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Literature Review

Innovation in dental conservation and their impact on forensic odontology

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ABSTRACT

Background: *Innovations in dental conservation are increasingly integral to advancements in forensic odontology. Integrating digital technologies, such as intraoral scanning, CAD/CAM, and 3D printing, has enhanced the precision and efficiency of dental record creation.* ***Purpose:*** *To examine and analyse new technologies and tools in dental conservation which play a crucial role in forensic identification, where accurate dental matching is essential for personal identification. Dental identification systems, including microchips and identification tags on prosthetics, are being implemented to aid in mass disaster victim identification.* ***Reviews:*** *Techniques like virtual dental autopsy offer reliable remote examination capabilities, making them invaluable in emergencies. These technologies facilitate more accurate and durable restorations, enhancing patient outcomes in clinical settings while also providing forensic odontologists with robust tools for human identification, especially under challenging conditions such as mass disasters. This paper explores various innovations in dental conservation and their impact on forensic odontology, emphasizing accuracy, speed, and ethical benefits for human identification processes.* ***Conclusion:*** *The advancements illustrate the transformative impact of digital innovation in dental science, setting new standards in both dental care and forensic applications.*

Keywords: *dental conservation, conservative dentistry, forensic odontology, dental innovation, identification*

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INTRODUCTION

Digital dentistry has increasingly replaced traditional methods by incorporating three-dimensional (3D) scanning, computer-aided design and manufacturing (CAD/CAM), and rapid prototyping. The 3D printed models and surgical guides, used alongside cone beam computed tomography (CBCT), assist dentists in planning complex surgical and non-surgical endodontic procedures. CBCT offers the added benefit of providing undistorted, three-dimensional, volumetric images of the maxillofacial skeleton, thus improving treatment outcomes.[1] Recent technological advancements in dental conservation have significantly reshaped dentistry's clinical and forensic fields. Traditionally, dental conservation, also called restorative dentistry, has centred on preserving and restoring damaged teeth. This field emphasizes restoring functionality and achieving natural aesthetics that align with a patient's unique oral structure. However, traditional techniques often involve manual impression-taking and fabrication processes, which could be time-consuming and less precise than desired. The adoption of digital technology has led to more efficient, precise, and individualized dental solutions, revolutionizing clinical outcomes and expanding the scope of dental conservation.[2,3]

Among the most transformative digital innovations in dental conservation is intraoral scanning. Digital impressions can be stored and shared electronically, reducing the need for repeated procedures and enhancing collaboration among dental professionals. This improvement in accuracy and patient comfort highlights the shift toward patient-centred care in modern dentistry.[3] In forensic applications, 3D-printed models can serve as valuable tools for training and simulations, assisting forensic odontologists in accurately analysing dental structures and identifying individuals based on dental characteristics.[4] Dental identification systems (DIS), including microchips embedded in dental prosthetics, allow for efficient identification by linking unique dental markers to a digital identifier, aiding forensic odontologists in swiftly accessing dental records during time-sensitive investigations.[5] Digital forensics has emerged as a critical component in managing and retrieving dental information. The digitization of dental records and the use of electronic databases have streamlined cross-referencing and information sharing, essential for both criminal investigations and disaster victim identification (DVI).[6,7]

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The implementation of 3D imaging technologies has further refined the process, enabling detailed visualization and reconstruction of dental structures. This facilitates more accurate comparisons and analyses, which are crucial in forensic investigations and court proceedings.[8] Techniques such as cone-beam computed tomography (CBCT) and 3D surface scanning provide detailed images of dental and skeletal structures.[9] The 3D imaging also facilitates the virtual reconstruction of damaged or incomplete skeletal remains, which is invaluable in both individual identification and mass disaster victim recovery efforts.[10] Digital forensics has become increasingly important in the modern era, where the management of vast amounts of data is essential.[11] The use of digital records also enhances the ability to share information across jurisdictions and with other forensic disciplines, fostering better collaboration and more comprehensive forensic analyses.[12] However, these advancements come with challenges, including ethical considerations, the need for standardized protocols, and the requirement for ongoing education and training. Addressing these challenges is essential to fully realizing the potential of these technologies and ensuring that forensic odontology continues to evolve responsibly and effectively.[13]

METHODS

An article search in English was conducted, through PUBMED database to identify studies about dental conservation and forensic odontology published from 2016 to 2024. The keywords searched are dental conservation, forensic odontology, conservative dentistry, dental innovation and identification. The information collected was obtained from secondary data of previously published studies.

