



Original Research Article

A preliminary study to assess the feasibility and application of 3D printing technology in forensic dentistry

Jimsha Vanathan Kumaran^{1*}, Mithunjith Kichenin², Jonathan Daniel M³

¹Dept. of Oral Medicine and Radiology, Mahatma Gandhi Postgraduate Institute of Dental Sciences Pondicherry, Puducherry (U.T), India.

²Private Practice, Formerly Reader, Conservative Dentistry and Endodontics, Faculty of Dentistry, Balaji Vidyapeeth (Deemed University), Pondicherry, Puducherry (U.T), India

²Dept. of Oral Medicine and Radiology, Mahatma Gandhi Postgraduate Institute of Dental Sciences Pondicherry, Puducherry (U.T), India.

Abstract

Introduction: The potential applications for 3D printed reconstructions in forensic science are numerous. Replicas could be utilized across the forensic science process: in crime scenes, in intelligence gathering, analysis and interpretation of materials, in police investigations, and in courtroom presentation of evidence. Further, 3D replicas could be beneficial in forensic science teaching and public outreach programs. In order for 3D printing to be utilized in forensic science, particularly in courts of law, the discipline needs a recognizable evidence-base that underpins its reliability and applicability. At present, there is a distinct lack of empirical research around 3D printing in the forensic sciences, an issue that needs to be addressed. The application of 3D printing is well established in dentistry and dental restorations, while more recently, 3D printing is beginning to be applied in forensic odontology. As with forensic anthropology or pathology, 3D printing is well suited to forensic odontology as replicas of human bones and teeth can be 3D printed by novel methods.

Aim and Objective: 1. To explore the applications of 3D printing in disciplines of forensic odontology. 2. To validate use of 3D printing in bite-mark analysis, facial reconstruction, gender, and forensic documentation.

Materials and Methods: Intraoral 3D scans of selected subjects were performed by appropriate infection control guidelines using "MEDIT i500" (South Korea) Intraoral 3D scanner. The generated STL files (3D virtual model) were prepared for printing using SATURN EL3D (ELEGOO, Shenzhen, China) using white/clear PLA material by the SLA technique and 3D replicas fabricated. For 3D reconstruction from CBCT scans, the images were saved as Digital Imaging and Communications in Medicine (DICOM) data and transferred to a compact disc (CD). The DICOM data were then reconstructed using EXOCAD (3D GmbH Germany), a free, open-source, cross-platform program. The 3D replicas were appropriately validated for forensic documentation, bitemark analysis and 3D reconstruction.

Conclusion: 3D printing can be applied in forensic odontology to maintain antemortem records, bite mark analysis and facial reconstructions from CT images for identification of individuals. This paper highlights few of the practical applications of 3D printing in forensic odontology.

Keywords: Bite mark, Evidence reconstruction, 3D printing, Forensic dentistry, 3D imaging

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1. Introduction

The 3D printing is adding up successive layer of material to make an object in three dimensions. 3D printing is also known as additive manufacturing. The 3D printing technology was used in the aerospace, defence, engineering art and design. The 3D printing technology can offer durable, reproducible, accurate models. Mainly applied in the field of reconstruction, rehabilitation, and regeneration.^{1,2}

In 1986 Charles Hull was the first person who patented the stereolithography and built a 3D printing system.

*Corresponding author: Jimsha Vanathan Kumaran
Email: dr.jimsha.mds@gmail.com

Followed by Scott crumb in 1990 who received a patent for fused deposition modelling. Consequently, 3D printing has increasingly progressed.³⁻⁵ Three dimensional digital models can be generated from volumetric data from CBCT scanning, laser scanners or from computer aided design. These digital models can be converted into STL file followed by transferring to a machine language via G code via slicing to enable reading by 3D printers.

