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3D Printing - An Overview of New Dimensions in Dentistry

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Abstract

Objectives: The aim of this review is to elaborate the concepts on which 3D printing is based and how this technology of additive manufacturing is currently overtaking subtractive manufacturing in dentistry. It also covers the implication of 3D technology in different fields of dentistry, including oral and maxillofacial surgery, orthodontics, endodontics, prosthodontics, periodontics and pedodontics in terms of clinical and educational approaches.

Data Sources: The search for literature on 3D printing in dentistry has been done in PubMed, Scopus and web of science data base with keywords 3D printing and dentistry, additive manufacturing, CAD/CAM, Orthognathic surgery, facial prosthesis, Digital designing, haptic device, guided endodontic surgery, autotransplantation, implant designing, bioprinting.

Study Selection: Inclusion criteria were articles in English language describing application of 3D printing in dentistry including case reports, original researches and reviews. Fifty-five articles met inclusion criteria. The exclusion criteria was articles in other languages.

Conclusions: High cost and difficulty in understanding of technical aspect are mere disadvantages, otherwise technique proves to be beneficial for patient as well as professionals in terms reducing risk of surgeries, customization, precision, accuracy, time saving and ease of record management for clinical case.

Clinical Significance: 3D printing technology has been already used in medical profession for printing orthopedic implant, creating artificial tissues, heart valves, knee meniscus, skin grafts and artificial organs. Thatswhy, digitization of this technique is called as fourth industrial revolution. In dentistry also it helps in research & innovation, treatment modalities, education and training.

Keywords: 3D printing, artificial organs, CAD/CAM, Orthognathic surgery.

Introduction

Dentistry has revolutionalised fast in terms of technology but still conventional methods are treatment of choice for

most of the professionals. Nowadays 3D technologies are used in almost each area which include clinical science. Its advances are boon for many patients of burn, plastic surgery, bone augmentation/reconstruction and trauma patients as well as for surgeons for pre planning and implementation during surgery [1]. Additive manufacturing (AM) is another term used for 3D printing because it builds the structure layer by layer, whereas Computer Aided Designing/Computer Aided Manufacturing (CAD/CAM) is based on subtractive manufacturing (SM). AM is better over SM in terms of precision, reduced waste and wider selection of materials [2-5].

The entire process of AM technology includes following four steps: (i) Use of intraoral scanners or CT scans (computed tomography) data for creating a digital 3D model. With the help of software program like MIMICS (Materialise, Leuven, Belgium) DICOM (Digital Imaging and Communication in Medicine) images are transformed to STL (standard tessellation language) files because 3D printers take information for printing only in this form. (ii) Reforming 3D image data into multiple 2D images by slicing in vertical, horizontal and sagittal sections (iii) final laid down of 3D model via layering process. (iv) Refinement of the final end product, these are removing residual debris, removing supporting structure, annealing, drilling, cutting, polishing, and if required, sterilization [6].

3D printers used in Dentistry

3D printers commonly used in dentistry are based on following process of selective laser sintering (SLS), stereolithography (SLA), fuse deposition modeling (FDM), and digital light processing (Table 1). [7]

Printers based on SLA utilizes a photosensitive monomer resin which polymerizes when a beam of UV light falls on it and end product is processed layer by layer [7,8]. Charles Hull in 1983 was first person to use it commercially for 3D printing [8].

FDM printers also build the object from bottom to top. In this technique the fused material generally a fibre or a metal wire is melted and oozed out through a heated nozzle to deposit layer by layer cross sections of an object [7].

In SLS technique is similar to SLA except in former technique powder material is used in place of liquid. The powder material is sintered together layer by layer using laser [7].

In multijet/polyjet printer a fine nozzle is used to spray multiple small droplets of the photopolymer in the form of the primary layer. The UV light is used to cure photo active polymer [7]. First a platform or supporting structure is built then successive layers are deposited one above the other [7]. This type of printer is very fast and its resolution is also very high.

