collection Method

Written informed consent was obtained from all eligible participants. A general physical examination was performed to evaluate overall health and rule out deformities. Only those meeting the inclusion criteria and not meeting the exclusion criteria proceeded to the next stage of the study. All the eligible students who came for a routine check-up were sent for radiological examination after explaining the complete process and obtaining consent.

Materials

The study utilized X-ray films, a view box, a magnifying lens, height and weight measuring machines, and a predesigned Performa for data recording.

Method

Personal information was documented. Participants were briefed about age estimation and radiation exposure risks. Clinical and dental examinations were conducted, and data were recorded. Digital X-rays of the shoulder and pelvis joints were taken and analyzed by a blinded radiologist to assess ossification center fusion. Findings were compared with existing regional studies.

Statistical Analysis

Data were compiled in Microsoft Excel and analyzed using statistical software, which is age estimation software. Qualitative data were presented in groups and percentages, while quantitative data were expressed as mean and standard deviation. Chi-square tests were used, and a significance level of $p < .05$ was considered.

Result and Observations

The study analyzed humeral head fusion in 33 females. Complete fusion was seen in 60.61%, partial in 36.36%, and near-complete in 3.03%, with no non-fusion cases. Fusion patterns varied by age: mixed stages appeared in 16–17 years, while from 20 years onward, 100% showed complete fusion. Findings suggest that in females, complete fusion of the humeral head typically occurs between 20 and 22 years of age.

X-ray findings showed complete fusion in 72% (humerus head), 42% (iliac crest), and 32% (ischial tuberosity), with varying degrees of partial or no fusion in the remaining cases across these anatomical sites. The study involved 100 cases with a mean age of 18.31 ± 1.85 years, mostly aged 16–21. Males comprised 67% and females 33%. Among males, most were 16–17 years (44.78%), while among females, 18–19 years (42.42%) was most common. Rural and urban representation was nearly equal (52% vs. 48%).

The study examined iliac crest fusion in 33 female subjects. Partial fusion was most common (54.55%), followed by complete fusion (30.30%) and non-fusion (15.15%), with no near-complete cases. In the 16–17-year group, partial fusion predominated (88.89%), with no complete fusion observed. Complete fusion increased with age, appearing in 42.86% at

Table 1. Radiological Age Distribution (in Years) Fusion of Head of Humerus (Female).

Radiological Age Distribution (in Years)	Fusion of Head of Humerus (Female)									
	Total		Completely Fused		Near Completely Fused		Partially Fused		Non-fused	
	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage
16–17	9	27.27	4	44.44	1	11.11	4	44.44	0	0
17–18	0	0.00	0	0.00	0	0.00	0	0.00	0	0
18–19	7	21.21	3	42.86	0	0.00	4	57.14	0	0
19–20	7	21.21	3	42.86	0	0.00	4	57.14	0	0
20–21	6	18.18	6	100.00	0	0.00	0	0.00	0	0
21–22	4	12.12	4	100.00	0	0.00	0	0.00	0	0
Total	33	100.00	20	60.61	1	3.03	12	36.36	0	0

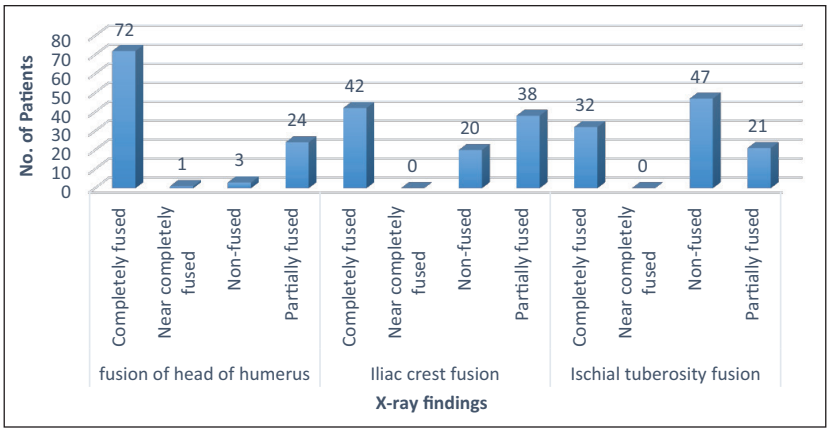

Figure 1. Distribution of Cases According to X-ray Findings.

Table 2. Radiological Age Distribution (in Years) Based on Iliac Crest Fusion in Female Cases.

Radiological Age Distribution (in Years)	Iliac Crest Fusion (Female)									
	Total		Completely Fused		Near Completely Fused		Partially Fused		Non-fused	
	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage
16–17	9	27.27	0	0.00	0	0.00	8	88.89	1	11.11
17–18	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
18–19	7	21.21	3	42.86	0	0.00	0	0.00	4	57.14
19–20	7	21.21	0	0.00	0	0.00	7	100.00	0	0.00
20–21	6	18.18	3	50.00	0	0.00	3	50.00	0	0.00
21–22	4	12.12	4	100.00	0	0.00	0	0.00	0	0.00
Total	33	100.00	10	30.30	0	0.00	18	54.55	5	15.15

18–19 years and reaching 100% by 21–22 years. These findings indicate that iliac crest fusion in females typically begins after age 17 and is completed by 21–22 years.

The study evaluated humeral head fusion in 67 males. Complete fusion was found in 77.61%, partial fusion in 17.91%, and non-fusion in 4.48%, with no near-complete cases. At 16–17 years, most had partial (56.25%) or no fusion. Fusion increased significantly at 17–18 years, with 78.57% complete. By 18–19 years, 100% showed complete fusion, a trend consistent in older age groups. These results indicate that humeral head fusion in males typically occurs between 17 and 19 years of age.

Table 3. Radiological Age Distribution (in Years) Based on Fusion of the Head of Humerus in Male Cases.

Radiological Age Distribution (in Years)	Fusion of Head of Humerus (Male)									
	Total		Completely Fused		Near Completely Fused		Partially Fused		Non-fused	
	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage
16–17	16	23.88	4	25.00	0	0.00	9	56.25	3	18.75
17–18	14	20.90	11	78.57	0	0.00	3	21.43	0	0.00
18–19	12	17.91	12	100.00	0	0.00	0	0.00	0	0.00
19–20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
20–21	11	16.42	11	100.00	0	0.00	0	0.00	0	0.00
21–22	14	20.90	14	100.00	0	0.00	0	0.00	0	0.00
Total	67	100.00	52	77.61	0	0.00	12	17.91	3	4.48

Table 4. Radiological Age Distribution (in Years) Based on Iliac Crest Fusion in Male Cases.

Radiological Age Distribution (in Years)	Iliac Crest Fusion (Male)									
	Total		Completely Fused		Near Completely Fused		Partially Fused		Non-fused	
	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage
16–17	16	23.88	0	0.00	0	0.00	1	6.25	15	93.75
17–18	14	20.90	7	50.00	0	0.00	7	50.00	0	0.00
18–19	12	17.91	0	0.00	0	0.00	12	100.00	0	0.00
19–20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
20–21	11	16.42	11	100.00	0	0.00	0	0.00	0	0.00
21–22	14	20.90	14	100.00	0	0.00	0	0.00	0	0.00
Total	67	100.00	32	47.76	0	0.00	20	29.85	15	22.39

Table 5. Radiological Age Distribution (in Years) Based on Ischial Tuberosity Fusion in Male Cases.

Radiological Age Distribution (in Years)	Ischial Tuberosity Fusion (Male)									
	Total		Completely Fused		Near Completely Fused		Partially Fused		Non-fused	
	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage	No. of Patients	Percentage
16–17	16	23.88	0	0.00	0	0.00	0	0.00	16	100.00
17–18	14	20.90	0	0.00	0	0.00	3	21.43	11	78.57
18–19	12	17.91	0	0.00	0	0.00	8	66.67	4	33.33
19–20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
20–21	11	16.42	11	100.00	0	0.00	0	0.00	0	0.00
21–22	14	20.90	14	100.00	0	0.00	0	0.00	0	0.00
Total	67	100.00	25	37.31	0	0.00	11	16.42	31	46.27

The study examined iliac crest fusion in 67 males. Complete fusion was observed in 47.76%, partial fusion in 29.85%, and non-fusion in 22.39%, with no near-complete cases. Most 16–17-year-olds (93.75%) showed non-fusion. Fusion advanced at 17–18 years, with equal cases of complete and partial fusion. At 18–19 years, all had partial fusion. Complete fusion was universal from age 20 onward. These findings indicate iliac crest fusion in males typically starts after 17 years and is completed by 20–22 years.

The study assessed ischial tuberosity fusion in 67 males. Non-fusion was most common (46.27%), followed by complete fusion (37.31%) and partial fusion (16.42%), with no near-complete cases. At 16–17 years, all showed non-fusion. Fusion activity began at 17–18 years, increasing at 18–19 years, with 66.67% partially fused. Complete fusion was observed in all individuals by 20–21 years and beyond. These results indicate that ischial tuberosity fusion in males typically begins after 17 and completes by age 20.

Discussion

Among 33 female subjects, complete humeral head fusion was seen in 60.61%, partial in 36.36%, and near-complete in 3.03%, with no non-fusion cases. Fusion stages were mixed at 16–17 years, while partial fusion predominated at 18–20 years. From 20 years onward, all showed complete fusion, indicating typical fusion completion between 20 and 22 years. In a similar study, Dalal D et al.[7] reported that the femoral head in females typically began to appear around age 8, with six early cases noted. By age 12, approximately 70% (21 cases) had visible ossification centers. The onset of fusion occurred near age 13, although the majority of cases remained in the "fusion not started" stage (62%) or the "fusion in progress" stage (28%). As age advanced, particularly after 16 years, a noticeable increase in complete fusion was observed, with several cases reaching full fusion by age 17. Likewise, Shivkumar K T et al.[8] documented rapid epiphyseal union at the lower end of the humerus among females. Complete fusion was noted in 100% of cases in the 15½–16, 16–16½, and 16½–17-year age groups, indicating a consistent and early pattern of skeletal maturity. These findings highlight a trend of accelerated and uniform fusion in the humeral epiphysis among females, aligning with the progressive increase in complete fusion observed in the current study.

Radiographic analysis revealed site-specific fusion patterns: the humeral head showed complete fusion in 72%, partial in 24%, no fusion in 3%, and near-complete in 1%. For the iliac crest, 42% had full fusion, 38% partial, and 20% none. At the ischial tuberosity, 32% were fully fused, 21% partially, and 47% remained unfused, with no near-complete cases noted. In a similar study, Naik S et al.[9] reported that none of the participants had visible ossification centers at the outset. As development progressed, early ossification (A stage) was seen in 6.67% of cases, while 20% reached the + stage, and another 6.67% showed partial fusion (++). Altogether, 26.67% attained at least the + stage, but full fusion was not seen in any patient. A significant portion, approximately 66.67%, exhibited either absent ossification or incomplete fusion throughout the study. Likewise, Dalal D et al.[7] observed the appearance of the femoral head in all study subjects, with 60% showing its presence. While some signs of fusion initiation were noted, the majority of cases remained either in the pre-fusion stage (78%) or at the early phase of fusion (11%), suggesting that most participants had not yet reached advanced stages of skeletal maturation.

In 33 female subjects, iliac crest fusion was complete in 30.30%, partial in 54.55%, and absent in 15.15%, with no near-complete cases. Partial fusion dominated at 16–17 years (88.89%), while complete fusion appeared from 18 to 19 years (42.86%). All 19–20-year-olds showed partial fusion. Fusion was evenly split at 20–21 years, and by 21–22 years, all showed complete fusion, indicating fusion typically begins after 17 and completes by 21–22 years. Similarly, Kumar R et al.[10] reported that younger females in the 12–15 years group had no appearance or fusion of the ossification center. Fusion activity initiated in the 16–17 years range, where 88.88% had partial fusion and 11.11% showed complete fusion. The trend of increased fusion with age continued, with 90% of females in the 17–18 group and all in the 19–24 age range achieving complete iliac crest fusion. Their overall findings noted complete fusion in 44.21% of cases, partial fusion in 17.89%, and unfused ossification centers in 24.21%. In a similar study, Singh P et al.[11] analyzed iliac crest fusion across five age groups. Among females aged 16–17 years, 50% had begun but not completed fusion, and 40% showed center appearance without union. By 18–19 years, 70% demonstrated incomplete fusion, and 30% had completed fusion. A marked increase was seen in the 20–21 years group, where 90% achieved full union, followed by 80% at 22–23 years. Complete fusion was universal by 24–25 years, confirming skeletal maturity in the mid-twenties.

Among 67 males, ischial tuberosity fusion was complete in 37.31%, partial in 16.42%, and absent in 46.27%, with no near-complete cases. All 16–17-year-olds were non-fused. Fusion began by 17–18 years (21.43% partial) and advanced at 18–19 years (66.67% partial). Complete fusion was seen from 20 years onward, indicating that fusion typically begins after 17 and completes by age 20 in males. Kumar R et al.[10] found no fusion between 12 and 15 years, with partial fusion in 86.67% by 16–17 years, and complete fusion by 20–21 years. Maqsood M et al.[12] showed 79.51% complete fusion by 22–25 years, with an average age of full fusion at 21.52 years. Naik S et al.[9] noted ossification beginning at 15–16 years, with partial fusion by 16–17 years. Dalal D et al.[7] observed fusion activity starting around 12 years, with most individuals remaining in early stages until later adolescence. Shivkumar K T et al.[8] reported complete fusion by 16½–17 years, further confirming the trend of advancing ossification with age.

Conclusion

The study reveals a consistent age-related epiphyseal fusion pattern in the humeral head, iliac crest, and ischial tuberosity among south-east Rajasthan individuals. Fusion occurs earlier in females, especially in the humeral head. The iliac crest and ischial tuberosity exhibit gradual fusion in both sexes, typically completing in the early twenties. Radiographic evaluation proves reliable for age estimation in forensic and medico-legal settings. Gender differences and regional variations are important factors in interpreting skeletal maturity accurately.

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

This study was ethically cleared by IEC, Jhalawar Medical College, Jhalawar & Associate Hospital, Jhalawar vide letter no 39 dated June 11, 2024.

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Informed Consent

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Original Research Article

The Role of Dental Patterns in Personal Identification: From Teeth to Identity

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Abstract

Forensic odontology is a fundamental approach to identifying people, especially if alternative methods may not be attainable. Dental pattern variation, such as virgin, decaying, filled, and missing teeth, constitutes a valuable resource enabling the identification of individuals and acts as a distinct characteristic. This research explores the relevance of the diversity of dental patterns by employing the nonradiographic dental records method in forensic odontology, assessing their efficacy and reliability for individual identification in Delhi NCR populations, and highlighting the necessity for keeping thorough and precise dental records. Clinical examination, though often overlooked, provides a wealth of information that can supplement forensic investigations, particularly in the absence of radiographic records. The study incorporated 120 individuals (60 males and 60 females) aged 18–55 years from Delhi NCR clinics. The criteria comprised virgin (V), decayed (D), filled (F), and missing (M) teeth, which were assessed using SPSS software version 27.0 and Simpson's Index of Diversity for determining diversity of dental patterns. The findings revealed a significant difference in virgin teeth across age groups (p = .001). Simpson's Diversity Index indicated that age was the predominant factor influencing dental diversity, while sex differences were not statistically significant. Clinical dental examination yields valuable forensic insights, offering a practical nonradiographic method of assessing dental diversity. While antemortem dental records remain the gold standard for accurate identification, clinical examination plays a crucial role where radiographic facilities are unavailable, thereby strengthening forensic investigations.

Keywords

Forensic odontology, dental records, personal identification, dental pattern, dental diversity, teeth

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Introduction

Over the last decade, there has been a drastic spike in criminal and disaster incidents.[1] The current high prevalence of violent and criminal actions has prompted the use of advanced techniques for criminal investigations.[2] Furthermore, the current prevalence of casualties related to mass disasters, such as travel and transportation accidents, terrorism, and exceptional meteorological conditions include earthquakes, tsunamis, landslides, and floods,[3] where the body is severely decomposed or mutilated to conceal the identity of the individual purposefully necessitates the development of novel effective approaches for identifying victims[4] is stated to as personal identification.[3] One of the greatest obstacles in forensic science is the identification process.[5] The initial step in establishing personal identity is determining whether or not the skeletal remains are human. If the remains are human, several anthropological procedures can be utilized to identify the deceased. The "big four" of personal identification are age, sex, stature, and ethnicity. These are the characteristics of "tentative identification."[6]

This needs to be established on trustworthy and objective approaches, as well as technological and scientific knowledge, to ensure that the conclusion of the technique of identification is not in controversy.[7] Forensic odontology is frequently used to identify victims of multiple-fatality

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disasters, although not always. Its effectiveness is dependent on sufficient dental remains surviving the natural disaster and the availability of dental documents. In 1970, Keiser-Neilson designated forensic odontology as "the branch of forensic medicine which, in the interest of justice, deals with the proper handling and examination of dental evidence, as well as the proper evaluation and presentation of the dental findings."[8] Natural teeth, with Knop Hardness 270–350, are highly resilient organs in humans, making them valuable for identifying people in large-scale disasters or accidents where visible methods are insufficient.

Forensic dentistry, originating in 49 AD, uses natural teeth to identify people in large-scale disasters. Disaster victim identification (DVI) involves comparing dental records from antemortem and postmortem bodies. Forensic Odontology helps ascertain socioeconomic status, past dental history, age, and race of unidentified individuals. Adams' research on adult dentition patterns has shown that dental patterns are a reliable method of identifying a person, similar to the variety of mitochondrial DNA structures.[9–15]

The dental pattern (DP), which can be used as a tool in the identification process, is characterized as the amalgamation of different symbols designated with particular dental conditions, such as virgin, missing, filling, and restored teeth on the entire dental arch, or a set of teeth. The application of dental patterns has been proven to be a great means of identifying an individual.[15,16] This study aimed to evaluate the diversity of dental patterns through clinical examination and to analyze the impact of sex and age on dental status. It became apparent that even in the lack of radiographic standards of comparison, charts, and notes that precisely describe the antemortem dental status of a missing person might be crucial for making an identification.[15] Dental radiographs are more objective and less subjective than dental charts, and postmortem investigators can assess both antemortem and postmortem radiographs, reducing potential inaccuracies.[17]

Materials and Methods

Sample Population

This is a cross-sectional study involving 120 participants (60 males, 60 females) aged 18–55 years by using simple random sampling technique, categorized into three age groups as shown in Table 1, selected from Delhi NCR clinics after attaining ethical approval from the ethical committee of the Department of Anthropology, University of Delhi, India. Informed written consent was obtained from all participants before collecting data based on pre-planned inclusion and exclusion criteria. Inclusion criteria included permanent, complete dentulous or partially edentulous teeth, aged 18 to 55 years, and a clinical method, with the geographical area being the Delhi region. Exclusion criteria included deciduous teeth, radiographs, age < 55 years, cysts, and any oral abnormalities such as supernumerary teeth, cleft lip, and cleft palate. The parameters were virgin (V), decayed (D), filled (F), and missing (M), with assigned dental codes as shown in Table 2.[17,18] Each of the teeth was assessed, documented in a tabular format, and statistically evaluated using SPSS 27.0 software. The variety of dental patterns has been assessed using **Simpson's Diversity Index** formula.

Result

This study evaluated dental diversity across a population of 120 individuals, considering sex and age variations. Descriptive statistics revealed that participants had an average of 26.96 virgin teeth (standard deviation [*SD*] = 3.354), with 1.67 decayed teeth (*SD* = 1.907), 0.53 filled teeth (*SD* = 1.614), and 1.36 missing teeth (*SD* = 1.878) (Table 3).

Only 4.1% of the participants retained all 32 virgin teeth, with a slightly higher prevalence in females (5.0%) compared to males (3.3%). Arch-wise distribution demonstrated that virgin dentition was more frequently preserved in the maxilla (15.8%) than in the mandible (10.0%) (Table 4, Figure 1)

The diversity percentage for unique patterns of teeth remained consistently high across the population. In males, the full-mouth diversity was 99.83%, with 98.87% in the maxilla and 99.55% in the mandible. In females, the values were slightly lower: 99.60% (full mouth), 99.27% (maxilla), and 99.04% (mandible). Overall, the population exhibited 99.86% diversity for the full mouth, 99.54% for the maxilla, and 99.65% for the mandible, suggesting minimal loss of virgin teeth across both sexes (Table 5, Figure 2).

Independent samples *t*-test showed no significant sex-wise differences in the mean number of virgin, decayed, filled, or missing teeth ($p > .05$). However, one-way analysis of variance (ANOVA) demonstrated a significant difference in virgin teeth across age groups ($F = 7.065$, $p = .001$), confirming that younger individuals retained more intact dentition than older individuals. No significant differences were observed across age groups for decayed ($p = .516$), filled ($p = .068$), or missing teeth ($p = .562$) (Tables 6 and 7).

Table 1. Sample Dispersion Based on Sex and Age ($n = 120$).

Sl. No.	Age Group (Years)	Male	Female	Total
1	18–30	20	20	40
2	31–42	20	20	40
3	43–55	20	20	40
4	18–55	60	60	120

Table 2. Parameters with Dental Coding.

Sl. No.	Dental Codes	Tooth Designated	Description
1.	V	Virgin tooth	No evidence of dental treatment, decaying
2.	D	Decayed	Defects by dental caries, tooth fracture, or fallen-out fillings
3.	F	Filling	Any kind of restoration
4.	M	Missing	Extraction or congenital missing teeth, clinically missing

Table 3. Descriptive Statistics of Dental Variables.

Variable	Mean	Standard Error of Mean	Standard Deviation	Variance
Virgin teeth	26.96	0.306	3.354	11.250
Decayed teeth	1.67	0.174	1.907	3.636
Filled teeth	0.53	0.147	1.614	2.604
Missing teeth	1.36	0.171	1.878	3.526

Table 4. The Frequency and Percentage of 32 Virgin Teeth Dental Patterns Sex-wise.

Sex	Full Mouth	%	Maxilla	%	Mandible	%
Male (n = 60)	2	3.3	8	13.3	6	10
Female (n = 60)	3	5	11	18.3	6	10
Whole (n = 120)	5	4.1	19	15.8	12	10

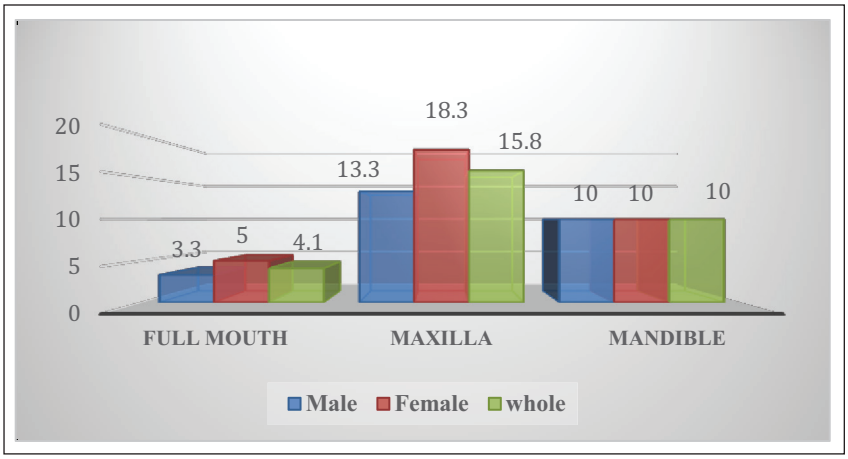

Figure 1. Percentage of 32 Virgin Teeth Common Dental Pattern Sex-wise.

Table 5. Diversity Percentage of Dental Pattern in the Sample.

Sex	Full Mouth (%)	Maxilla (%)	Mandible (%)
Male	99.83	98.87	99.55
Female	99.60	99.27	99.04
Whole	99.86	99.54	99.65

Simpson's Diversity Index values reinforced these findings, indicating that dental diversity was influenced more strongly by age than by sex. Younger age groups exhibited greater homogeneity in dental status, while older groups showed increased variability due to the cumulative effects of caries and dental intervention. Overall, the results demonstrate that although most individuals retained a majority of their teeth intact, complete virgin dentition was rare in adults.