The technology has expanded to every field, now the technology has a particular resonance to dentistry. In

dentistry models and drill guides printed are used for implant rehabilitation and mandibular reconstruction. 3D printed drill and sculpting guide for planning surgery in the oral and maxillofacial region with the help of intra oral scanners. Applications of 3 D printing in digital orthodontics are tremendous. In every aspect of dentistry now 3D printing has emerged. Recently 3D printing is beginning to be applied in forensic odontology.3D printing can play a great role in forensic odontology,especially in bite mark analysis, facial reconstruction, age estimation and individual identification.⁶

With this background a preliminary in house study was done to assess the viability of basic 3 D printing techniques and their applications in forensic odontology.

2. Aim and Objective

1. To explore the applications of 3D printing in various disciplines of forensic odontology.
2. To validate use of 3D printing in bite-mark analysis, facial reconstruction, gender and forensic documentation.

3. Methodology and Workflow

Intraoral 3D scans of select subjects willing to participate in the study were performed by appropriate infection control guidelines using “MEDIT i500” (South Korea) Intraoral 3D scanner. The generated STL files (3D virtual model) were prepared for printing with “SATURN EL3D” (ELEGOO, Shenzhen, China) 3D printing machine using white/clear PLA material by the SLA technique and 3D replicas fabricated. For 3D reconstruction from CBCT scans, the images were saved as Digital Imaging and Communications in Medicine (DICOM) data and transferred to a compact disc (CD).The DICOM data were then reconstructed using EXOCAD (3D GmbH Germany), a free, open-source, cross-platform program. The 3D replicas were then appropriately validated for forensic documentation, bite mark analysis and 3D reconstruction.(Figure 1)

Bite marks are the physical alterations within the medium caused by the forceful contact of teeth either alone or in combination with other parts of the mouth.3D printing helps to avoid the rapid loss of information that occurs in some bite marks and helps preserve maximum information.Traditionally, two-dimensional bite mark analysis used photographic documentation to preserve the bite marks and dental cast made from stone for recording the impression of the bite mark evidence. These have the limitation of angular distortions and dimensional inaccuracy, if proper technique is not followed. Using digital scanners to document the bite marks, eliminates any chance of distortion and also allows easy handling of the physical models that do not suffer for loss of details on handling. (Figure 2,Figure 3) Thus, 3D scanning preserves maximum detail and seems to be a reliable, accurate, and reproducible technique. The scans themselves can be used for digital comparison of the suspect’s teeth using various software. Hence, 3D scanning helps to preserve the information obtained and can be used as secure evidence in the court of law.^{3,6,7}

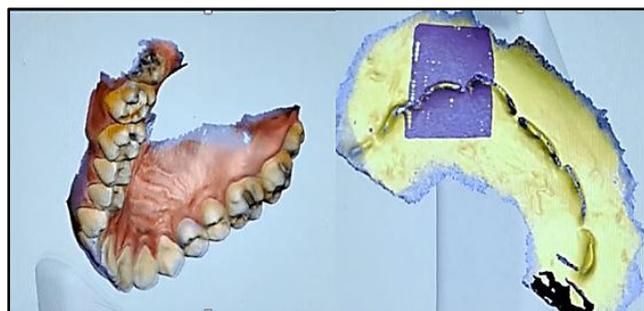


Figure 2: Scan of bitemark and scanned stl file



Figure 3: Virtual docking and 3d printed bitemark replica



Figure 1: Intraoral 3D scanner 3D printer and software

4. Discussion

4.1 Bite mark and pattern analysis

MacDonald defined a bite mark as “a mark caused by the teeth either alone or in combination with other mouth parts.” Like fingerprints, the marks made by human teeth can be a tool for identification, as this is unique in every individual.

