NARRATIVE REVIEW

Imaging to Evidence: An Introduction to Forensic Radiology - Part I

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Abstract

Forensic radiology communicates through images in ways that words often cannot, particularly within the field of oral and maxillofacial sciences. The unique patterns of dentition and the resilience of skeletal structures provide reliable evidence in medico-legal investigations. Radiographic techniques such as cone beam computed tomography, panoramic radiography, and cephalometric analysis play a vital role in human identification, age estimation, bite mark assessment, trauma evaluation, and disaster victim identification. With the advancement of three-dimensional reconstruction, digital imaging, and artificial intelligence, forensic radiology now offers an unprecedented level of precision, enabling accurate and rapid comparison with antemortem records. Part I of this review article highlights the critical intersection of advanced dental imaging and legal justice, underscoring the role of oral and maxillofacial radiologists as both scientific experts and interpreters of hidden narratives within human remains. The details of the imaging techniques used and their interpretation are intended to be covered in the part II of the review.

Keywords: Forensic radiology, Maxillofacial imaging, Human identification, Legal justice.

Introduction

Forensic radiology is a specialized branch of medical imaging that applies radiological techniques to law enforcement, medico-legal investigations, and the administration of justice. It involves the acquisition, interpretation, and preservation of imaging data to aid in human identification, age and sex estimation, trauma evaluation, and determination of cause of death. Within this domain, oral and maxillofacial radiology holds a pivotal role, as the craniofacial complex contains highly individualistic and resilient anatomical features that can withstand extreme environmental conditions such as decomposition, burning, and submersion.[1]

Dental and maxillofacial structures including teeth, restorations, bone trabeculation patterns, and sinus morphology are unique to each individual and remain stable over time, making them valuable for comparative

identification in both single-case investigations and mass disaster victim identification scenarios.[2]

Forensic maxillofacial radiography has become a standard practice in many dental and medical facilities, playing an important role in assisting forensic odontologists with dental identification. This process can be broadly divided into two categories. *Comparative identification* involves establishing a definitive match by comparing the dental features of the deceased with their available dental records. *Reconstructive identification*, also known as dental profiling, focuses on deducing characteristics such as ethnicity, gender, age, and even occupation of the individual when direct records are unavailable.[3]

The integration of three-dimensional reconstruction and artificial intelligence has further strengthened the reliability of forensic evaluations by enabling automated matching, virtual autopsy, and predictive modelling for age estimation.[4] This review provides a comprehensive overview of the applications, advantages, limitations, and future prospects of forensic radiology in the oral and maxillofacial region, highlighting its indispensable role in bridging the gap between dental science and legal justice.

History of Forensic Radiology

- 1895 – Wilhelm Conrad Roentgen's groundbreaking discovery of X-rays revolutionized medical imaging.

- 1896 – Prof. Arthur Schuster made history by using X-rays to locate lead bullets in the head of a deceased individual.[5]
- 1898 – In the *American X-Ray Journal* (October issue), Dr. Fovau d'Courmelles remarked, *"Knowing the existence of a fracture in a person who has been burned or mutilated beyond recognition, we can hope to identify him by the X-ray."*[6]
- 1921 – Schuller introduced the idea of using frontal sinus radiographs for identification.[7]
- 1927 – Culbert and Law demonstrated complete skull identification by analysing the pneumatic cells of the sinuses.[7]
- 1990-Kultman reported 100% success in comparison of antemortem and postmortem radiographs of the frontal sinuses.[8]
- 1991 – Happonen and colleagues advocated for orthopantomography, allowing the jaws and related structures to be visualized in a single panoramic view. That same year, Haerting et al. described panoramic dental radiography as the only regularly updated and "truly reliable identification card" for comparative purposes.

