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TECHNOBYTES

Digital and Three-Dimensional Technologies in Forensic Odontology: Equipment, Casework Applications, and Educational Practice

Hemlata Pandey Gala*

Centre for Forensic and Legal Medicine and Dentistry, School of Dentistry, University of Dundee, Scotland, UK

Abstract

Forensic odontology increasingly relies on digital and three-dimensional (3D) technologies for the capture, analysis, and presentation of dental evidence. Equipment such as intraoral scanners, cone-beam computed tomography (CBCT), forensic photography systems, 3D modelling and printing, virtual reality, digital comparison software, and artificial intelligence (AI)-assisted analysis is increasingly accessible across academic dental institutions and forensic odontology units internationally. This techno-byte reviews this equipment's application to forensic casework and dental and forensic education, drawing on the published literature and illustrative research examples from the author's own research group at the University of Dundee. A typical digital workflow linking data acquisition, processing, and output for casework versus educational use is outlined, alongside practical considerations such as cost, standardisation, workforce sustainability, and data governance, that shape adoption of these technologies wherever they are used. Continued investment in equipment, validation, and interdisciplinary training is recommended to translate the research potential of these tools into consistent forensic odontology practice and education.

Keywords: 3D printing; artificial intelligence; cone-beam computed tomography; digital dentistry; forensic education; forensic odontology; intraoral scanning; virtual reality

Introduction

Forensic odontology work requires accurate capture, comparison, and presentation of dental evidence for human identification, age estimation and analysis of oral/perioral injuries and those inflicted by teeth. The foundation of a scientific and rigorous practice lies in effective methods for teaching these skills to students and trainees.[1] Advances in digital dentistry and three-dimensional (3D) technology originated primarily in restorative and prosthodontic practice.[2] The first commercially available computer-aided design/computer-aided manufacturing (CAD/CAM) system, CEREC, was introduced to the dental field in 1985 for chairside fabrication of ceramic restorations such as inlays and crowns,[3] and 3D printing has since become deeply embedded in prosthodontic workflows, from dental implants and surgical guides to crowns, bridges, and removable prostheses.[4] These technologies are increasingly finding application within forensic casework and forensic odontology education. Access to this equipment varies between academic dental institutes, hospital departments, and forensic or law enforcement units. National and international professional bodies publish guidelines, standards, and continuing-education resources supporting practitioners working in this space.[5-8] This techno-byte, written primarily from a dental and forensic education perspective, reviews the digital and 3D equipment currently used in forensic odontology, drawing on the wider published literature and on illustrative examples from the author's own research group at the Centre for Forensic and Legal Medicine and Dentistry, University of Dundee, which maintains an active research programme in 3D digital modelling for forensic dental education and casework support.

Address for Correspondence: Hemlata Pandey Gala, University of Dundee, Email id- hpandeygala001@dundee.ac.uk

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Digital and 3D Equipment in Forensic Odontology

Forensic Radiography and Photography Equipment

A complete forensic dental post-mortem examination is generally considered incomplete without dental radiography, since it reveals restorations, root morphology, and pathology that are not visible on visual charting alone; post-mortem forensic dental radiography is described in the specialist literature as a core, non-negotiable component of dental



Figure 1: Portable forensic mortuary kit, comprising a Nikon DSLR camera with ring flash, a Nomad Pro 2 handheld dental X-ray unit, for on-site radiography and photography

autopsy protocols, not an optional adjunct.[9, 10] Our own portable mortuary kit reflects this (Figure 1): alongside a Nikon® Digital Single-Lens Reflex (DSLR) camera (Nikon Corporation, Tokyo, Japan) with a macro lens and macro-capable ring flash for forensic photography, it includes a NOMAD™ Pro 2 handheld dental X-ray unit (KaVo Dental, Brea, CA, USA), allowing radiography, photography, and (with the surface scanner noted in the next section) 3D capture to be performed directly at the mortuary without reliance on fixed, wall-mounted equipment.

