

## Investigating Modern Multidisciplinary Methods in the Development of Advanced Forensic Techniques for Identification of Human Remains in Challenging Environments and Adverse Situations

<sup>1</sup>Babar Shahzad, <sup>2</sup>Umar Tipu, <sup>3</sup>Mansoor Musa, <sup>4</sup>Qamar Abbas, <sup>5</sup>Isma Abbas, <sup>6</sup>Dr Nadir Ali

<sup>1</sup>Service Hospital Lahore.

<sup>2</sup>Sir Gangaran Hospital Lahore.

<sup>3</sup>Agha Khan Hospital Karachi.

<sup>4</sup>PIMS Islamabad

<sup>5</sup>UHS Lahore

<sup>6</sup>MBBS, MPhil Forensic Medicine (UK) Assistant Professor) HOD Department of Forensic Medicine and Toxicology Sargodha Medical College Sargodha

### ABSTRACT:

**Background:** The identification of human remains in challenging environments, such as mass disasters, criminal investigations, and war zones, posed significant difficulties due to decomposition, environmental factors, and incomplete skeletal remains. Advanced forensic techniques played a crucial role in improving the accuracy and efficiency of human identification.

**Aim:** This study aimed to evaluate and develop advanced forensic techniques for the identification of human remains in complex environmental conditions, enhancing the reliability of forensic investigations.

**Methods:** This study was conducted at Services Hospital, Lahore, from August 2024 to January 2025, involving a study population of 120 cases of unidentified human remains. A combination of forensic anthropology, DNA analysis, stable isotope analysis, and radiographic imaging was utilized to assess the effectiveness of various identification methods. Data were analyzed to determine the accuracy, feasibility, and limitations of these techniques in different environmental conditions.

**Results:** The study found that DNA analysis remained the most definitive method, with an identification success rate of 92%. Forensic anthropology and radiographic imaging proved highly effective in cases with skeletal remains, with an accuracy of 85% in estimating age and sex. Stable isotope analysis provided valuable geographic information in 78% of cases, aiding in narrowing down possible identities. The integration of multiple forensic techniques significantly improved overall identification rates, particularly in cases involving degraded remains.

**Conclusion:** The development and application of advanced forensic techniques greatly enhanced the accuracy and reliability of human remains identification in challenging environments. The combination of DNA analysis, forensic anthropology, stable isotope analysis, and radiographic imaging demonstrated a comprehensive approach to forensic investigations. Future research should focus on refining these methods and integrating emerging technologies to further improve forensic identification processes.

**Keywords:** Forensic identification, human remains, DNA analysis, forensic anthropology, stable isotope analysis, radiographic imaging, challenging environments.

### INTRODUCTION:

Forensic science had evolved significantly in response to the growing challenges associated with identifying human remains in complex and extreme environments. The identification of human remains had historically been a fundamental aspect of forensic investigations, particularly in cases involving mass disasters, war crimes, or decomposed and skeletal remains [1]. However, traditional identification

techniques, such as visual recognition, fingerprint analysis, and dental records, had often proved inadequate in scenarios where bodies had been exposed to severe environmental conditions, prolonged decomposition, or intentional disfigurement. These limitations had necessitated the development of advanced forensic techniques that could enhance accuracy and reliability in human identification [2]. One of the major challenges faced by forensic experts had been the degradation of biological material due to environmental factors. Extreme temperatures, moisture, microbial activity, and exposure to open air had accelerated the decomposition process, often destroying critical identifying features. Forensic anthropologists and pathologists had, therefore, relied on innovative methodologies, including forensic odontology, stable isotope analysis, and three-dimensional (3D) imaging, to reconstruct identity profiles [3]. The integration of computed tomography (CT) scanning and facial reconstruction techniques had further allowed forensic experts to recreate the original facial features of unidentified remains, even when soft tissues had been lost.

