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REVIEW

Role of 3d photogrammetry and automated imaging in forensic dental identification: Literature review

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ABSTRACT

Background: Forensic odontology is integral to human identification in legal investigations, with recent technological advancements particularly in three-dimensional (3D) imaging and photogrammetry revolutionizing traditional practices.

Objectives: This review aims to synthesize current research on the application of automated digital instruments, 3D scanning, and photogrammetry in forensic odontology, emphasizing their roles in identification, reconstruction, and evidence preservation.

Methods: A comprehensive literature search was conducted using PubMed, Scopus, and Google Scholar for studies published between 2004 and 2023. Keywords included "3D dental scan," "forensic odontology," and "photogrammetry." Studies were selected based on their relevance to digital imaging and 3D modelling in forensic dental identification.

Results: Recent studies highlight the effectiveness of 3D-printed devices such as CHAD and MEAD in improving radiographic accuracy for ante-mortem and post-mortem comparisons. Open-source software and 3D modelling tools have advanced forensic facial reconstruction, while medical imaging and rapid prototyping enable the creation of anatomically precise models for educational and legal purposes. Digital Light Processing (DLP) 3D printing has demonstrated high accuracy in replicating dental structures. Smartphone-based photogrammetry offers a cost-effective alternative for bite mark analysis and identification. Digital models and non-contact scanning improve diagnostic consistency and trauma documentation. However, challenges remain regarding technical limitations, accessibility, and the need for standardized protocols and larger validation studies.

Conclusions: The integration of 3D imaging, photogrammetry, and digital modelling has significantly enhanced the reliability, efficiency, and scope of forensic odontology. Continued research, technological development, and standardization are essential to fully realize the potential of these methods in forensic science.

KEY WORDS

Forensic odontology;
3D imaging;
Photogrammetry;
Dental identification;
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Introduction

Forensic odontology (FO) is defined by Keiser-Neilson as a branch of forensic medicine that focuses on the appropriate handling and examination of dental evidence, along with the evaluation and presentation of dental findings in the interest of justice. Forensic odontology, a subdivision of forensic medicine, is recognized as a reliable and cost-effective scientific method for identifying individuals following mass disasters, as well as in cases involving crimes and accidents [1]. Dental forensic human identification methods have proved effective over time. A conclusive identification may be made using accurate and complete dental evidence from before death. Many dental data coding methods have been developed for forensic odontology reports and computer-assisted identifications [2]. Forensic dentistry, commonly known as forensic odontology, is one of Interpol's three major victim identification methods for mass casualties. Legal and dental issues are examined in forensic dentistry. Digital radiographs and pictures must be scanned for forensic dentistry clearance [3]. Clinical practice uses intra-oral and extra-oral X-rays for diagnosis and therapy planning. The medical record includes patient images and oral charts and notes. Record comparisons dominate forensic dental investigations. This technique requires radiographs of the teeth and facial tissues. Dental x-rays may determine a person's developmental stage for identification or legal considerations like sentence or immigration. Court investigations may also utilize it to discover facial and

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dental injuries [4]. Forensic dentistry uses standard radiography to determine age and gender. Forensic dentistry uses panoramic, cephalometric, lateral, oblique, and intraoral periapical radiographs. Digital radiographs have also become more popular, used to distinguish between premortem photos from dental offices and centers and post-mortem radiographic photographs used for independent identification [5].

Dental records and dentition radiographs are crucial to identifying a person. Over the last two decades, many semi-automatic research proposals have been made [6, 7] and automatic dental identification using 2D radiographs [8]. However, 2D radiography approaches have drawbacks. Blurring dental radiographs made tooth segmentation time-consuming and imprecise. Automated 2D radiography retrieval and identification might be difficult owing to significant tooth form and arch changes from multiple imaging views [9, 10].

To get around the limitations of 2D methodologies, an effective and automated 3D dental identification system is requisite for improving identification accuracy. In recent years, 3D imaging in dentistry has expanded significantly. Clinical practices and laboratory procedures are transitioning to digital workflows [11]. An alternative to using traditional imprint materials, the development of intra-oral scanners allows for the direct digitalization of a patient's dental arches [12, 13]. Laser scanners turn dental molds into 3D models. With its reduced imprint time, patient burden, storage and retrieval efficiency, precision, instant access to 3D diagnostic information, and mobility, this digital system offers several advantages [14, 15]. These models can subsequently be used for alignment and matching, as well as for an automated study of comparable dental structures [16]. However, 3D photo scan data in forensic odontology also poses some challenges including Data Quality and Resolution, Variability in Anatomical Structures, Segmentation and Reconstruction Issues and Integration with Other data types. The aim of this review is to critically evaluate the current and prospective use of 3D photogrammetry and automated imaging technologies in forensic dental identification, highlighting their advantages, limitations, and future directions for research and application.