Handheld units such as the Nomad Pro 2 have been shown to produce image quality comparable to wall-mounted dental X-ray systems, with some advantage for anterior tooth imaging, supporting their use in portable forensic and mortuary settings.[11] Digital SLR photography with a reference scale, alongside handheld radiographic units, remains central to forensic dental documentation more broadly. In a Dundee study of tooth loss and alveolar bone change across a historic skull collection, dental data were recorded using DSLR intraoral photography and a handheld dental X-ray device, with alveolar socket changes represented diagrammatically using image-editing software; the resulting descriptive dataset was proposed as a teaching and casework reference for interpreting ante-mortem versus peri-mortem tooth and bone trauma.[12] Bite mark photography, typically using a reference scale such as the American Board of Forensic Odontology (ABFO) No. 2 scale, remains central to patterned-injury documentation.[13] In education, structured training in forensic photographic documentation, and in recognising sources of bias, is considered essential for anyone undertaking forensic dental work, especially bite mark investigations.[14]

Intraoral Scanners and Digital Impressions

Structured-light and confocal laser intraoral scanners are now widely available across dental schools and hospitals for clinical purposes, and are increasingly repurposed for forensic applications.[15] These devices enable non-contact, 3D digital capture of dental remains for comparative identification against 3D ante-mortem (AM) records. Where AM records are unavailable, 3D surface scans can instead be used to digitally reconstruct fragmented or damaged dental remains; such 3D datasets are generally preferable to conventional two-dimensional (2D) photography for this purpose, as they preserve spatial and morphological detail that flat images cannot capture.[16] Besides dental identification and profiling, intraoral scanning also enables non-invasive digital capture of a living suspect's or victim's dentition for bite mark analysis,[14] and of ante-mortem dental morphology for identification and age estimation, without the distortion risks associated with physical impression material.[17] The department's routine intraoral scanner, Primescan® (Dentsply Sirona, Charlotte, NC, USA), is also used routinely for research work. It was used in a study in which ten permanent, deciduous, and animal tooth models, including damaged and fragmented specimens, were captured and shared with 60 forensic odontologists worldwide via an online 3D-model platform to test remote tooth identification; the study found substantial agreement for broad tooth classification but a marked drop in accuracy for badly damaged or less familiar teeth (e.g. third molars), supporting the case for remote consultation with forensic dental experts in disaster or conflict settings where local expertise is scarce.[16] In addition to the intraoral scanner used for dental impressions, the department has access to handheld structured-light surface scanners for capturing larger anatomical surfaces such as skulls, dental casts, or bone specimens where intraoral scanning is not practical. In education, intraoral and surface scanners give dental and forensic students hands-on experience of digital record-keeping and direct scan-to-scan comparison exercises.

Cone-Beam Computed Tomography (CBCT) and Volumetric Imaging

CBCT units are available in many dental hospitals and university dental schools, offering 3D radiographic imaging



Figure 2: 3D visualisation of dental hard-tissue exposure patterns associated with illicit and recreational substance use.[24] Source of 3D model: Chiu A. Illicit & Recreational Drugs Exposure Pattern. Sketchfab, 2024. Available from: https://sketchfab.com/3d-models/illicit-recreational-drugs-exposure-pattern-7d316964e0414b89bf77052c979d54e5

at substantially lower radiation dose than medical computed tomography (CT). Reviews of forensic odontology methods describe CBCT as enhancing radiographic identification by enabling volumetric reconstruction of maxillofacial structures that can be digitally aligned with ante-mortem images, reducing errors introduced by differing imaging angles.[1] CBCT and panoramic radiography also underpin dental age estimation; large multi-population studies of the third molar maturity index, for example, have used panoramic and CBCT datasets across multiple ethnic groups to support age-of-majority assessment in legal contexts.[18, 19] In education, CBCT and panoramic datasets are used to teach radiographic interpretation and to simulate age-estimation methodology on realistic case material.

Beyond age estimation and volumetric reconstruction, CBCT is increasingly applied in forensic trauma assessment: its reduced sensitivity to metallic artefact compared with conventional CT makes it particularly well suited to imaging gunshot and other high-density projectile injuries, including reconstruction of likely bullet trajectory, as well as characterising fracture patterns in blunt-force craniofacial trauma.[20] CBCT can also retrospectively reveal treatment-related complications such as nerve-canal proximity, sinus perforation, or implant malposition that may become relevant when dental records are reviewed in cases of alleged clinical negligence.[21]

3D Modelling, Printing, and Digital Comparison Software

Academic and forensic units increasingly hold in-house 3D printers and modelling software to produce digital and physical exhibits from scanned or CBCT data such as teaching models, replica dentition, and demonstration aids, complementing the international 3D-printing techniques and accuracy considerations.[22] This approach has been used to build 3D anatomical models depicting the destructive effects of heat, trauma, and post-mortem 'pink teeth' on the dentition; a survey of qualified forensic odontologists and students found that 79% considered such models useful for training, while also revealing specific gaps in participants' knowledge of thermal and traumatic dental change.[23] The same modelling approach has since been used to build 3D reference models of substance-induced dental damage such as licit drugs, illicit drugs, and chemical/trace-element exposure (Figure 2); an accompanying global survey of 160 professionals across 37 countries found that only 35.6% had received formal training on substance-related dental change, and just 8.1% correctly identified all five conditions shown in image-based test questions, underlining an educational gap that such models aim to address.[24]

Beyond modelling for teaching, quantitative 3D dental-comparison methods are also being developed for casework use: a recent study using 3D scan data of full jaws, single teeth, and heat-damaged specimens reported that curvature-based similarity scoring could distinguish matching from non-matching dental comparisons with high accuracy (ROC-AUC 0.90–1.00), even for fragmented or heat-traumatised remains.[25] In education, hands-on 3D modelling, printing, and comparison exercises help students and trainees understand the principles of pattern comparison and evidence reconstruction before encountering them in casework.