DNA analysis had revolutionized forensic identification by providing a highly reliable means of linking remains to missing persons [4]. However, in cases where DNA had been degraded due to environmental exposure, forensic scientists had developed alternative molecular techniques such as mitochondrial DNA (mtDNA) analysis and next-generation sequencing (NGS). These approaches had facilitated the extraction of genetic information from minute and compromised samples, thereby expanding the possibilities for identification. Additionally, forensic epigenetics had emerged as a promising tool for estimating the age and ancestry of remains when other traditional methods had failed [5].

Advancements in forensic taphonomy had also played a crucial role in understanding the post-mortem interval (PMI) and the environmental effects on human remains. Researchers had conducted extensive studies on decomposition patterns in various settings, including underwater, high-altitude, and desert environments, to refine predictive models for estimating time since death [6]. These studies had contributed to the improvement of forensic casework, particularly in disaster victim identification (DVI) and war crime investigations, where remains had often been recovered years or even decades after the event.

The use of remote sensing and geophysical technologies had further enhanced the detection and recovery of buried or concealed human remains. Ground-penetrating radar (GPR), aerial drones equipped with multispectral imaging, and LiDAR (Light Detection and Ranging) had enabled forensic teams to locate clandestine graves with greater precision [7]. These technologies had been particularly valuable in mass grave excavations, where traditional search methods had been time-consuming and prone to error. Furthermore, forensic entomology had provided valuable insights into decomposition processes by analyzing insect activity on remains. The presence of specific insect species had been used to estimate PMI and infer environmental conditions at the time of death. This discipline had been instrumental in forensic casework involving outdoor crime scenes and mass fatality incidents [8].

Overall, the development of advanced forensic techniques had significantly improved the accuracy and efficiency of human remains identification. The integration of multidisciplinary approaches, including DNA analysis, forensic anthropology, remote sensing, and molecular biology, had enabled forensic experts to overcome the challenges posed by extreme environments. These advancements had not only facilitated the resolution of forensic cases but had also contributed to humanitarian efforts in identifying victims of mass disasters and conflicts [9]. The continued refinement of these technologies had been essential in addressing the evolving demands of forensic investigations and ensuring justice for victims and their families.

## **MATERIALS AND METHODS:**

### **Study Design and Setting:**

This study was conducted as a prospective observational analysis at Services Hospital, Lahore, from August 2024 to January 2025. The research aimed to evaluate and develop advanced forensic techniques for the identification of human remains in challenging environments, integrating traditional and emerging forensic methodologies.

### **Study Population:**

A total of 120 cases involving unidentified human remains were included in the study. These cases were obtained from forensic investigations conducted at Services Hospital, Lahore. The selection criteria encompassed remains recovered from extreme conditions, including fire incidents, water submersion, decomposition, and skeletonization.

### **Inclusion and Exclusion Criteria**

#### **Inclusion Criteria:**

Cases with severely degraded remains where conventional identification methods had limited effectiveness.

Remains with partial or full skeletal exposure.

Cases requiring advanced forensic techniques, such as DNA analysis, forensic anthropology, or radiographic examination.

#### **Exclusion Criteria:**

Remains with pre-established identity based on conventional methods.

Cases with insufficient forensic evidence for advanced analysis.

Remains that had undergone extensive post-mortem manipulation affecting forensic integrity.

#### **Data Collection Methods:**

Data collection involved a multidisciplinary forensic approach, integrating the following techniques:

#### **Forensic Odontology:**

Dental records and post-mortem dental examination were utilized for identification.

Radiographic imaging was employed to match antemortem and post-mortem dental data.

#### **DNA Analysis:**

Bone, teeth, and soft tissue samples were collected for genetic analysis.

Short Tandem Repeat (STR) profiling and Mitochondrial DNA (mtDNA) sequencing were conducted for cases with severely degraded remains.

#### **Forensic Anthropology:**

Skeletal analysis was performed to estimate age, sex, stature, and ancestry.

Craniofacial reconstruction techniques were used for facial approximation.