Methodology

A thorough literature search was carried out in PubMed, Scopus, and Google Scholar, web of science and ScienceDirect which permitted the identification of papers that were relevant to the topic at hand. In order to do the search, the terms "3D dental scan," "forensic odontology," and "photogrammetry" were used. All of the publications that were examined were published between the years 2004 and 2023. When it came to forensic dental identification or other related applications, studies were considered for inclusion if they addressed the use of digital imagery, three-dimensional modelling, or photogrammetry.

Table 1 . Overview of Significant Research on the Utilization of 3D Imaging and Digital Technologies in Forensic Odontology (2004–2023).

Author & Year	Aim	Sample Used	Methodology/Approach	Conclusion	Limitation
(Newcomb et al., 2017) [17]	Evaluate CHAD device for PM intraoral imaging	24 participants	Compared CHAD and MEAD with traditional devices	CHAD and MEAD reduced exposure errors and improved image quality	Small sample size; results need confirmation in larger studies
Moraes et al. (2014) [18]	Demonstrate FFR using free software and photogrammetry	Not specified	Used Blender, PPT GUI, and MeshLab	Open-source protocol feasible; ML and VR could enhance precision	Sample size not specified; precision could be improved with ML/VR
Ebert et al. (2011) [19]	Develop 3D anatomical forensic models using imaging/printing	Not specified	Used CT, MRI, and 3D printing	Effective for education and court; accessibility needs improvement	Accessibility for non-experts is limited
Singare et al. (2017) [20]	Apply CAD/CT & 3D printing in craniofacial reconstruction	Clinical cases	CAD/CAM/CNC with custom templates	Precise implant modelling; cost-effectiveness not assessed	Cost-effectiveness not assessed; lacks comparison with traditional methods
(Knivsberg et al., 2022) [21]	Create digital forensic odontology education modules	Norwegian dental records	Integrated intraoral scans, X-rays in LMS	Improved student engagement: multilingual support suggested	Multilingual support and broader validation needed

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Turkyilmaz & Wilkins (2021) [22]	Review 3D printing in dentistry	Literature-based	Summarized 3D printing workflow	Accurate, efficient; implementation challenges remain	Implementation and standardization challenges remain
Im et al. (2020) [23]	Evaluate IOS and 3D printing compatibility	90 STL files from typodonts	Accuracy test using three IOS and printing techniques	i500 with DLP was most precise; device combination important	Findings may not generalize to all clinical situations
Errickson et al. (2014) [24]	Assess 3D visualization of osteological trauma	Not specified	Literature review	3D reduces emotional distress in court; improves clarity	Lack of empirical data; review-based only
Simon & Poór (2022) [25]	Evaluate 3D printing in forensic pathology	Literature-based	Systematic review	Supports ID and trauma modelling; standards needed	Need for standards and further validation
Johnson et al. (2021) [26]	Assess accuracy of 3D printed tooth replicas	12 extracted teeth	Used five 3D printing methods	DLP most accurate; suitable for forensic replication	Small sample size; limited to extracted teeth
urniawan et al. (2023K) [27]	Use smartphone/photogrammetry for 3D bitemark analysis	Review-based	Smartphone monoscopic photogrammetry	Low-cost and accessible; further validation needed	Further validation and quality control required
Jani et al. (2021) [28]	Overview of 3D technologies in forensic odontology	Literature-based	Reviewed existing applications	Potential for long-term digital preservation and analysis	Current limitations not fully explored
Chaudhary et al. (2018) [29]	Assess 3D printing in various forensic odontology applications	Literature-based	Use cases of age estimation, ID, and facial reconstruction	Promising tool: standardization and validation required	Standardization and validation required
Kurniawan et al. (2020) [30]	Minimum teeth needed for ID using 3D scans	Maxillary casts from healthy volunteers	ICP + RMSE analysis of 120 permutations	Six anterior teeth sufficient for accurate ID	Only healthy volunteers; may not apply to all forensic cases
Kašparová et al. (2018) [31]	Evaluate digital vs. traditional dental models	20 models from one individual	Intraoral scans and mathematical processing	Digital methods reduce variability; further validation recommended	Single subject: further validation needed
Shamata (2019) [32]	3D scanning for injury documentation	20 patients	Hand-held scanner for 3D surface scans	High reliability; better than conventional techniques	Sample size limited; technology availability
Gavli et al. (2019) [33]	Review rapid prototyping in forensic odontology	Literature-based	Discussed 3D printing vs. conventional radiology	Promising shift: limitations not critically explored	Limitations not critically discussed
Gaboutchian et al. (2021) [34]	Propose Automated Digital Odontometry for morphometric analysis	Palaeolithic archaeological samples	Tomographic imaging + coordinate mapping system	Useful for enamel/dentine comparison; CBCT integration recommended	CBCT integration and broader validation needed
Sinha (2018) [35]	Assess CBCT potential in forensic odontology in India	Commentary/review	Reviewed radiology and database gaps	Urges CBCT-based studies; highlights underutilization in India	Underutilization; lack of population data
Reesu & Brown (2022) [36]	Assess use of selfies and 3D scans in AM-PM comparison	18 selfies + 15 scans per subject	2D visual comparison & 3D superimposition (1620 comparisons)	3D method improved accuracy; selfies viable when dental records absent	Small sample size; needs larger multicenter studies