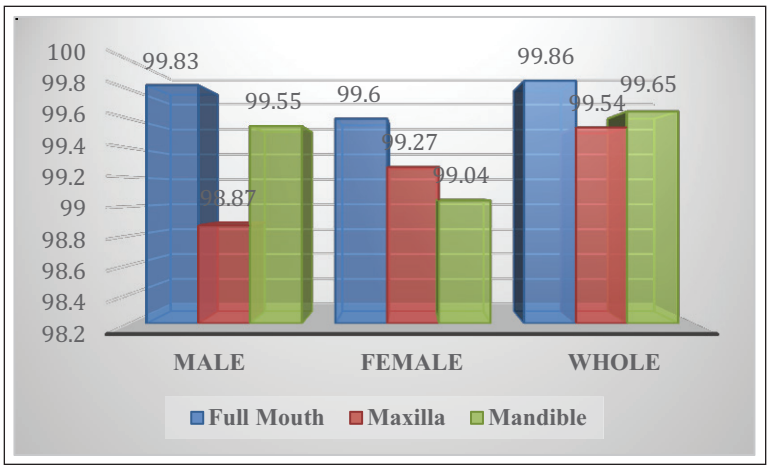

Figure 2. Diversity Percentage of Dental Patterns.

Table 6. Independent *t*-test (Sex-wise Comparison).

Variable	Male Mean ± *SD*	Female Mean ± *SD*	*df*	*p* Value
Virgin teeth	27.2 ± 3.157	26.80 ± 3.560	118	.607
Decayed teeth	1.82 ± 1.987	1.52 ± 1.827	118	.391
Filled teeth	0.62 ± 1.833	0.43 ± 1.370	118	.536
Missing teeth	1.15 ± 1.516	1.57 ± 2.174	118	.226

Table 7. One-way ANOVA Test (Age-wise Comparison).

Variable	F Value	*p* Value	Interpretation
Virgin teeth	7.065	.001	Significant difference across age groups
Decayed teeth	0.665	.516	Not significant
Filled teeth	2.757	.068	Not significant
Missing teeth	0.580	.562	Not significant

Age emerged as the most significant determinant of dental diversity, whereas sex differences were minimal. These findings underscore the forensic potential of dental diversity patterns in age estimation and biological profiling.

Discussion

Identification is the process of distinguishing the living from the dead. It will be more significant in forensic identification cases involving deaths that are suspicious in both single and mass fatality instances for moral, social, spiritual, compassionate, and legal purposes.[19–21] Dental identification is an easy and efficient technique for identifying individuals by comparing antemortem and postmortem data for similar characteristics.[22] Forensic dentistry can help identify persons when other methods are ineffective. The unique characteristics of our dental anatomy, along with the appropriate use of custom restorations, confirm precision when methods are used appropriately.[23]

This study observed a variety of dental patterns using a nonradiographic method within the full mouth (99.86%), corresponding with previous research which had been conducted using an orthopantomogram (OPG).[24–27] However, the outcomes differed substantially when the maxilla (99.54%) and mandible (99.65%) were examined independently compared to other authors. The authors structured the study using characteristics of virgin, missing, restored, and impacted using an OPG, contributing to the low heterogeneity rate within the maxilla (59%) and mandible (82%),[18] whereas this study is structured using characteristics of decayed, virgin, missing, and filled teeth using the nonradiographic method.

Earlier research by different authors has stressed the implications of using OPGs for forensic identification. These studies concentrated on dental diversity through radiographic examination. While radiographic approaches have already been widely explored in person identification, there is a lack of research specifically focused on the potential of the nonradiographic method as a standalone tool for the same reason.

This study seeks to fill the aforementioned gaps by exploring the effectiveness of nonradiographic methods in establishing individual identity when antemortem dental records are lacking.

According to Adam (2003), even in the lack of a dental radiograph, dental variety was sufficient for forensic identification. On a basic dental chart, he just contrasted missing, restored, and unrestored teeth. Adam used actual findings of substantial information to provide insight into the variety of adult dental patterns and to illustrate the diversity through nonradiographic dental comparisons using dental charts.[15] Dental radiography holds a greater objective and exhibits comparatively fewer mistakes when compared to postmortem investigators for identification, notwithstanding the subjectivity of dental charts. The study emphasizes assessing the nonradiographic method's efficacy where no antemortem dental data is available. This limitation may restrict the depth of analysis and the ability to detect subtle dental variations that are critical for forensic identification. Similarly, this study also highlights the diversity of dental patterns, without relying on dental radiographic records, as a whole in establishing personal identification using four dental characteristics and emphasizing the importance of preserving complete and accurate dental records for positive dental identification.

Conclusion

This study highlights that dental diversity, expressed through virgin, decayed, filled, and missing teeth, serves as a valuable parameter in forensic science. While most individuals retained a majority of their dentition intact, the rarity of complete virgin dentition and the age-related decline in tooth integrity underline the importance of dental examination in biological profiling and age estimation. Sex-related differences were minimal, reinforcing the observation that age exerts a greater influence on dental diversity.

Importantly, this study reaffirms that clinical examination yields a wealth of information in personal identification, offering a practical, cost-effective, and noninvasive approach to forensic investigations. However, it must be recognized that antemortem dental records remain the gold standard, providing objective, verifiable, and highly accurate details for personal identification.

Nevertheless, in contexts where imaging techniques and radiographic records are unavailable, nonradiographic clinical examination plays a critical role. It bridges the gap by offering preliminary yet significant insights that can assist forensic experts in narrowing down identity, establishing biological profiles, and corroborating other forms of evidence.

Thus, the findings emphasize that clinical dental examination, while complementary to antemortem dental records, continues to be an indispensable tool in the forensic identification process, particularly in resource-limited or challenging investigative settings.

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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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Informed Consent

Informed written consent was obtained from all participants prior to data collection.

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Profile of Medico-legal Autopsies of Pediatric Age Group Conducted at a Tertiary Health Care Center, Indore

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Abstract

The well-being of infants, children, and adolescents and their physical, mental, and psychological development is taken into consideration in a branch of medicine known as pediatrics. Pediatric forensic autopsy is useful to evaluate the natural and unnatural childhood deaths, their reasons, steps for prevention, and their management, which is useful to the branch of forensic medicine and medical researchers. A 1-year retrospective study was conducted in the Department of Forensic Medicine and Toxicology in the Medical College, Indore, from January 2023 to December 2023. In our study, a total of 271 cases belonging to the pediatric age group were studied. Out of 271 cases, the maximum number of cases were male (170, 62.90%), and the maximum number of cases belonged to the age group of 12–18 years. The most common cause of death among the pediatric age group was road traffic accidents (RTA). The analysis of pediatric deaths was an effort to elucidate the various aspects of pediatric death and establish the profile. This study helps us to interpret the general profile of pediatric deaths and the various factors affecting the death rate.

Keywords

Natural deaths, pediatric age group, road traffic accidents (RTA), unnatural deaths

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Introduction

Taking care of the well-being of infants, children, and adolescents and their physical, mental, and psychological development comes under the branch of medicine known as pediatrics.[1] The pediatric age group includes children up to 18 years of age (infant, toddler, preschool, school, and teen). Childhood mortality is a reliable indicator of the healthcare facilities of a country and its development.[2]

To find out the cause of death in children and whether it is a natural or unnatural death is the need of the hour. India is rapidly moving toward becoming a developed country, but there are still cases of female infanticide, illegal abortion, premature delivery of children, and children's deaths due to pneumonia, diarrhea, and other causes. Determine the cause of death, age in case of unknown, and whether live-born or stillborn is very challenging for an autopsy surgeon. There were also cases of deaths of children due to assault; in such cases, examining the pattern of injuries and giving an opinion about the cause and manner of death is again a very challenging task for an autopsy surgeon. Nowadays, we are seeing an increase in the number of suicide cases among adolescents because of unstable mindsets, which create undue pressure and stress on the child, starting from strained relationships between the parents, high-performance expectations in academics, comparison with other children, a sense of self-neglect, and other contributing factors. The pattern of deaths has changed from infections to social etiologies during the last 10 years.[3] Due to the emerging effects of social, physiological, economic, and medical issues, injury and violence are

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one of the major killers of children and young adults under the age of 18 years throughout the world.[3]

Objectives

The objective of this study was to determine the pattern of deaths in the pediatric age group, which will contribute to the establishment of a database for the formulation of national and international policies helping to lower the mortality rate in the pediatric age group.

Material and Methodology

The present study is a retrospective study of autopsies in the pediatric age group performed in the Department of Forensic Medicine and Toxicology at the Medical College, Indore, from January 2023 to December 2023, and a total of 271 pediatric cases were analyzed. No objection certificate has been obtained for this study from the institutional ethical committee as per the guidelines. Information regarding the deceased's age, sex, incident duration (month-wise), and cause of death was collected from the department records, police inquest papers, and postmortem reports. A pro forma has been formed to collect data. The collected data was compiled on an Excel sheet, observed, and the results were drawn.

Results

During this study period, a total of 271 pediatric cases were brought to our department for post-mortem examination, out of which 170 cases (62.90%) were male and 101 cases (37.10%) were female (Figure 1).

Taking the age group into consideration, the maximum number of male cases, 97 (35.80%), were in the age group of 12–18 years (35.80%), followed by the 5–12 years of age group with 22 cases (8.10%). Similarly, in females also, the 12–18 years age group has the maximum number of cases, that is, 70 cases (25.80%), followed by the 5–12 years age group with 10 cases (3.69%). The least number of males was 13 cases (4.79%) belonging to the age group of 0–1 year (4.79%), and the least number of females was 6 cases (2.21%) belonging to the same age group as males. Considering the overall population, the 12–18-year age group had the maximum number of cases, with 167 cases (61.50%), whereas the 0–1-year age group had the lowest number with 19 cases (7.00%) (Table 1).

Among all the 271 cases in the present study, natural death cases were 34 cases (12.50%), which includes death due to pathological cause and congenital anomaly, and unnatural death cases were 214 cases (78.9%), Out of 214 cases of unnatural deaths, the maximum number of cases were of accidents, 136 cases (50.4%), followed by suicide, 73 cases (26.7%), and the least number of cases were homicidal, 5 cases (2.0%). In 23 cases (8.40%), the manner of death could not be determined (Table 2).

In the present study, unintentional deaths were present in 170 cases (62.90%), which included deaths due to road traffic accidents (RTA), burns, electrocution, drowning, pathology, and congenital anomaly. Intentional deaths were present in 78 cases (28.70%), which included deaths due to hanging, poisoning, assault, and firearm cases. Intention could not be determined in 23 cases (8.40%) (Table 3).

In our study, it was observed that RTA was the most common cause of death in the pediatric age group, involving 98 cases (36.10%), in which death due to head injury was found in 53 cases (19.70%), and death due to multiple injuries was found in 45 cases (16.60%). The second most common cause of death in the pediatric age group was poisoning in 42 cases (15.49%), followed by pathological deaths in 33 cases (12.25%) (including cardiac pathology, lung pathology, and brain pathology). Deaths due to hanging were seen in 31 cases (11.43%). Deaths due to burns were found to be present in 18 cases (6.60%) (including thermal burns and

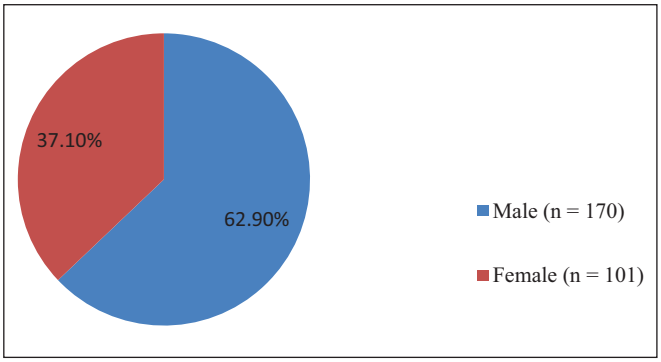

Figure 1. Gender-wise Distribution of Cases (*n* = 271).

Table 1. Age- and Gender-wise Distribution of Cases (*n* = 271).

Age	Male	Female	Total
0–1 years (infant)	13 (4.79%)	06 (2.21%)	19 (7.00%)
1–3 years (toddler)	20 (7.38%)	07 (2.58%)	27 (10.00%)
3–5 years (pre-school)	18 (6.84%)	08 (2.85%)	26 (9.60%)
5–12 years (school)	22 (8.10%)	10 (3.69%)	32 (11.90%)
12–18 years (teen)	97 (35.80%)	70 (25.80%)	167 (61.50%)
Total	170 (62.90%)	101 (37.10%)	271 (100%)

Table 2. Manner of Death-wise Distribution of Cases (*n* = 271).

Manner of Death		Male	Female	Total
Natural	Pathology	19 (7%)	14 (5.2%)	33 (12.2%)
	Congenital anomaly	01 (0.3%)	0 (00%)	1 (0.3%)
Unnatural	Accidental	86 (32%)	50 (18.4%)	136 (50.4%)
	Suicidal	42 (15.4%)	31 (11.33%)	73 (26.7%)
	Homicidal	04 (1.5%)	01 (0.4%)	5 (2.0%)
Unknown		18 (6.5%)	05 (1.80%)	23 (8.40%)
Total		170 (62.90%)	101 (37.10%)	271 (100%)

Table 3. Intentions-wise Distribution of Cases (*n* = 271).

Pattern of Death	Male	Female	Total
Intentional	46 (16.90%)	32 (11.80%)	78 (28.70%)
Unintentional	106 (39.40%)	64 (23.61%)	170 (62.90%)
Unknown	18 (6.64%)	05 (1.80%)	23 (8.40%)
Total	170 (62.90%)	101 (37.10%)	271 (100%)

scald burns). Deaths due to drowning are present in 15 cases (5.50%), while 5 (2.00%) children died due to electrocution. Death due to assault was also present in 3 cases (1.00%), including stab injuries, and multiple injuries over other parts of the body. Deaths due to firearm injuries in the pediatric age group were found in 2 cases (0.73%). There were 23 cases in which the cause of death could not be determined during the time of autopsy (8.40%) (Table 4, Figure 2).

In males, the most common cause of death was RTA (44.70%), followed by poisoning (8.11%), and in females, the most common cause of death was poisoning (7.38%), followed by RTA (7.0%). The least common cause of death in males was death due to congenital anomaly, present in 1 case (0.3%), followed by death due to assault and firearm injuries with 2 cases (0.73%) each. In females, the least common cause of death was assault, present in 1 case (0.30%), followed by electrocution in 2 cases (0.70%) (Table 4, Figure 2).

Discussion

In the present study, out of 271 cases, 170 (62.90%) were male and 101 (37.10%) were female, indicating male predominance. This similar finding of male predominance was observed in various other studies conducted in the pediatric age group, such as the study done by Punia et al.[1] who studied 65 cases, out of which 40 cases (61.54%) were male and 25 cases (38.46%) were female; Rathod et al.[2] with 55.9% males; and Khanna et al.[4] with 56.4% males. The reasons contributing to male predominance, especially in the teenage group, are their greater involvement in outdoor activity as compared to their female counterparts, making them more vulnerable to accidental deaths. Males in the teenage group were also more involved in violent activity, crimes, and substance use, such as drugs and alcohol, making them more prone to accidental, suicidal, and homicidal-related deaths.

In our study, the most common age group involved in all the cases and in both sexes was 12–18 years, which involved 167 cases (61.50%), followed by 5–12 years with 32 cases (11.90%), which is consistent with the study conducted by Rathod et al.[2] showing the most common age group is 12–17 years with 106 cases, but the second most common age group in their study was 0–3 years with 62 cases. Similar findings were also seen in various other studies conducted in the pediatric age group, such as Varma et al.[3] showing 82.2% of cases belonging to the 12–18 years, and the study by Pathak A.K.[5] with 71.7% of cases in the 11–19 years of age group. These findings are inconsistent with the study done by Khanna et al.[4] in which the most common age group affected was 5–10 years. Children in the 12–18 years of age group were frequently involved in outdoor activities such as going to school, attending tuition, playing sports, going camping, and taking trips, which make them more vulnerable to accidental deaths. Also, children of the 12–18 years age group were involved in love affairs, drug or alcohol addiction, and their more competitive behavior, which may affect them physically and psychologically, resulting in committing suicide and homicide.

In our present study, natural deaths were seen in 34 cases (12.50%) and unnatural deaths in 214 cases (78.9%). Among the unnatural deaths, accidental deaths were the most common, seen in 136 cases (50.40%), followed by suicidal deaths in 73 cases (26.7%), and the least common were homicidal deaths, which occurred in 5 cases (2.0%). Similar findings are observed in the study conducted by Rathod et al.[2] Varma et al.[3] and Kumar et al.[6] The unnatural deaths in children indicate the developmental status of a country. These deaths are avoidable by proper education and awareness among the parents, and also by the implementation of strict legislation.

Table 4. Cause of Death-wise Distribution of Cases (n = 271).

Cause of Death		Male	Female	Total
Head injury	RTA	34 (12.7%)	19 (7.00%)	53 (19.70%)
Multiple injuries		29 (10.7%)	16 (5.9%)	45 (16.60%)
Assault		02 (0.70%)	01 (0.3%)	3 (1.00%)
Burn		11 (4.05%)	07 (2.55%)	18 (6.60%)
Pathology		19 (7.01%)	14 (5.24%)	33 (12.25%)
Poisoning		22 (8.11%)	20 (7.38%)	42 (15.49%)
Hanging		20 (7.38%)	11 (4.05%)	31 (11.43%)
Drowning		09 (3.30%)	06 (2.20%)	15 (5.50%)
Congenital anomaly		01 (0.3%)	00 (00%)	1 (0.3%)
Electrocution		03 (1.30%)	02 (0.70%)	5 (2.00%)
Firearm injury		02 (0.73%)	00 (00%)	2 (0.73%)
Unknown		18 (6.60%)	05 (1.80%)	23 (8.40%)
Total		170 (62.90%)	101 (37.10%)	271 (100%)

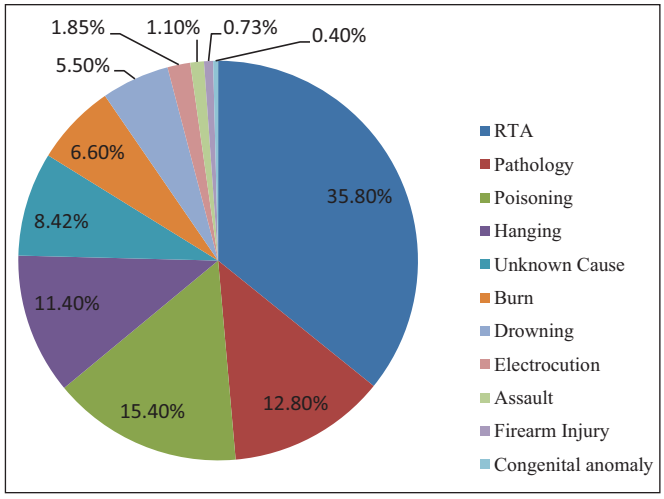

Figure 2. Cause of Death-wise Distribution of Cases (n = 271).

Unnatural deaths are common in children because of many reasons, such as improper care and guidance of the children by parents and elders, not following the traffic rules because of improper or incomplete knowledge and training, improper safety measures near the construction sites and roads in residential areas, and many more.

In this study, observations were also done on the basis of intentions. Out of the total 271 cases, an unintentional pattern of death was found in 170 cases (62.90%), and an intentional pattern was found in 78 cases (28.7%). This finding is consistent with the study done by Punia et al.[1] and Sonawane et al.[7] in which unintentional deaths were seen in 49 cases (75.3%) and 55 cases (70.5%) respectively. But in contrast to our study, Varma et al.[3] study showed intentional death (60%) was more than unintentional deaths (40%). The majority of unintentional deaths can be prevented by properly guiding and communicating with children about the safety and preventive measures, and also by improving healthcare facilities and promoting routine vaccination. Intentional death can also be prevented by healthy routine communication of teachers and parents with children and making them aware of the pros and cons of their unhealthy behavior toward themselves or toward others, also by supporting and motivating them in their bad situation, such as failure in exams, love failure, and many more. by proper guidance. We also need to improve our behavior toward children by stopping blaming them for their mistakes. Instead of blaming the children for their mistakes, we should try to teach them to correct them, reduce the restrictions, and lessen the burden of studies. Stop putting an overbearing burden of study on them, and also stop putting too many restrictions on their daily activities.

In the present study, the most common cause of death was RTA, accounting for 98 cases (36.1%). The second major cause of death was poisoning in 42 cases (15.49%), followed by hanging in 31 cases (11.4%), and burns in 18 cases (6.60%). The least common cause of death is congenital anomaly, 1 case (0.3%), followed by firearm injury, 2 cases (0.73%). Similarly, in other studies done by Punia et al.[1] Rathod et al.[2] and Khanna et al.[4] RTA accounts for the major cause of death. RTA was the major cause of death in males, which can be due to rash driving by adolescents and not following traffic rules and regulations. Whereas, deaths due to poisoning and hanging indicate an increase in the number of suicidal deaths, and are helpful for us to know that children are getting ideas of suicide because of easy access to social media, which influences them to take such steps. Parents and caretakers must give utmost importance to paying attention to their child, what their child is doing, and if using a mobile phone, they must keep an eye on the content watched by children and try to explain to them the harmful effects of social media.

Conclusion

The analysis of pediatric deaths was an effort to elucidate the various aspects of pediatric death and establish the profile. This study helps us to interpret the general profile of pediatric deaths and the various factors affecting the death rate. As we observed, the male population is more prone to RTA deaths, which are caused by rash and negligent driving by adolescents, not following the traffic rules and regulations, and not using proper safety precautionary measures. So, steps must be taken to give knowledge to adolescents and their parents about road safety rules, and by strengthening and reinforcing legislation in time to avoid deaths due to RTAs. It was also observed that female children, especially teens, are more prone to commit suicide by either consumption of poison or by hanging, which indirectly indicates the social and mental pressure faced by females in day-to-day life, which can be avoided by comforting her, and a friendly environment should be generated by parents so a girl child can express her emotions and incidents that happened with her. Children are more eager to explore their environment, which in turn makes them more vulnerable to injuries. Their risk perception is very much limited; hence, they are more prone to accidental deaths (RTA, burns, drowning, and electrocution). Parents must explain to their children the importance of life and also should assure them and provide them with the security and safety needed.

Recommendations

As in our study, accidental deaths were major in number, and among them, the major cause of death was RTA, so to reduce such types of deaths, the government should focus more on strict implementations of rules for the pediatric age group and start various programs and courses in schools to teach them about the importance of traffic rules and the employment of safety methods regarding the same.

Similarly, in our study, the second most common manner of death is suicide, so to reduce suicidal deaths, schools should start the mentor-mentee program so that the students can comfortably share their problems with their respective mentors. Also, various social programs should be started by the government to teach parents how to create a child-friendly environment at home and deal with problems related to the adolescent age group.

As we also see in our study, the number of pathological deaths was also high, so to reduce such kinds of deaths, the government should be focusing on linking various pediatric age group health programs with multiple government schemes; for example, parents have to attend the pediatric age group health programs compulsorily, to avail the advantages, and benefits of various government schemes.

