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3-D Printing In Forensic Odontology

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ABSTRACT
Three-dimensional(3D) scanning and printing technologies has proved to be a boon that revolutionized the medical and dental field in recent years. Three-dimensional (3D) printing is a procedure that is used to reconstruct a 3D object by deposition of successive layers of material one layer on top of the other,under computer control. . It involves establishing a real-world physical 3D model from a computer model where information in all three dimensions are produced. The technology is growingly being used in the fields of forensic medicine, anthropology, ballistics ,radiology, anatomy and odontology. The technology of 3D printing can be of great advantage to forensic odontology as well. The application of 3D printing in Forensic odontology includes Bite mark analysis, Tomographic Facial Reconstruction, Age- Gender Determination , Construction of Physical Models and Disaster Victim Identification . 3D printing also has a humanitarian approach as the evidence is reconstructed without touching the evidence, thereby not damaging the actual evidence. With this back ground, this paper highlights the benefits of3-D printingbought aboutin the field of forensic odontology .

KEYWORDS
3D Printing, Forensic Odontology, Gender and AgeDetermination, Reconstruction,Forensic Medicine.

I. INTRODUCTION

Three-dimensional (3D) printing is an approach that is used to produce a 3D object using digital model data. It involves establishing a real-world physical 3D model from a computer model where information in all three dimensions are produced.3D printing is a technology provides a tactile response and a substantial depth of information about the structure that is being recreated.3-D models are printed from imaging modalities that provides information about all 3 dimensions and has sufficient contrast such as computed tomography (CT) data, cone beam computerized tomography(CBCT) data, optical surface scan data slices etc. Additive manufacturing process is the technique that is used because the slices are printed sequentially in layers, and these are added one layer on top of the other to create the 3D model.[1]Specialized softwares like computer-aided design (CAD), Lux Align, GrabCAD etc are used for 3D printing in dentistry. 3D printing has an accurate production of single product at a time with complex structures in different types of materials with properties that are highly desirable in various disciplines of dentistry. This technologyhas got a particular resonance in themedical field, chiefly in the specialties like maxillofacial surgery, radiology/imaging and anatomy. 3D printing had also been used increasingly in the field of forensic odontology . It allows better visualization, interpretation, preservation and analysis of the forensic evidence.[2] The use of 3D printing in Forensic Odontology includes Bite mark analysis, Tomographic Facial Reconstruction, Age- Gender Determination , and construction of physical modelsWith this back ground, this paper highlights the benefits of3-D printingbought aboutin the field of forensic odontology .

FORENSIC ODONTOLOGY

Forensic dentistry has been defined by the Federation Dentaire Internationale (FDI) as that branch of dentistry which, in the interest of justice, deals with the proper handling and examination of dental evidence, and with the proper evaluation. A significant outgrowth of Forensic odontology, has enabled an appropriate examination, handling and demonstration of dental evidence in the court of law.It plays animportant part in relating the human remains of victims, not only those of crippled, mutilated, burnt and perished but also victims of bioterrorism and mass disasters. Forensic odontologists are also called upon in cases of catastrophic events like industrial blows, airline accidents, natural disasters, and terrorist attacks including that of explosive, chemical, radiological or nuclear disasters, for identification of the victims. The call for forensic identification arises in mass disasters to resolve criminal investigations, legal problems of insurance settlement, inheritance,funeral rites, and for grief resolution of family and friends.3D printing can be used as a

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demonstrative evidence in court and has a more humanitarian approach in collecting and visualizing the evidence as it is reconstructed without touching the evidence, thereby not damaging the actual evidence.

PRINCIPLES OF THREE- DIMENSIONAL PRINTING

Digital imaging and communications in medicine (DICOM) is the leading standard in medical imaging field where the biomedical images and image related information can be interpreted and exchanged for reference.3D printers do not accept DICOM images, hence these images have to be converted to standard tessellation language (STL) file, where they take in individual objects defined by surfaces that surround a region of space[3]. Additive Manufacturing File Format (AMF) is a new format that is being introduced to overcome the limitations of STL. It has the added advantage of incorporation of various features in the images such as colour, surface texture and different properties of material.[3,4]The AMF formatted data is now transferred to AM machine for file manipulation and the model is prepared for printing by creating slices of the image. The sliced data is now sent to the printer,where slices are printed sequentially in layers or in additive manner i. e, the material is laid down layer by layer.Post processing procedures such as cleaning, finishing, polishing((sandblasting, jet-washing) and sterilization is done using various techniques. The process of 3D printing can be understood under three parts: Image acquisition, Image processing and 3D printing(Image1)