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Discussions

This research investigates an innovative methodology in forensic odontology using automated digital instruments. It assesses photogrammetry and 3D imaging for the identification of dental remains from cadavers, concentrating on ante-mortem (AM) and post-mortem (PM) comparisons. The CHAD device, a 3D-printed targeting instrument, was evaluated in conjunction with two others for the mitigation of radiography inaccuracies. Results indicated that CHAD and MEAD yielded the most favorable outcomes, with negligible exposure errors. The research indicates that these technologies enhance precision in forensic dental radiography; nevertheless, bigger sample sizes are required to confirm the results [17]. This research highlights the significance of forensic facial reconstruction (FFR) in the identification of unknown human remains. This protocol utilizes open-source software to generate 3D head models, sculpt facial features in Blender, and enhance reconstructions using templates. Tools such as PPT GUI and MeshLab facilitate a process that depends solely on digital cameras. This paper details the reconstruction process and proposes enhancements, including machine learning and virtual reality, to improve accuracy, interaction, and reliability in forensic and research contexts [18].

The study examines the application of medical imaging and rapid prototyping in the development of anatomically precise 3D models for forensic applications. Techniques such as CT, CT angiography, MRI , and photogrammetry were employed to construct detailed models illustrating bone fractures, organ damage, and bite marks. These coloured models, produced through 3D printing, serve educational and legal purposes. The study emphasizes the promise of this method and recommends additional investigation into its accessibility for non-experts [19]. This research emphasizes the significance of computer-aided design (CAD), computed tomography (CT) scans, and three-dimensional printing in the management of craniofacial abnormalities. These technologies facilitate the development of individualized surgical templates and implants, enhancing precision and decreasing production time. Techniques such as CAM/CNC and rapid tooling facilitate precise modelling for surgical planning. The study addresses benefits like improved visualization and implant design; however, it fails to analyze cost-effectiveness and lacks comparisons with traditional methods [20]. This study examines the impact of 3D printing technology on dentistry, highlighting its role in producing precise and economical dental appliances, including models, restorations, and surgical guides. This study emphasizes the application of intraoral optical scanners and cone beam CT images, which are transformed into 3D models through standard tessellation language, facilitating accurate digital design and streamlined production of dental products [22]. This research assessed the compatibility and accuracy of different intraoral scanners (IOSs) and 3D printing techniques through a scan quadrant model. Researchers conducted scans of a typodont model utilizing three intraoral scanners and produced models through DLP, FDM, and SLA printing technologies. The i500 scanner utilizing DLP printing demonstrated superior accuracy. The findings underscore the importance of selecting optimal IOS-3D print combinations to achieve clinical success [23].

By assessing the precision of manufactured human tooth reproductions, this research investigates the use of 3D printing in forensic odontology. Twelve removed teeth were used to evaluate five different printing techniques. The models' accuracy was within 0.5 mm, according to the results. Due of its simplicity of use and accuracy, Digital Light Processing (DLP) was suggested [23].

This review paper examines the feasibility of using smartphone cameras with monoscopic photogrammetry for three-dimensional bitemark analysis in forensic odontology. It emphasizes the use of dental characteristics in identification within legal situations, particularly via bitemark analysis. The authors examine contemporary literature, highlighting issues such as tooth morphology and picture quality that influence analytical precision. They assert that this method provides an economical, readily available option [24]. With an emphasis on 3D printing, non-contact scanning, and modelling, this article examines the expanding use of 3D technology in forensic research. Without harming physical remains, these procedures improve evidence preservation and processing. Forensic anthropology, odontology, archaeology, rebuilding crime scenes, and court visualization are all areas that may benefit from this technology. While 3D printing is still in its infancy, technology has the potential to alleviate human suffering by shielding delicate species from harm. Focusing on the potential of digital archives and 3D technologies as trustworthy, long-term resources for forensic investigations, the paper summarizes current developments without offering fresh conclusions [25]. An examination of the possible uses of 3D printing in the field of forensic odontology is presented in this article. It describes the process by which three-dimensional printing constructs actual models from digital data by stacking material under the supervision of a computer. Bite mark analysis, face reconstruction using three-dimensional computed tomography, dental age estimate, and gender identification are some of the applications that the authors highlight [26].