Bioprinting is a relatively new technique of 3D printing and emerging field for the printing of cytocompatible substances for the fabrication of clinical devices as well as substitutes of living tissues and organs [9,10]. Bio-ink is used in bioprinting, these are cross linked living cells with polymers which form hydrogels. 3D printed scaffolds are commonly used in stem cell therapy. [11,12,13]. Bio-printers produced artificial tissues which are complex in structure like native tissue but most challenging part is to maintain their vitality through blood supply. The biomaterials as well as bioprinters still need improvement in terms of physical properties, microstructure and vitality of final product. [14].

In this review we will discuss application of AM in different fields of dentistry based on previous studies and also future perspectives.

Oral and Maxillofacial Surgery and Implantology

AM technology has emerged as a boon to maxillofacial surgeons as they can study, pre plan and execute entire surgical procedure on CT images on software and also perform surgery on 3D printed models before performing on patient, so that both surgeon and patient would be aware of after effects of surgery. With the help of software like Materialise ProPlan CMF patients pre-op and post-op images can be compared for aftereffects. The risk of previous surgical procedures were minimized which were based mainly on 2D or 3D images [15]

Apart from diagnosis and treatment planning 3Dprinting techniques can be used for making surgical guides, cutting & drilling guide for autogenous bone graft eg., fibula implant to augment bone defects, and study/anatomical models of maxilla and mandible for learning modules so that students can see, touch and feel (based on density of different parts) landmarks for nerve block or surgical procedures [16,17].

Orthognathic surgeries uses this technology for fabrication of personalized orthognathic surgical guide (POSG) system for advancement or retraction cases. With the help of software program advancement/retraction of maxilla and mandible, cutting & drilling guide for screws/surgical aids were predetermined and precised. Accordingly, customized titanium plates can be seated precisely on bony parts; thereby minimizing recurrence and failure of surgical procedure [18.]

For orofacial defects like cleft lip or palate custom made implants can be used to augment bone defect, even tissue regeneration is possible via bioprinting [19-21]. Hydroxyapatite scaffolds are used for bone tissue regeneration, apart from this PGA, PLA, PC are also used [20,22,23,24].

For pre-fabricated implant placement customized surgical guides can be printed and customized implants and abutments are also fabricated using additive manufacturing [6,8,25,26].

Restorative dentistry

Conventional techniques used in restorative dentistry for crown fabrication, Rapid Partial Denture, Fixed Partial Denture and Complete Denture preparation are time consuming, discomfort to the patients like severe gag reflex, , restricted mouth opening and pain in TMJ disorders ; record maintenance is also difficult because as time passes cast broke or deteriorate over time. 3D technique has advantage of ease to patient as intraoral scanners are used for scanning pre-op, op and post-op for record maintenance in place of cast so no need of multiple steps of impression taking and cast pouring. Either images from scanner or CT images can be used for crown preparation, inlays/onlays, RPD, FPD, CD fabrication with the help of software like MIMICS, GEOMAGIC [27,28]. The final impression tray can be customized via 3D printing which provide accuracy, precision and almost zero chances of error for final impression.

Additive Manufacturing can be used for facial prosthesis, ear prosthesis and finger prosthesis. 3According to Abdullamir et al., rapid prototyping using 3D printing technology of maxillofacial prosthesis is useful technique in reducing time and increasing the quality of the final product while, conventional procedures have to depend on the patient's siblings or close relatives or prefabricated casts along with photographs which may not be available at all times. Computer-Aided Design offers limitless shapes and sizes of digitized nose that can be checked virtually on the patient's digitized face. Although it may seem to be costly in terms of money, it does reduce patient's number of visits and chairside time [29].

In case report by Katreva et al., digital impressions were taken with intraoral scanners proved to be better than conventional method in terms of accuracy, stability and

patient comfort. Digital data make the conversation easier between the dental workplace and the laboratory. The whole procedure is stored in a file. After storage of patient data software tools can be used for minor corrections like undercuts in preparation, final cervical line for abutment, determination of occlusal plane, clearance between prepared teeth and its antagonist or neighboring teeth. Such corrections are very difficult and some of them are not possible with plaster models. There is no need of articulation for occlusion setting and only segmental cast patterns can be printed for final press ceramic crowns. The whole procedure is time saving and requires less no of patient's visit but devices and instruments used requires expertise and high cost [30].

