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Applications of 3D Printing in Dentistry – A Review

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Abstract

Advancement of technology in dentistry have improved the diagnostic accuracy, eased treatment delivery and reduced chair-time allowing the dentist to provide more effective treatment.3D Printing allows the dentist to visualise, record hard and soft tissue significantly with precise measurement and print the models. Multiple 3D printing methods such as Stereolithography (SLA), Inkjet based system, Selective laser sintering (SLM) and Fused deposition modelling (FDM) allows us rapid prototyping. Each technology offers specific advantages in the creation of particular type of products. In the dental field SLA and Inkjet based systems are most commonly used .3D printing can be advantageous in various treatment modalities. The implications of 3D printing in dentistry include orthognathic surgeries, surgical templates for implants, micro guided endodontics, drilling and cutting guides, digital orthodontics, crowns, bridges, pre-operative treatment planning, fabrication of splints and restorations

Keywords: 3D Printing, Rapid prototyping, Additive manufacturing, Stereolithography, Computer Aided Designing

INTRODUCTION

3D printing generally describes a manufacturing process that creates an object by building one layer at a time adding multiple layers which results in the formation of an object.3D printing can be precisely described as Additive manufacturing or Rapid prototyping.3D Printing is emerging as a promising technology over a wide variety of fields including aerospace, defence, art, design, architecture, engineering, medicine, dentistry by allowing the individuals to personalise designs and fabricating. There has been a revolutionary growth of 3D printing in medicine and dentistry with the help of CAD CAM technology(1).3D printing promises to improve patient care and enhance the relative contribution to that care by radiologist if implemented correctly.3D printing can deliver customised medicine based on the anatomic data radiologists acquire and interpret everyday(2).3D printing has been useful to create more naturalistic models in the medical field for educational, training and research purposes, treatment and surgical planning. In dental field it has been used in various treatment modalities. This article reviews the recent advances in the applications of 3D printing in dentistry.

HISTORY OF 3D PRINTING

A 3Dimensional object was printed for the first time by Charles Hull in the year 1983.Hull invented 3D printing which he named “stereolithography”. Stereolithography interprets the data in a CAD file by using the file in STL format. Apart from shape the instructions may also include information on colour, texture and thickness of the object to be printed. Hull later founded the company 3D Systems which introduced the first commercially available 3D printer named SLA-250 in 1988(3).

3D PRINTING TECHNOLOGY

In medical and dentistry field the volumetric data is readily accessible using CT and CBCT data, and also using intra-oral or laboratory optical surface scan data. Advancement in the computer technology and the software applications has contributed a lot to 3D printing (1).3D printing process begins by designing a virtual image of the object to be constructed, then converts the information into a digital file.3D modelling program provides the virtual design for the printer to follow. This requires CAD software which enables to create objects from scratch (4).

3D PRINTING TECHNIQUES

STEREOLITHOGRAPHY(SLA)

It was invented by Charles Hull in 1980s and was the first commercially available printer for rapid prototyping. UV light is focussed onto the surface of a vat filled with liquid photopolymer and as beam draws the object onto the surface of liquid each time a layer of resin is polymerised (5).It is used in making implant guides and surgical stent (6).The advantages of Stereolithography include high accuracy, good surface finish, high mechanical strength and smooth surface finish. Disadvantages are the cost of the equipment, requirement for post-cure and it can be only used for polymers (7)

INKJET PRINTING

Inkjet printers jet ink onto paper and is allowed to dry, similarly material jetting 3D printers jet micro droplets of liquid photopolymer resin onto a build tray and polymerise it with UV light. It has a gel like material as a support system which is used during production and this supporting material can be easily eliminated using water instantly after the printing is finished. It is relatively simple and can be used immediately after printing without the need to wait for a final cure. It can be used to print dental or anatomical study models and implant drill guides (6). The advantages of inkjet printing are low material cost, fast fabrication time, low toxicity and relative material variety. The disadvantages are lower strength of models and rough surface finish (7)

SELECTIVE LASER SINTERING (SLS)