Materials used in 3D Printing: Biodegradable polymeric acid (PLA)is a commonly used material; or similar materials such as polyvinyl chloride (PVC), nylon, acrylonitrile butadienestyrene (ABS) ainvestment casting wax, Polypropylene,Poly carbonates, Photopolymers have been used as key components of 3D printing in dentistry.[15]

Technologies used in 3DPrinting: The quality of the 3D printed model depends on the technology such as

- Fused deposition modelling (FDM)
- Stereolithography (SLA),
- Digital light processing (DLP)
- Photopolymer jetting (PPJ)
- Powder binder printers (PBP)
- Selective laser sintering (SLS)

3D PRINTING IN FORENSICS APPLICATIONS

1. BITE MARK AND PATTERN ANALYSIS

a)Bite Mark Analysis MacDonald defined bite mark as "a mark caused by the teeth either alone or in combination with other mouth part ."Like fingerprints, the marks made by human teeth can be a tool for identification as this is unique in every individual. Bite marks disclose individual tooth imprints. Bite marks can be obtained with Tooth pressure marks, Tongue pressure marks,Tooth scrape marks or a combination of these. The dynamics of biting, makes the analysis of bite mark and its comparison to the suspect's teeth a highly challenging aspect of forensic dental investigation.It is important to recognize uncommon characteristics of the bite mark such as presence or absence of a particular tooth, its dimension, rotation, fracture, diastema and other unusual features of the teeth as these can aid in implicating a suspect. Digital scanning can be performed with the bite mark in the crime scene and theentire bite mark can be recreated by developing overlay with suitable material, using 3D printing. This scan is then compared with a suspect's dentition casts. The scans itself can be used for digital comparison of the suspect's teeth using various softwares. Hence, 3D scanning helps to preserve the information obtained and can be used as a secure evidence in the court of law.[3,6,7]

b)Analysis of lip print pattern (cheiloscopy), palatal rugae pattern (palatoscopy), tongue print pattern.

c)Finger print analysis: Fingerprint analysis using 3D printing were replica prints are produced has been researched recently. 3D printing helps to replicate the 3 dimensional curvature features of the finger prints. However, Printing a latent fingermark that is obtained from a surface would be conceivably more difficult due to the difficulty in adequately capturing the mark, or given that the mark is only perceivably present in two dimensions [8,9].

d)**Tool marks in crime scenes**: Tool marks can be documentes from the crime scenes either for a forced entry to the house or it can be used to attack the victims causing injury. Using a 3D printing, the tool marks can be recreated to identify the tool, the type of mark it makes (impressed mark,crushed mark,crape mark) type of injury it causes and this model can be used as a source of evidence.

2.FORENSIC FACIAL RECONSTRUCTION

It is a method by which deceased individuals faceis is reconstructed from the skull by making use of tissue depth markers and other

anatomical landmarks. Conventionally a 2 dimensional and 3 dimensional reconstruction using different methods such as Anthropometrical American method, Anatomical method, British method are followed which then got replaced with computerized3D facial reconstruction using different soft wares with haptic feed back system[10] . In 3Dprinting, the model of the skull in the form of STL (Steriolithography) with minium 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. Hence 3Dprinting coupled with CT scan allows facial reconstruction that can be reproduced multiple times and can be preserved for forensic investigations and in intelligence gathering.[11,2]

3. BALLISTIC RECONSTRUCTION

Fired bullets or evidence from firearms can leave microscopic marks on the bullet and the catridge which can be considered as ballistic fingerprints in forensics.These can be compared with the victim for deformation as well. 3Dprinting helps to reconstruct the bullet trajectories,i.e the path of a bullet from or through an object as well as the trajectory of the bullet within a human body . This helps the forensic expert to identify the type of firearms as well as the nature of injury caused, which can be used as an alternative source for visualization of the crime scenes.

4.FORENSIC MEDICINE

3D printing in forensic medicine has helped to find out the internal pathology with the aid of different imaging modalities such as CT angiography, MRI, and surface scanning etc. Rather than understanding the disease mechanism, models produced in such a way has added advantages as it can be used for medical education and aids in improving the skills of pathologists and surgeons. 3D printed models helps to find out the causes of death of the victim in forensic cases where a demonstration of the internal pathology may serve as an evidence in courtroom demonstrations..

