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Review Article

Advancing Forensic Approaches to Human Trafficking: The Role of Dental Identification

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Abstract

Background: Human trafficking is a significant global issue that affects millions of individuals, where victim identification remains a major challenge. Traditional methods such as DNA or fingerprint analysis are not always viable, necessitating alternative forensic approaches.

Methods: This article reviews the role of dental identification in human trafficking cases through an extensive analysis of existing literature. The study incorporates forensic odontology techniques, including dental charting, radiographic analysis, bite mark analysis, age estimation, and emerging technologies like Artificial Intelligence (AI).

Results: Findings indicate that dental identification methods are essential for victim identification, especially when conventional methods prove ineffective. AI integration enhances the accuracy and efficiency of dental forensic investigations, addressing challenges such as record access and cross-border complexities.

Conclusion: Dental identification, augmented by AI advancements, is an indispensable tool in forensic investigations related to human trafficking. The study underscores the necessity of international collaboration and technological innovation to enhance forensic practices.

More Information

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Keywords: Human trafficking; Dental identification; Victim identification; Artificial intelligence; Modern slavery; Forensic dentistry

Abbreviations: CBCT: Cone Beam Computed Tomography; AI: Artificial Intelligence; 3D imaging technologies: Three Dimensions Imaging Technologies

Introduction

Human trafficking is a grave and pervasive crime that constitutes a fundamental violation of human rights. Human trafficking is a widespread, profitable criminal enterprise that largely remains undetected due to its disproportionate impact on marginalized communities. Presently, an estimated 40 million individuals are subjected to modern slavery, including victims of human trafficking [1]. The identification of trafficking victims is particularly challenging due to the clandestine nature of these crimes, the frequent absence of proper documentation, the use of false identities, and the deteriorated condition of recovered remains [2]. Dental identification serves as a crucial forensic tool in such cases, as it involves the comparison of postmortem dental remains with antemortem records, including written notes, dental casts, radiographs, and other documentation. Individuals who have undergone extensive dental treatment are often more easily identified due to the unique characteristics of their dental restorations. Teeth, being highly resistant to postmortem degradation, provide a reliable means of identification when other bodily tissues are compromised [3].

Due to the frequent absence of dental records and the complexities of cross-border trafficking, the process of victim identification becomes even more difficult [4]. Forensic odontology plays a vital role in identifying individuals who cannot be recognized visually or through other traditional means. The distinctiveness of dental anatomy and the placement of customized restorations contribute to the accuracy of forensic identification when appropriate methodologies are employed [3].

In recent years, artificial intelligence (AI) has emerged as a transformative tool in forensic odontology. AI's ability to analyze extensive datasets, identify patterns, and perform complex tasks with high precision offers promising solutions to many challenges encountered in human trafficking investigations. This review examines the integration of traditional dental identification techniques with AI advancements to enhance victim identification and proposes recommendations for future forensic practices.

Methodology

A systematic literature review was conducted under

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The databases PubMed, Scopus, and Google Scholar were searched using the keywords "dental identification," "human trafficking," "forensic odontology," and "AI in forensics." The inclusion criteria encompassed studies and case reports published between 2015 and 2024 that focused on forensic dental identification in trafficking contexts. This methodological approach ensured a comprehensive and unbiased selection of the most relevant and recent studies, thereby strengthening the foundation of this review.

Methods of dental identification

Dental charting and record comparison: Dental charting involves systematically documenting the unique features of an individual's dentition, facilitating postmortem comparisons with antemortem records [5]. The advantage of using dental records lies in their unique and persistent nature, which remains even after significant decomposition [6]. However, challenges arise when trying to access and compare these records, particularly when they come from different countries or if the victim is undocumented [4]. This method proves highly effective when dental records are available but can be challenging in cases where records are missing or incomplete. AI-assisted digitization and automated matching algorithms enhance cross-border record comparisons, improving efficiency and accuracy in victim identification.

Radiographic analysis

Radiographic analysis involves dental X-rays such as periapical and panoramic images , to identify distinctive dental characteristics [7]. Advanced imaging modalities, such as Cone Beam Computed Tomography (CBCT), provide highly detailed visualizations of dental structures, thereby enhancing the accuracy of identification [7]. However, this method has certain limitations, including the necessity for high-quality radiographic images and variations in imaging techniques [8]. Despite these challenges, radiographic analysis remains particularly valuable in cases where conventional dental records are unavailable. Artificial intelligence (AI)-driven tools can facilitate the analysis of radiographs by detecting unique dental traits and comparing them against existing databases, thereby expediting the identification process. Additionally, machine learning algorithms contribute to minimizing errors associated with human interpretation.