The advantages of additive manufacturing during implant placement are that lengthy manual laboratory procedure are no longer needed. For final implant impression the space for impression material between the custom tray and splints is measured by software program, which minimizes waste of extra material, no extra time is needed for repetition as designed guided path of insertion of tray allows only one accurate fit in the mouth. To unscrew implant abutments space for holes are also measured by software. [31].

Orthodontics

Like other fields of dentistry 3D printing has proved itself beneficial in orthodontics also in terms of precision, reproducibility, ease of record maintenance of multiple no of patient for long term and delivering customized appliances [32]. 3D face scan and 3D printing can be used to print dental arches, customized brackets and aligners [33,34]. The customized splints for patient having malocclusions like cross-bites releases tension in their masticatory muscles caused by TMJ disorder. Salmi et al., used this technology for printing occlusal splints in their clinical study [35].

For minor malalignment customized 3D printed aligners are useful. For postorthodontic treatment 3D printed retainers can be used. Indirect bonding and clear aligners {Invisalign®, 3Shape} are based on this technology. The advantage of these are reduced chairside time and less no of clinical visits [36,37].

For pre-planning cranio-maxillofacial cases a scanner based image processing software called Materialise ProPlan CMF Software is available with 3D visualization effects. It also gives variable option for Cephalometric analysis and treatment planning for desirable outcomes using CT data. 3D printers used this data to print splints, anatomic guide, the fibula cutting guide, and positioning guides [15].

Endodontics

The endodontic cases of teeth with calcified canals, curved/angulated roots, developmental defects, apical periodontitis cases with root apex situated next to a nerve/foramen/sinus etc., or under thick covering of cortical bone, requires surgeon's expertise to decrease chances of procedural error and minimize risk of compromised treatment outcomes. With the advent of 3D technology these risk can be minimized and precision can be achieved easily with better treatment outcomes.

In a case report described by Krastl et al., for treatment of maxillary central incisor with pulp canal obliteration (PCO), they used CBCT data and coupled it with optical intra-oral scan data. Implant planning software (coDiagnostiX™) used for printing directional guide for access opening preparation. A customized guide sleeve metal tube of internal diameter 1.5 mm and length 6 mm was fabricated using MJM technique. A Single depth calibrated implant drill was used (diameter 1.5 mm and length 37 mm) to prepare access cavity [38]. Similar case reports were described by Zubizarreta Macho et al., and

Van der Mer et al., for treatment of *dens invaginatus* and PCO respectively [39,40].

Surgical endodontic requires removal of cortical bone and root end resection for treatment of periapical lesions. Extent of lesion decides area for bone removal, with the help of guided surgical endodontics 3D printed surgical guides are designed based on implant planning software coupled with CT and optical scan data sets. One such case report was reported by Strbac et al. for retreatment of maxillary first molar and second premolar. Customized surgical guides located osteotomy site and piezoelectric instruments were used for apical resections. Guide also helped for removal of extra filling material beyond the apex precisely without disturbing the sinus membrane. One year follow up showed healing of periapical lesion. The author claimed less working time, precision, accuracy and less patient discomfort [41].

In cases of autotransplantation extra-oral times plays crucial role in success of treatment plan, apart from this multiple trial of templates also disrupts periodontal (PDL) fibres which results in delayed healing or may be failure. 3D printed tooth or template before surgery reduces the extra oral time, also precision lead to accurate fit without hampering PDL fibres. Strbac et al., described the autotransplantation of immature premolars in a maxillary incisor avulsion scenario using a completely digital workflow [42].

Apart from clinical approach 3D printing also help in educational field. 3D printed study models can be used in place of typodont, plaster models as an educational aid for students to study internal as well as external morphologic features of tooth, and to practice different steps of root canal treatment extraorally. These printed study models have more defined features than plaster models/monoblocks and it can be stained with different colours/pigments. Additive manufacturing offers varying texture as well as colours during processing stage to differentiate between enamel, dentine, cementum and pulp space, so that students can easily understand the differential anatomy [43,44]. Even their mechanical properties can be altered to simulate natural tooth anatomy and ease for students to have tactile sensation similar to natural teeth while access cavity preparation. Studies have also been done on comparing skill progression of group of students on Duplicate 3D printed models and other group on natural teeth for standardized unbiased skill assessments [45].