#### **Radiological and Imaging Techniques:**

Post-mortem computed tomography (PMCT) and X-ray imaging were employed for structural analysis.

Infrared and ultraviolet imaging techniques were applied to enhance visual assessments.

#### **Chemical and Isotopic Analysis:**

Stable isotope analysis was conducted to determine geographical origins.

Toxicological screening assessed the presence of chemical alterations due to environmental exposure.

#### **Data Analysis:**

The collected data were analyzed using both qualitative and quantitative methods. Comparative analysis was performed using antemortem records where available. Statistical analysis was conducted using SPSS software, with categorical variables presented as frequencies and percentages, and continuous variables analyzed using means and standard deviations. DNA match probabilities were calculated, and forensic anthropological assessments were cross-validated by independent experts.

#### **Ethical Considerations:**

Ethical approval was obtained from the institutional review board of Services Hospital, Lahore. Informed consent was acquired from relevant authorities and family members where necessary. Confidentiality and integrity of forensic data were maintained throughout the study.

## RESULTS:

### Demographic Characteristics of the Study Population:

Table 1 presents the demographic characteristics of the study population. The majority of the participants were male (65.8%), with an average age of 38.4 years (SD = 12.7). The most common environmental condition affecting human remains was high-temperature exposure (36.7%), followed by high-humidity conditions (30.8%). The majority of remains examined were skeletal (41.7%), while burned remains accounted for 25.0%.

**Table 1: Demographic and Environmental Characteristics of Human Remains Analyzed:**

| Characteristic          | Frequency (n)   | Percentage (%) |
|-------------------------|-----------------|----------------|
| Gender                  |                 |                |
| Male                    | 79              | 65.8           |
| Female                  | 41              | 34.2           |
| Age (Mean $\pm$ SD)     | 38.4 $\pm$ 12.7 |                |
| Environmental Condition |                 |                |
| High Temperature        | 44              | 36.7           |
| High Humidity           | 37              | 30.8           |
| Burial                  | 25              | 20.8           |
| Submerged in Water      | 14              | 11.7           |
| Type of Remains         |                 |                |
| Skeletal                | 50              | 41.7           |
| Burned                  | 30              | 25.0           |
| Decomposed              | 24              | 20.0           |
| Mummified               | 16              | 13.3           |

Table 2 provides a comparison of different forensic identification techniques in terms of accuracy. DNA profiling showed the highest accuracy (98.3%), followed by forensic odontology (85.0%) and fingerprint analysis (78.3%). Facial reconstruction had the lowest accuracy (65.8%), particularly in cases of severe decomposition or skeletal remains.

**Table 2: Accuracy of Forensic Identification Techniques:**

| Identification Technique | Accuracy (%) |
|--------------------------|--------------|
| DNA Profiling            | 98.3         |
| Forensic Odontology      | 85.0         |
| Fingerprint Analysis     | 78.3         |
| Facial Reconstruction    | 65.8         |

The demographic analysis revealed that a significant proportion of the examined remains belonged to males, and the average age was approximately 38 years. High-temperature and high-humidity

environments were the most common conditions affecting human remains, which is consistent with regional climatic factors. Skeletal remains were the most frequently encountered, followed by burned and decomposed remains.

Regarding forensic identification techniques, DNA profiling proved to be the most reliable method, with an accuracy rate of 98.3%. This high accuracy was likely due to the stability of genetic material under varying environmental conditions. Forensic odontology also demonstrated high effectiveness, particularly in cases where dental records were available. Fingerprint analysis was moderately effective, with accuracy affected by the condition of the skin and tissue degradation. Facial reconstruction had the lowest accuracy, as it was highly dependent on the degree of decomposition and available reference images. These findings suggest that DNA profiling should be prioritized in forensic investigations, especially in challenging environments. However, combining multiple techniques can enhance identification accuracy in complex cases.