4.2. Analysis of palatal rugae pattern (palatoscopy)

Palatoscopy, cheiloscopy and lingual print analysis are emerging biometric tools in forensic identification due to their uniqueness and permanence.Palatal rugae (palatoscopy) and tongue prints offer stable anatomical markers resistant to trauma and decomposition,(Figure 4)while lip prints (cheiloscopy) assist in identifying individuals based on groove patterns. The integration of three-dimensional (3-D) printing with these techniques enables accurate replication of

oral structures for comparison, preservation, and courtroom presentation. 3-D models enhance visualization, improve training, and facilitate interdisciplinary collaboration. This transformative technology elevates traditional pattern analysis into a digitized, reproducible, and legally admissible format, significantly advancing forensic odontology's role in human identification.

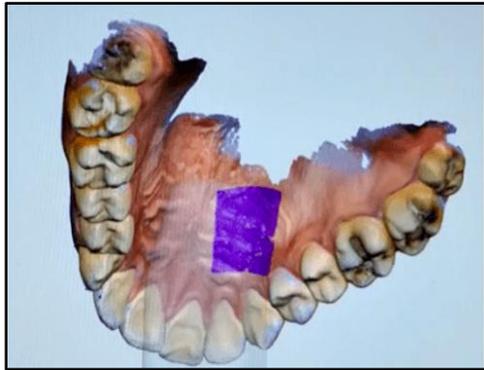


Figure 4: Intraoral scan of palatal rugae

4.3. Forensic facial reconstruction

Forensic facial reconstruction also known as facial approximation can be used to identify unknown human remains. With the advancement in 3D technology, quick, efficient, and cost effective computerized 3D forensic facial reconstruction method enables visual identification of the victim. Computerized remodelling of missing individual can be made by using software that also allow the data to be saved in the standard triangulation language file (STL) formats. These further, can be converted to the 3 D models that can be examined thoroughly. In 3D printing, the model of the skull in the form of STL with minimum slice thickness, produced from the CT scan, is used. Appropriate material like acrylonitrile butadiene styrene (ABS) filament is used, and the layers are additively laid down to produce anatomically accurate models.(Figure 5) Hence, 3D printing coupled with CT scans allows facial reconstruction that can be reproduced multiple times and can be preserved for forensic investigations and in intelligence gathering.⁸

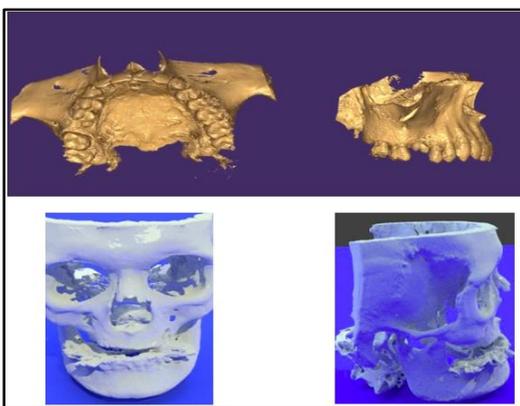


Figure 5: Dicom stl files to 3d print reconstruction

4.4. Dental age estimation and gender determination

An accurate 3D dentition model may aid in assessing the individuals age by removing the need of direct examination in the oral cavity. (Figure 6, Figure 7)3D models would eliminate the problems faced due to improper visualization, saliva, and improper access. 3D models of the mandible can also be used for age estimation using the mandibular gonial angle.⁹ (Figure 5)

An important aspect of forensic odontology is the age determination of an individual based on a sequence of dentition eruption status. The number and sequence of the teeth erupted can equitably determine the age of an individual. Radiographic methods can further show in detail the different stages of mineralization and help in a more accurate estimation of age.^{10,11} Models produced by 3D printing from existing scans help in the calculation of a person's dental age. 3D models can also be used for average grading of attrition (Li and Ji method), where the age range of the patient can be approximated. Age estimation with printed models removes the need for direct examination in the oral cavity as well as eliminating other difficulties such as improper visualization and visual access secondary to rigor mortis.⁵