Haptic Devices (fig 1) are also used to simulate clinical condition using virtual reality to trained students procedures like cavity preparation, access opening, osteotomies and root resection. Haptic Devices are like robotic hand which stimulate a sensory tactile experience, generating vibrations and counter-forces [46,47]. So, when a student will wear glasses for virtual reality, operating field will be visible on screen and with the help of software one haptic device will act like one hand used for retracting mirror and other one will act like your operating hand for drilling or cutting in patient mouth with same pressure and resistance feel during operating actual patient. Haptic devices can provide 6 degrees of freedom (DOF) in unconstrained free movement but 3 DOF in three spatial dimension for force feedback, which means touching a space with a stick or fingertip. Commercially available haptic devices are Geomagic® Touch™ and Touch™ X (3D Systems Inc., Rock Hill, SC, USA) and Virtuose™ 6D Desktop (Haption S.A., Soulgé-sur-Ouette, France).

Periodontics

3D printed surgical guides in Periodontics are used for correction of irregular or unaesthetic form of gingiva, gingivectomy and smile designing. Advantages of these templates are precision, accuracy and customization [48].

Bioprinting has role in regenerative periodontics. 3D printed scaffold loaded with growth factors has been used to improve alveolar tissue regeneration [49]. Advantage of such type of scaffolds are that they are both osteoinducive and osteoconductive properties [50]. However, commercially available graft materials are only osteoconductive. So, help in better healing and faster regeneration than conventional methods.

Pedodontics

3D technology is used in pediatric patient in case of premature loss of deciduous teeth for fabrication of customized space maintainers. Impression procedure can be replaced by intaoral scans and data obtained can be used with the help of software for 3D printing. Pediatric patient are not so co-operative like adults and they also have fear of being hurt but patient discomfort and chair-side time can be reduced using 3D technology. One such case report was reported by Pawar [51].

Apart from clinical approach 3D printing can be used for educational approach for studying deciduous tooth anatomy, pediatric mandible, maxilla, cleft-lip, cleft palate cases etc.

Conclusion

3D printing has not only improved outcome of clinical cases but also reduced risk factors by predicting post-operative scenarios before surgery. However, it requires technical aspect to be thoroughly understood by practitioner or should be in contact with a technical team for software usage. The technique is not only sensitive but also quite expensive in terms of 3D printers, material used and software updates. But overall benefit overweigh cost factor because ultimately patient health is more important. Proper training programs needed to trained practitioners. 3D printed models, typodont, anatomic models and devices like haptic simulators can be accompanied in professional curriculum to make learning easy and interesting. Bioprinting has vast role in healthcare profession once we succeed to print organs, teeth, body parts etc. So, proper training, surgeon expertise and future researches are required to implement its advantageous usage in dentistry.

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Legends Figure

Table 1: Showing 3D printers, materials used for printing and their application in Dentistry.

3D Printer	Materials used	Application in Dentistry
Stereolithography	Liquid resin in the form of photosensitive polymer or monomer	Typodont, single tooth replica, Monoblock for RCT in vitro condition, surgical guides and templates, orthodontic appliances (customized aligners, brackets and retainers), ceramic/porcelain crowns, denture and FPD.
Fused Deposition Modeling (FDM)	polymers which set by heat such as polyether ether ketone (PEEK), polyglycolic acid (PGA), polylacticacid (PLA), polycarbonate (PC), acrylonitrile butadiene styrene (ABS) etc.	Study models, anatomical models
Selective Laser Sintering (SLS)	Resin in the form of Powder such as polyurethane, alumide, polyamide, glass-particle filled polyamide, etc.	Metal or resin partial denture frameworks, crowns, copings and bridges.
Polyjet printing or Multijet modelling (MJM)	Photopolymers	Craniomaxillofacial implants, sophisticated anatomical models, drilling and cutting guides for screw placement/bone removal/ dental implant placement, facial prosthesis
Bioprinter	Bio-ink and hydrogels, cross-linked polymer resins, alginate, agar-agar, chitosan, etc.	Skin graft, bony tissue, vascular grafts, etc. scaffold for stem cell therapy/regenerative dentistry.

Figure 1 (a),(b) showing 3DS Touch Haptic device used with desktop

(a) (b)