5. FORENSIC ODONTOLOGY

a) Dental Age Estimation

An important aspect of forensic odontology is the age determination of an individual based on 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 detail about the different stages of mineralization and help in a more accurate estimation of age[14].Models produced by 3Dprinting from the existing scans helps in the calculation a person's dental age. Also, 3D models can 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 of direct examination in the oral cavity as well as eliminates other difficulties such as improper visualization and access secondary to rigor mortis[3].

b)Gender Determination

By considering dimensions of teeth, sex of an individual can be determined. Tooth size, Root length and crown diameter , canine diamorphism, intercanine and intermolar distance , arch length assessment are the parameters used for gender determination. 3D printed models produced by scanning and additive layout has decreased chances of variation with the original teeth morphology. This dimensional accuracy of 3Dprinted models are best made use in gender determination . No significant difference in the various parameters of tooth models and 3D printed models were found in studies. Hence, an accurate printed model could improve the accuracy of sex determination procedures and for population identification.[3,13]

c)Human Identification

Forensic odontology plays an important role in identification of victims in mass disasters i.e. earthquake, tsunamis,aviation accidents, in crime investigations and identification of decomposed and disfigured bodies. Teeth withstand degradation from extreme conditions even after death of individual and hence enables analysis of ante mortem and postmortem dental variables. Dental remains as teeth are superior material in living and nonliving populations for anthropological, genetic, odontologic and forensic investigations . Being hardest, rigid and chemically the most stable tissue in the body, they are selectively preserved and lapidifieded, thereby used as the best records for evolutionary change. Their resistance in the combustion and bacterial disintegration makes them indispensable in forensic identification. A 3D-printed model obtained from postmortem computed tomography , helps to reduce the difficulties found in traditional autopsies and for the better identification of the deceased. Avery minimal or null dimensional change is reported between the tooth and the 3D

printed models hence making it a valuable tool for human identification and record referral.

d)Disaster Victim Identification

Disaster victim identification (DVI) is used in scenerios where there is a mass fatality incident with the deceased body being burned or utmostly destroyed. Uniqueness of concordant postmortem and ante mortem dental records provides a proof to identify the person.[12]If the ante-mortem dental records are not available for comparison, then forensic anthropologist or odontologist can give clues regarding the age, race and sex of the deceased from the dental evidence recovered from the scene[14]. 3D printed models from the scans of the victims helpsin the personal identification and it helps in better handling of the charred remains. Once obtained the scan can be preserved and also multiple models can be produced from the data aviailable without the tedious handling of the remains every single time.

e)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 has to 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 can ultimately serve to convey important details to the court and jury, without offending anybody or causing bias.[2]

ADAVANTAGES

1. Smooth detailed prototyping of the models that serves as a strong evidence
2. Accurate models are produced that can aid in better understanding of the case scenerio as well as victim for identification.
3.Photographs produce a 2 dimensional aspect whereas 3Dprinting helps in visualization in all 3 dimensions.
4.In case of mass disasters or charred remains, 3D printed evidence can be re-visited and re-evaluated
5. Sterilization of the 3D models is possible.
6.Evidence is evaluated on a more humanitarian approach in a non-invasive manner.

DISADVANTAGES

1.Limited material availability for printing the models
2.Technique sensitive and less economical.
3. No specific moral or legitimate guidelines has been developed for 3D printing..
4, Modelling parameters such as slice thickness can affect the the printing quality accuracy of the model
5. The 3-Dmodels created can be modified using various soft wares which can affect the integrity and fidelity of the evidence

II. CONCLUSION

Introduction of 3D printing has bought a boon in different fields of medicine and dentistry especially in the field of forensic odontology. With the identification of fast growing potential for 3-D printing technology, an effort should be put to create good practice guidelines for the same. Accurate reconstruction of the complex human anatomy their visualization and understanding and the non-invasive nature of the 3Dprinted models has made this technology more acceptable among the professionals.The potential for the technology has to be explored and has to be made more popular by the introduction of simple softwares and in a more cost effective manner. Despite all these, it is clear that 3D printing will have an increasingly important role to play in forensics in the forthcoming years.

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