Declaration of Conflicting Interests

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Profile of Unnatural and Non-accidental Deaths Among Females: An Autopsy-based Prospective Study in a Tertiary Care Hospital of Ganjam District, Odisha

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Abstract

Gender-based violence is recognized as a major public health concern and an intolerable violation of human rights. Unnatural death refers to fatalities from external causes, including intentional injury such as homicide or suicide, and accidental deaths. This study examined unnatural and non-accidental deaths among females of all age groups to suggest measures for reducing mortality and morbidity. Between September 1, 2018, and August 31, 2020, in the Department of Forensic Medicine, MKCG Medical College, Berhampur, Ganjam, 259 cases meeting inclusion criteria were analyzed using MS Excel and SPSS version 22. The highest deaths occurred in females aged 20–39, comprising 52% of cases. Suicide was predominant, accounting for 89.2%, while homicide was 10.8%. Most homicides resulted from mechanical injuries by assault (85.7%), with sharp-cutting weapons causing 50% and blunt weapons 30%. Poisoning was the most frequent suicide method at 67.5%. Family disputes accounted for 60.6% of underlying reasons for suicide or homicide, followed by love affairs at 34.4%. Illiterate and undereducated females were more vulnerable due to lack of rights awareness, whereas qualified women showed the least incidence. Marital disharmony, family disputes, and dowry demands remained major causes of unnatural deaths among women.

Keywords

Homicide, suicide, sharp-cutting weapon, blunt weapon

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Introduction

The term "unnatural death" refers to death brought on by outside factors, such as intentional injury—like murder or suicide—or accidental injury and death. Any death that results from a deliberate act and has a purpose is considered intentional.[1] It is now acknowledged that gender-based violence is a serious public health issue and an unacceptable human rights violation. Because of the dominant values, norms, and customs of many societies, as well as personal shame, guilt, fear of retribution, and the social taboo associated with victimization, the majority of abuse and torture go unreported to neighbors, family members, clinicians, and researchers.

The relationships between spouses and family members, social standing, health, education, and financial independence—all of which are critical to a woman's or any person's well-being in the modern world—are the factors that influence unnatural deaths in women. As per NCRB data 2018, the number of suicides all over India in 2017 was 129,887, and in 2018, the number was 134,516, with a percentage increase of 3.6%. The data in Odisha in 2017 is 4,493, and in 2018 is 4,592, with a percentage increase of 2.2%. The purpose of the study was to identify various factors that contribute to unnatural and non-accidental deaths in females of all ages and to recommend appropriate actions to lower the mortality and morbidity rates among the same.

Objectives

To estimate the incidence of homicidal and suicidal deaths in females in this part of the state, so that it will be beneficial to develop preventive strategies to reduce the incidence in the future.

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To know epidemiological aspects like age, marital status, literacy, occupation, cause of death, perpetrating factors, etc.

To study the means of fatal injuries in homicidal and suicidal deaths in females.

Methods and Materials

It is a prospective study conducted among the female victims of homicide and suicide of all age groups in the Department of Forensic Medicine, MKCG Medical College, Berhampur, Ganjam, from September 1st, 2018 to August 31, 2020, after approval by the Institutional Ethical Committee. The detailed history of the incident and the circumstances related to the incident were taken from the friends and relatives and the police in a predesigned proforma. Other details like history, family history, behavioral history, and psychological history were also taken in the predesigned proforma. The inclusion criteria consist of all female dead bodies of all age groups brought for autopsy with a history of homicide and /or suicide. All proven accidental death cases, natural death cases, and cases of obscure autopsy were excluded from the study. A total of 259 cases that met the various inclusion and exclusion criteria were included in the study out of a total 2649 numbers of autopsies conducted in the department during the study period. The data collected was entered into MS Excel, and the data was analyzed using SPSS version 22.

Result

In Table 1, out of the total 813 female dead bodies brought for autopsy during the study period, 259 were due to unnatural/non-accidental causes, constituting 31.85% of the total. The remaining 68.15% were due to natural/accidental causes.

From Table 2, the highest percentages (34.7%) of deaths were found in the age group of 20–29, followed by 10–19 (24.7%). The mean age of cases was 30.343 ± 14.69 years. The range was between 9 and 76 years. The incidence of deaths due to unnatural and non-accidental causes decreases with advancing age beyond the fourth decade.

The highest (59.1%) number of cases was found among married ladies, followed by unmarried (33.6%), and widows (7.3%) constituted the least (Table 3).

A maximum number (60.6%) of the deceased had an educational qualification between the 5th and 12th standards. A good number of deceased also belonged to the illiterate (15.1%) and graduation and above categories (11.2%) (Table 4).

Suicide constituted 89.2% whereas homicide was the manner of death in 10.8% of cases (Table 5).

Out of the total 28 homicides, the majority (85.7%) was due to assault, followed by burning (10.7%), and the least common (3.6%) method was drowning (Table 6).

Almost half of the cases (50%) of assault were done by sharp-cutting weapons, followed by blunt weapons (30%). Ligature strangulation and manual strangulation (throttling)

Table 1. Distribution of the Total Number of Deaths Due to Various Causes Among Females During the Study Period that Came for Autopsy.

Unnatural and Non-accidental	Natural and Accidental	Total
259 (31.85%)	554 (68.15%)	813

Table 2. Distribution of Deaths Due to Unnatural and Non-accidental Causes Among Females According to Their Age Group.

Sl. No.	Age Group	Frequency	Percentage
1	<9 years	1	0.4
2	10–19 years	64	24.7
3	20–29 years	90	34.7
4	30–39 years	45	17.4
5	40–49 years	23	8.9
6	50–59 years	15	5.8
7	60–69 years	15	5.8
8	>70 years	6	2.3
	Total	259	100.0

Table 3. Distribution of Death Due to Unnatural and Non-accidental Causes Among Females According to Marital Status.

Sl. No.	Marital Status	Frequency	Percentage
1	Married	153	59.1
2	Unmarried	87	33.6
3	Widow	19	7.3
	Total	259	100.0

Table 4. Distribution of Death Due to Unnatural and Non-accidental Causes Among Females According to Educational Status.

Sl. No.	Literacy	Frequency	Percentage
1	Illiterate	39	15.1
2	Up to 5th Std	34	13.1
3	5th–10th Std	69	26.6
4	10th–12th Std	88	34.0
5	Graduate and above	29	11.2
	Total	259	100.0

Table 5. Distribution of Death Due to Unnatural and Non-accidental Causes Among Females According to Manner of Death.

Sl. No.	Manner of Death	Frequency	Percentage
1	Homicide	28	10.8
2	Suicide	231	89.2
	Total	259	100.0

Table 6. Distribution of Homicidal Deaths Among Females According to the Method Used.

Sl. No.	Cause of Death According to the Method Used	Frequency	Percentage
1	Assault	24	85.7
2	Burning	3	10.7
3	Drowning	1	3.6
	Total	28	100

Table 7. Distribution of Homicidal Deaths Among Females According to Means of Assault.

Sl. No.	Cause of Death According to Means of Assault	Frequency	Percentage
1	Blunt weapon	7	30
2	Firearm	1	4
3	Sharp-cutting weapon	12	50
4	Ligature strangulation	2	8
5	Throttling	2	8
	Total	24	100

Table 8. Distribution of Homicidal Deaths Among Females According to Location of Incident.

Sl. No.	Location of Incidence	Frequency	Percentage
1	Home	24	85.7
2	Away from home	4	14.3
	Total	28	100

Table 9. Distribution of Suicidal Deaths Among Females According to the Cause of Death.

Sl. No.	Cause of Death in Suicide	Frequency	Percentage
1	Poisoning	156	67.5
2	Hanging	59	25.5
3	Burning	15	6.5
4	Railway	1	0.5
	Total	231	100

were used in 8% of cases each, and only one case (4%) of assault by firearm was found (Table 7).

Of the total 28 homicide cases, 85.7% were recorded at home, and only 14.3% of cases occurred away from home (Table 8).

Out of a total 231 numbers of suicide cases, poisoning was responsible for the maximum number (67.5%) of deaths, constituting more than half of the cases, followed by hanging (25.5%). Burning was seen in 15 cases, constituting 6.5% of cases and suicide by railway was observed in one case (0.5%) only (Table 9).

Table 10. Distribution of Death Due to Unnatural and Non-accidental Causes Among Females According to Alleged Perpetrator/Abettor.

Sl. No.	Alleged Perpetrator/ Abettor	Frequency	Percentage
1	Blood relatives	34	13.1
2	Father	67	25.9
3	Husband	107	41.3
4	In-laws	33	12.7
5	Mother	1	0.4
6	Other	17	6.6
	Total	259	100.0

Table 11. Distribution of Death Due to Unnatural and Non-accidental Causes Among Females According to the Underlying Reason for Suicide/Homicide.

Sl. No.	Underlying Reason for Suicide/Homicide	Frequency	Percentage
1	Family dispute	157	60.6
2	Love affair	89	34.4
3	Not known	5	1.9
4	Other	8	3.1
	Total	259	100.0

The husband was the alleged perpetrator/abettor in the largest number of cases, constituting 41.3% of total cases, followed by the father (25.9%). The in-laws were responsible in 12.7% of cases, whereas blood relatives were responsible in 13.1% of cases (Table 10).

Family disputes were responsible for the highest number (60.6%) of cases, followed by love affairs (34.4%). In 3.1% of cases, other causes than the above two were responsible, whereas in 1.9% of cases, the reason could not be assessed (Table 11).

Discussion

During the study period, among the total of 813 female cases that were subjected to autopsy, 259 deaths were due to unnatural and non-accidental causes and were included for the study purpose. This constituted 31.85% of the total number of female autopsies. The lesser number of deaths among females appears to be due to several factors, such as low sex ratio, predominant confinement of females indoors, and also lesser exposure of females to quarrels, violence, etc.

About 59.1% of the study subjects were married. A total of 33.6% were unmarried, and only 7.3% of the subjects were widows. Kitulwatte et al.[2] also found that most victims, 81%

were married. Anitha[3] found in the married group, maximum cases (33.65%) were seen belonging to 0–7 years of married life, whereas three out of four cases of homicide were seen in 0–7 years of married life.

A total of 34.0% of the study subjects had an education of 10th–12th standard, followed by 26.6% of the population with study up to 5th–10th standard. A total of 15.1% were illiterate. Anitha[3] in her study found the maximum number, that is, 43.90% studied High School, followed by intermediate/diploma 21.46% and middle school 19.02%. A study by Hussain et al.[4] showed a maximum number of cases in the illiterate group. From the study, it is evident that the highest number of deaths occurred between 20 and 39 years of age, accounting for about 52% of the total caseload. This is very critical, as this is the age that is among the most productive groups. Also, it was found that several incidents, from violence to suicides, are common in this age group.

Suicide was the most common manner of death, which was observed and amounted to 89.2% followed by homicide, which amounted to only 10.8%. Similar findings were also noted in studies by Srivastava et al.[5] and Radhika et al.[6] The increased incidence of suicide among females is due to depression as a result of domestic violence, marital disharmony, dominance by the male members of the family, reluctance of parents to allow for higher study, failure in love affairs, etc. The predominant means of death in suicidal cases was poisoning (67.5%), followed by hanging (25.5%). Burning was found in 6.5% of cases, and only one case (0.5%) of suicide by railway was found. Family dispute (60.6%) was the most common underlying reason for both suicide and homicide. It was followed by love affairs (34.4%). The reasons were unknown for 1.9% of cases.

The most common (85.7%) cause of death in homicide cases was found to be assault, followed by burning in 10.7% of cases, and only one case (3.6%) of homicidal drowning was encountered during the study period. Considering the methods of assault, almost half of the cases (50%) of assault were caused by sharp-cutting weapons, followed by blunt weapons (30%). Ligature strangulation and manual strangulation (throttling) were used in 8% of cases each, and only one case (4%) of assault by firearm was found. Similar findings were observed in the study by Kitulwatte et al.,[2] where sharp injuries accounted for the majority of murders (39%). Kiran Kumar Patnaik et al.,[7] observed that strangulation or smothering, amounting to 48.5% of cases, was the most common cause of homicidal deaths in women of reproductive age, and 30.9% of cases of burns were next on the list. Other (firearm, blast, sharp-cutting injuries, stab injuries) causes were encountered in 13.2% of cases and poisoning, at least, that is, 7.3% number of homicides.

The husband was the alleged perpetrator/abettor in the highest percentage (41.3%) of the cases; followed by the father (25.9%), other blood relatives (13.1%), and in-laws 12.7%. In 6.6% of cases, the perpetrator/abettor was not known. Kitulwatte et al.[2] found similar data, constituting that the alleged perpetrator in 30.5% of homicides was the husband, while a similar percentage was inflicted by a known person to the victim. Rajesh Kumar Verma et al.,[8] also found that quarrels with husband/in-laws and dowry demands by a husband or his family members were two important reasons behind suicidal as well as homicidal deaths. Home was the most common location of the incident for both suicide and homicide. 96% of suicides and 85.7% of homicides took place inside the home. Only 4% of suicides and 14.3% of homicides were reported from somewhere other than home. Kitulwatte et al.,[2] also found similar data, constituting most of the suicides (84%) as well as homicides (76%) taking place at home. Mohanty et al.[9] also observed that the majority of victims (84.6%) were killed in their homes. This is so because female persons usually stay inside the home the whole day and are engaged in household work only. Only a small fraction is employed in some office or business, so they have to go outside.

Conclusion

Out of the total 813 females that came for autopsy during the study period, 259 were due to unnatural/non-accidental causes, constituting 31.85% of the total.

Of the 259 cases included in the study, the mean age of cases was 30.3 43 ± 14.69.

The highest (34.7%) number of deaths was found in the age group of 20–29, followed by 10–19 years (24.7%). 59.1% of the study subjects were married, and a total of 34.0% of the study subjects had education up to 10th–12th standard. Most of them were married and housewives, 59.1%. The majority resided in joint families (56%). Suicide was the most common manner of death, 89.2%. The most common means of homicide was assault, inflicting mechanical injuries at 85.7%. Half of the cases (50%) of assaults were caused by sharp-cutting weapons, followed by blunt weapons (30%). The most common means of suicide was poisoning, 67.5% followed by hanging, 25.5%. 44% of the cases occurred in the late hours of the day, that is, after 12 noon to 8:00 PM. Husband was the alleged perpetrator in 41.3% of cases, and home was the most common location of the incident in both homicide and suicide cases. Family dispute was the most common (60.6%) underlying reason for suicide or homicide, followed by love affairs (34.4%).

Suggestions

The following are the steps that can be taken at various levels to prevent unnatural death in females.

1. Suicide is a social problem that is preventable by boosting confidence and courage.
2. Creating awareness about dedicated suicide helplines for women in distress. Giving ample freedom to the other spouse.

3. Discouraging dowry demands and costly and ostentatious marriage rituals through education.
4. Counseling to deal with love failure, exam stress, and inter-familial disputes are reasons for a handful of cases.
5. Pre-employment counseling among working couples to beat stress and work-related issues and to promote a healthy work-life.
6. Education about stress management for women, such as meditation, exercise, yoga, counseling, and group therapy, to help beat stress and depression.
7. Proper assessment of the symptoms and prompt treatment for women suffering from physical illness and mood disorders.
8. Promoting literacy and professional courses and encouraging employment among girls to make them economically independent at the time of marriage.

By addressing these issues related to women and by implementing the preventive measures suggested, unnatural deaths in women of reproductive age can be reduced, thereby helping in the progression of society, community, state, and the Nation.

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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Informed Consent

Consent was not required as the data was collected about the dead persons and in medico-legal cases only, without exposing the identity of the deceased.

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E-cigarette and Vaping-associated Lung Injury (EVALI): A Systematic Review of Forensic Pathology and Toxicological Perspectives

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Abstract

E-cigarette and vaping-associated lung injury (EVALI) has emerged as a significant public health concern, leading to severe respiratory complications and fatalities worldwide. This systematic review analyses the medico-legal implications of vaping-related deaths, emphasizing postmortem toxicology, autopsy findings, and medico-legal challenges. A comprehensive literature search was conducted across multiple databases, including PubMed, Scopus, Web of Science, Embase, and Google Scholar, to identify relevant studies from 2010 onward. A total of 280 studies were identified, of which 11 met the inclusion criteria, covering 156 cases across multiple countries. The findings indicate that tetrahydrocannabinol (THC) and nicotine exposure vary geographically, with vitamin E acetate being a primary suspect in EVALI-related toxicity. Autopsy results commonly reveal bilateral lung opacities, diffuse alveolar damage, and lipid-laden macrophages, often leading to misdiagnoses such as COVID-19 pneumonia. Forensic investigations face challenges in establishing standardized diagnostic criteria, determining the exact cause of death, and addressing regulatory gaps in e-cigarette formulations. Despite corticosteroid therapy and vaping cessation being the mainstay of treatment, fatalities still occur, underscoring the need for stringent regulatory policies and improved forensic assessment techniques. This review highlights the importance of postmortem toxicology in differentiating vaping-related deaths from other pulmonary conditions, providing critical insights for forensic pathologists, toxicologists, and policymakers. Medico-legal experts must adopt a standardized investigative protocol to accurately document and analyze EVALI-related cases to guide future public health planning. The protocol for this systematic review was registered prospectively with International Prospective Register of Systematic Reviews (PROSPERO) (CRD420251041017).

Keywords

E-cigarette and vaping-associated lung injury (EVALI), e-cigarettes, vaping-related deaths, forensic toxicology, lung injury, toxicological analysis

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Introduction

The rise of e-cigarette use has sparked global concerns regarding its health consequences, particularly the emergence of e-cigarette and vaping-associated lung injury (EVALI). Since its initial recognition by the Centers for Disease Control and Prevention in 2019, EVALI has been implicated in numerous hospitalizations and deaths, highlighting the potential lethality of vaping-related complications.[1] The exact pathophysiology remains under investigation, but studies suggest that chemical exposure from vaping devices, particularly vitamin E acetate and other toxic substances, plays a critical role in the onset of lung injury.[2]

From a forensic perspective, vaping-related deaths present significant challenges in terms of autopsy findings, toxicological analysis, and determination of the cause and manner of death. Unlike traditional cases of respiratory failure or pulmonary toxicity, EVALI-related fatalities exhibit

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distinct pathological characteristics, including diffuse alveolar damage, lipid-laden macrophages, and acute lung injury.[3] Additionally, forensic toxicologists must navigate the complexities of analyzing various vaping-related compounds, including nicotine, tetrahydrocannabinol (THC), and heavy metals, which may contribute to fatal outcomes.[4]

Beyond the pathological and toxicological dimensions, forensic investigations must also consider legal and policy implications. The rapid evolution of the vaping industry, coupled with inconsistencies in regulatory frameworks, complicates efforts to establish clear forensic guidelines.[5] Moreover, distinguishing between accidental, suicidal, and homicidal cases involving vaping-related deaths adds another layer of complexity for forensic pathologists and medical examiners.[6]

While EVALI was first recognized in the United States, cases have since been reported globally, including in Canada, the United Kingdom, India, and Japan. Variations in vaping habits, product formulations, and surveillance affect the reported prevalence.

This systematic review aims to provide a comprehensive analysis of the forensic implications of vaping-related deaths, synthesizing available literature on postmortem findings, toxicological profiles, and investigative challenges. By consolidating current knowledge, this review will contribute to improved forensic protocols, enhance the understanding of EVALI's impact on mortality, and inform regulatory policies aimed at mitigating vaping-related health risks.

Objectives

- To analyze postmortem findings in vaping-related deaths.
- To review toxicological profiles associated with EVALI fatalities.
- To identify forensic challenges in determining cause and manner of death in vaping-related cases.
- To propose forensic guidelines related to vaping-related deaths.

Forensic Relevance of this Review

Given the increasing complexity of vaping-related fatalities, this review holds critical forensic relevance by offering insights that can aid in accurate postmortem diagnosis, toxicological interpretation, and the determination of the cause and manner of death in suspected EVALI cases.

Methods

Search Strategy

A comprehensive and systematic literature search was conducted using the following electronic databases:

- PubMed (for medical and forensic pathology studies)
- Scopus (for interdisciplinary research, including toxicology and forensic science)
- Web of Science (for high-impact forensic and medical literature)
- Embase (for pharmacological and toxicological aspects)
- Google Scholar (for gray literature, policy documents, and relevant conference proceedings)

Search Terms and Boolean Operators

A structured search strategy was applied using Medical Subject Headings and free-text terms. The search will include variations and synonyms of the following:

- EVALI-related terms: "EVALI," "e-cigarette or vaping-associated lung injury," "vaping-related deaths," "vaping lung disease."
- Toxicological aspects: "Electronic cigarette toxicity," "nicotine poisoning," "THC toxicity," "vitamin E acetate poisoning," "heavy metal exposure in vaping."
- Forensic implications: "Forensic pathology," "autopsy findings," "postmortem toxicology," "cause and manner of death," "sudden unexplained deaths in vaping."

A combination of these terms was applied using Boolean operators: ("EVALI" OR "vaping-related deaths" OR "electronic cigarette toxicity") AND ("forensic pathology" OR "autopsy findings" OR "toxicology" OR "cause of death").

Search Limits

- Timeframe: Studies published from 2010 to present (considering the recent emergence of vaping-related lung injuries)
- Language: English
- Study Types: Case reports, case series, retrospective studies, systematic reviews, meta-analyses, and forensic investigations

Manual Search and Citation Tracking

- Reference lists of selected articles were reviewed to identify additional relevant studies.
- Key forensic and toxicology journals were manually searched.
- Government and regulatory reports on EVALI-related forensic cases were examined.

Inclusion Criteria

- Studies reporting postmortem findings in vaping-related deaths.

- Studies discussing forensic toxicology in EVALI cases.
- Case reports, case series, retrospective studies, systematic reviews, and meta-analyses.
- English language publications.

Exclusion Criteria

- Studies without forensic relevance.
- Experimental or animal model studies.
- Non-English language articles.

Data Extraction and Analysis

Two independent reviewers extracted relevant data, including:

- Case demographics (age, sex, and region)
- Cause of death
- Toxicological findings (nicotine, THC, vitamin E acetate, heavy metals, etc.)
- Pathological findings (lung histopathology, systemic effects)
- Legal and forensic challenges in interpretation

PROSPERO Registration

The protocol for this systematic review was registered prospectively with the International Prospective Register of Systematic Reviews (PROSPERO). Details are as follows: Available from: https://www.crd.york.ac.uk/PROSPERO/view/CRD420251041017.

Quality Assessment and Risk of Bias Assessment (Figure 2)

The Joanna Briggs Institute (JBI) Critical Appraisal Checklist was used to assess the quality of the included articles. Since our review encompasses observational studies, case reports, and case series, the JBI checklist is the most appropriate tool for evaluation. The stacked bar chart, as displayed in Figure 1, illustrates JBI checklist scores across five countries, namely Denmark, India, Italy, the UK, and the USA, based on six assessment criteria: Patient demographics, pre-intervention condition, intervention clarity, post-intervention reporting, adverse event consideration, and takeaway message. Variations in stacked segments highlight differences in study rigor and adherence to JBI quality standards. In our review articles, all JBI checklist criteria were satisfied, ensuring methodological rigor and reliability in our findings.

Results

A total of 280 studies were identified through database searching and other sources, with 230 remaining after duplicates were removed. Following title and abstract screening, 110 studies were excluded due to lack of forensic relevance, non-English language, or experimental models. 120 full-text articles were assessed, of which 11 studies met the inclusion criteria, covering 156 cases across multiple countries, including the USA, UK, Italy, Denmark, and India. The studies consisted of four case reports, four case series, two website reports, and one original research study, highlighting geographical differences in vaping exposure and forensic challenges.