RESULTS

Digital Impression Techniques

Digital impression techniques, particularly intraoral scanning, have transformed dental conservation by replacing traditional physical moulds. The precision of digital impressions is a cornerstone in the effectiveness of modern restorative dentistry. High-quality digital data reduces human error, which can lead to misfits or repeated procedures when using traditional methods. This precision also reduces the margin of error when designing crowns, bridges, and other restorations, providing a more secure fit and longer-lasting results. For example, CAD/CAM systems can then use these digital files to mill custom-fit restorations that are nearly perfect in their alignment and fit, ensuring the durability and functionality of the final product.[14] Digital impressions are also advantageous from a forensic perspective, as they can be securely stored in digital archives, making them highly accessible for future reference. In the event of mass disasters or complex cases where traditional identifiers such as fingerprints and DNA may not be available, digital dental records provide a robust alternative for identifying deceased individuals. Forensic odontologists can accurately identify dental structures that are often resistant to decomposition and extreme conditions by comparing postmortem digital impressions with antemortem records.[4]

Digital Imaging Technologies

The development and integration of various imaging technologies, such as radiography, Cone Beam Computed Tomography (CBCT), and 3D scanning, have enhanced the capability of forensic odontologists to perform comprehensive analyses of dental evidence. Digital imaging technologies, such as cone-beam computed tomography (CBCT) and 3D scanning, have significantly enhanced forensic odontology practices. These technologies provide highly detailed images of dental structures, allowing for more precise Identification and analysis. CBCT, for instance, offers three-dimensional views that are invaluable for comparing antemortem and postmortem dental records. Research indicates that these technologies improve the accuracy of forensic identifications and facilitate the documentation and comparison of dental evidence. These technologies enable forensic experts to visualize and reconstruct dental and skeletal remains with unprecedented detail. This capability is precious in comparing antemortem and postmortem records, facilitating more accurate identifications. Additionally, 3D imaging aids in reconstructing damaged or fragmented remains, which is crucial in individual cases and mass disaster scenarios.[15]

CAD/CAM Systems In Dental Restoration

The introduction of CAD/CAM systems in dentistry has revolutionized the creation of custom dental restorations, transforming dental conservation by enhancing precision and efficiency. CAD/CAM technology allows dentists and dental technicians to digitally design and manufacture dental restorations. According to studies, CAD/CAM-produced restorations exhibit excellent marginal fit and strength, contributing to their durability and functionality.[16] CAD/CAM systems integrate seamlessly with intraoral scanning technology, using digital impressions to guide the design and fabrication of dental restorations. This digital workflow increases the accuracy of the final product, improving patient outcomes and reducing the need for follow-up adjustments.[17] CAD/CAM systems can be stored and accessed long-term, providing a valuable resource for forensic Identification. In mass disasters, where many victims must be identified, access to precise digital dental records expedites the process, helping forensic experts make quick, accurate matches. This application has far-reaching implications for the future of forensic odontology, as it could lead to a standardized, AI-supported system for identifying individuals based on dental features, streamlining workflows across both clinical and forensic domains.[17]

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3D Printing and Its Forensic Applications