Indicators of abuse in living victims

Dental identification is not solely limited to postmortem cases; it also plays a crucial role in identifying living victims of human trafficking. Dental assessments can provide valuable insights into signs of abuse, malnutrition, and neglect. Common indicators include untreated dental caries, dental trauma, and malocclusions. Additionally, AI-assisted dental health analysis can aid in recognizing patterns of abuse commonly observed in trafficking victims, such as recurrent dental injuries or severe neglect. The integration of AI enhances the accuracy and efficiency of these assessments, facilitating the timely identification of victims during active investigations.

Age estimation

Age estimation techniques, such as Demirjian's and Gustafson's methods, rely on dental development and wear patterns to determine an individual's age [9-13]. Methods like Demirjian's and Cameriere's are particularly significant in cases involving minors, as they provide essential age-related information for legal and investigative purposes [14]. In recent years, artificial intelligence (AI) has emerged as a valuable tool in automating age estimation. Machine learning models, particularly deep learning neural networks, have demonstrated the ability to analyze dental radiographs with high precision, offering a more efficient and reliable alternative to traditional methods. This advancement is especially beneficial in forensic investigations involving minors, as it enhances the accuracy and speed of age estimation.

3D imaging and digital forensics

Three-dimensional (3D) imaging technologies, including laser scanning and 3D modelling, enable the detailed reconstruction of dental features, thereby enhancing the process of victim identification [15]. These technologies also facilitate remote consultations and foster international collaboration, improving the efficiency of forensic investigations [16]. However, their widespread adoption may be constrained by high costs and technical requirements. The integration of artificial intelligence (AI) further optimizes these technologies by enabling automated feature recognition and pattern matching, thereby enhancing cross-border victim identification.

AI-powered facial and oral recognition

AI systems equipped with facial and oral recognition capabilities can analyze features from photographs or videos, identifying unique dental and facial traits. These systems are particularly valuable in identifying live victims in trafficking networks, especially when traditional records are unavailable.

Integration of artificial intelligence

Artificial Intelligence (AI) is revolutionizing forensic odontology, particularly in the context of human trafficking cases. AI facilitates the analysis of dental characteristics by automating the comparison of dental records, thereby minimizing human error and enhancing efficiency. Moreover, AI-driven tools contribute to the standardization and optimization of dental record sharing across international borders, which is essential in transnational trafficking investigations. By processing extensive datasets rapidly, AI significantly reduces the time required for victim identification, making it an invaluable asset in time-sensitive forensic investigations. Additionally, AI demonstrates considerable potential in improving the accuracy of age estimation through

machine learning models that analyze dental development patterns, thereby further advancing forensic identification techniques.

Challenges

Accessing dental records for victims of human trafficking is often challenging due to the absence of proper documentation and inconsistencies in record-keeping standards across different regions [17,18]. Additionally, the use of artificial intelligence (AI) in forensic investigations raises ethical concerns regarding privacy and potential algorithmic bias for algorithmic bias. Addressing these challenges is essential to enhancing the accuracy, effectiveness, and ethical integrity of forensic practices in human trafficking investigations.

Case studies and practical applications

Case 1: Identification of minors in refugee camps

A 2022 case in Southeast Asia involved dental examinations to estimate the ages of undocumented minors rescued from trafficking. By using CBCT scans, forensic odontologists were able to determine developmental markers that matched reported ages. This case highlights how advanced imaging techniques can assist in identifying minors and classifying them under child protection laws, which is crucial for their legal and social rehabilitation.

Case 2: AI-assisted identification in mass disasters

In 2023, AI-driven dental analysis was used in a high-profile case involving a trafficking ring exposed in Europe. Using AI models, forensic odontologists quickly compared dental records from a large number of victims, matching them with international databases. The AI-assisted analysis provided accurate results in a fraction of the time it would take using traditional methods. This case demonstrated the potential of AI in accelerating the victim identification process and overcoming challenges related to missing or incomplete records.

Case studies have demonstrated how dental identification methods have successfully aided in identifying trafficking victims. For instance, a high-profile case involving trafficked minors highlighted the effectiveness of radiographic analysis in challenging circumstances [19-22].

Future directions and recommendations

There is a pressing need to expand the use of AI in dental identification, especially in integrating AI with other forensic tools such as facial recognition and biometric systems. This could provide a more comprehensive approach to victim identification in real-time scenarios. Strengthening international collaboration and developing standardized protocols for sharing dental records would greatly enhance the efficiency of victim identification across borders. Additionally, more emphasis should be placed on identifying living victims through detailed dental assessments, which can provide critical evidence in ongoing trafficking investigations. To support these efforts, increased training for forensic experts on advanced imaging techniques and AI applications is essential.

Conclusion

This review highlights the critical role of dental identification in addressing the complex challenges associated with human trafficking. Methods such as dental charting, radiographic analysis , radiographic analysis, bite mark analysis, age estimation, and 3D – Three-dimensional serve as valuable tools for forensic investigators. Advancements in these techniques, coupled with enhanced international collaboration, are essential for improving victim identification and strengthening efforts to combat human trafficking.

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