Review Article

Emerging Applications of 3D Printing in Forensic Odontology: A Review

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ABSTRACT

"Forensic odontology" is an essential branch of forensic science that has long played a role in criminal investigations. It is crucial for identifying people who have died in big disasters or crimes who cannot be identified visually or by other means. Although it is common practice to exhibit physical representations of evidence in court, a variety of legal and ethical problems frequently restrict investigators from presenting any physical evidence with human origins in court. Laser scanners, photogrammetry, structured light scanners, and other three dimensional (3D) digitizing techniques have changed the field of forensic sciences. 3D printing can aid in the depiction of evidence spatial connections within a scene and the comprehension of complex terminology. As a result, these 3D digitizing technologies can be effectively applied to the advancement of forensic sciences.

Key words: 3 Dimensional printing, forensic odontology, forensic science

INTRODUCTION

Forensic odontology has evolved into an important component of forensic science, helping to identify people who have died and cannot be identified visually or by other methods.[1] Dental tissues are frequently utilized to assess a person's gender, age, and ethnicity, which can be used to identify a victim or a suspect. In every industry ranging from aerospace research to military, art, and even health and dentistry, 3D printing has revolutionized the development and manufacturing process.[2] In the forensic sciences field, 3D printing is still relatively new.[3] Because of the process of adding materials, additive manufacturing or rapid prototyping is other terms for 3D printing.[4] One definition of digital forensics is "the use of computer science and investigation techniques for a legal purpose involving the study of digital evidence."[5] Additive manufacturing is a complicated process that starts with computerized scanning of the piece to be created, then digitally slices it into numerous thin layers, and eventually uses this geometric data to build each layer progressively until the desired three-dimensional product is completed.[6] Digital forensic investigations are becoming more widely used, particularly in major calamities such as terrorism, aviation, tsunamis, and earthquakes.[7] Furthermore, after a tentative identification of a suspect, dental radiographs are useful for identifying people and estimating their ages by comparing antemortem (AM) and postmortem (PM) data.[8] In the aftermath of mass tragedies, earthquakes, terrorism, and other natural calamities, computerized software allows for a quick comparison of AM and PM data of deceased victims.[9] Furthermore, software allows for the superimposition and comparison of digital radiography and images of the deceased.[10] The present review will highlight the different methods of 3D printing and its emerging applications in forensics.

3D PRINTING METHODS

The various methods of 3D printing are standardized into seven groups

1. Material extrusion (or fused deposition modeling, [FDM]) – An extrusion head heats up to distribute the material through a nozzle, which is subsequently placed in layers onto a build platform in FDM.[11]
2. Vat polymerization (e.g., stereolithography) – The usage of a liquid photopolymer substance (plastic or polymer) that is selectively cured within the build chamber using a light source is known as vat polymerization (e.g., a laser).[12]
3. Binder jetting – A bed of powder (e.g., gypsum, metal, or acrylic) is selectively bound by a jet of liquid bonding agent. The layers are added and fused in order, and any unfused powder is discarded after printing.[13]

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4. Material jetting (MJ) (Polyjet) – Similar to a standard inkjet printer, and MJ liquid, photopolymer material (e.g., plastic, metal, or wax) is used that is jetted on top of a build tray and cured (e.g., using light/heat).
5. Powder bed fusion (e.g., selective laser sintering, [SLS])-A high-energy source selectively fuses a powder bed of material (metal, plastic, ceramic, or glass) in a chamber (e.g., a laser or electron beam).[14]
6. Sheet lamination – Using an adhesive, layers of substance (e.g., paper, plastic, or metal composite) are glued together as they are set down. Each layer is sliced to the appropriate form (e.g., using a knife or laser).
7. Direct energy deposition – With a high energy source, the material (e.g., ceramic, metal, or polymer) is fused layer by layer as it is deposited on the top of the build platform (e.g., laser or electron beam).[15]

The method chosen will be dictated by the replica's intended purpose and appearance, the required material properties, and the printer's limitations (e.g., cost, time, and print volume). When compared to the original, printed reproductions are said to have an accuracy of <1 mm (or 3%).[16]

Applications of 3D printing in forensic science

Documentation

However, due to a variety of ethical and legal issues associated with the storage, transportation, and presentation of human remains to the trial and the jury, the justice system primarily relies on photographs and electronic copies in cases where human remains would otherwise provide conclusive proof in the field of forensics.[17] In this situation, 3D printing can be utilized to create accurate, 3D copies of human remains from actual evidence that can be used to inform the judge and jury of crucial details without offending anyone or introducing bias.[18]

Human identification

When estimating age, a precise 3D model of a dentition may be helpful, for instance, in identifying the dentition's condition. A 3D-printed model created using PM computed tomography can reduce some of the challenges associated with traditional autopsy, like the inability to examine a subject due to rigor mortis or a lack of adequate visualization.[19] A 3D model of the maxilla and mandible can also be used to determine gender using a variety of metric and non-metric features, as well as to estimate age. In addition to assisting in morphometric analysis, 3D scanning and printing of the face, finger, lip, palatal rugae, palm, and sinuses would provide documentation for upcoming referrals. It can be difficult to take reliable impressions of those areas with traditional impression techniques, and accuracy can also be compromised due to shrinkage. 3D modeling may be useful in these cases.[3]

Dental anthropology and comparative dental anatomy

One of the few fields in forensic odontology where the use of 3D printing is regularly advocated is dental anthropology. The accuracy of population identification using non-metric dental features could be increased with the use of an appropriately printed dental model. From a forensic practical, legal, as well as a scientific point of view, variations in the morphology of arches and dentition among different animals can play a significant role.[20]