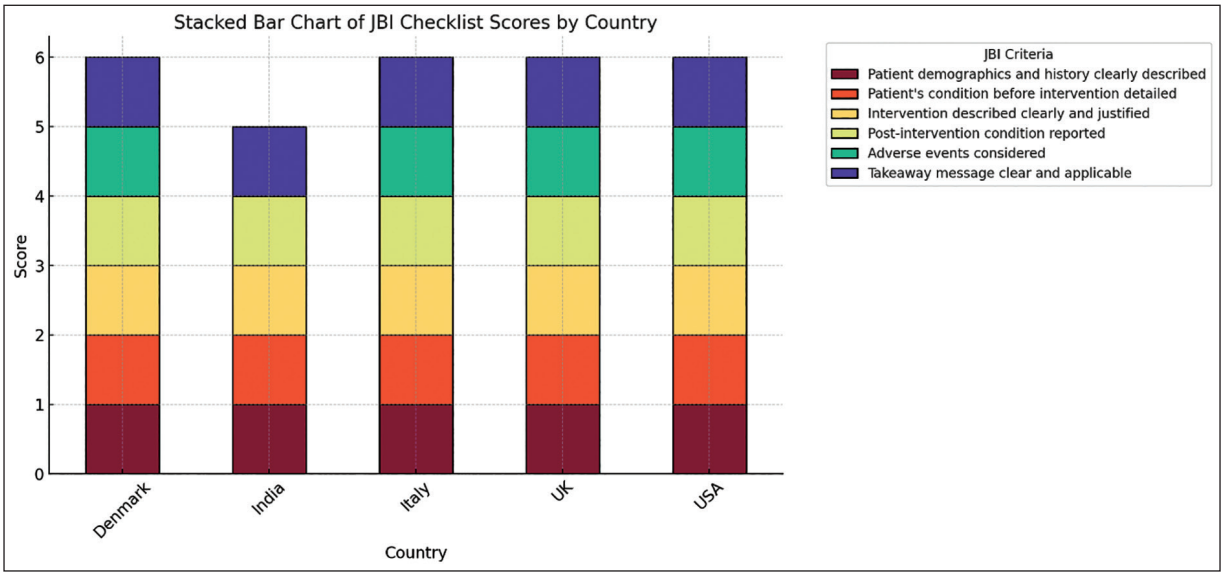

Figure 1. Stacked Bar Chart of JBI Checklist by Country.

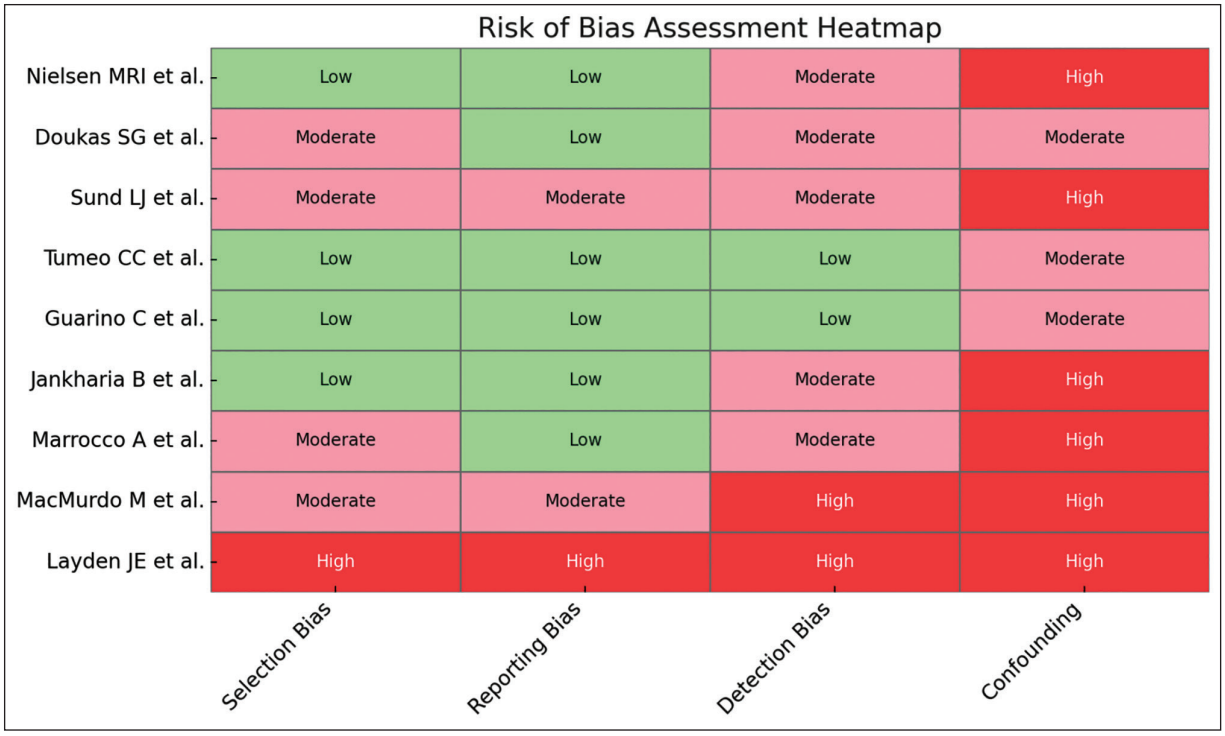

Figure 2. Risk of Bias Assessment Heatmap.

Note: Here is the risk of bias assessment heatmap, where different risk levels are color-coded: 1 (low risk): Represented in blue shades; 2 (moderate risk): Represented in neutral shades; 3 (high risk, if present): Represented in red shades allowing for an easy comparison of patient selection, exposure assessment, outcome assessment, confounding, reporting bias, and overall risk.

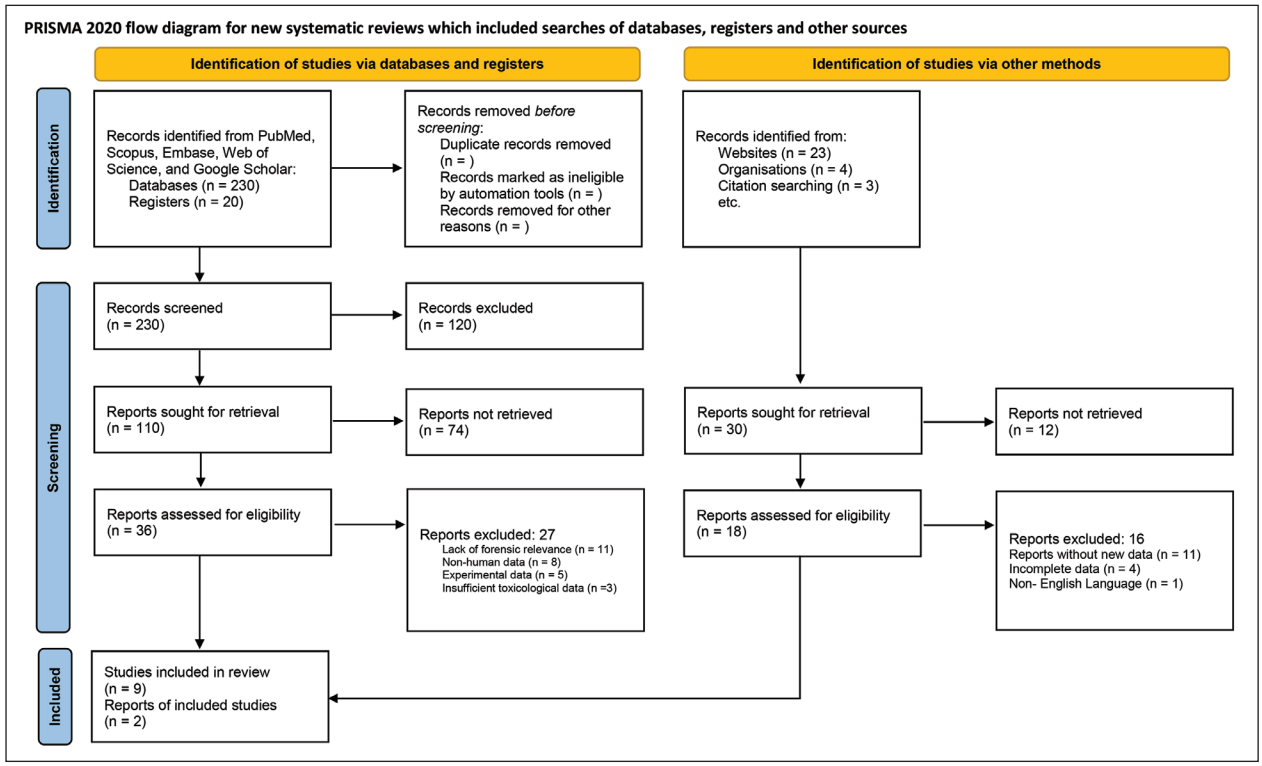

Figure 3. PRISMA 2020 Flowchart Showing Selection Process of Articles for the Review.

Source: PRISMA 2020 statement.[25]

Table 1 and the PRISMA flowchart (Figure 3) illustrate the study selection process and key findings. Toxicological findings varied, with THC detection ranging from 0%[7] to 100%,[8] while nicotine-based exposure was more common in non-USA cases. Vitamin E acetate, a suspected EVALI toxicant, was absent in some cases. Pathological findings included bilateral lung opacities, diffuse alveolar damage, and lipid-laden macrophages, with some cases misdiagnosed as

Table 1. Summary of Included Studies.

Author(s)	Country	Year	Study Design	Sample Size	Toxicological Findings	Pathological Findings	Key Findings	Outcome of Cases	Forensic and Legal Challenges
Nielsen et al.	Denmark	2025	Case report	1	No THC/Vitamin E Acetate detected	Interstitial lung disease, respiratory failure	Severe EVALI, no confirmed THC exposure, required ECMO support	Survived, discharged	Limited awareness and underdiagnosis in Europe
Doukas et al.[18]	USA	2024	Case series	14	71% THC-positive	Lung infiltrates, systemic symptoms	EVALI involves multiple organ systems, not just the lungs	Survived, discharged	Limited awareness of systemic symptoms
Sund et al.[19]	UK	2023	Review of case reports	17	More nicotine-based exposure than in US cases	Pulmonary infiltrates, lung injury	International cases differ in vaping exposure types	Varied severity, all discharged	Diagnostic awareness challenges
Tumeo et al.[20]	Italy	2022	Case report	1	Nicotine, occasional marijuana use	Ground-glass opacities in the lungs	Severe EVALI, rapid improvement with corticosteroids	Survived, discharged	EVALI misdiagnosis due to COVID-19
Guarino et al.[21]	Italy	2021	Case report	1	Five-year e-cigarette use	Organizing pneumonia, lipid-laden macrophages	Chronic EVALI form identified, underestimated cases	Survived, discharged	Difficulty in differentiating from infections
Jankharia et al.[22]	India	2020	Case report	1	No marijuana use, vaping with nicotine	Bilateral peribronchovascular opacities	EVALI with organizing pneumonia pattern, treated with vaping cessation	Survived, discharged	Lack of standardized diagnostic protocols
Marrocco et al.[23]	USA	2020	Case series	8	THC, nicotine, and CBD oils	Bilateral lung opacities, inflammation	Excellent corticosteroid response in EVALI cases	Survived, discharged	Off-label THC product use
MacMurdo et al.[24]	USA	2020	Case series	15	All THC-positive	Diffuse alveolar damage, lipid-laden macrophages	EVALI is likely a form of acute lung injury, and vitamin E acetate involvement is suspected	Survived, discharged	Lack of uniform diagnostic criteria
Layden et al.	USA	2020	Original research	98	89% used THC products	Bilateral infiltrates, severe lung injury	EVALI, as an emerging syndrome, requires further studies needed	2 deaths, 95% hospitalized	The substance cause has not been definitively determined

Notes: ECMO: Extracorporeal membrane oxygenation; CBD: Cannabidiol.

COVID-19 pneumonia or infectious lung disease. Chronic EVALI cases displayed organizing pneumonia patterns, complicating forensic differentiation from other pulmonary conditions. Key forensic challenges included diagnostic inconsistencies, a lack of standardized forensic criteria, and systemic involvement beyond lung pathology.

Legal complexities emerged due to off-label THC use, regulatory gaps, and difficulty in attributing the cause of death solely to vaping products. 95% of cases survived with corticosteroid therapy and vaping cessation, but two fatalities[1] were linked to severe lung injury and multi-organ failure, underscoring the forensic importance of postmortem toxicology in determining the cause of death in vaping-related fatalities.

Due to the heterogeneity in study design, sample size, diagnostic criteria, and reporting methods, a meta-analysis was not feasible. Therefore, a systematic review with descriptive synthesis was conducted.

Discussion

The findings from this systematic review highlight the global burden of e-cigarette or vaping product use-associated lung injury and the varying patterns of exposure, clinical manifestations, and diagnostic challenges. EVALI remains a multifactorial condition, predominantly reported in the United States, where the adulteration of THC-based vaping products with vitamin E acetate has been widely implicated.[1–2] However, international case reports and case series suggest that nicotine-only e-cigarettes can also lead to lung injury under certain conditions.[9] This global variability underscores the complexity of vaping-related lung injuries and the necessity for comprehensive regulatory frameworks.

Toxicological Concerns and Exposure Variability

One of the primary toxicological concerns is the composition of vaping products, including nicotine, THC, and flavoring additives. Studies in the USA have directly linked illicit THC products containing vitamin E acetate to lung toxicity,[2,10] whereas cases from India and Europe are more frequently associated with nicotine-based products.[4,11] This distinction raises concerns about country-specific vaping regulations, the presence of unregulated products in markets, and the need for stringent product labeling and quality control measures. The presence of various chemical additives, including metal particles from heating coils and diacetyl, further complicates risk assessments.[5]

Pathological and Clinical Manifestations

From a pathological perspective, most EVALI cases exhibit features such as diffuse alveolar damage, lipid-laden macrophages, and organizing pneumonia.[3,12] Radiological findings frequently include ground-glass opacities and bilateral lung infiltrates, resembling other conditions such as infectious pneumonia or COVID-19-associated lung injury.[13,14] This similarity has contributed to delayed or missed diagnoses, particularly during the COVID-19 pandemic, when EVALI was often misdiagnosed as viral pneumonia.[15]

The symptomatic presentation of EVALI is heterogeneous, with patients often experiencing respiratory symptoms such as dyspnea, cough, and chest pain, along with gastrointestinal and systemic symptoms.[1] In severe cases, patients present with acute hypoxemic respiratory failure requiring intensive care.[8] Given these diverse presentations, the diagnosis of EVALI remains largely one of exclusion, necessitating a thorough patient history and toxicological screening.

Forensic and Legal Challenges

The forensic and legal challenges surrounding EVALI are significant. Many countries lack clear regulations on vaping products, leading to underreporting and misclassification of EVALI cases.[4] In the USA, illicit and counterfeit vaping products played a major role in the 2019 outbreak, prompting calls for stricter regulatory oversight.[16] Conversely, in Europe and India, the lack of standardized diagnostic protocols has led to inconsistencies in recognizing and reporting EVALI cases.[9] Forensic investigations into vaping-related fatalities require comprehensive toxicological screening and standardized postmortem protocols to identify vaping-related lung injuries accurately.

Patient Outcomes and Treatment Considerations

Patient outcomes varied across studies, with most cases responding well to corticosteroid therapy.[17] Early recognition and intervention significantly reduced morbidity, with corticosteroids demonstrating efficacy in resolving inflammation and improving lung function.[13] However, severe cases required intensive care, mechanical ventilation, and prolonged hospital stays, with fatalities occurring primarily in patients with delayed diagnoses or extensive lung damage.[12]

In terms of treatment, cessation of vaping is a crucial first step, followed by supportive care, oxygen therapy, and corticosteroids in moderate-to-severe cases.[10] Given the evolving nature of vaping-related lung injuries, there is a need for further research on long-term pulmonary outcomes, potential steroid-sparing therapies, and rehabilitation strategies.

Public Health Implications and Future Directions

The widespread use of e-cigarettes among adolescents and young adults raises concerns about future health implications. Public health interventions should focus on increasing awareness regarding the risks associated with vaping, particularly the dangers of illicit THC products and unregulated nicotine e-cigarettes. School-based education programs, stricter advertising restrictions, and public health campaigns can help

mitigate the growing trend of e-cigarette use among youth populations.[5]

Future research should aim to establish standardized diagnostic criteria, identify biomarkers for early detection, and evaluate the long-term pulmonary consequences of EVALI. Moreover, international collaborations are needed to monitor trends in vaping-associated lung injuries and develop regulatory policies that ensure product safety across different regions.

Limitations of the Review

This review has several limitations. The majority of included studies were case reports and small case series, which introduces selection and publication bias. Significant heterogeneity was observed in diagnostic criteria, toxicological testing methods, and pathological findings, limiting comparability. Sample sizes were generally small, and regional variations in vaping practices, particularly differences between THC and nicotine exposure, restricted the generalizability of the results. Furthermore, incomplete toxicological data and evolving diagnostic practices over time may have influenced findings. The lack of standardized forensic protocols for investigating vaping-related deaths across different countries further complicates interpretation. Due to these factors, a meta-analysis was not feasible, and only a descriptive synthesis could be performed.

Recommendations

Based on the findings of this review, several regulatory changes are urgently needed. Mandatory disclosure of all vaping product ingredients and standardized pre-market toxicological testing should be enforced. Harmful additives such as vitamin E acetate must be banned, and robust age verification mechanisms must be strengthened. Prominent health warnings regarding EVALI risks should be mandated on all vaping products. Establishing centralized post-market surveillance systems and standardized forensic protocols for vaping-related deaths is essential. Additionally, THC-containing vaping products from unregulated sources should be restricted, and public education campaigns must be intensified. Global harmonization of vaping regulations would further ensure product safety and facilitate international monitoring of vaping-associated health risks.

Conclusion

This systematic review underscores the global burden of EVALI, revealing significant regional differences in exposure patterns and diagnostic challenges. While THC-containing products adulterated with vitamin E acetate remain a predominant cause in the USA, international cases suggest that nicotine-based vaping products can also lead to lung injury. Early recognition, standardized diagnostic criteria, and regulatory measures are essential to mitigate the risks associated with vaping. The forensic and legal challenges surrounding EVALI highlight the need for robust postmortem protocols and toxicological investigations. Ultimately, a combination of public health interventions, clinical vigilance, and regulatory oversight is necessary to address this emerging public health crisis. Future research should focus on long-term pulmonary outcomes, risk stratification, and harm-reduction strategies to mitigate EVALI incidence worldwide.

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Authors' Contribution

Nani Gopal Das: Conceptualized the study, designed the methodology, and supervised the overall research.
Nirmalendu Das, Amitava Baidya, and Monica Debbarma: Independently conducted the literature search, data extraction, and quality assessment.
Nirmalendu Das and Amitava Baidya: Performed the initial data analysis.
Monica Debbarma: Contributed to data synthesis and interpretation.
Nani Gopal Das and Monica Debbarma: Led the manuscript drafting and revisions.
All authors contributed to the review and final approval of the manuscript.

Data Availability Statement

All data analyzed in this systematic review were obtained from previously published studies, which are publicly available and cited within the manuscript. No new primary data were generated or collected for this study. Any additional information can be provided upon reasonable request.

Declaration of Conflicting Interest

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

Ethical Approval

Ethical approval was not required for this systematic review as it is based solely on publicly available data from previously published studies and does not involve human participants, animal subjects, or direct data collection.

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Informed Consent

Since this study is a systematic review of existing literature and does not involve direct interaction with human participants, obtaining informed consent was not applicable.

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A Systematic Review of Non-intimate Skin-cell Touch DNA

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Abstract

Forensic genetics tends to be an experimental, diverse, and revolutionary area of science, and the proportion of information gathered from the tiniest remnants of DNA keeps expanding. DNA profiles are complex, and propositions are uncertain; therefore, legal professionals consistently seek novel investigative blueprints by relying on reliable forensic resources and judicial admissions of guilt. Researchers do not rely solely on visible and bulk amounts of conventional biological samples such as semen, saliva, and blood to generate a DNA profile. However, some sample sizes are so small and invisible that coming from such a brief encounter or transfer can appear seemingly useful. This small amount of DNA is known as "touch DNA" or "abandoned DNA," which refers to "any amount of human tissue capable of DNA analysis and separated from a targeted individual's person inadvertently or involuntarily, but not by police coercion." The existing level of understanding pertaining to the cellular makeup of touch residues and the potential source of trace DNA contained therein is inadequate. The objective of the present review study is to conclude that how non-intimate skin-cell DNA accidentally or indirectly transfers from a targeted person under certain scenarios affects the potential results and could also be a reasonable explanation as conclusive evidence in the criminal justice system.

Keywords

Touch DNA, criminal cases, genetic profiles, contamination, DNA profile

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Introduction

Forensic genetics primarily focuses on non-coding regions of DNA, often referred to as "junk DNA," which constitute approximately 0.1% of the total genome. These regions are highly polymorphic and play a crucial role in generating a unique genetic blueprint for each individual. Biological samples serve as valuable evidence for identification purposes, facilitating the comparison of DNA profiles. Since 1984, DNA analysis has been a reliable, valid, and confidential method in criminal trials, aiding in both convicting offenders and exonerating the wrongly accused. The process of DNA analysis involves extracting genetic material from biological specimens retrieved from a crime scene, analyzing specific genetic markers, and comparing them to potential suspects' profiles. This results in the generation of a unique genetic identifier, commonly known as a DNA profile, which can be matched against forensic samples to establish identity.[1]

Challenges in DNA Profiling

The occurrence of heterogeneous or incongruous genetic profiles within a DNA specimen can lead to inaccurate forensic conclusions. Several factors contribute to such discrepancies, including external contamination, genetic mosaicism, and hematopoietic stem cell transplantation.

External contamination occurs when DNA samples are mishandled or improperly stored, leading to contamination

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by laboratory personnel or previous samples and potentially causing mismatched profiles.[2]

Genetic mosaicism refers to an individual having multiple genetic profiles due to mutations or alterations affecting certain cells or tissues.[2]

Hematopoietic stem cell transplantation involves transferring stem cells from a donor to a recipient, replacing the recipient's bone marrow and producing new leukocytes that contain the donor's genetic information. This can result in mixed DNA profiles, leading to potential false inclusions or exclusions in forensic investigations.[2]

Evolution of DNA Evidence: The Introduction of Touch DNA

Initially, forensic DNA analysis relied exclusively on bodily fluids (e.g., blood, semen, and saliva) and hair samples to establish genetic profiles. However, in 1997, Australian forensic scientists Roland Van Oorschot and Maxwell Jones revolutionized the field with their Nature publication, "DNA fingerprints from fingerprints." Their findings demonstrated that DNA could be recovered from traces left behind by a mere handshake.[3]

"Trace DNA" or "touch DNA" refers to biological material containing minimal DNA amounts, presumed to be left behind through physical contact. The expansion of touch DNA applications has significantly broadened forensic investigations, aiding in solving crimes such as theft, homicide, armed robbery, sexual assault, and clandestine laboratory cases. It has been detected on various objects, including tools, fabrics, vehicles, doorknobs, countertops, weapons, food items, glass, skin, paper, cables, and stones.[4]

Touch DNA plays a crucial role in cases of sexual assault, including non-consensual groping, fondling, and touching over or under clothing. The collection of touch DNA can help identify perpetrators in such cases.[1] Other commonly tested items for touch DNA include toothbrushes, phones, facemasks, toothpicks, cigarette butts, facial wipes, tissues, and lip prints.[4]

Touch DNA in India: Case Studies

India witnessed the potential impact of touch DNA in forensic investigations during the high-profile Aarushi-Hemraj double murder case. Due to the lack of standard procedures, high costs, and regulatory frameworks, authorities rejected the use of touch DNA. The parents of the victim, the Talwar couple, emphasized the significance of low copy number (LCN) or touch DNA testing in proving their innocence. However, investigative agencies relied on conventional evidence, considering touch DNA too speculative at the time.[5]

Conversely, in the 2013 Bodh Gaya blast case, the National Investigation Agency successfully employed touch DNA to identify a terrorist disguised as a monk. DNA samples obtained from the suspect's discarded clothing were compared with those of arrested suspects a year later, narrowing down the list of potential perpetrators. This marked a milestone in the use of touch DNA as crucial circumstantial evidence in India.[6]

Nomenclature and Ambiguities in Touch DNA

Touch DNA is also referred to as contact DNA or abandoned DNA, encompassing minute genetic traces obtained through limited interaction, such as conversation, perspiration, or "wearer DNA" from fabric.[7]

Kawecki[7] defines touch DNA as "any amount of human tissue capable of DNA analysis and separated from a targeted individual's person inadvertently or involuntarily, but not by police coercion." Humans shed approximately 400,000 epithelial cells daily,[8] primarily composed of keratinocytes, which lose their structural components and nuclei before being naturally removed from the skin's surface.[9] Nucleated cells from different body areas can transfer to the hands or be shed through sweat ducts.[10]

A major misconception is that touch DNA is always obtained from a touched surface. In reality, it can also be airborne or transferred indirectly. Additionally, it is often mistaken as synonymous with low-template DNA (LT-DNA), LCN-DNA, and trace DNA.[7] Trace DNA generally refers to biological samples containing less than 100 picograms of DNA,[7] while LCN-DNA refers to methods requiring increased amplification cycles due to low DNA quantity.[7]

Systematic Methodology of Touch DNA

The successful development of a touch DNA profile requires rigorous procedures in forensic genetics laboratories. These include retrieval, isolation, measurement, and short tandem repeat (STR) amplification. However, touch DNA does not establish the biological origin of evidence. Three key factors impact touch DNA formation:

1. Duration of contact with the object
2. Degree of force applied during contact
3. Number of individuals who have handled the object

Transfer of Non-intimate Touch DNA

Touch DNA transfer occurs in two primary ways:

Direct transfer (Primary transfer): Cellular material is directly transferred through physical contact, speaking, coughing, or sneezing.[8,11,12]

Indirect transfer (Secondary transfer): DNA is transferred via an intermediary object rather than direct contact.[3]

The recovery and persistence of touch DNA depend on several unpredictable factors, making its transfer highly variable.