Radiographic Fingerprints in Forensic Dentistry

In forensic radiology, the process of identification relies on precise imaging techniques performed by skilled professionals with specialized expertise in biology and dental anatomy. These techniques are crucial for achieving accurate human identification.[9]

A primary approach involves the comparison of antemortem and postmortem radiographs. Distinct anatomical and dental characteristics—such as the shape and length of teeth and roots, the presence of supernumerary or missing teeth, patterns of attrition and abrasion, coronal fractures, periodontal bone loss, pathological bone changes, diastemas, carious lesions, endodontic treatments, interradicular or intracoronal posts, dental implants, extraction sockets, and prosthetic restorations—serve as reliable markers for comparison.[10]

Traditionally, two-dimensional radiographs, such as frontal sinus views and bite-wing films, served as dependable tools for dental identification. With technological advancements, digital imaging methods such as radiovisiography have transformed the process by enabling precise evaluation of tooth roots and surrounding structures. These high-resolution images allow accurate comparison of antemortem and postmortem records, thereby enhancing both the speed and reliability of forensic analysis.[11]

In modern forensic odontology, dental profiling has emerged as a valuable tool for reconstructing a victim's identity prior to death, drawing on available clinical and radiological evidence. The advent of three-dimensional imaging has further revolutionized this process— antemortem computed tomography scans can now be matched with postmortem data to accurately locate and measure craniofacial landmarks. In addition, cone beam computed tomography plays a vital role in postmortem imaging, providing exceptional detail in identifying high-density metallic fragments, such as those resulting from gunshot injuries, thereby enhancing both accuracy and investigative value.[12]

From Film to Pixels: The Revolution of Radiography

Digital Radiography in Mass Disaster Forensics
- Rapid Identification – Accelerates comparison of antemortem and postmortem dental records.
- Onsite Imaging – Portable X-ray units enable imaging directly at disaster sites.
- Protection of Fragile Remains – Reduces the risk of damage during transport.
- Real-Time Data Sharing – Secure satellite transfer allows immediate communication with command centers.
- Lossless Data Preservation – Digital copies can be stored indefinitely without quality degradation.
- Enhanced Efficiency – Provides faster turnaround, improved productivity, and greater flexibility.

Recent Advances

Computed Tomography (CT) is widely used in forensic maxillofacial investigations due to its ability to reconstruct teeth in three dimensions, locate bullets, and determine entry and exit wounds. It is also valuable for detecting barotrauma and gas embolism in drowning cases, as well as for identifying broken blade fragments in stabbing incidents. The technique offers precise assessment of bone width and high image detail. However, it is not yet fully developed for complete virtual three-dimensional modelling, has limited application in cases of self-poisoning, and cannot accurately correlate wound size with the weapon if the weapon has been removed.[13,14] Cone Beam Computed Tomography (CBCT) plays a significant role in forensic applications, particularly in estimating the biological age of infants through detailed analysis of tooth development. It is also applied in superimposing skull images to aid in the identification of missing persons and in reconstructing skulls by comparing antemortem and postmortem records. This technique provides high precision in evaluating individual teeth, panoramic images, and skull volumes. However, its accuracy can be affected by the presence of metal artifacts, which may compromise image quality.[15]

Virtual three-dimensional facial reconstruction is a forensic technique that employs specialized software to recreate a person's face from their skull, enabling comparison between antemortem and postmortem records. In addition to visual identification, this method can be supplemented with DNA testing for confirmation. It is particularly valuable in mass disaster scenarios where conventional identification methods are challenging. However, its effectiveness depends on the

availability of an intact and supportive skeletal structure to ensure reliable reconstruction.[16]

Virtual Autopsy Innovations in Forensic Maxillofacial Imaging

Virtopsy is a modern, non-invasive alternative to traditional autopsy that combines advanced imaging with three-dimensional body surface scanning for detailed forensic analysis. Using computed tomography (CT) and magnetic resonance imaging (MRI), it reconstructs three-dimensional anatomy, enabling assessment even in decomposed or severely damaged remains. MRI provides high-resolution soft-tissue imaging, while contrast-enhanced MRI can reveal injuries in living victims of abuse. Magnetic resonance spectroscopy assists in estimating time of death by analysing tissue metabolites, and magnetic resonance microscopy captures fine soft-tissue details. In addition, microtomography is useful in identifying weapon characteristics and injury patterns.[17,18]

Virtopsy offers several advantages: it enables detailed three-dimensional analysis, allows digital storage for repeated review, assists in weapon matching, and provides precise assessment of fractures and pathologies. Despite its accuracy and minimal infection risk, the method also has limitations. It is costly, prone to artifact-related interpretation errors, unable to capture fine surface details or skin changes, and lacks the tactile feedback provided by conventional manual examinations.

