



Integrating 3D Printing into Digital Workflows for Reconstruction and Visualisation of Dental Evidence

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Abstract

Three-dimensional technology is an emerging and valuable tool in forensic odontology. It allows for the creation of digital models and their conversion into physical models. 3D printing specifically provides advantages in the preservation, reconstruction, and visualisation of dental evidence for analysis, education, and courtroom presentation. This techno-byte provides an overview of major 3D printing techniques and their possible applications in forensic odontology. Based on published literature, various techniques, their working mechanisms, the materials utilised for printing, and their accuracy are discussed. A typical digital workflow is also outlined, beginning with data acquisition through 3D surface scanning or medical imaging modalities, followed by segmentation, model generation, slicing, and post-processing. Despite its potential, 3D printing in forensic odontology remains largely research-based. Further validation, standardisation, and interdisciplinary collaboration are essential for its routine use in forensic casework and disaster victim identification.

Keywords: 3D printing; forensic odontology; accuracy; 3D scanning

Introduction

Three-dimensional (3D) printing is the fabrication of a physical model from a digital file.¹ Also known as additive manufacturing or rapid prototyping, it is a rapidly developing technology that has been adopted across various disciplines of medicine and forensic science.² A physical object is built in three dimensions by the deposition of successive layers of material.³ There are several steps from data acquisition to the post-processing of 3D-printed models for building a 3D model. 3D-printed models offer an added advantage for preservation, restoration, and conservation.^{3,4} In forensic odontology, 3D printing technology can be useful for analytical purposes, virtual and crime scene reconstructions, court presentations and demonstrations, and facial reconstructions. This techno-byte provides a

brief overview of different 3D printing techniques, their potential applications in forensic odontology, and the workflow involved.

3D Printing Techniques in Forensic Odontology

The 3D printing methods are standardised into seven groups by the American Society for Testing and Materials in the US (ISO/ASTM 52900).⁵

Material Extrusion

One of the most commonly used 3D printing methods. The method uses a thermoplastic polymer in different colours that is extruded from a nozzle onto the printer bed. Fused deposition modelling (FDM) is one such technique. The structure is built layer by layer, and overhanging parts are supported by support structures, which are removed and smoothed during post-processing.¹ (Figure 1A) This method is not recommended for analytical purposes due to dimensional error. The reported accuracy of this method is low, and when compared with the original tooth specimen, it has a mean RMS of 0.12 mm.⁶ The method is used for prototyping, demonstrations, and the printing of educational models in forensic odontology and forensic facial reconstruction.^{1,7} Figure 2 3D-printed models of teeth and a skull for demonstrative and teaching purposes.

Binder Jetting

The method utilises a powder bed of gypsum, acrylic, or metal, which is bound with a liquid bonding agent.⁸ Excess

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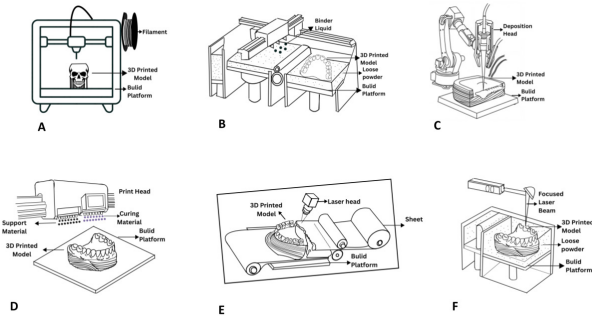


Figure 1: Schematic representation of the working principle of different 3D printing techniques

powder is removed during post-processing. (Figure 1B) The method demonstrates low accuracy and low tensile strength. This method can be utilised for prototyping and for demonstration purposes.^{7,9}

Vat Polymerisation

The method utilises a liquid photo-polymer that is selectively cured using a laser. It utilises methods such as stereolithography (SLA), digital light processing (DLP), and continuous liquid interface production (CLIP).¹⁰ The technique utilises UV light to strengthen the final object, followed by the removal of support structures. Studies reported the best accuracy for DLP technology in forensic odontology, with a mean RMS of 0.07 mm, whereas for SLA it was 0.08 mm. These methods can be used for analytical purposes as well as for reconstructive forensics.^{6,11,12}

Direct Energy Deposition

This technique utilises metal, ceramic, or polymer, which is fused onto the workpiece using a high-energy source. It is used to build complex structures and is generally not used in forensic work due to its cost.^{7,13} (Figure 1C)