Factors Influencing Touch DNA Recovery

1. Shedding characteristics: Some individuals, known as "good shedders," naturally deposit higher amounts of DNA upon contact. Factors such as gender, age, and dermatological conditions (e.g., dandruff, eczema, and psoriasis)[13,14] affect shedding rates. Studies suggest that men are generally better shedders than women, and younger males shed more DNA than older individuals. However, individuals can alternate between good, intermediate, and poor shedding states over time, and hand washing can significantly reduce DNA deposition. Research indicates that children are typically good shedders, while adults and elderly individuals exhibit lower shedding tendencies.[15]
2. Contact type: Increased contact time and pressure result in higher touch DNA deposition.
3. Individual habits: Frequent self-touching (e.g., nose, ears, and hair) contributes to DNA transfer, a phenomenon termed "loading DNA fingers."[16]
4. Surface texture and area: Rough surfaces, such as wood, can trap cells more effectively than smooth surfaces such as glass. However, smooth, non-porous surfaces tend to retain more DNA due to increased convection rates during contact. Larger surface areas also facilitate greater DNA transfer. DNA recovery varies across different materials, with brass-plated metals yielding the highest recovery rates.[17]
5. Duration of contact and time between deposition and recovery: The yield of DNA decreases over time, particularly when exposed to environmental factors. Though a minimum of two seconds of contact is sufficient for successful profiling, DNA yield is higher from recently touched surfaces. Proper storage can mitigate degradation, with studies showing minimal loss after 12 weeks under controlled conditions.[18] However, DNA recovery significantly decreases over extended periods, especially in harsh environmental conditions.
6. Environmental factors: DNA samples in forensic investigations are often exposed to environmental stressors such as heat, humidity, ultraviolet (UV) light, and chemicals, leading to degradation. High temperatures and UV exposure accelerate DNA breakdown, while humidity and contaminants can further compromise sample integrity.[19] Proper handling and storage conditions are crucial to preserving DNA for forensic analysis.

Non-intimate Touch DNA Collection Methodologies

Touch DNA collection is often referred to as a "blind search" because the analyst does not have prior knowledge of whether epithelial cells or touch DNA are present in a given area. To ensure reliable forensic results and prevent contamination or degradation of the samples, systematic and validated collection and sampling methodologies should be employed. The selection of a collection method depends largely on the type and condition of the surface being sampled. Despite the widespread use of innovative touch DNA evidence collection techniques, there remains no standardized protocol for touch DNA collection. The initial step in trace sample collection involves identifying suitable regions for sampling. Trace samples on surfaces are typically not visible to the naked eye, making their collection challenging. Traditional laboratory methods for low copy DNA specimens were originally optimized for high-copy-number DNA evidence.

The "standard swab" technique is frequently employed due to factors such as cost, expertise requirements, and laboratory-specific validation procedures. Wet/dry double cotton swabbing expands upon the single swab technique by incorporating a second sterile swab to collect residue from the damp surface after an initial moist swabbing. The swabs are then combined before extraction. This method is widely applied to non-absorbent surfaces.[20,21] Castella and Mangin[21] examined 1,739 forensic cases and found that the double swab technique was significantly more effective than single swabbing. The mean DNA yield was 0.494 ng/µl with double swabbing compared to only 0.312 ng/µl with single swabbing. However, a recent review of sampling techniques suggests that the double swab method does not always enhance touch DNA recovery.[22]

Despite the effectiveness of cotton swabbing, a considerable amount of trace DNA is lost within the cotton fibers, leading researchers to explore alternative materials. Self-saturating mini-papules, Isohelix™, Dacron, Rayon, FLOQSwabs™, Bode SecurSwab™, and nylon or polyester-tipped swabs, have been recommended to reduce sample dispersion and entrapment. To mitigate DNA loss, many swabs are now designed without an internal absorbent core.[23]

A significant breakthrough in touch DNA recovery involved soaking fired cartridge cases and bullets in tissue lysis buffer.[24] A study of 616 criminal cases using this method recovered usable genetic profiles in 163 cases (26.5%). Prasad et al.[25] evaluated this methodology across different ammunition types and confirmed its suitability for DNA recovery.

Hansson et al.[26] compared the Scene Safe FAST™ minitape, manufactured in the UK, with cotton, flocked, and foam swabs. Their results demonstrated that minitape achieved the highest trace DNA recovery. Similarly, Sessa et al.[27] analyzed DNA retrieval from brassieres worn by female volunteers

using dry swabbing, tape lifting, and cutting techniques. Although no significant differences were found among these methods, the ''cut-out'' technique exhibited the highest DNA recovery, whereas adhesive tape sampling was statistically significant for ''wearer'' findings. The most recent handler of an item was often the primary contributor to its DNA profile, even after brief contact. This observation remained unchanged regardless of the identities of the handler and wearer.

To collect trace DNA from large surface areas, researchers have suggested filtered tips and vacuum-based techniques.[28–30] The Mac Vac system employs a "mini hurricane" effect under the sampling head, created by spray and vacuum forces. The solution collects DNA content into a sterile container, dislodging epithelial cells, touch DNA, or contact DNA from porous or rough surfaces. This enhances forensic evidence collection capabilities (https://www.m-vac.com).

Comte et al.[31] compared four swab types under controlled and quasi-operational conditions, including a reference swab (Prionics cardboard evidence collection kit) used by police forensic units, and three challenger swabs (COPAN 4N6FLOQSwabs™, Puritan fast and automated bacterial MINI typing by arbitrarily primed PCR (FAB-MINI-AP), and Sarstedt Forensic Swab). COPAN 4N6FLOQSwabs™ proved most efficient, yielding significantly more touch DNA from collars, steering wheels, and screwdrivers than the reference swab.

Fluorescent probes and laser microdissection techniques have been investigated to differentiate between trace DNA contributors. Anslinger et al.[32] and Vandewoestyne et al.[33] explored whether these methods could distinguish between male and female cells or two individuals of the same gender within mixed samples.

Non-intimate Touch DNA Extraction

Efficient DNA extraction is essential for isolating DNA while removing cellular debris, excess reagents, and polymerase chain reaction (PCR) inhibitors that can affect downstream applications such as restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD), variable number of tandem repeats (VNTR) and single nucleotide polymorphism (SNP) analysis.[34] These DNA markers are distributed across the human genome and exhibit high polymorphism, making them ideal for forensic DNA profiling and human identification. In forensic contexts, genotype and gene frequency data help estimate match probabilities in inclusion cases, and many ethnic groups now have published STR allele frequency data.[35]

Each extraction procedure begins with cellular lysis, followed by deproteinization and DNA recovery. Extraction methods vary in deproteinization intensity and DNA fragment size retention. Many laboratory protocols fail to recover all extracted DNA, with losses of up to 75% observed in Chelex and organic extraction methods.[4] Substrate type and extraction technique significantly impact yield.

Forensic DNA extraction methods include solution-based, column-based, magnetic bead-based, and commercially available kits.[36] Common forensic touch DNA extraction kits include Chelex® 100, the QIAamp® DNA Blood Mini Kit, the QIAamp® DNA Investigator Kit, QIAsymphony®, the DNA Investigator® Kit, the DNA IQ™ system, and the PrepFiler® Express BTA.

Non-intimate Touch DNA Quantification

DNA quantification determines the DNA concentration necessary for downstream applications such as sequencing, PCR, and cloning. Proper quantification assists in approximating DNA quantity and evaluating profile relevance. However, in cases where touch DNA recovery is low, it may not always be possible to obtain a minimum viable DNA portion.[3,10,19] Quantifiler® Duo DNA Quantification Kits and the Applied Biosystems® 7500 Fast Real-Time PCR System are commonly used for touch DNA quantification.[37]

As forensic DNA techniques advance, the demand for precise trace DNA quantification increases.[38] If DNA quantities are insufficient, laboratories may struggle to generate viable DNA profiles, even after processing.[39] To ensure accurate low-level quantification, two key frameworks are recommended: (a) Targeting an amplicon of a similar base-pair size as intended for subsequent analysis (99–214 bp in major commercial kits), and (b) maximizing the dynamic range of standard curves at low concentrations (Quantifiler Duo, 2008; Qiagen, 2012).[40]

Non-intimate Touch DNA Amplification

Following extraction and quantification, DNA amplification enables forensic analysts to generate millions of copies from minimal DNA samples for qualitative and quantitative analysis. Direct PCR amplification has gained preference over STR amplification because it retains DNA typically lost during extraction and purification.[41]

ISO 17025 accreditation bodies have validated direct PCR for limited forensic applications. Despite its cost-effectiveness and time efficiency, direct PCR consumes the entire sample, making it unsuitable for re-examination in defense testing.[42] To ensure reliable touch DNA amplification, laboratories must use validated kits such as Identifier® Plus and GlobalFiler®, which effectively amplify LT-DNA.[43]

Precautions for Minimizing Contamination

Crime scene investigators must take precautions during evidence collection to prevent contamination. Rutty (2001) advised restricting crime scene access and maintaining an exclusion database of investigator fingerprints. Wearing

crime scene suits, gloves, facemasks, and overshoes minimizes contamination risks, whereas actions such as scratching, sneezing, coughing, eating, or talking increase the likelihood of contamination.[44]

Issues Related to Touch DNA

Touch DNA analysis faces challenges such as non-reproducibility, undefined interpretation guidelines, and unvalidated mixture analysis results.[38] Compliance with forensic sample collection, preservation, and analysis standards can mitigate errors in forensic investigations.[45] Addressing issues such as stochastic effects, allele dropout, and stutter effects is crucial to prevent false conclusions. An exclusion database of investigators' DNA and fingerprints can further reduce wrongful convictions. Laboratories analyzing touch DNA must meet stringent quality standards, and policymakers must ensure ethical regulations balance forensic advancements with constitutional rights.[46]

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A Brief Historical Overview of the Past of Forensic Medicine

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Abstract

Forensic medicine is a large and multifaceted science that blends legal concerns with medical knowledge. It has a long history that has evolved alongside advances in the legal and medical professions. By combining medical and legal sciences, forensic medicine provides critical insights into various criminal investigative duties, such as victim identification, determining the cause of death, and examining injuries. This subject has its origins in ancient societies. Establishing systematic guidelines and training programmes for medical examiners in the 19th century marked a significant advance in forensic medicine. The development of scientific techniques such as toxicology and pathology greatly increased the precision and dependability of forensic operations, allowing for more useful contributions to the court system. Throughout its long history, forensic medicine has evolved in line with scientific and legal advances. It began with simple facts and common sense before evolving into a complicated field that combines methodologies from other academic disciplines, including pathology, chemistry and biology. Because of its interdisciplinary nature, forensic medicine acquires depth and complexity, cementing its place as a critical link between health and the law and providing insights that significantly impact court judgements.

Keywords

Historical emergence, forensic toxicology, future of forensic medicine, forensic pathology

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Introduction

Forensic or legal medicine is the application of medical knowledge in the pursuit of justice. It refers to the field of applying medical ideas and knowledge to civil and criminal law.[1] Discussion in this discipline mostly centres on the medico-legal assessment of cases.[2]

Historically, it was frequently used synonymously with 'forensic pathology', the medical discipline that examines mortality. The subject is further confused by words such as 'forensic and legal medicine' or 'legal and forensic medicine', which are acknowledged as separate fields of medical specialisation. These phrases typically encompass all facets of medicine related to justice systems and may differ from one nation to another. The phrase 'forensic medicine' currently encompasses all facets of forensic activities in medicine.[3] The speciality was chosen to cover the essential mortality characteristics and related issues commonly faced in medico-legal practice. The mysteries of disease and criminality are forever veiled within the silent psyche. A forensic medicine specialist learns through experience, practical reasoning, and scientific analysis. As this speciality deals with poisoning cases, it is also called forensic medicine and toxicology. Combined, they offer scientific proof that courts and law enforcement employ to solve crimes and carry out justice.

The history of this speciality will shed light on how the subject evolved. The fields have developed over time, including developments in chemistry, medicine and judiciary enforcement tactics. This review article explores the field's ancient beginnings and early practices, focusing on the foundations of forensic medicine and toxicology and the contributions of Greek and Roman civilisations.

Brief Review

Branches

Clinical forensic medicine is an important division of this subject that evaluates, analyses, interprets, and reports on

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living people for medico-legal purposes, including victims and accused perpetrators of sexual assault, child abuse, and domestic violence. There are also activities such as evaluating intoxication cases, assessing age, resolving identity disputes, traffic medicine (mainly examining injured pedestrians), determining driver vs passenger status, and assessing driving fitness.[2] Analysing the medical requirements for establishing criminal culpability and assessing competency for detention and questioning within the context of justice administration.

Forensic pathology studies the various signs of violence on the human body and investigates unnatural fatalities such as car accidents, hanging, drowning, and both suspected and spontaneous mortality. It establishes the cause of death through scientific study of autopsy results on cadavers. The investigation and interpretation of histological tissues retrieved during the autopsy are also discussed.

Previously, medical jurisprudence referred to the application of law in the realm of medicine and its legal consequences. It covers the physician's responsibilities in the doctor-patient connection, doctor-doctor relationship, doctor-state interaction, medical negligence, licensed medical practitioner rights and privileges, professional misconduct, inquests, consent concerns, and ethics. The state regulates contemporary medicine, requiring medical personnel to submit evidence and testify as expert witnesses in medico-legal cases involving death, sexual assault, and other related issues. As a result, the two disciplines have historically been linked.[4] However, forensic or legal medicine has become increasingly relevant. It is known as forensic medicine and toxicology because it also deals with cases of poisoning. It was also referred to as 'state medicine'.

Historical Event

Documents about the medico-legal quandary can be found in Egypt, Samaria, Babylon, China, and India. The Egyptians mastered mummification and developed their legal system circa 3000 BC, whereas Chinese law emerged around 4000 BC.[2,5] In ancient Egypt, detailed records of injury and cause of death were kept on papyrus, illustrating early forensic documentation.

The Jewish and Greek legal systems were important, dating back to 1200 BC. The Materia Medica of China, written around 3000 BC, includes information on drugs and poisons. The King of Babylon developed the Code of Hammurabi, a Babylonian law text created in 1755 BC. It is the oldest, longest, and best-preserved medico-legal text, with a considerable impact on the evolution of medico-legal practices.[2,5]

Hippocrates (460–377 BC) was a Greek physician from the ancient period who is regarded as one of the most famous figures in medical history. His impact on medico-legal practices is considerable, as he is credited with inventing the Hippocratic Oath, a key ethical code for physicians, and his contributions to the study of ethics have affected the growth of medico-legal practices.[2,5]

Socrates (470–300 BC), an Athens-based philosopher and reformer, was poisoned with hemlock for corrupting Greece's youth. Antistius, the Roman physician, performed Julius Caesar's first autopsy in 44 BC without dissection and decided that only one of the 23 stab wounds, located in the chest between the first and second ribs, was fatal. This is the oldest documented autopsy.[2,5]

The first medico-legal autopsy was performed in Bologna in 1302 BC by Bartolomeo da Varignana, an Italian physician and pioneer in forensic pathology. His pioneering work laid the groundwork for future growth in the discipline. Dr Ambroise Paré performed the first systematic autopsy on the remains of King Henry II in 1589.[2,5]

The Constitutio Criminalis Carolina, which outlined procedures for capital punishment, was published in Germany in 1532 and approved by King Charles V. This document was a watershed moment in the formation of legal medicine.[2,5]

Paulus Zacchias, the founder of forensic medicine and psychiatry, wrote and published Questiones Medicolegalis in 1657. His work was critical in defining the concepts and methods for both fields, and his contributions continue to influence medical-legal research and practice today.[2,5]

Mathieu Joseph Bonaventure Orfila (1787–1853), a Spanish academic in chemistry and toxicology in Paris, pioneered chemical procedures for toxin extraction, earning the title of creator of modern toxicology. His efforts significantly advanced the field of toxicology. Johann Ludwig Casper (1796–1864), a German forensic scientist, criminologist, pathologist, paediatrician, pharmacologist, professor, and author of forensic medicine, released the ninth edition in the 17th century.[2,5]

Alfred Swaine Taylor's The Principles and Practice of Medical Jurisprudence was published in 1865. Sidney Smith defined forensic medicine as we know it today in 1951. Professor Alec Jeffreys invented DNA fingerprinting for identity verification in 1984.[2,5]

Phylogeny of Forensic Medicine in India

The thoughts of numerous philosophers from ancient Indian history had a tremendous impact on India's legal framework. Their significant ideas have been critical to the government's operations, shaping the course of justice and legal practice.

The oldest legal treatise is Manava-dharma-sastra, or Manusmriti, which predates the Hammurabi Code of 2600 BC. It discusses the legal marriage age, sexual offences, punishments, and how sickness and intoxication affect court attendance and contract creation. It was intended to be written in 1200 BC. Manu may have been recognised as the originator of legal medicine in ancient India.[2,5]

The Rig Veda, written during the Vedic period (2000–1000 BC), mentions various transgressions, including abortion, incest, adultery, and murder, as well as their respective consequences. The Atharva Veda (1500 BC) describes snake bites, piercing wounds, arrow injuries, and their treatment. In

Vedic law, illegal abortion is known as brunahatya, while suicide is known as Atmahatya.[2,5]

The Arthashastra, the most comprehensive work on statecraft from classical India, was written by Kautilya (Chanakya) in the 4th and 3rd centuries during the Mauryan Empire. The book covered various topics, including the monarchy, legal codes, medico-legal criminal investigation, law administration, foreign policy, and covert and esoteric procedures. Despite the passage of more than 2000 years, the brilliant strategist, often known as India's Machiavelli, continues to inspire modern spiritual leaders in the country. He advocated medical inspections in cases of fatalities caused by assault, poisoning, or asphyxiation, like the autopsy performed today.[2,5] Medical practice was strictly regulated, and the King's authorisation was required. Negligence in treatment may result in harsh charges, highlighting the high standards of care expected of medical practitioners.[2,5]

During the Buddha era, King Ashoka established hospitals, roadside clinics, and the Ayurvedic medical school in the 4th and 5th centuries BC. Dr Edward Bulkley conducted India's first medico-legal autopsy in 1693, following the death of Mr Wheeler, a council member and Chief Justice of Choultry Chennai, on August 28, 1693, from suspected arsenic poisoning.[1,2]

The first medical school in India was established in Kolkata in 1822 and then evolved into a Medical College in 1835. Madras Medical College was founded in the same year. Madras Medical College established the first professor of medical jurisprudence position in 1857.[2]

The inaugural Central Fingerprint Bureau of India was founded in Kolkata in 1897 and commenced operations in 1904. Since that time, forensic science has been systematically integrated into crime investigation practices in India.[6,7] Modern dactylography represents India's most significant contribution to legal medicine during the British era. Sir William Herschel of the Indian Civil Service pioneered this identification method in 1858. Sir Francis Galton of England created a systematic study and methodology for using fingerprints in personal identification in 1892, drawing on Herschel's idea.[1,2] The British authorities changed the method until 1862, when the Indian Penal Code was established. Our criminal laws are based on Mohammedan law but have been extensively modified and augmented by our rules, resulting in a deviation from their original forms.[8]

The criminal investigation police system was formed in India in 1861, and coroners' systems were introduced in 1871 in the presidential towns of Bombay and Calcutta.[1] Professor JP Modi of Agra Medical College wrote the Medical Jurisprudence and Toxicology textbook in 1920. The Indian Medical Council was established in 1933. Forensic medicine has evolved significantly, moving from a subset of pathology to a unique speciality. This accomplishment illustrates the sector's progress and advancement, necessitating all physicians' ongoing dedication to meeting social expectations.[2]

The teaching of forensic medicine has advanced due to the establishment and expansion of academic departments in forensic medicine and toxicology. Most universities provide postgraduate degrees in forensic medicine and toxicology. It is projected that many qualified medico-legal professionals will soon be available in various parts of India. Continuous efforts have been made to improve the capacity of forensic medicine in the country.

Religious and Social Perspectives on Autopsies[2,9]

In 1374 AD, the Pope authorised permission to perform a medico-legal autopsy. There were substantial religious and cultural objections to autopsy during the Tertullian and Augustine eras. Despite the lack of an explicit ecclesiastical prohibition in the early days of Christianity, the predominant opinion among church leaders was negative. Vindician, a physician and Augustine's associate, is quoted in a 10th-century manuscript from Monte Cassino as saying, 'The ancient anatomists found it agreeable to investigate the viscera of the deceased to ascertain the cause of death, but for us, humanities forbid this'.[2,10] Wolf-Heidegger and Cetto Singer have determined that dissections were performed in Italy between 1266 and 1275, with the earliest dissections being medico-legal.[2]

No official ecclesiastical rules addressed the issue; however, at the Council of Tours in 1163, it was stated that the church despises bloodshed. This meant that clerics were not permitted to perform surgery on both the living and the dead. Because most physicians were clergy, autopsy was effectively inhibited while remaining permissible. In 1299, Boniface VIII forbade the cremation of corpses to extract flesh from bones. This was done to recover the remains of those who died during the Crusades. The edict specifically mentioned boiling the body, but many people misinterpreted it as barring dissection.[11]

However, during this time, some physicians began dissection, which caused the church's viewpoint to change. Pope Alexander died abruptly in 1410, and Pietro D'Argelata performed an autopsy. Pope Sixtus IV (1471–1484) issued a decree enabling anatomical studies on human cadavers by students at Bologna and Padua, which was later approved by Clement VII (1523–1534). In 1556, an autopsy was performed on Ignatius Loyola, which revealed the presence of calculi in his kidneys, bladder and gallbladder.[12]

As a result, by that time, the Catholic Church had fully accepted the practice of autopsy. An autopsy was performed in 1533 for religious reasons. A double monster, female twins united at the umbilical area to a point in the thorax just below the breast, was born in Espafiola (present-day Dominican Republic) in 1533, according to Oviedo y Valdés' New World History. The infants were baptised, though the priest was not sure if one or two souls required baptism. The parent reported that one of the children wailed while the other stayed silent. One may sleep while the other remains vigilant. Consequently, two baptisms were performed, yet the priest remained concerned. To address the situation, an autopsy was performed

eight days after the infants died. The discovery of two complete sets of internal organs led to the conclusion that there were most certainly two souls. Chavarria and Shipley, who unearthed and translated this fascinating story, stated that it was most likely the only post-mortem examination ever conducted to probe the deceased's soul.[2,13]

Reverence for the body was an important component of Jewish tradition, as the Scriptures state that God created humans in His image. Interacting with a dead body made a person impure for several days. It was emphasised that the body should be treated with care and buried immediately. Even if a criminal is punished by hanging, 'his body shall not remain overnight on the tree but must be buried that day'. The rabbis interpreted these restrictions to ban post-mortem dissection, which would disgrace the body. It is written that around 100 AD, Rabbi Ismael's pupils obtained the remains of a young prostitute who had been executed and boiled them to count the bones. They found 252.[9]

According to one Talmudic scripture, an autopsy is acceptable if it saves the life of an alleged murderer. Jewish authorities did not permit autopsies until the 18th century, when Rabbi Landau was asked about the permissibility of incising a cancer patient's body to determine suitable therapy for future cases. He claimed that an autopsy is a degradation of the departed and is only permitted to save the life of a current patient rather than a prospective future patient.[14] Orthodox Jews upheld this policy until the 20th century, when the Knesset, Israel's parliament, passed legislation allowing autopsy under certain conditions.[15]

Several indications of widespread hostility to autopsy can be found here. In 1538, Guillaume Rondelet (1507–1566), a Montpellier scientist, performed an autopsy on his infant son before ordering examinations on his sister-in-law and first wife.[16]

Vesalius, a physician who performed countless autopsies, died in 1564 while returning from a trip to Jerusalem. Years later, biographer Melchior Adam published a letter reportedly written by Hubert Languet in 1565, claiming that Vesalius was forced to make this pilgrimage as atonement for the sins of murder and defilement. According to O'Malley, this tale lacks a factual basis.[17] However, he observes that it may have originated from the same myth as Ambroise Paré, who warned against early dissection in 1573 and reported an instance involving a well-known anatomist living in Spain. He was sent to perform an autopsy on a woman who was thought to have died from womb suffocation. Following the second incision, the woman demonstrated movement and other indications of life. As a result, the revered master was forced to quit the country and eventually succumbed to sadness, a significant loss for the Republic.[18]

Jarcho emphasised the difficulties associated with doing an autopsy in Germany in 1670. A medical journal from that year includes an autopsy report stating, 'The examination of other structures was not conducted due to a female relative's change of mind. Our community harbours a profound aversion to autopsies and seldom permits them without considerable persuasion'. The journal's editor appended a discourse on the difficulties of obtaining consent and potential counterarguments to relatives' objections.[19]

A widespread aversion to autopsy later emerged, as the Republic of Lucca's 1699 decree, meant to reduce the spread of disease while calling for autopsies, was withdrawn due to public outrage.[20] Such sentiments continue today; additional investigation would deviate from the main theme.