Artificial Intelligence in Forensic Odontology Workflows

Artificial intelligence (AI), particularly convolutional neural networks applied to radiographs, intraoral scans, and photographs, is an emerging addition to the forensic odontology digital workflow. A 2026 systematic review of 116 studies found that AI models achieved a mean absolute error as low as 0.0079 years for dental age estimation, up to 98% accuracy for gender estimation, and up to 100% accuracy for dental identification under optimal conditions, though performance fell to around 69% sensitivity in more realistic post-mortem scenarios; the review identified data privacy, algorithmic bias, and legal admissibility as the principal barriers to routine forensic use.[26] These challenges mirror those raised in the wider dental literature on AI adoption, including calls for population-specific validation datasets, clear regulatory frameworks, and safeguards against over-reliance on automated output without clinical supervision.[27]

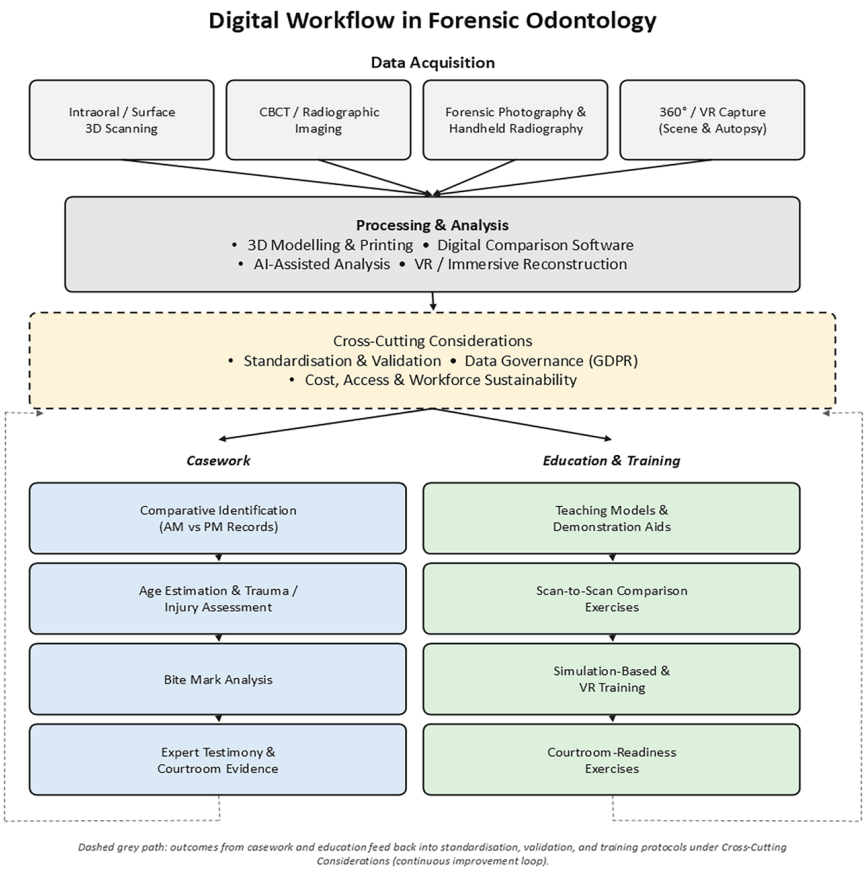


Figure 3: Digital workflow in forensic odontology, from data acquisition to casework and educational application

The quantitative 3D dental-matching approach described above is itself an early example of algorithm-assisted casework support in forensic odontology. In education, AI-based tools are beginning to be trialled for automated feedback on radiograph interpretation and age-estimation exercises, though their formal integration into forensic odontology curricula remains limited.[28]