Advantages of Forensics Radiology

Radiographs provide a fast, simple, and non-invasive method for obtaining crucial information from both the living and the deceased. They are cost-effective when compared with DNA analysis and hold strong credibility as admissible evidence in courts of law, making them a trusted and valuable tool in forensic investigations.[19]

limitations of Forensic Radiology

Postmortem intraoral radiography presents significant challenges, particularly when rigor mortis restricts mouth opening, making film placement and retention difficult. In situations where only a tooth fragment or a section of the jaw requires imaging, achieving accurate radiographic orientation becomes even more complex. Radiographs are also vulnerable to mishandling and require a high level of technical expertise to produce error-free images. Any imaging errors may mimic foreign objects or pathologies, potentially misleading investigators and complicating forensic analysis.

Future Scope of Forensics Radiology

The future of forensic radiology in oral and maxillofacial sciences is poised for rapid advancement with the integration of artificial intelligence, machine learning, and three-dimensional imaging technologie s. AI-driven image analysis will enable faster and more accurate identification, age estimation, and trauma interpretation, even in degraded remains. Portable digital radiography and mobile cone beam computed tomography units will make on-site forensic imaging more accessible, particularly in mass disaster situations. Advancements in magnetic resonance imaging and micro-computed tomography will enhance both soft- and hard-tissue visualization without the need for invasive procedures. The development of global forensic radiology databases and standardized protocols will further improve antemortem and postmortem comparisons across borders. Virtual autopsy methods, combined with robotic-assisted imaging, are expected to reduce reliance on traditional invasive autopsies, ensuring both preservation of evidence and dignity of the deceased. These innovations promise to make forensic oral and maxillofacial radiology an even more precise, reliable, and indispensable tool in medico-legal investigations. Further details of the radiographic techniques and their interpretation will be discussed in Part II of this review.

Conclusion

- Forensic radiology in oral and maxillofacial sciences serves as a bridge between technology, medicine, and justice by transforming hidden details into reliable evidence.
- Its non-invasive ability to capture, preserve, and analyse anatomical structures makes it an indispensable tool for both the living and the deceased.
- The permanence of digital imaging ensures that evidence can be revisited and reinterpreted as technology advances.
- Despite challenges in technique and logistics, the future appears promising with artificial intelligence, immersive three-dimensional imaging, and virtual autopsy expanding its applications.
- These innovations will not only strengthen medico-legal investigations but also redefine the ways in which truth is uncovered and preserved.

Conflicts of Interest

None.

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References

1. Rai, S., Misra, D., Misra, A., Kalita, P., & Krishna, A. (2022). Forensic outlook of Maxillofacial Radiology – An inevitable tool revisited. UNIVERSITY JOURNAL OF DENTAL SCIENCES, 8(3). https://doi.org/10.21276//ujds.2022.8.3.23

2. Pretty IA, Sweet D. A look at forensic dentistry--Part 1: The role of teeth in the determination of human identity. Br Dent J. 2001 Apr 14;190(7):359-66. doi: 10.1038/sj.bdj.4800972. PMID: 11338039.

3. Rajendran, R. (2009). Shafer's Textbook Of Oral Pathology (6 Th Edition) India: Elsevier

4. B. Mamabolo, A. Alblas, D. Brits, Modern imaging modalities in forensic anthropology and the potential of low-dose X-rays,

Forensic Imaging, Volume 23, 2020, 200406, ISSN 2666-2256, https://doi.org/10.1016/j.fri.2020.200406.

5. Eckert WG, Garland N. The history of the forensic applications in radiology. Am J Forensic Med Pathol. 1984 Mar;5(1):53-6. doi: 10.1097/00000433-198403000-00010. PMID: 6369961.