Legislative Stipulations

The DNA bill, which has been delayed for several years, must be enacted promptly to furnish a legal basis for forensic research in India. The passage of the Forensic Legal and Development Authority Bill is essential to establish the requisite legal frameworks for forensics in India.

Although the Government of India has implemented the Information Technology Statute of 2008,[21] which encompasses standards for the practice of digital forensics, specialists must be informed of the statute's requirements. Nevertheless, the existing system is deficient, necessitating the rapid implementation of the DNA and Forensic Regulatory and Development Authority laws. The reports continue to be provided by the document specialists following Section 45 of the Indian Evidence Act [Bharatiya Sakshya Adhiniyam (BSA) 39(1)].[22] In 2023, the new criminal laws (Bharatiya Nyaya Sanhita, BSA, and BNSS) replace IPC, CrPC, and the Indian Evidence Act, effective from 1 July 2024.[21]

The State of Indian Mortuaries

Several Indian hospitals and medical institutes still lack contemporary facilities within their mortuaries. They lack the latest post-mortem toolkits, photographic and videographic equipment, and cold storage facilities for preserving cadavers intended for autopsy.[23] The government is equipping hospitals with essential facilities. Standard tertiary care hospitals, including AIIMS, have advanced facilities like virtopsy[23]; however, extending these capabilities to state and district-level hospitals is crucial.

The Renaissance: Foundations of Modern Forensics

By combining medical knowledge with legal laws, forensic medicine started to form alliances during the Middle Ages, establishing the groundwork for contemporary forensic investigations. By publishing 'De humani corporis fabrica' in 1543 and offering meticulous human dissections, Andreas Vesalius transformed anatomy, rectifying centuries of anatomical mistakes and establishing a solid foundation for forensic pathology.

The Renaissance emphasised empirical evidence and direct observation more than superstition and unreliable texts to promote forensic accuracy. In forensic instances, a

thorough understanding of anatomy facilitated a better understanding of trauma, cause of death, and injury timing. The ability to assess biological evidence was boosted with the development of early microscopy and better dissection techniques. Anatomists started recording pathological alterations in tissues to establish a connection between physical discoveries and clinical and legal outcomes.

The Renaissance period established a crucial foundation for contemporary forensic medicine through developments in anatomy, critical observation, and early scientific procedures. This period established concepts as the foundation for modern forensic investigations by bridging the gap between mystical beliefs and empirical science.

Conclusion

In toxicology and forensic investigations, artificial intelligence (AI) and machine learning have revolutionised the discipline by facilitating quick and precise data processing. Portable forensic technologies that enable real-time, on-site toxicological testing have been developed because of these advancements. It has also sparked the creation of molecular and genetic techniques that offer a more profound understanding of drug interactions and fatalities.

It must be acknowledged that cooperation between forensic medicine specialists, forensic scientists, legal experts, and technology developers is critical to enhancing the interpretation of evidence and the results of court cases. Every group contributes distinct knowledge and viewpoints that improve comprehension. Furthermore, a significant focus on data protection and ethical norms is required as forensic technologies advance. History demonstrates the significant contributions of forensic medicine to society. Professionals in this field must continue to devote their efforts to advancing their subjects.

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Review Article

Rights of Transgender During Taking Custody Which Question Their Dignity: A Review

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Sage

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Abstract

A transgender individual, often referred to as a trans person, is someone whose gender identity differs from the sex they were designated at birth. Worldwide, fewer than 1% of individuals identify as transgender, with estimates generally falling between under 0.1% and 0.6%. In April 2014, the Supreme Court of India officially acknowledged transgender people as a "third gender" in accordance with Indian law. The transgender community in India, which includes Hijras and others, possesses a rich heritage and profound connections to Indian culture and Hindu mythology. Unfortunately, society seldom recognizes or strives to comprehend the trauma, suffering, and pain endured by members of the transgender community. Additionally, there is a lack of understanding regarding the significant emotional turmoil experienced by those whose mental identity does not correspond with their assigned biological sex. In this review of case reports, which we encountered in our esteemed department, we try to find out the answers which were left behind by the authorities. It typically depicts the discrimination against them. It also portrays the socio-cultural relationships and support they need from us as an involved and evolving society.

Keywords

Transgender, third gender, biological sex, Hijras, society

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Introduction

A transgender (or trans) person is someone whose gender identity does not align with the sex they were assigned at birth. Numerous transgender individuals pursue medical assistance to transition from one gender to another, and those who do may refer to themselves as transsexual. The term "transgender" lacks a universally accepted definition, even among scholars, and is frequently utilized as an inclusive term. This definition includes binary trans men and trans women, and it may also cover non-binary or genderqueer individuals. Furthermore, related groups like third-gender individuals, cross-dressers, drag queens, and drag kings are occasionally encompassed within wider definitions of transgender. A significant number of transgender individuals face gender dysphoria, and some seek medical interventions such as hormone replacement therapy, gender-affirming surgery, or psychotherapy. Nonetheless, not every transgender person pursues these treatments, and certain individuals may face obstacles in obtaining them because of legal, financial, or medical challenges. Typically, under 1% of the global population identifies as transgender, with estimates varying between <0.1% and 0.6%.[1] In April 2014, the Supreme Court of India recognized transgender individuals as a "third gender" under Indian law.[2] India's transgender community, which encompasses Hijras and various other groups, boasts a profound history intertwined with Indian culture and Hindu mythology. In his ruling, Justice K.S. Radhakrishnan emphasized the disregard and misunderstanding that society frequently exhibits toward the trauma, pain, and emotional challenges encountered by transgender individuals, especially those whose gender identity does not align with their biological sex. Historically, Hijras

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have endured systemic discrimination, including being denied driving licenses and social benefits. Additionally, they often face ostracism and exclusion from their communities.[3] While sexual orientation and gender are separate concepts, historically, gay, lesbian, and bisexual communities have frequently served as the sole environments where individuals who are gender-variant could discover acceptance in the gender roles they resonate with. This was particularly true during times when legal or medical gender transitions were nearly impossible. Nonetheless, this acceptance has a complicated past. Up until the 1970s, a large portion of the gay community in Western societies, similar to the wider world, did not distinctly separate sex from gender identity. Consequently, the important contributions of the transgender community to the history of LGBT rights are frequently neglected. Transgender individuals encounter elevated rates of employment discrimination. A 2011 review of multiple studies revealed that around 90% of transgender Americans had experienced harassment or mistreatment in the workplace. Additionally, 47% reported facing negative employment outcomes because of their transgender identity, with 44% being passed over for a job, 23% denied a promotion, and 26% terminated due to their gender identity.[4] The cultures of the Indian subcontinent recognize a third gender, commonly known as hijra in Hindi. On April 15, 2014, the Supreme Court of India officially acknowledged the third gender, stating that "The recognition of transgenders as a third gender is not merely a social or medical concern, but fundamentally a human rights issue." Previously, in 1998, Shabnam Mausi made history by becoming the first transgender individual elected to public office in India, representing the central state of Madhya Pradesh.[5] The prevalence of transgender individuals in the general population is not well understood, as estimates vary widely depending on how transgender is defined. A recent systematic review revealed that around 9.2 individuals per 100,000 have either sought or undergone gender-affirming surgery or hormone therapy, while 6.8 out of every 100,000 have received a diagnosis specific to transgender individuals, and 355 out of every 100,000 identify as transgender. These discrepancies underscore the necessity for consistent terminology in the study of transgender experiences. Research that concentrates on surgical or hormonal gender affirmation may not correspond with studies that investigate diagnoses such as "transsexualism," "gender identity disorder," or "gender dysphoria," nor with those that rely on self-reported identity. The lack of standardized terminology across studies contributes to inconsistent population estimates.[6]

Case Scenario

At the most unexpected hour, we encountered six transgender individuals accompanied by police personnel seeking an opinion regarding which cell to put them in. A medical board was formed, consisting of a Medical Jurist and an obstetrician. As it was midnight, no investigations were performed; only a physical examination was possible. So, on the basis of physical examination and by examining the external genitalia, an opinion was given that phenotypically all the transgender individuals were female and logically should be kept in the female cell. But still, the query remained unanswered: what is suitable for them? As a medical professional, is not it our utmost duty to make them feel comfortable while examining and to help they identify themselves.

Discussion

As India is a developing nation, it requires more time and strength to change, which does not happen overnight. The transgender community encompasses a wide range of individuals whose gender identity does not align with the sex they were assigned at birth. This group includes trans men, trans women, non-binary individuals, genderqueer people, and others who defy conventional gender norms.

Aspect	Sex	Gender
Focus	Biological and physical traits	Social and cultural roles, identity, and expression
Determination	Determined at birth (biological)	Determined by personal and social factors
Flexibility	Typically static	Can evolve over time and vary across cultures
Expression	Physical characteristics	Behavior, clothing, pronouns, roles

The transgender community often serves as a vital support network, fostering solidarity, advocacy, and shared understanding among its members. Despite progress in societal acceptance, transgender individuals frequently face challenges such as discrimination, lack of access to healthcare, legal barriers, and social exclusion. Community organizations, advocacy groups, and allies work together to promote transgender rights, ensure visibility, and create safe spaces for individuals to express their authentic selves.

Globally, transgender communities are shaped by unique cultural, legal, and societal contexts, but the shared goal of equality and recognition unites their efforts. As per the Prison Act, 1894, Chapter 5, Section 27, separation of prisoners: The requirements of this act regarding the separation of prisoners are as follows:

1. In prisons housing both male and female prisoners, females must be confined in separate buildings or distinct sections of the same building. This arrangement should ensure they cannot see, converse with, or interact with male prisoners.
2. In prisons accommodating male prisoners under the age of 21, provisions must be made to completely separate them from other prisoners. Additionally,

those who have reached puberty must be kept apart from those who have not.
3. Unconvicted criminal prisoners must be kept separate from convicted criminal prisoners.
4. Civil prisoners must be kept separate from criminal prisoners.[7]

The Supreme Court of India has also declared that transgender prisoners should be treated equally to other categories of inmates and must have the same rights. Experiences of transgender people in jail are often marked by significant challenges and systemic inequities. Transgender individuals, particularly trans women, face elevated risks of violence, harassment, and discrimination in correctional facilities. Some of the key issues they encounter include:

Placement in Facilities

- Misclassification: Transgender individuals are frequently assigned to facilities according to their sex assigned at birth instead of their gender identity, which heightens their risk of experiencing violence and mistreatment.
- Policies for placement: Some jurisdictions have begun implementing policies to house transgender individuals in alignment with their gender identity, though such policies are not universal.

Violence and Harassment

- **Physical and sexual violence:** Transgender inmates, especially trans women placed in male facilities, are disproportionately subjected to physical and sexual violence by both other inmates and staff.
- **Solitary confinement:** To "protect" transgender individuals, some facilities place them in solitary confinement, which may result in significant mental health issues.

Access to Healthcare

- **Gender-affirming care:** Many transgender individuals in jail struggle to access necessary gender-affirming healthcare, such as hormone replacement therapy or mental health support.
- **Legal challenges:** In some regions, inmates must legally advocate for their right to gender-affirming treatments, with mixed success depending on the jurisdiction.

Legal Protections and Advocacy

- **PREA standards:** The Prison Rape Elimination Act (PREA) includes provisions to protect transgender inmates, such as assessing housing placement and ensuring their safety. However, the implementation of these standards is inconsistent.
- **Advocacy efforts:** Organizations and activists continue to work toward ensuring the rights and dignity of transgender people in jail, including proper housing, access to healthcare, and protection from violence.

Reform and Progress

There is increasing awareness of the unique challenges faced by transgender inmates, prompting some jurisdictions to adopt policies aimed at improving their treatment. Individuals may also experience gender dysphoria, which is characterized by significant or ongoing distress stemming from a mismatch between their gender identity and biological sex.[8] These reforms include housing transgender individuals according to their gender identity, providing access to necessary medical care, and training staff on LGBTQ+ inclusivity. Transgender individuals ought not to be viewed as marginalized segments of the community; they deserve respect, acknowledgment, and appreciation. It is essential to create a consistent and systematic approach for gathering data regarding the status of transgender individuals and gender identity, which is crucial for effective policymaking and intervention initiatives.[9] These individuals require acknowledgment of their identities as genuine, improved access to healthcare resources, and educational and preventive materials that are suitable for their experiences.[10] However, much work remains to be done to ensure equitable treatment for transgender people in correctional systems nationwide.

Conclusion

The Transgender Protection Person (Protection of Rights) Act, 2019, Chapter 5, Section 10, obligations of establishments states that every establishment should ensure compliance with the provisions of this act and should provide such facilities to transgender people.[11] The authorities have announced that 16 states have verified that prisoners are categorized and separated based on evaluations carried out by jail medical personnel or through biological identification and/or genital characteristics, instead of giving precedence to the gender identified by the prisoners themselves. Under the Transgender Persons (Protection of Rights) Act, 2019, Section 11 requires the appointment of a "complaint officer" to address grievances related to the rights of transgender inmates in prisons. Nevertheless, only 13 states and two Union Territories have adhered to this requirement. Furthermore, the majority of states and UTs have not established specific welfare programs for transgender prisoners. Instead, they are applying existing welfare programs to this group.[12–14] Only seven states and two UTs have taken steps to enhance transgender prisoners' access to appropriate welfare

programs. It is essential for prison departments to guarantee that correctional facilities provide sufficient sanitation amenities, including designated bathing and toilet facilities solely for transgender prisoners. Moreover, a thorough health assessment, along with a socio-psychological evaluation, should be performed for each transgender prisoner upon their admission. Prison authorities must ensure that transgender prisoners who are interested in engaging in vocational training and skill enhancement programs receive encouragement from prison staff to pursue these opportunities without any limitations or fears.[15,16]

National Crime Records Bureau compiled prison statistics reported to it by the states and UTs in the year 2020, and as per it, there is a total of 70 transgender inmates, and a major number are residing in Gujarat, UP, and Maharashtra.[12] Even after these groundbreaking reports, states and UTs have terribly failed to set up a healthy and friendly environment in prisons for transgender people.

Recommendations & Suggestions

- Accommodated in suitable facilities according to the gender they identify themselves with.
- Separate ward or enclosure by prison authorities.
- Housed separately but not segregated, a hospitable environment.
- Protect their right to privacy, identity, and bodily integrity.
- Uniform procedure to be followed while examining.
- Not to violate the fundamental rights.
- More body positivity and inclusivity.
- Should not be inhibited from any kind of vocational training.
- Have full access to health services.

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Analysis of Close-range Firearm Injury Patterns: An Interesting Case Report

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Abstract

The authors present an unusual death of a 21-year-old female with an alleged history of firearm injury. On autopsy, a firearm entry wound was present over the lateral aspect of the left side of chest, and margins were found to bevel inside. Abrasion collar situated over superolateral aspect of wound. On its course, the bullet pierces the skin, muscles and ricochets off the underlying structures found at the back of the body. Margins of the exit wound were found to be beveled outside. Another stellate-shaped firearm entry wound with flame effects present over the right side of the face situated lateral to lateral canthus of right eye. Direction of wound found going downward medially and underneath temporal bone, which was found fractured with one associated radiated fracture, which was found running backward posteriorly and placed horizontally. The track of the bullet was found bright red and discolored, and the bullet was found embedded in the left occipital region of scalp. Two hard blackish abrasions due to heat effects and rubbing of bullet are present over right maxillary region of face. Tattooing of the skin was seen over the medial aspect of abrasion. The injuries seen over the body indicate close-range firearm discharge.

Keywords

Stellate shape, tattooing, abrasion collar, close-range

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Introduction

Gunshot wounds are violent, complex, and traumatic injuries that are frequently seen in forensic investigations. Such injuries result from the penetration of the body by projectiles expelled from the barrel following the ignition of gunpowder.[1] In addition to the projectile and the resultant wound, the forensic pathologist must also consider the accompanying effects of flame, gases, smoke, unburnt powder, metallic residues, and barrel grease, which may be deposited on the surrounding skin or within the wound track.[2] Gunshot entry wounds are broadly classified as close-range, comprising contact, near-contact, and intermediate-range injuries, or as those without features of close-range discharge. The term 'distant' shot merely denotes the absence of close-range characteristics, which may occur when the firearm is discharged beyond the effective range of soot and powder deposition or when an intermediate object, such as clothing or other barriers, lies between the muzzle and the body.[3] This case is reported for its distinctive demonstration of close-range firearm injury patterns, which provide valuable insight into their forensic interpretation and medico-legal importance.

Case History

On April 4, 2024, a 21-year-old female was brought to the mortuary of our institute with an alleged history of death due to a firearm injury. On further inquiry from the investigating officers, it was revealed that the present case constituted a dyadic death. The victim, along with his companion, was intentionally killed by another acquaintance (Figure 1). Following the incident, the perpetrator committed suicide at a location in close proximity to the crime scene, where the

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Figure 1. Crime Scene Showing the Position of the Deceased (Encircled in Yellow).

alleged firearm was recovered (Figure 2). The sequence of events and the relationship between the individuals involved were established through police investigation and corroborated by eyewitness accounts.

Observation

Wearing one kurti, one salwar, one bra with strip and one strip-less bra. Salwar found torn over left side, below knee at anterior aspect, situated 25.0 cm above the lower end. Blood stains are present on clothes in places. Clothing found torn over the left axillary region, along with a blackish burn margin over the clothing surface, along with effusion of blood associated with the existing firearm injury. Dry clotted blood present over both nostrils, face smudged with dry clotted blood. Hairs were smudged with blood and in clotted form. Blood coming out of right ear.

Firearm Injuries

1. Firearm entry wound of size 2.1 × 2.0 cm, stellate-shaped present over right side of face, situated 3.6 cm right lateral to lateral canthus of right eye, and margins found beveling inside (Figure 3). The direction of wound was found going downward medially and

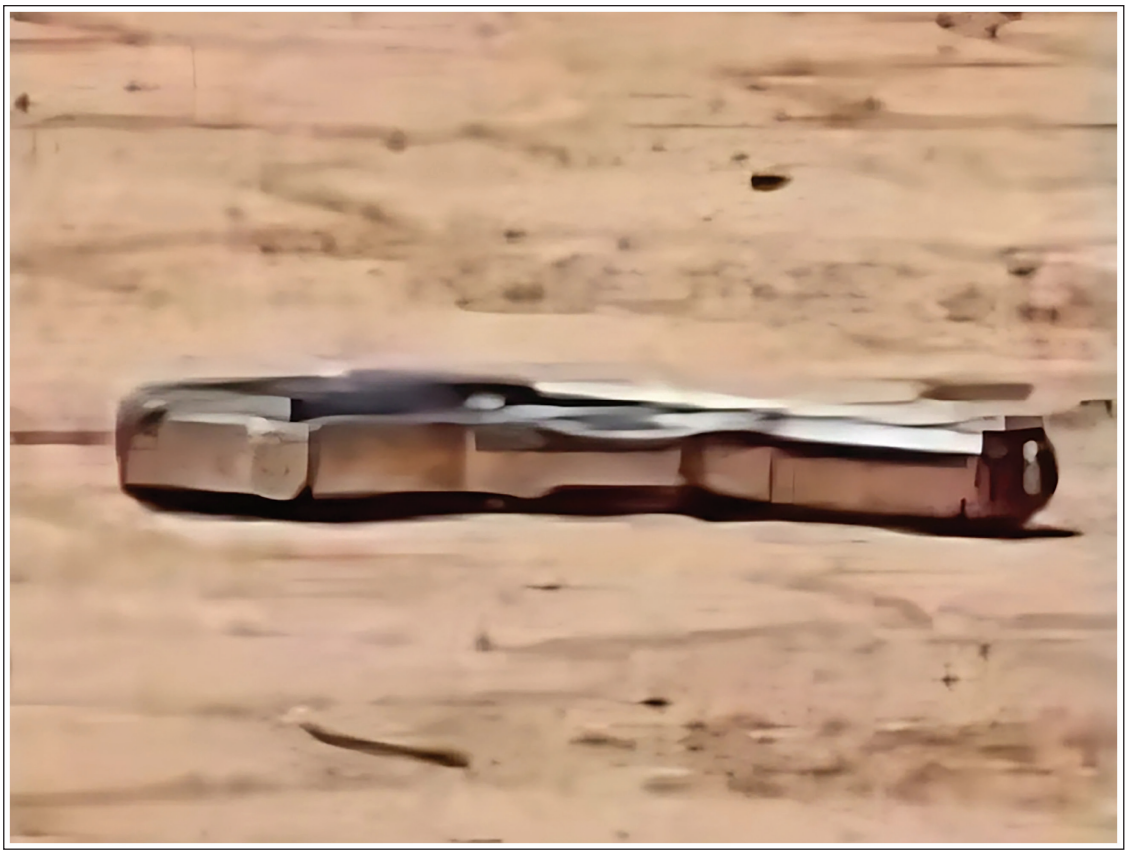

Figure 2. Alleged Firearm Recovered from the Crime Scene.