3D printing technology has transformed dental conservation by enabling the rapid production of precise, custom dental models and prosthetics. Integrating 3D printing with CAD/CAM systems, dental professionals can fabricate accurate dental structures that align with each patient's specific anatomical needs, including crowns, aligners, and dentures.2 The customization and rapid production capability of 3D printing are particularly beneficial in clinical settings where patient satisfaction and quick adjustments are priorities. For example, if a patient requires a prosthetic replacement or adjustment, 3D printing enables immediate and accurate production, minimizing patient discomfort and treatment time. The use of 3D printing in disaster victim identification (DVI), where the technology is employed to produce durable models for identification in cases involving large-scale disasters or highly decomposed remains. 3D printing enhances training for forensic professionals, allowing them to practice and refine their analysis skills using accurate dental models that mimic real-life scenarios.[1]

Virtual Autopsy Techniques: The Case of VIRDENTOPSY

Virtual autopsy techniques have been a transformative innovation in forensic odontology, particularly with the development of VIRDENTOPSY. Introduced during the COVID-19 pandemic, VIRDENTOPSY (Virtual Dental Autopsy) was designed to enable forensic odontologists to perform remote analyses of dental data when physical access to remains is limited. This method uses high-resolution 3D imaging, CT scans, and other digital tools to create a comprehensive virtual model of a deceased individual's dental structures, allowing experts to assess dental features without needing to be physically present. This process offers a practical solution for maintaining quality in forensic analysis under restrictive conditions, making it particularly valuable in emergency or disaster scenarios where onsite access may not be feasible.[4] Beyond practical benefits, VIRDENTOPSY holds educational value in the field of forensic odontology. Digital dental models created through VIRDENTOPSY are helpful training tools for forensic students and professionals looking to refine their skills in identifying dental structures and understanding forensic data analysis.

Dental Identification Systems (DIS)

Dental Identification Systems (DIS) represent a significant innovation in forensic odontology by integrating technology into dental prosthetics to streamline the identification process. DIS can include microchips or identification tags embedded within dental restorations, allowing each restoration to carry a unique identifier linked to a specific individual's records. This method provides a durable and efficient means of tracking and identifying dental features, especially in forensic scenarios where dental remains might be one of the few intact identifiers available.[1,3] As dental records become digitally accessible and traceable through embedded devices, there is a growing need for clear regulations to protect individuals' privacy rights. Patients must be informed about the purpose and implications of DIS, especially when considering that these identifiers could potentially be used to trace or access personal data.2 The importance of informed consent and secure data handling as essential aspects of integrating DIS into mainstream dental and forensic practice, ensuring that technological advancements are balanced with respect for patient autonomy and ethical standards.

Ethical and Legal Implications of Digital Innovations

Using artificial intelligence in forensic odontology introduces various ethical concerns that must be addressed to ensure responsible and equitable implementation. One of the main concerns is privacy and data protection. Data security and privacy are two significant issues. Integrating digital technologies in dental conservation and forensic odontology has raised essential ethical and legal questions, particularly concerning patient privacy, informed consent, and data security. Forensic investigations may require inter-agency collaboration; handling dental records across jurisdictions can complicate privacy safeguards, making a global framework for dental data protection increasingly necessary. Another critical ethical consideration involves implantable identification systems, such as microchips, in dental prosthetics. While these systems enhance identification efficiency in forensic cases, they raise concerns about individual autonomy and the right to privacy.

DISCUSSION

Adopting digital technologies in dental conservation has transformed the clinical landscape by significantly enhancing accuracy, efficiency, and patient comfort. Techniques like intraoral scanning allow for the rapid capture of 3D impressions, which surpass traditional molds in precision and convenience. This advancement has elevated the standards of dental restorations, with intraoral scanning ensuring accurate fits and improving patient satisfaction during the dental impression process. The precision offered by digital impressions reduces the likelihood of errors, creating a smoother workflow and ultimately providing more reliable clinical outcomes. CAD/CAM systems have revolutionized the fabrication of dental prosthetics, facilitating the creation of restorations that precisely match a patient's dental anatomy. Through CAD/CAM, dental technicians can digitally design custom restorations that are then milled with accuracy and efficiency, often within a single appointment. The seamless integration of CAD/CAM into restorative workflows enables same-day restorations, reducing patient visits and minimizing the need for temporary prosthetics. CAD/CAM restorations have excellent marginal fit and durability, which not only benefits