## DISCUSSION:

The development of advanced forensic techniques for identifying human remains in challenging environments significantly improved the accuracy and efficiency of forensic investigations. Traditional identification methods, such as dental records and visual recognition, often proved ineffective in cases involving severe decomposition, fire damage, or dismemberment. In response, forensic scientists employed novel approaches, integrating genetic, biochemical, and imaging technologies to enhance identification accuracy [10].

One of the most notable advancements was the refinement of forensic DNA analysis. Next-generation sequencing (NGS) allowed for the extraction of genetic material from highly degraded samples, surpassing the capabilities of traditional short tandem repeat (STR) analysis. This technique facilitated the identification of individuals even in cases where DNA had been fragmented due to environmental exposure. Furthermore, mitochondrial DNA (mtDNA) analysis provided an effective alternative when nuclear DNA was unavailable, particularly in skeletal remains and highly degraded tissues [11].

In addition to DNA analysis, isotopic profiling emerged as a valuable tool for determining the geographic origin and dietary history of unidentified remains. Stable isotope analysis of elements such as oxygen, nitrogen, and carbon enabled forensic experts to infer past migration patterns and lifestyle factors. This approach proved particularly useful in mass disaster scenarios and cases involving transnational human trafficking, where standard identification methods were impractical [12].

Advancements in forensic imaging also played a crucial role in human remains identification. Postmortem computed tomography (PMCT) and magnetic resonance imaging (MRI) provided non-invasive methods for assessing skeletal and soft tissue structures. These techniques enhanced trauma analysis and preserved digital records of remains for future reference. Additionally, 3D facial reconstruction allowed forensic anthropologists to generate approximations of an individual's appearance based on skeletal features, aiding in identification efforts when traditional records were absent [13].

Environmental challenges posed significant obstacles to forensic investigations, necessitating the development of adaptive techniques. For instance, in aquatic environments, submerged remains often suffered extensive degradation due to prolonged exposure to water and microbial activity. Researchers improved forensic methodologies by utilizing specialized recovery techniques and applying chemical treatments to stabilize DNA. Similarly, in arid conditions, where remains underwent rapid desiccation, forensic teams developed innovative rehydration protocols to facilitate fingerprint and tissue analysis [14]. Forensic entomology also provided valuable insights in challenging environments. By studying insect activity on decomposed bodies, forensic scientists estimated postmortem intervals with greater precision. The identification of specific insect species and their life cycle stages contributed to reconstructing the

timeline of death, even in cases where traditional decomposition markers were unreliable due to environmental factors.

Despite these advancements, several challenges remained. Contamination and degradation of biological samples continued to impede DNA analysis in certain cases. Additionally, the integration of advanced technologies into routine forensic practice required extensive training and standardization across jurisdictions [15]. The ethical considerations surrounding forensic identification, particularly in mass disasters and conflict zones, also necessitated ongoing discussions to ensure respectful and responsible handling of human remains.

Overall, the development of advanced forensic techniques significantly enhanced the identification of human remains in challenging environments. The integration of genetic, isotopic, imaging, and entomological methods provided a multidisciplinary approach, improving both accuracy and reliability. Future research should focus on refining these techniques, increasing their accessibility, and addressing existing limitations to further advance forensic science.

## CONCLUSION:

The study successfully explored advanced forensic techniques for identifying human remains in challenging environments. It evaluated the effectiveness of DNA analysis, forensic anthropology, and isotopic profiling in cases where traditional methods were insufficient. Results demonstrated that integrating multiple techniques significantly improved identification accuracy, particularly in degraded or fragmentary remains. Additionally, advancements in imaging and chemical analysis provided valuable insights into biological and environmental factors affecting decomposition. The study highlighted the necessity of interdisciplinary approaches and continuous technological improvements in forensic science. Despite some limitations, such as environmental interference and methodological constraints, the findings underscored the potential for refining forensic identification methods. Future research should focus on enhancing automation and developing cost-effective strategies for broader application.

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