6. Brogdon BG, Vogel H. Conventional radiologic identification. In: Brogdon BG, Vogel H, McDowell JD, editors. A Radiologic Atlas of Abuse, Torture, Terrorism, and Inflicted Trauma. Boca Raton, FL: CRC Press LLC; 2003. p. 255-6

7. Carvalho SP, Alvesda Silva RH, Lopes-Junior C, Peres AS. Use of images for human identification in forensic dentistry. Radiologia Brasileira 2009;42:125-30.

8. Singal, Kusum. (2016). History of Dental Radiographs in Forensics. Indian Journal of Forensic Medicine & Toxicology. 10. 123. 10.5958/0973-9130.2016.00076.1.

9. Chandrasekhar, T & Vennila, P. (2011). Role of Radiology in Forensic Dentistry. Journal of Indian Academy of Oral Medicine and Radiology. 23. 229-231. 10.5005/jp-journals-10011-1134.

10. Eastman JR, Raibley S, Schwartz L. Trabecular bone patterns in dental radiographs: a further aid to dentists involved in forensic dentistry. Ill Dent J. 1982 May-Jun;51(3):161-3. PMID: 6957392.

11. Kumar, Raghav & Athota, Appaji & Rastogi, Trisha & Karumuri, SunilKumar. (2015). Forensic radiology: An emerging tool in identification. Journal of Indian Academy of Oral Medicine and Radiology. 27. 416. 10.4103/0972-1363.170478.

12. Issrani R, Prabhu N, Sghaireen MG, Ganji KK, Alqahtani AMA, ALJ amaan TS, Alanazi AM, Alanazi SH, Alam MK, Munisekhar MS. Cone-Beam Computed Tomography: A New Tool on the Horizon for Forensic Dentistry. Int J Environ Res Public Health. 2022 Apr 28;19(9):5352. doi: 10.3390/ijerph19095352. PMID: 35564747; PMCID: PMC9104190.

13. Sidler M, Jackowski C, Dirnhofer R, Vock P, Thali M. Use of multislice computed tomography in disaster victim identification--advantages and limitations. Forensic Sci Int. 2007 Jul 4;169(2-3):118-28. doi: 10.1016/j.forsciint.2006.08.004. Epub 2006 Sep 25. PMID: 16997522.

14. Garetier M, Deloire L, Dédouit F, Dumousset E, Saccardy C, Ben Salem D. Postmortem computed tomography findings in suicide victims. Diagn Interv Imaging. 2017 Feb;98(2):101-112. doi: 10.1016/j.diii.2016.06.023. Epub 2016 Sep 26. PMID: 27687828.

15. Hassanaly, Moustansir & Caldas, Ines & Teixeira, Alexandra & Pérez-Mongiovi, Daniel. (2023). Application of CBCT Technology in Forensic Odontology: A Narrative Review. Current Forensic Science. 1. 10.2174/2666484401666230516103852.

16. Miranda GE, Wilkinson C, Roughley M, Beaini TL, Melani RFH. Assessment of accuracy and recognition of three-dimensional computerized forensic craniofacial reconstruction. PLoS One. 2018 May 2;13(5):e0196770. doi: 10.1371/journal.pone.0196770. PMID: 29718983; PMCID: PMC5931631.

17. Arumugam, Vidhya & Doggalli, D Nagabhushana & Patil, Dr & Narayan, Keerthi & Thiruselvakumar, Dhanuskodi & Arthanari, Abirami. (2019). Virtual Autopsy: An Imaging Technological Integration in Forensic Odontology. International Journal of Forensic Odontology. 4. 10.4103/ijfo.ijfo_5_19.

18. Badam RK, Sownetha T, Babu DBG, Waghray S, Reddy L, Garlapati K, Chavva S. Virtopsy: Touch-free autopsy. J Forensic Dent Sci. 2017 Jan-Apr;9(1):42. doi: 10.4103/jfo.jfds_7_16. PMID: 28584475; PMCID: PMC5450483.

19. Bhuyan R, Mohanty S, Bhuyan SK, Pati A, Priyadarshini S, Das P. Panoramic radiograph as a forensic aid in age and gender estimation: Preliminary retrospective study. J Oral Maxillofac Pathol. 2018 May-Aug;22(2):266-270. doi:10.4103/jomfp.JOMFP_90_17. PMID: 30158784; PMCID: PMC6097381.