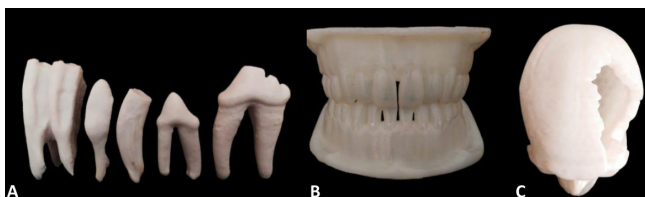


Figure 2: 3D-printed models for teaching and demonstration purposes: A) 3D printed Animal teeth, B) 3D printed human dentition, C) Trauma in the skull

Source of 3D models: <https://sketchfab.com/vetanatMunich/collections/teeth-equidae-bbd82647281048869a29ddd1c3c4302e>
<https://sketchfab.com/vetanatMunich/collections/teeth-equidae-bbd82647281048869a29ddd1c3c4302e>
<https://www.printables.com/model/1164481-major-headache-skull>
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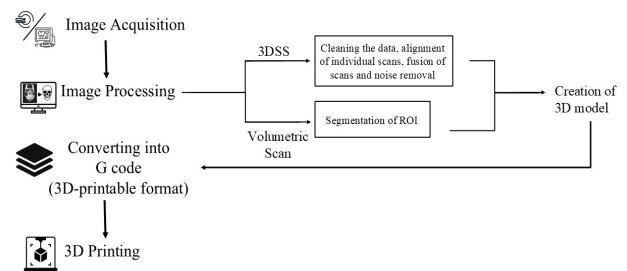


Figure 3: Schematic representation of a typical digital workflow

Material Jetting

In this technique, a liquid photo-polymer is used, which is cured using light or heat. Multiple colours can be used in a single print. The reported accuracy of this technique for printing teeth is high. The study showed a mean RMS of 0.07 mm when compared to the original model.¹¹ The technique can be used for various analytical applications and for bitemark analysis; however, it might not be cost-effective for printing large numbers of samples. (Figure 1D)

Sheet Lamination

In this technique, the layers of materials are bonded together, and the shape of the desired object is cut with a knife. This technique is generally used in industries.⁷ (Figure 1E)

Powder Bed Fusion

A powder bed of metal, plastic, glass, or ceramic is fused using high-beam energy. Overhanging structures are supported by unsintered powder. Selective laser sintering (SLS) is one technique that uses this method. (Figure 1F) The technique has shown the highest level of accuracy for bone, whereas for teeth, it showed a mean RMS of 0.10 mm when compared with the original tooth.¹⁴ Due to its high accuracy and fine surface texture, this technique can be used for various analytical procedures and documentation. However, the cost of this technology is very high and cannot be used in high-volume cases.

Workflow: From 3D Scan to 3D Printing

A typical digital workflow (Figure 3) involving 3D printing begins with image acquisition. Data is acquired as a 3D image either through 3D surface scanning (3DSS) or through volumetric scanning using computed tomography (CT), cone beam computed tomography (CBCT), or magnetic resonance imaging (MRI).^{7,14} The data acquired through 3D scanning is then either segmented or processed and converted to a 3D model.

The raw data acquired with 3DSS is cleaned of background noise and unwanted structures, and the individual scans are then aligned and fused into a single object. The final sample

is then smoothed, decimated, corrected for unnecessary features, and subsequently converted to an .stl, .obj, or .ply file, depending on the requirement¹ Data acquired with medical imaging modalities is stored as Digital Imaging and Communications in Medicine (DICOM) files, which are then segmented into a region of interest (ROI) and converted into a 3D model.^{15,16} This processed 3D model is sliced and prepared for 3D printing by adding support structures if needed, adjusting infill, and finally converting it into a 3D printer-readable file.¹⁰ The final 3D model is a post-processed version based on the 3D printing method.

Conclusion

Techniques such as 3D printing and 3D scanning must be considered a distinct field of special interest, as they require explicit knowledge of different 3D scanning techniques and printing materials. Based on the discussion above, 3D printing methods such as material extrusion can be used to print models for teaching, demonstration, display, and prototyping. Conversely, techniques such as binder DLP and SLA can be used to print teeth for analytical methods such as age estimation and bitemark analysis. The SLS technique, due to its high surface definition, can be specifically used for analysing non-metric traits and surface details.

Currently, the application of 3D printing is primarily research-based; more empirical data are required to apply this technique in casework and disaster victim identification. Collaboration between research, policy, and practice is highly recommended and is the need of the hour.

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