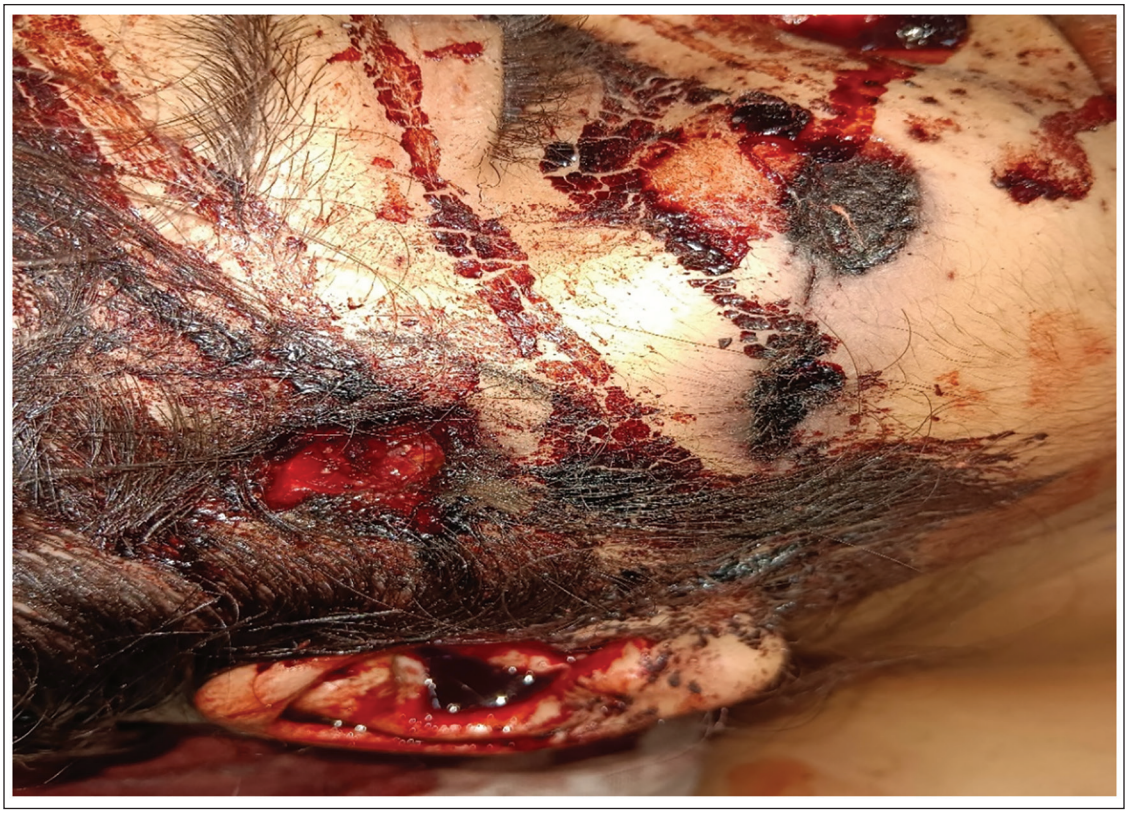

Figure 3. Stellate-shaped Firearm Entry Wound Over Right Side of Face.

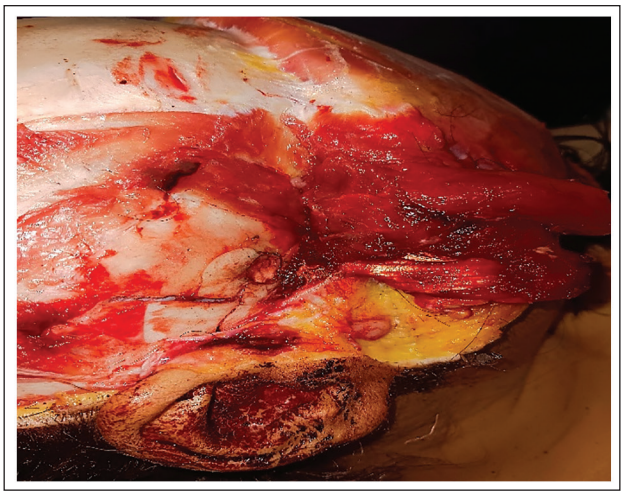

Figure 4. Fracture of the Right Temporal Bone with Associated Radiating Linear Fracture.

underneath temporal bone, which was found fractured with one associated radiating linear fracture, which was found running backward posteriorly and placed horizontally (Figure 4). The track of the bullet was found bright red, discolored, creating an exit wound over left occipital bone, and the bullet was found embedded between scalp and skull bone. Subdural and subarachnoid hemorrhages were present throughout the brain and cerebellum at multiple sites. The recovered bullet, which was measured to be 1.1 cm in length, has been preserved for further examination.

2. Blackish burn abrasion 02 in number horizontally placed with a distance of 1.3 cm apart, present over right side of face over maxillary region situated 2.3 cm below the lateral canthus of right eye. The first abrasion was measured 2.6 × 1.2 cm in size, and second abrasion was measured 1.8 × 0.7 cm in size. Firearm tattooing in an area of 5.0 × 3.7 cm in size, varying from pinpoint to 0.3 cm, circular in shape, present over right side of face, situated between first abrasion wound and right ala of nose. Margins of abrasion wounds are found slightly hard and elevated, which appears to be due to rubbing of bullet over the skin. The direction of bullet in the above-mentioned abrasion wounds is from left to right (Figure 5).
3. A firearm entry wound measuring 0.7 × 0.7 cm, with a 0.2 cm abrasion collar at its superolateral margin, was present over the lateral aspect of the left chest, 124.1 cm above the left heel (Figure 6). The wound exhibited internal beveling consistent with an entry wound. The bullet traveled downward from left to right, passing through the 8th–9th intercostal space, fracturing the upper border of the 9th rib, perforating the left lower lobe of the lung, and then the diaphragm and spleen. Along its trajectory, the bullet coursed medially and

Figure 5. Blackish Burn Abrasions and Firearm Tattooing Over Right Side of Face.

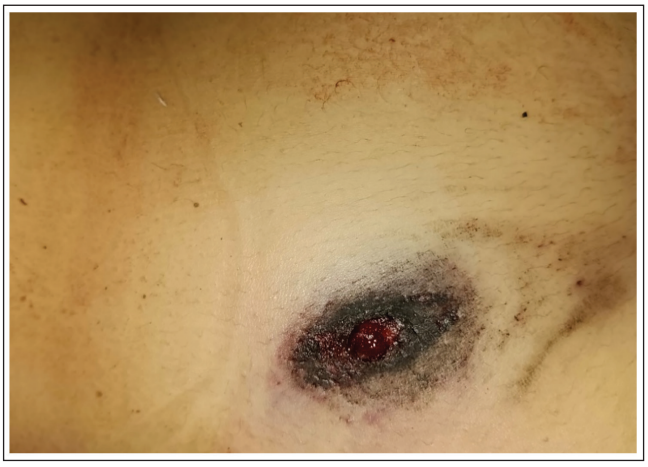

Figure 6. Firearm Entry Wound Over Lateral Aspect of Left Side of Chest.

inferiorly, striking the left posterolateral border of the 5th lumbar vertebra, perforating it, and exiting from the right posterolateral margin of the 5th lumbar vertebra. The exit wound measured 0.6 × 0.5 cm, with outward beveling, located 104.0 cm above the right heel, 4.1 cm lateral to the midline, and 36.7 cm inferolateral to the nape of the neck. Along the bullet track, muscles, soft tissues, and internal organs exhibited ecchymosis and blood effusion.

Internal Examination

The thoracic cavity contained approximately 800 ml of blood. The heart was found empty. About 1.0 L of blood was present in the abdominal cavity, and the spleen was noted to be ruptured. The stomach was empty, and the gastric mucosa appeared pale. In the cut section, all internal organs appeared pale. The trachea was empty, and the uterus was also empty on a cut section.

Discussion

The presence of seared, blackened edges along with red discoloration of the track of the bullet and stellate-shaped wound is suggestive of a hard-contact wound. In hard-contact firearm wounds, the muzzle is firmly pressed against the skin, producing an indentation and allowing the surrounding skin to envelope the muzzle. The margins of the entry wound are typically seared by hot combustion gases and blackened by soot, which becomes embedded within the seared tissue and cannot be removed by washing or scrubbing. When contact wounds occur overlying bony prominences, they often assume a stellate configuration. This pattern results from the propellant gases striking the underlying bone, reflecting into the subcutaneous tissues, and causing a sudden expansion that produces explosive tearing and laceration of the overlying skin and soft tissue. These findings are consistent with those reported in the textbooks authored by Dimaio VJM and Molina DK,[3] Aggrawal A,[4] Reddy KSN and Murty OP,[5] and Bardale R.[6] These findings are also consistent with research work done by other researchers like Shrestha R et al.[2]

The presence of flame effects, along with the presence of soot, which is baked into the skin, resulted in tattooing are suggestive of a near-contact wound. In near-contact firearm wounds, the muzzle is held a short distance from the skin without being pressed against it. At this proximity, the powder grains expelled from the muzzle do not have sufficient distance to disperse and instead become deposited in a concentrated manner around the entry site. Such residues are often grossly visible within the subcutaneous tissue and may extend into deeper structures. These features are of considerable medico-legal importance, as they assist in estimating the firing distance and differentiating near-contact injuries from hard-contact and distant gunshot wounds. These findings are

consistent with those reported in the textbooks authored by Dimaio VJM and Molina DK,[3] Aggrawal A,[4] Reddy KSN and Murty OP.[5] These findings are also consistent with research work done by other researchers like Shrestha R et al.[2]

The presence of the majority of the seared, blackened zone in the downward direction suggests it is an angled contact wound. When the barrel is held at an acute angle to the skin, the muzzle does not make complete circumferential contact. The escaping gases and soot radiate outward through the gap, creating an eccentrically distributed soot pattern. The entrance wound is typically situated at the base of the seared blackened zone, with the bulk of the zone lying opposite to the point of muzzle contact, thereby indicating the direction of fire. These findings are consistent with those reported in the textbooks authored by Aggrawal A.[4]

Based on the external and internal examination, the cause of death in the present case was attributed to shock and hemorrhage resulting from firearm injuries. The circumstances and wound characteristics were consistent with a homicidal manner of death. The post-mortem findings further suggested that the survival period was less than 24 hours prior to examination.

Conclusion

Illegal firearms pose a significant public health and forensic concern. Our analysis of close-range firearm injuries demonstrates that increased availability of illicit weapons contributes to a higher incidence of gunshot fatalities. This case report will aid in the estimation of firing range based on injury patterns, providing valuable guidance for law enforcement agencies during investigations. Effective reduction of homicidal deaths requires dismantling illegal firearm manufacturing and trafficking operations, alongside vigilant and coordinated efforts by law enforcement. Continued monitoring and analysis of firearm injury patterns are essential to inform preventive strategies and medico-legal interventions.

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

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Informed Consent

Authors declare consent for publication.

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Interstitial Pneumonitis: A Rare Complication of Electrocution—A Case Report

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Abstract

Electrocution injuries are associated with high morbidity and mortality, most deaths occurring instantly due to cardiac arrhythmias or respiratory arrest. Delayed deaths and rare organ complications are seldom reported in the literature. We present a case of a 70-year-old woman who survived for five days following an accidental domestic electrocution and subsequently died due to interstitial pneumonitis (IP) and renal tubular necrosis. This case highlights the unusual pulmonary sequelae of electrocution and underscores the importance of meticulous histopathological examination in forensic practice.

Keywords

Delayed deaths, electrocution, interstitial pneumonitis

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Introduction

Determining the cause and manner of death is the critical role of the forensic expert, aiding investigating authorities in distinguishing between natural and unnatural deaths. Electrical injuries, though uncommon, carry high morbidity and mortality with a unique pathophysiology. They may result from lightning, high-voltage, or low-voltage currents, producing manifestations from transient tingling to fatal arrhythmias.[1–4]

In India, 9,986 electrocution deaths were reported in 2015 (NCRB). Approximately 1,000 deaths and 3,000 burn-centre admissions occur annually due to electrical injuries, with up to 40% of serious cases proving fatal.[5] Around 20% of injuries occur in children, mostly from household appliances and outlets, while workplace exposures remain the fourth leading cause of occupational traumatic death.

Common causes of death include ventricular fibrillation, respiratory paralysis, cerebral anoxia, burns, or secondary trauma.[6] Intestinal perforations, along with necrosis of the intestines and arteries, are considered to be more frequent complications of electrocution.[6–8] Wanton et al. (1988) also showed the incidence of myocardial infarction subsequent to electrocution.[9] In addition, Sprecher et al. showed the rupture of an intracranial aneurysm as a complication of electrocution.[10] Sparse literature exists on the studies determining the changes in organs in electrocution deaths.[11] However, pulmonary sequelae like interstitial pneumonitis (IP) are rarely reported. This prompted us to present this case, where delayed fatality occurred due to pulmonary and renal complications of electrocution.

Case Report

A 70-year-old female accidentally sustained an electrocution injury while doing cleaning work at her home when she held a live wire with her right hand on 19 March 2016, at 06 PM and became unconscious. While doing the cleaning in the home, she was barefoot, and the floor was not wet. Information about the faulty plug with live wire was given by the relatives, and no official electrical engineer report of faulty electrical equipment was provided by the relatives. She was initially treated at a private

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hospital in Ratnagiri and then transferred to a tertiary care hospital in Mumbai on 22 March 2016 for further treatment. During treatment, she was declared dead on 24 March 2016. The victim survived for 5 days and died due to late and unusual sequelae and complications of electrocution injuries involving vital organs. There is no history of any illness or chronic disease. There is no history of any type of addiction by the deceased.

On External Examination

Injuries were as follows: (a) Electrocution injury with crater formation present over the proximal and distal phalanx of the right thumb measuring 3 cm by 1 cm, suggestive of an entry wound (Figure 1). (b) Electrocution injury with blackening evident over the distal phalanx of the right index finger measuring 1 cm × 1 cm suggests an entry wound (Figure 1). (c) An electrocution injury with flattening of skin creases, hard to touch, measuring 2 cm by 1.5 cm, was present over the proximal phalanx of the right middle finger, palmar aspect, suggesting an entry wound (Figure 1). Electrocution injury present over the left heel measuring 3 cm × 2 cm, area hard to touch, pale, flattening of skin creases present associated with the surrounding area showed a hyperaemic border suggestive of an exit wound. Internal examination showed that the brain was markedly congested and oedematous, the lungs were congested and oedematous, and other organs were congested. The samples from various organs were preserved for histopathological examination. Histopathological findings: The cerebrum showed

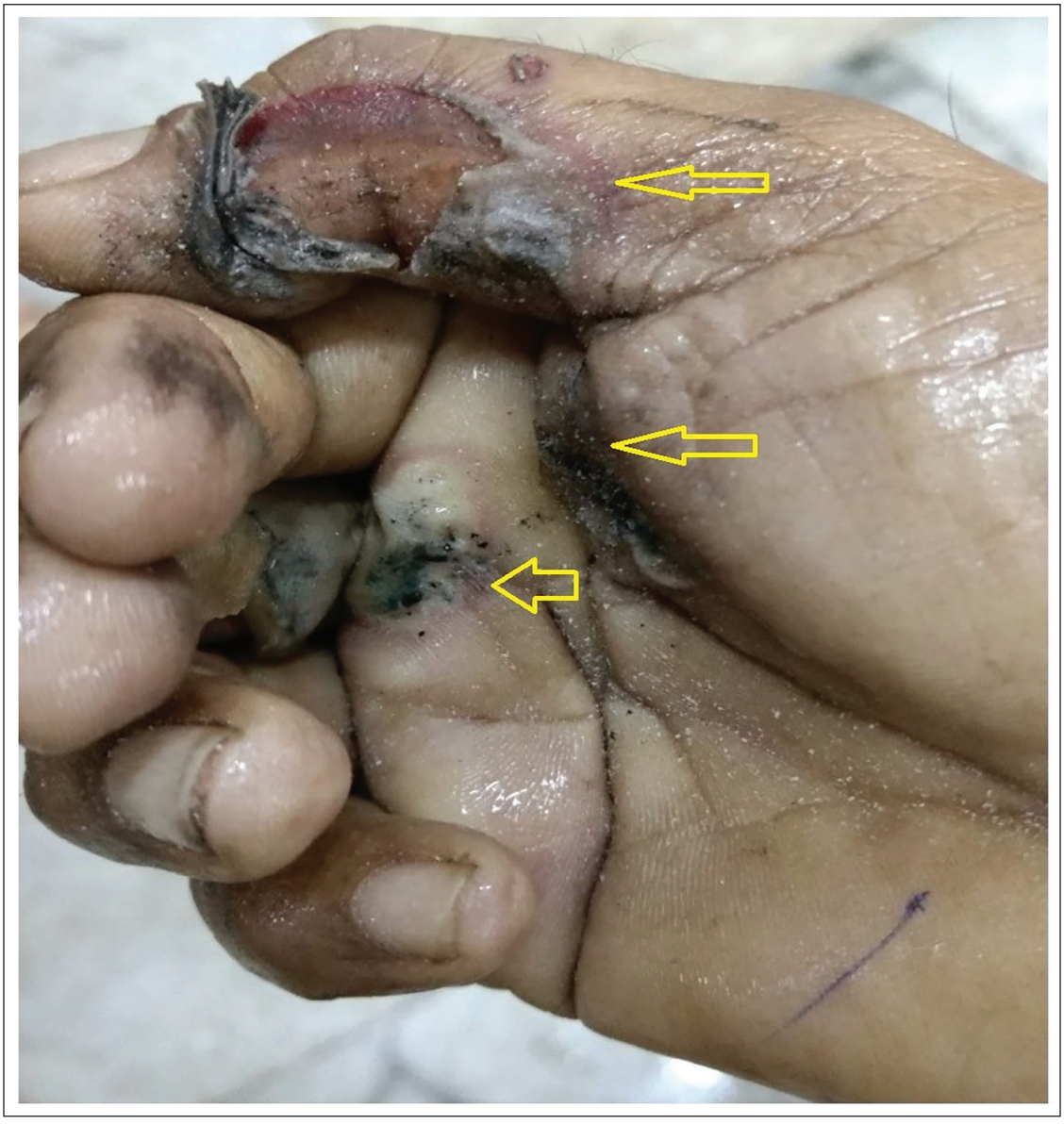

Figure 1. Photograph of an Electric Entry Wound as a Joule Burn (Arrow) Present Over Palmer Aspect of Right Hand.

hypoxic changes. The lung showed a feature of IP with areas of pulmonary haemorrhage (Figure 2). The kidney showed focal tubular necrosis (Figure 3). Skin from the heel epidermis lining was not seen; sub-epithelial tissue showed few congested vessels. No abnormality was detected in the heart. Opinion as to the cause of death was furnished as IP, and tubular necrosis of the kidney as sequelae and complications of electrocution.

Discussion

Since the advent of electricity, both fatal and non-fatal injuries due to electrocution have increased.[12,13] Immediate deaths usually result from cardiac arrhythmias (especially ventricular fibrillation when current traverses the thorax) or respiratory arrest due to brainstem involvement.[6] Joule burn is

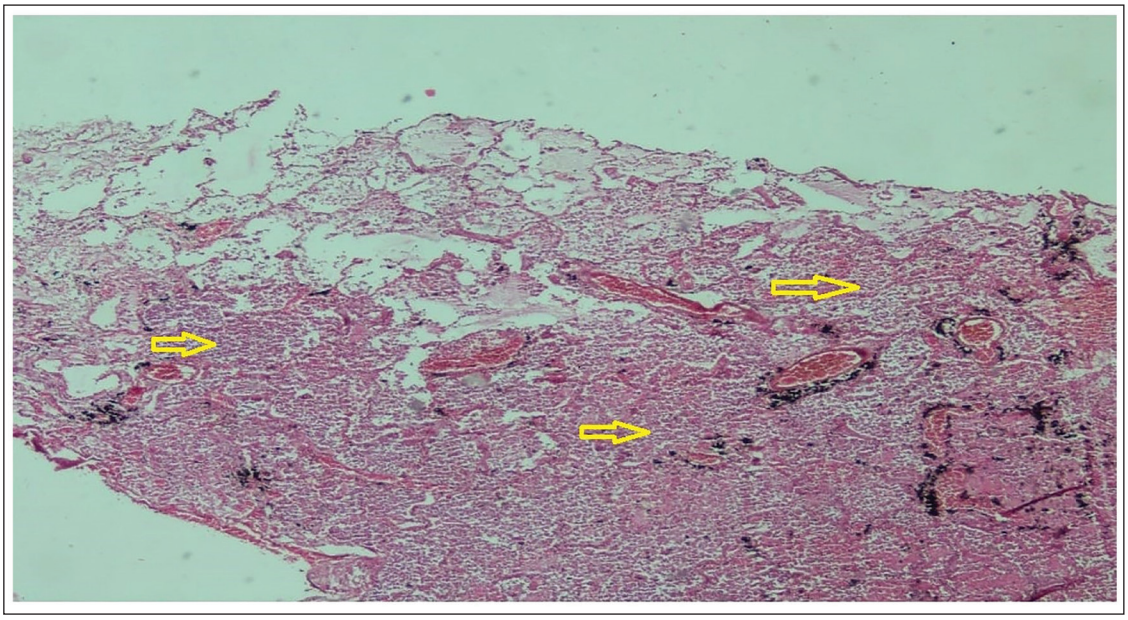

Figure 2. Microscopic Image of Lung Tissue Showing Interstitial Pneumonitis (Arrow) with Areas of Pulmonary Haemorrhage.

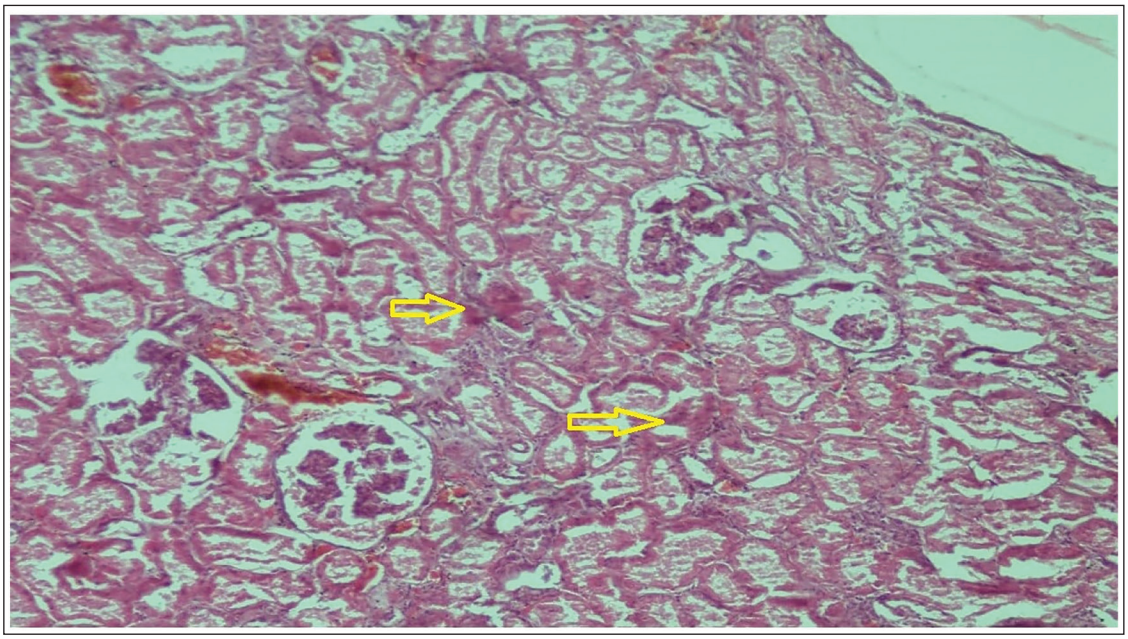

Figure 3. Microscopic Image of Kidney Tissue Showing Renal Tubular Necrosis (Arrow).

considered to be a very specific and diagnostic finding of death due to electrocution seen at the site of contact with a live electric conductor. These are round or oval-shaped craters and have a ridge of skin about 1-3 mm in the whole circumference or part of the circumference.[6]

Delayed fatalities occur in 7%–22% of cases, commonly from sepsis, haemorrhagic shock, anoxic encephalopathy, or multisystem failure. Pulmonary involvement is seldom described.[14–16]

IP refers to inflammation of the lung interstitium, usually linked to autoimmune disorders, environmental toxins, radiation, or drugs. Acute IP is rare and often fatal. Global incidence of ILD ranges from 1 to 31.5 per 100,000 person-years, with hypersensitivity pneumonitis forming nearly 47% of Indian cases.[17] Throughout the world, the relative frequency of connective ILD reported an enormous variation, with the least in Belgium (7.5% of cases) and greatest in Canada (33.3%) and in Saudi Arabia (34.8%). Pulmonary findings directly caused by electrocution are seldom reported in literature. Though pulmonary contusions can be found due to a fall from heights subsequent to electrocution.[18] Acute IP is considered to be a rare reported disease which is associated with a higher mortality rate.[19]

Studies by Masanes, Michui, and Kanchan have reported pulmonary oedema, alveolar haemorrhage, congestion, and mild fibrosis.[20–22] Singh et al. documented non-cardiogenic pulmonary oedema in a child.[23] However, IP specifically following electrocution has not been described widely.