Bite mark and pattern analysis

Bite marks can be compared to the suspect's dental structure through 3D printing. Bite mark analysis is based on comparisons between the morphological characteristics of the bite mark and the teeth, like most forensic studies. Because it allows for the archiving of the alleged suspect's dentition as it was during a given time period, 3D printing is a promising technique in this sector. When a suspect's teeth have been altered by restorations or any other morphological change, it is crucial to 3D print the suspect's dentition.[21]

Dental age estimation

An accurate 3D model of a dentition could be useful in age estimation, for example, in grading the average stage of attrition of molar teeth. A 3D-printed model, in this case, may help remove some of the difficulties indirect examination of an individual due to saliva or lack of proper visualization. Similarly, a 3D model of the mandible might also be used for age estimation using the gonial angle.[20]

Forensic facial reconstruction

It is a technique for approximate reconstruction of a person's face from their skeletal remains using tissue markers and a material like clay. Due to the ability to model the faces of significant characters, facial reconstruction has a significant impact on cultural, religious, and historical aspects as well. The ability to print skulls from computed tomography allows for repeated face reconstructions without causing damage to the original skull.[22]

Crime and accident scene reconstruction

Multiple times in the literature, 3D documentation of a crime scene or accident scene has been referenced. According to a study, 3D printing of different car models can help accident reconstruction experts show how the environment and the other involved automobiles are related during the collision.[23]

Ballistic reconstruction

Printing scanned bullets with 3D printing is a possibility. The possibility of scanning and 3D printing the fired bullets has been posited. To check for distortion, these can be compared to their counterparts.[24]

Disaster victim identification (DVI)

In a study on the use of 3D printing in DVI cases, the researchers used CT scans of severely burned remain to 3D print the maxillary and mandibular teeth, which helped in positive identification. The use of 3D scanning and subsequent printing of the burned human remains would make handling and analyzing the remains easier, as well as making them more presentable in court.[25]

Table 1: Literature review including studies and case report regarding applications of 3D printing in forensic dentistry

Article	Type	Purpose	Significance
Carew 2019	Study	Using six commercially accessible printers, human bones that had been CT scanned were rebuilt as virtual 3D models and 3D printed, with osteometric data being gathered along the way.	This study establishes a solid evidentiary base for validating 3D-printed bones as evidence and offers a unique perspective on the accuracy of 3D printing osteological samples.
Valenzuela 2002	Study	This work collects data to calculate dental age estimates and create fresh mathematical regression models for age estimation based on postmortem intervals.	To compute age dependent on the postmortem interval, he finished by offering various regression models.
Jurischka 2020	Study	To ensure that the product can be printed effectively, materials' melting characteristics and autoflouresence should be examined.	Although it can be employed in tests as a reference signal, autofluorescence was not inherently undesirable.
Wozniak 2012	Case Report	An instance when the victim suffered head injuries that were not immediately apparent.	Using these cutting-edge methods, researchers were able to gather enough information to form a hypothesis regarding the mode of damage and the most likely weapon.
Shanbhag 2016	Review	Many lawyers and dentists are completely unaware of this intriguing area of forensic odontology. A need to close this gap was recognized.	This article focuses on the numerous facets of forensic dentistry as well as the role of dentists in forensic sciences and any potential contributions they may make.
Awad 2018	Review	A highly disruptive technology, three-dimensional printing (3DP) has the potential to alter how medicines are developed, prescribed, and manufactured.	The state-of-the-art in FDM technology for medical and pharmaceutical research was evaluated in this paper.

ADVANTAGES AND DISADVANTAGES OF 3D PRINTING IN FORENSICS

Advantages

A key benefit of using 3D printing in forensic reconstructions is the fabrication of a tangible, handle able 3D model. Through the use of 3D reproductions, evidence that would normally be unable to be presented in court can now be seen. Data obtained from non-contact and non-invasive scanning methods can be used for 3D printing, creating a moral workflow that does not disturb any human remains or trace materials further.[26]

Disadvantages

Depending on the technology employed, 3D printing may result in some detail loss, and post-processing steps may make it even more difficult to depict the object visually. The physical characteristics of 3D printers vary greatly depending on the materials used and the printers themselves. For instance, a print may be anisotropic or lack robustness, and powder-based techniques like SLS can produce surfaces that are brittle or granular. The intended result of 3D imaging and printing heavily depends on the professional's skill set.[27]

A research was done which discovered that accurate 3D printed copies may be made from CT scanned skeletal pieces. Each printer tested generated replicas with mean variations of <1.2 mm. The confirmation of 3D printed forensic anthropological samples as demonstrative evidence in court began with this study. A study, done in the year 2002, found that computer-based translucency measurements contributed the most to age estimation.[28] There was also a case report in the literature in which 3D printing was used to gather enough information to form a hypothesis regarding the mode of damage [Table 1].

CONCLUSION

The medical and dental sectors have benefited greatly from 3D printing technology, which has especially made procedures easier. In India, however, the use of this technology in forensics is still in its infancy. The technology's non-intrusive nature can be a huge benefit in forensics. The primary benefit of the 3D printed model is that it facilitates greater interpretation, visualization, and understanding. The original evidence scans can be resized, printed, and used as demonstrative evidence in court as well as for analysis. Results from early studies have demonstrated that the technology produces reliable results. The technology has the potential to completely change the forensics industry in India with additional in-depth studies, the use of more modern 3D printing techniques, and sensitivity training for forensic practitioners in India.

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