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patients clinically but also provide a robust identification tool in forensic settings.[16,17]

In forensic odontology, CAD/CAM-generated dental prosthetics contribute to the accuracy of postmortem identifications by providing durable and uniquely identifiable structures that remain intact even in extreme conditions. The high precision and durability of CAD/CAM restorations make them reliable for identifying individuals based on their dental records, particularly in cases where other identifiers are unavailable. The role of CAD/CAM in forensic settings emphasizes that digital restorations help create a standardized approach to forensic dental identifications, which is essential for large-scale forensic operations. The advent of 3D printing has expanded the applications of dental conservation in both clinical and forensic domains. In clinical practice, 3D printing enables the rapid and precise production of dental models, aligners, and prosthetics that cater to a patient's unique dental anatomy—this technology's ability to produce custom-fit structures quickly and accurately has dramatically improved clinical outcomes. From a forensic perspective, 3D printing allows forensic odontologists to reconstruct and examine dental features for identification purposes. It is a critical tool for analysing cases where remains may be incomplete or damaged.[4]

Virtual autopsy techniques, especially VIRDENTOPSY, have emerged as innovative solutions in forensic odontology, particularly during situations where access to remains is limited. VIRDENTOPSY enables forensic experts to remotely conduct dental examinations using 3D imaging and photogrammetry to create detailed digital models of dental structures. These models allow for accurate analysis even without physical access, a capability that proved invaluable during the COVID-19 pandemic when travel and access to facilities were restricted. The role of VIRDENTOPSY in disaster victim identification (DVI) is especially significant, as it allows forensic experts to collaborate remotely on complex cases. In mass disaster scenarios, rapid and accurate Identification is crucial, and VIRDENTOPSY provides a digital platform for forensic teams to examine and cross-reference dental data from multiple locations in real-time. This collaborative capacity increases efficiency in DVI operations by expediting identifications and facilitating information sharing across jurisdictions. Such digital solutions make VIRDENTOPSY an essential advancement in forensic odontology, contributing to speed and accuracy in high-stakes situations.[4]

Dental Identification Systems (DIS), including implantable microchips and identification tags, are another innovative tool in forensic Identification. Embedded within dental prosthetics, these systems allow for quick and accurate Identification by linking dental features to individual records. DIS can significantly reduce the time required for Identification, especially in large-scale forensic cases, by directly tracing dental structures back to their respective records. Such devices withstand extreme conditions, making them reliable identifiers when other methods are compromised, as noted by. However, as digital technologies become more prevalent in dental conservation and forensic odontology, they raise critical ethical and legal questions. Issues of patient privacy, informed consent, and data security are paramount when using digital records and implantable identification devices. Patients must be fully informed of the uses and implications of these technologies, particularly in how personal data might be accessed posthumously for forensic purposes. Clear regulatory guidelines are essential to balance the benefits of these innovations with the ethical considerations surrounding patient autonomy and privacy, ensuring that advancements in forensic odontology are applied responsibly and respectfully.[3]

In conclusion, recent innovations in dental conservation, including intraoral scanning, CAD/CAM systems, 3D printing, and virtual autopsy techniques, have substantially advanced clinical and forensic dentistry by improving precision, efficiency, and accessibility. These technologies facilitate more accurate and durable restorations, enhancing patient outcomes in clinical settings while also providing forensic odontologists with robust tools for human identification, especially under challenging conditions such as mass disasters. Dental Identification Systems (DIS) further streamline forensic procedures by enabling quick and reliable identification through implantable identifiers, though they raise essential ethical questions surrounding patient privacy and consent. Together, these advancements illustrate the transformative impact of digital innovation in dental science, setting new standards in both dental care and forensic applications.

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