This research investigates the application of three-dimensional (3D) imaging in forensic dental identification. Maxillary dental casts from healthy individuals were scanned and analyzed with Rapid form and MATLAB software to ascertain the minimum number of teeth and surfaces required for precise identification. Findings from 120 data permutations indicate that only six teeth, specifically the labial surfaces of anterior teeth, may be adequate [27]. This article examines the application of digital models in dentistry for the analysis of dental arch components in the context of diagnosis and treatment.

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Traditional plaster casts are being supplanted by digital models generated via intra-oral scanning and magnetic recordings. The models enhance accuracy and minimize errors through the alignment of 3D images on a standardized plane and the application of mathematical processing. The research indicates that digital methodologies improve measurement consistency and decrease variability [28]. This research investigates the application of non-contact 3D surface scanning in forensic medicine for the documentation of traumatic injuries. This underscores the shortcomings of conventional methods and the benefits of 3D technology, including enhanced accuracy and objectivity. The study utilized a hand-held scanner on 20 patients, demonstrating that the produced models exhibited high reliability [29]. This article delves into the evolution and present state of forensic odontology, a subfield of forensic science that deals with the identification of humans using dental evidence. It emphasizes the change from conventional radiography to more contemporary techniques like computer-based imaging and CBCT. A new player in the area, rapid prototyping (3D printing), is also included in the research. The article highlights the possibility of 3D technology to improve the precision of forensic investigations, but it fails to critically examine the constraints [30].

The study emphasizes the scientific and practical significance of understanding dental morphology. It presents a novel approach to accurately analyzing 3D tooth reconstructions called Automated Digital Odontometry (ADO). Specifically for the Upper Palaeolithic site of Sunghir, this technique evaluates dental features using tomographic imaging and a novel coordinate system. Future applications may include integrating CBCT and micro-CT for more precise diagnoses and morphological study in the field of dentistry, since this method enables the objective comparison of dentine and enamel [31]. With an emphasis on the need for novel investigations using Cone Beam Computed Tomography (CBCT), this article summarizes the present status of forensic odontology research in India. Though studies on palatal rugae and lip prints have been conducted, this study emphasizes the restricted use of forensic radiology and population-based data. The authors underline the need of developing CBCT databases, standardizing procedures, and doing CBCT-based research on persons who have passed away. Although the report does not provide any new data, it does advise immediate research with an emphasis on India to investigate the possibilities of CBCT in forensic identification [32]. Forensic dental identification using selfies captured with high-quality smartphone cameras in situations when conventional dental records are inaccessible is the focus of this investigation. Forensic odontologists compared the participants' selfies and 3D dental scans. By effectively eliminating 94.2% of non-matches, the findings demonstrated that 3D superimposition improved match confidence and accuracy. The results indicate that selfies, when combined with 3D post-mortem (PM) images, may aid in dental recognition [33]. Although there have been great strides, there are still a number of limits to forensic odontology's use of 3D imagery and photogrammetry. Some of these issues include insufficient study samples, technological difficulties such being light-and motion-sensitive, and an absence of standardized techniques. Furthermore, accessibility and broad acceptance in normal forensic practice might be hindered by the often-required specialized training and costly equipment.

Conclusions

3D photo scan technologies in forensic odontology offer significant potential to enhance the accuracy, efficiency, and objectivity of human identification. While challenges remain, particularly with respect to equipment precision, data quality, and operator expertise, current evidence suggests that 3D imaging especially when combined with photogrammetry—can serve as a reliable method for comparing AM and PM data. Continued research should focus on developing automated systems, standardizing methodologies, and expanding validation studies to ensure wide-scale, reliable application.

Future direction

- Standardizing protocols and validation methods for 3D imaging in forensic applications.
- Conducting large scale, multicenter studies to compare different technologies and establish best practices.
- Developing accessible, cost-effective solutions for use in diverse forensic settings, including resource-limited environments.
- Integrating artificial intelligence and machine learning to automate analysis and reduce operator dependency.
- Expanding training opportunities to ensure effective and accurate use of these technologies by forensic professionals.

Disclosure Statement

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