Virtual Reality and Immersive Simulation

Virtual reality (VR) headsets and 360-degree cameras are increasingly being explored as tools for forensic dental education, training, and, more tentatively, casework support, reflecting a broader uptake of extended reality (XR: encompassing virtual, augmented, and mixed reality) across the forensic sciences.[29] A recent integrative review of XR in forensic science found such applications cluster around crime scene reconstruction using 360-degree capture devices and head-mounted displays, and the training of both practitioners and students, with several included studies conducted in genuine or reconstructed crime scenes and autopsy settings.[29, 30] VR-based simulation similarly allows forensic odontology trainees to rehearse complex, high-stakes scenarios such as dental evidence assessment within a simulated autopsy suite or a crime scene in a controlled, low-risk environment. A comparative study of VR-based crime scene investigation training found significantly better learning outcomes, knowledge retention, and engagement than conventional simulation-based instruction.[31] A recent pilot study demonstrated the feasibility of simulated courtroom training for forensic odontology trainees.[32] The same review cautions, however, that XR adoption in forensic science remains constrained by high equipment and operational costs, the absence of standardised protocols across devices and jurisdictions, and unresolved questions around the legal admissibility of digitally reconstructed evidence in court; within forensic odontology specifically, these technologies remain at an early, exploratory stage, and their formal validation for casework use has yet to be established.[29, 33]

Figure 3 summarises this overall digital workflow: equipment for data acquisition (intraoral and surface scanning, CBCT, forensic photography and radiography, and 360°/VR capture) feeds into a shared processing and analysis stage encompassing 3D modelling, digital comparison software,

and AI-assisted analysis, which in turn supports two parallel applications, casework and education and training, shaped throughout by the cross-cutting considerations discussed below.

Practical Considerations

None of the equipment and workflows described above translates automatically into forensic capability: access, cost, and the trained personnel required to operate this technology vary considerably between academic, hospital, and forensic or law-enforcement settings worldwide, and remain a significant barrier to routine adoption in smaller units. These resourcing gaps are compounded by workforce pressures reported across the specialty more broadly. A recent international survey of forensic odontologists identified job insecurity, underpayment, and a lack of formal professional recognition as common career challenges, alongside a desire for more available training and stronger support networks, factors that constrain not only who can afford this equipment but who remains available to use it.[34] Even where equipment and staffing are adequate, its forensic value depends on standardised protocols and realistic expectations of what any single method can achieve: comparative dental analysis alone, for example, is estimated to identify only around one-third of victims in mass-disaster scenarios, with roughly three-fold higher success in closed versus open disasters, underlining why it is typically used alongside other identification methods rather than in isolation, and why consistent training matters as much as the technology itself.[35] This need for structured training increasingly extends beyond technical competence to courtroom performance. A pilot study of simulated courtroom training for forensic odontology trainees found the exercise improved self-reported expert-witness preparedness, supporting simulation-based approaches, including the VR-based training discussed above, as a complement to equipment-focused teaching.[32] Such attention to preparedness reflects a broader recognition that the operational and psychological demands of forensic dental work, often conducted in acute, high-pressure settings such as disaster scenes and mortuaries, are as important to practitioner sustainability as the equipment itself, an area increasingly examined through research into disaster victim identification practitioners' experiences and wellbeing.[36] The increasingly digital nature of this equipment also brings governance obligations, with data protection and information-governance requirements applying to the storage and transfer of digital dental records under regimes such as the General Data Protection Regulation (GDPR) or equivalent national legislation.[37] Finally, the admissibility and courtroom presentation of 3D-printed, AI-assisted, or digitally derived evidence continues to develop across jurisdictions, reinforcing the need for locally validated studies rather than uncritical reliance on equipment-accuracy data generated elsewhere.

Conclusion

Forensic odontology internationally now draws on a growing range of digital and 3D equipment, spanning intraoral scanning, CBCT, forensic photography, 3D modelling and printing, virtual reality, digital comparison software, and early AI-assisted analysis. Access and routine casework application vary considerably between academic, hospital, and law-enforcement settings, and between countries, and are shaped as much by workforce sustainability, training, and practitioner wellbeing as by equipment cost itself. As the examples described here, several drawn from an active university programme, illustrate, these technologies deliver the greatest evidential and educational value when supported by validation, standardised protocols, and dedicated training, including simulation-based and courtroom-readiness training alongside technical instruction. Their growing use also raises data-governance and evidentiary questions, from compliance with data protection regimes such as the GDPR to the still-developing legal admissibility of AI-assisted and digitally derived evidence, that will need to be resolved locally rather than assumed from equipment-accuracy data generated elsewhere. Continued investment in equipment, cross-sector collaboration between academia, forensic services, and law enforcement, and deliberate integration of digital and AI-assisted methods into forensic dental education and workforce support will help translate the research potential of these tools into consistent, defensible forensic odontology practice, applicable to any setting where such equipment is available.

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