Figure 6: Scanned image of upper dentition

Gender determination is a sub division of forensic odontology that is especially useful when the information relating to the deceased is unavailable.3D-printed dental models are clinically acceptable. It has been demonstrated that there is no dimensional change between the tooth and the 3D model. The 3D printed models aid in direct assessment and measurements of tooth size, shape, orientation, inter-canine distance, intermolar distance, the overjet, the overbite, and arch length. An accurately printed model could improve the accuracy of sex determination procedures and for population identification from the nonmetric dental traits such as Carabelli formation.(Figure 6,Figure 7) 3D-printed models produced by scanning and additive layout have decreased chances of variation with the original teeth morphology. This dimensional accuracy of 3D printed models is best made use of in gender determination. No significant difference in the various parameters of tooth models and 3D-printed models was found in various studies

done so far. Hence, an accurate printed model could improve the accuracy of sex determination procedures and aid in population identification.^{5,10}

4.5. Forensic documentation

The use of unique features and morphological variations of the teeth in personal identification is well accepted in forensic examinations and in the court of law. The transfer and presentation of human remains and evidence to the court room must be done strictly in legal context with utmost care, as it has legal and ethical protocols associated with their handling and storage. In such cases, realistic 3D replicas of human remains can be produced using 3D printing technology and can ultimately serve to convey important details to the court and jury without offending anybody or causing bias.²



Figure 7: 3D Printed replicas of upper arch

3D printed replicas allow for a higher level of interaction by the observer. 3D replica would not have the ethical considerations or safety limitations. 3D Printing can be carried out by scanning technique that are noninvasive and contactless and that does not disturb human remains and trace materials. The labially placed right upper central incisor with chipped incisal edge at the disto-incisal angle can be seen as depicted in the figure. Thus they aid in reevaluation of the model even after many years and also helps to evaluate minute and complex geometries. (Figure 7)

5. Limitations

These newer technologies have to be sufficiently explored to make them into a main stream evidence to be presented for cross-examination in court of law. An empirical evidence-base needs to be formed to underpin the reliability and reproducibility of 3D printing. The issues surrounding the validity and reliability of printed replicas and their evidential value must be evaluated and addressed, to avoid risk of misleading evidence. The need for technically trained personal with a keen knowledge on the available printing technologies and applied skill in practice of 3D printing is a major requisite. Another concern is the cost of the equipment, maintenance, and adherence to strict health and safety protocols. Complex technology and factors such as expense, maintenance and repair, cleaning, difficult post processing, and onerous health are other concerns. Errors can be generated during any step of the process. The challenge

focuses on determining which combinations to use to achieve the best results.

6. Advantages

1. High accuracy in replicating dental structures.
2. Enhance visualization for forensic analysis and courtroom presentation.
3. Preserves fragile or decomposed remains safely.
4. Allows digital storage and reprinting of models.
5. Enables interdisciplinary collaboration.
6. Ideal for education and training without ethical concerns.
7. Assists in accurate trauma and facial reconstruction.
8. Minimizes repeated handling of original remains.

7. Disadvantages

1. High initial cost of equipment and materials, requires technical expertise and training.
2. Time-consuming processing and post-production steps.
3. Risk of data loss or corruption during digital conversion.
4. Limited accessibility in low-resource or remote areas. Output quality depends on printer type and material.
5. Legal acceptance may vary across jurisdictions
6. Errors possible if imaging data is incomplete or improperly captured.

8. Conclusion

The technology of 3D printing may open new doors in forensic odontology. Though, the applications in this domain are still in infancy, it definitely has a promising future. 3D-printed models assist the forensic expert in the examination and identification of the suspect. The non-invasive nature of this technique allows us to get maximum anatomic details in minimal time. It allows construction of the complex facial structures, that can be used to solve crime and also enables the experts to demonstrate the evidence in a presentable form to non-medical personnel in the court of law for more clarity of the details. The findings from this preliminary piece of work will enable future studies to have practice informed research, facilitating improved applicability and practical approaches to forensic 3D printing.

9. Source of Funding

None.

10. Conflict of Interest

None.

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