In the present case, the victim was previously healthy, with no risk factors for IP (no smoking, toxins, autoimmune disease, radiation, or drugs). The only plausible trigger was electrocution, leading to delayed pulmonary injury and renal tubular necrosis. Thus, electrocution can induce atypical inflammatory responses in the lung parenchyma, culminating in fatal IP.

Most electrocution deaths are immediate; delayed sequelae complicate cause-of-death determination. Absence of classical skin burns can obscure diagnosis, making histopathology vital. Establishing accidental origin influences insurance claims, compensation, and liability.

Conclusion

Electrocution typically causes sudden cardiac or neurological death, while pulmonary complications are rarely encountered. This case documents IP as an unusual, delayed sequela of electrocution, leading to death five days after injury.

Awareness of such complications is crucial for forensic experts, particularly when classical electrical marks are minimal. Histopathology plays a decisive role in attributing death to electrocution in these scenarios. Preventive household electrical safety measures and awareness campaigns remain essential to reduce such avoidable fatalities.

Abbreviations

IP: Interstitial pneumonitis
ILD: Interstitial lung disease
DILD: Drug-induced interstitial lung disease

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.

Funding

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Informed Consent

The consent for the study was taken from the participants.

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Sudden Death Due to DeBakey Type III Thoracic Complete Aortic Dissection (DBTTCAD) with an Allegation of Homicide

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Abstract

An aneurysm is a localized dilation of a blood vessel or heart, with true aneurysms involving all three layers of the arterial wall. DeBakey Type III thoracic aortic dissection (DBTTCAD) is a fatal condition, commonly associated with chronic hypertension, which weakens the aortic wall. In this case, a heated quarrel triggered the sudden rupture of a pre-existing aneurysm, causing immediate death. Factors such as stress, physical exertion, or collapse can precipitate such fatal events. Five individuals involved in the altercation were charged with murder. Autopsy and microscopic examination were crucial in determining the cause of death, highlighting the forensic importance of sudden deaths during violent encounters.

Keywords

Aneurysm, aortic wall, aortic dissection, DeBakey Type III

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Introduction

DeBakey Type III aortic dissection originates distal to the subclavian artery in the descending aorta and is further subdivided into IIIa that extends distally to the diaphragm and IIIb that extends beyond the diaphragm into the abdominal aorta[1] (Figure 1). An aneurysm is a localized dilatation of the lumen of the blood vessel or heart, which may be congenital or acquired, single or multiple. A true aneurysm involves all three layers of the arterial wall. We reviewed the literature and found not a single case reports of DeBakey Type III thoracic complete aortic dissection (DBTTCAD). Hypertension is a major risk factor for aortic dissection.[2] Aortic dissection occurs when blood separates the laminar planes of the media to form a blood-filled channel within the aortic wall.[3] Thoracic aortic dissection (TAD) is an emergency procedure. Approximately 22% of the patients with TAD do not reach the hospital.[4]

Case History

A 58-year-old male presented with a history of fighting and intense arguments with others. The deceased fell down on the ground and immediately rushed to the hospital, and the clinician declared them dead. There was an alleged allegation of murder by the beatings. The deceased was sent to the mortuary for an autopsy examination by an investigating agency. The deceased had been taking hypertensive medicine for the last five years. The history of cardiac disease and coronary artery bypass grafting (CABG) was done two years ago.

Observations

Multiple whitish areas were observed over the pericardium. The circumference of the aortic valve was 06 cm, and numerous yellow plaques were observed in the ascending aortic

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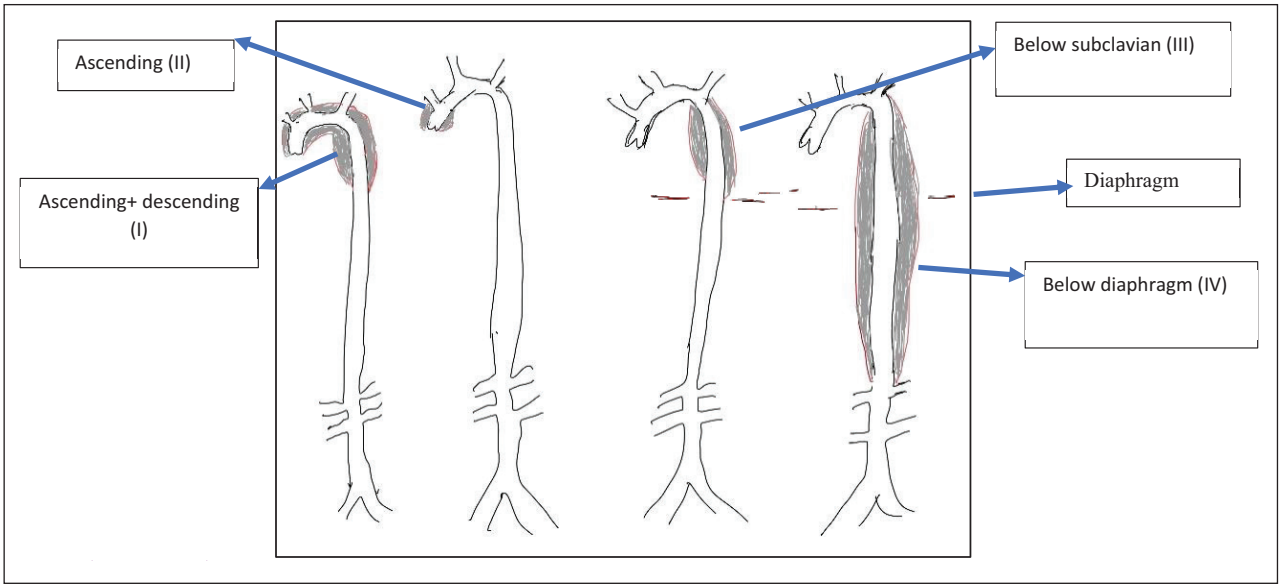

Figure 1. DeBakey Classification of Aortic Dissection (Mentioned as I–IV).

wall. The coronary arteries exhibited narrowing of their lumens, which appeared gritty upon cutting. Stainless steel stents were found in the LCA (left coronary artery) and LAD (left anterior descending artery) walls.

The descending aorta was ruptured and was completely separated 10 cm below the origin of the left subclavian artery (Figure 2A). Near the edges of the transection, the tunica intima of the aorta is stripped and attached in situ (Figure 2B). No other internal or external injuries were observed over the body. The descending aorta had multiple small aneurysms, with the largest measuring 0.5 cm in diameter (Figure 2C).

Histopathological Observations

The thoracic aorta showed aortic dissection as a tear site in the tunica intima, and the tunica media was completely torn (Figure 3A and B). Each kidney showed focal glomerular sclerosis, thyroidization of tubules, hyalinized and thickened blood vessels, chronic inflammatory cell infiltration, and interstitial fibrosis (Figure 3C and D) Several atheromatous plaques were found in the LCA (Figure 4A), LAD (Figure 4B), and right coronary artery (RCA) (Figure 4C and D) along with thrombosis with the feature of recanalization. The anterior, posterior, and lateral walls of the left ventricle and the posterior wall of the right ventricle showed fibrosis.

Discussion

Aneurysm formation owing to atherosclerotic changes induces pressure or ischemic atrophy of the underlying media, resulting in elastic tissue loss, wall weakness, or rupture. Weakening of the tunica media predisposes the patient to an intimal tear, resulting in an intramural hematoma that cleaves the media layers, leading to aortic dissection.[3,4] Herein, we report a case of complete TAD. Hypertensive changes in the kidneys were seen as (Figure 4). The evidence of atherosclerotic changes with coronary artery intervention in the form of percutaneous coronary interventions in both the LCA and left anterior descending arteries was present. No other external or internal injury observed during autopsy.

Intimal tears occur in the ascending aorta 65% of the time, the descending aorta 25%, and the arch or abdominal aorta 10%.[3] One study found that chronic hypertension accounted for 49% of ischemic heart disease cases.[5] Formation of aortic aneurysms is nine times more frequent in the abdominal aorta than in the thoracic segment.[6] An autopsy revealed a massive left hemothorax and a tear in the descending aortic aneurysm. Microscopic examination confirmed complicated atherosclerosis in the descending thoracic aorta. Autopsies, clinical presentations, and treatment histories aid in the diagnosis.[5]

Evidence of CABG was present, indicating a prior surgical intervention to restore blood flow in occluded coronary arteries. Hypertensive changes were observed in the vertebral and basilar arteries, characterized by the presence of atheromatous plaques. Chronic hypertension leads to structural alterations in cerebral arteries, which impair cerebral perfusion. These hypertensive changes result in a reduced arterial lumen and an increased wall-to-lumen ratio.[7-10] The kidney shows evidence of focal segmental glomerular sclerosis, consistent with chronic hypertensive injury. Additional findings include thyroidization of the tubules, thickening and hyalinization of blood vessels, chronic inflammatory infiltrates, and interstitial fibrosis.[11] Hypertensive changes in the kidney were seen in microscopic examination. Upon autopsy, no signs of

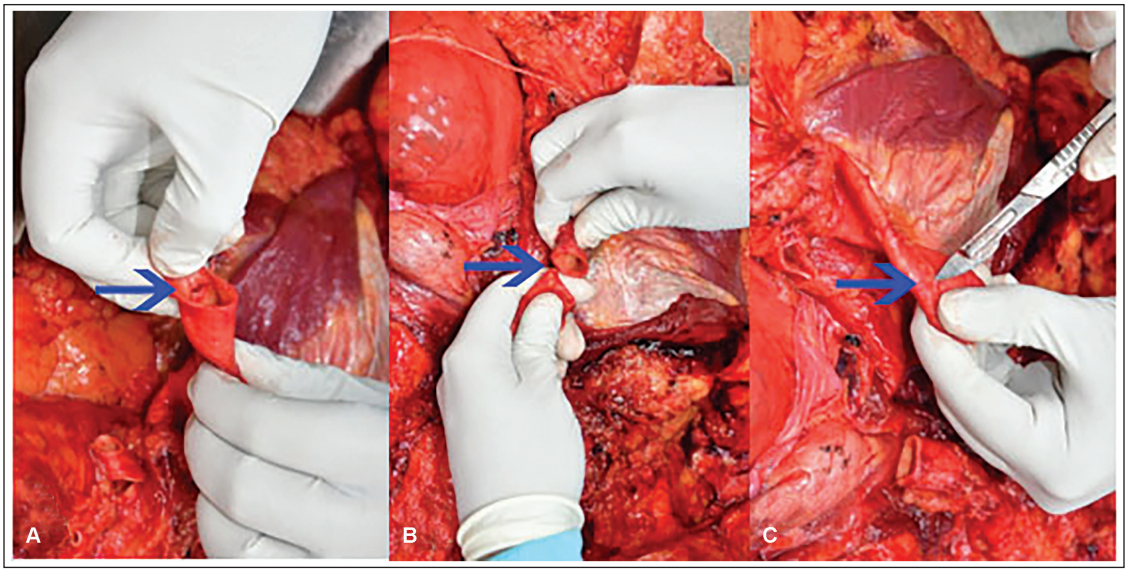

Figure 2. (A) Tearing of Aortic Wall. (B) Complete Dissection of the Thoracic Aortic Wall with Stripped Wall. (C) Multiple Aneurismal Aortic Walls.

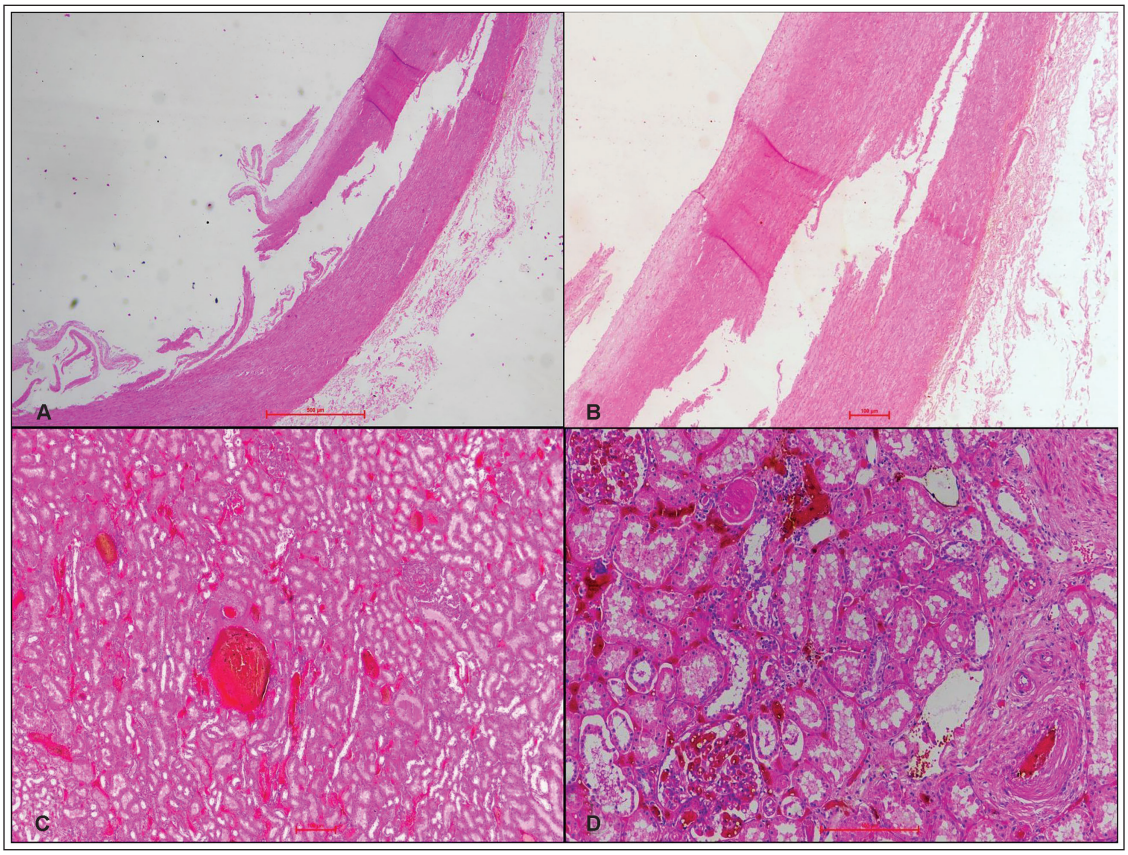

Figure 3. (A) Large-size Blood Vessels Showing Tears in Tunica Intima and Media (Hematoxylin and Eosin (H&E); 4×), (B) Complete Dissection of Tunica Media (H&E; 10×), (C and D) Renal Parenchyma Shows Markedly Congested Blood Vessels, with Renal Vasculature Exhibiting Concentric Thickening of the Vessel Wall with Minimal Cellularity (H&E; 4× &10× Respectively).

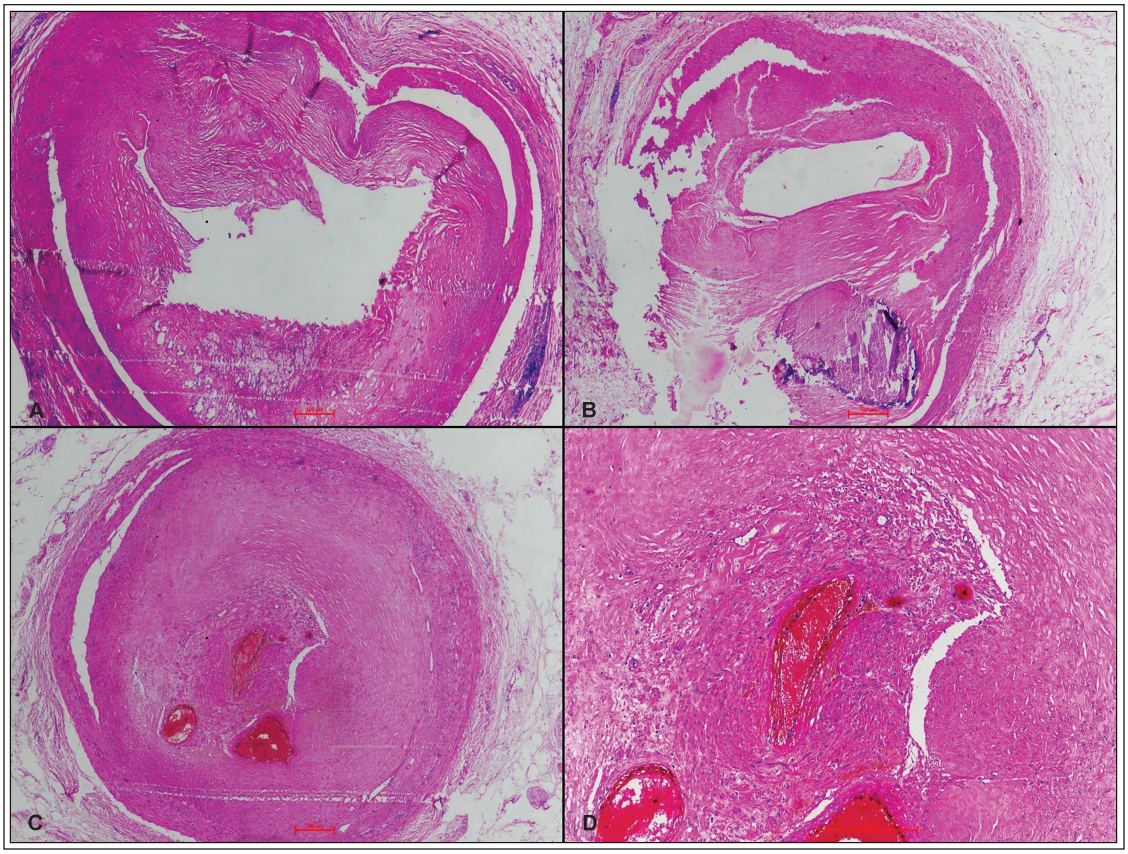

Figure 4. (A) LCA Showing Atheroma (H&E; 4×). (B) RCA Showing the Presence of Fibro Atheromatous Plaque with the Presence of Calcification (H&E; 10×). (C) RCA Showing Near Complete Occlusion of the Lumen (H&E; 4×). (D) RCA Showing Recanalization (H&E; 10×).

mechanical injury were found, either internally or externally. The cause of death was opined to be due to pathological complete thoracic aortic dissection. An autopsy examination ruled out the possibility of foul play in the murder case.

Conclusion

DBTTCAD is commonly associated with hypertension and aneurysmal dilation, both of which contribute to the development and progression of the dissection. Complete rupture of the thoracic aorta is fatal and may cause sudden death. Triggers include emotional stress, aneurysm rupture, sudden falls, or collapse. Such cases may raise medicolegal concerns, including the possibility of foul play. Autopsy and microscopic examination are hallmarks of opinion in cases of DBTTCAD.

Declaration of Conflicting Interests

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Ethical Approval

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Informed Consent

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Book Review

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N. Srinivasa Reddy, *Forensic Medicine and Toxicology: Quiz Book*, 2024, pp. 156. Innovative Publication Pvt. Ltd. ISBN: 978-81-19613-81-6

The book titled *Forensic Medicine and Toxicology: Quiz Book*,[1] edited by Dr N. Srinivasa Reddy, is an essential resource for every budding student of forensic medicine and criminalistics. It is structured in a way to enrich and deepen the knowledge of medical students and professionals. The book stands out for its engaging approach, especially for those having a keen interest in quizzes and trivia.

While quiz-based books are plentiful in fields such as mathematics, chemistry, physics, and general sciences, there are very few in medicine and even fewer in the branch of forensic medicine and toxicology. This book fills that gap with distinct quiz sections for both undergraduate and postgraduate medical students, covering a wide range of topics. It highlights synonyms, eponyms, historical milestones, and notable pioneers across various allied forensic specialties, and also charts the timeline of the evolution of forensic medicine and toxicology as a distinct branch. The author shares his insight by emphasizing the fundamental principle of framing a good quiz question: *"frame things in context"* to elicit a precise answer. Thus, through the use of carefully framed quiz questions, the author not only contextualizes knowledge but also illustrates how curiosity and enthusiasm can be cultivated in learners. By presenting information in a manner that stimulates active engagement, the book motivates students to explore facets of the subject that are often overlooked in conventional textbooks of forensic medicine and toxicology. In doing so, it encourages learners to transcend surface-level memorization and instead develop a deeper, more meaningful intellectual engagement with forensic medicine and toxicology.

The description given for all the terms is clear, concise, and captivating. For instance, several terms begin with the same word, "*devil's,"* such as *devil's bread*, *devil's snare*, *devil's weed*, *devil's trumpet*, and *devil's helmet*. This pattern helps students associate multiple concepts with a single term, making them easier to learn and remember. The book contains some truly valuable information; for example, the term *"Vitullo kit,"* which may be unfamiliar to many readers. It refers to a kit used in the investigation of sexual offenses and serves as an excellent example of the rare but important information included in the book.

The section on torture provides macabre information on ancient, medieval, and modern methods that were used across different countries and cultures. For example, *"white torture,"* where a person is isolated from all forms of sensory stimulus, depriving them of their senses and identity, ultimately leading to depersonalization and psychosis. Another example is *scaphism*, an execution method used in ancient Persia.

The compilation of the toxicology section is extremely well done, providing a clear timeline of the major milestones in the field over time. The section on famous professional poisoners provides details about criminal poisoning trends over the centuries, from Locusta of Gaul to the poison panic of the 19th century. It was fascinating to learn that the pen-tailed tree shrew of Malaysia has a remarkably high tolerance for ethyl alcohol.

A quiz book can be an effective tool for implementing the competency-based medical education (CBME) curriculum as prescribed by the National Medical Commission by promoting active learning, self-directed assessment, and formative feedback. Periodically, students can be divided into small groups to participate in quizzes followed by supervised peer discussion sessions on the relevant topics. This approach enhances reasoning and strengthens core competencies through case-based and scenario-driven questions. By aligning with Miller's pyramid,[2] supporting continuous assessment, and fostering learner-centric engagement, a quiz book can make CBME teaching more interactive, measurable, and outcome-driven. Moreover, quizzes have consistently been

regarded as a readily acceptable learning method among medical students, effectively complementing other forms of learning.[3]

While there are several other multiple-choice question books available in the field of forensic medicine and toxicology, this book stands out because it introduces several "firsts" and highlights aspects related to the history and evolution of the branch. It develops a sense of curiosity in students, encouraging them not merely to memorize facts but to actively seek more knowledge in the field and appreciate the practical significance of what they learn in the practice of medicine.

The author has provided accurate and well-structured answers to the questions; however, a notable limitation is the absence of references or citations for further reading, which would have enhanced authenticity and offered readers greater scope for continued learning. We hope the future editions of the book will be improved in this aspect. Overall, the book is informative, entertaining, and engaging. Unlike other quiz books, it is not limited to a question-and-answer format. This book is one of its kind, and the information it contains would be valuable to both students and professionals who seek an engaging blend of curiosity and learning.

Although the book contains a few minor proofreading errors—for example, "Jach the Ripper" instead of "Jack the Ripper" on page five, or the unintended insertion of country names within words such as "revENGLANDe fantasies" instead of "revenge fantasies," and "FinGERMANY prints" instead of "fingerprints" on page 85—these do not compromise the clarity or comprehension of the content. The intended meaning remains evident from the surrounding context, and such minor lapses have no impact on the reliability, readability, or overall value of the book, which remains a boon for quizmasters and student enthusiasts alike.

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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.

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.

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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

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