In this method a high power laser is directed using mirror at a substrate consisting of fine layer of powder, when the beam hits the powder it forms a melt pool and powder particles fuse together. After scanning of each cross-section the powder bed is lowered by one layer thickness and a new layer of material is applied on top. This process continues until the object is completed (5). It can be used to print anatomical study models, cutting and drilling guides, implant bridge frameworks and Cobalt chromium RPD frameworks(6).They are available in different material variety and hundred percent density possible. But the material and equipment are expensive (7)

FUSED DEPOSITION MODELLING (FDM)

It creates an object layer by layer by deposition of a thermoplastic polymer material. This material is delivered through a nozzle apparatus which is controlled by temperature and the motion of the material is computer controlled. The thermoplastic material is in semiliquid state, it becomes solid within 0.1sec and bonds to the previous layer. The entire process takes place in a chamber in which the temperature is set just below the melting point of the thermoplastic material(5).It can be used to print anatomic models without too much complexity such as edentulous mandible. Fused Deposition Modelling requires support structures to be removed and can be used with thermoplastic material only. It has a rough surface finish and does not have hundred percent density(7).

ORAL SURGERY

Using 3D printing methods anatomical models can be constructed which can be used as a new approach for surgical treatment planning and simulation. This allows the surgeon to get an overview of the complex structures before performing the surgery (8). In the early 1990s Anderl et al using CT guided stereolithography fabricated an acrylic model that allowed pre-operative treatment planning and intraoperative management in surgical correction of a wide midline craniofacial cleft in a 8 month old successfully (9).

In reconstruction of maxillofacial defects apart from maintenance of anatomic uniformity and appearance, it is also important to restore the tissue functions. Autologous bone grafts remain as the gold standard in reconstruction of maxillofacial defects due to their osteoconductive and osteo-inductive properties. But the major disadvantage of autologous bone graft is that they require manual sculpting of defect shape. Hence a treatment which is less invasive to treat bone defects are in need. Computer animated modelling and rapid manufacturing requires a series of events during which a computer designed virtual 3dimensional image turns into a solid model for clinical application (10). 3D printing can also be used to produce customised reconstruction plates and morphological reconstruction of bony defect area for cases of fractures and reconstruction surgery. It can also be used to design and construct a customised non-absorbable barrier of titanium mesh (11).

An experimental design was developed to simulate distraction osteogenesis in 3D printed models of patients with cranio-facial deformities. CT data were manipulated to add in series of rulers and markers on the models. CT scans were imported onto a software, a virtual distractor was built and installed on the model, the osteotomies and distraction process were simulated. A surgical technique to enable accurate installation of the distractor as indicated in the pre-surgical plan was developed. The transfer of information regarding pin position and orientation from the computer model to the patient was achieved by 3D printing(stereolithographic) surgical template. Mock surgery was done on 3D Printed models and the results were compared with those predicted by the computer. Difference between the actual and the predicted position was recorded. Results indicated that combining the planning process and surgical technique was very accurate. If the results of this study are evaluated in clinical practise, this technique will enable clinicians to improve the clinical outcomes of the patients treated with distraction osteogenesis (12).

IMPLANTOLOGY

Since the emergence of osseointegration, the use of dental implants has evolved rapidly over last few decades. Studies in the field of implantology has led to modifications resulting in highly successful and predictable restorative options for partially as well as completely edentulous patients. However improper placement of implant affects the success of implant supported prostheses. The use of CAD/CAM Technology and 3D printing technology has gained popularity in implant dentistry (13).

A study was conducted on implants, in which a total of 110 3D printed Titanium dental implants were installed in healed alveolar ridges (75) and post extraction socket (35). The implants were fabricated layer by layer method using powders of titanium alloy (Ti-6Al-4V) by a Yb (YTTERBIUM) fibre laser system. After 3 years 6 implants failed, among 104 surviving implant supported restorations, 6 showed complications and were therefore considered unsuccessful. Mean distance between implant shoulder and first visible bone implant contact was 0.75mm and 0.89mm after 1 and 3 years of installation of implants .3D printed dental implants seems to represent a successive clinical option for replacement of single tooth gap in both jaws (14).

Digital Light Processing is an efficient method for printing customised zirconia dental implants with sufficient dimensional accuracy. Mechanical properties showed flexure strength close to traditionally produced ceramics. Further research should aim at improving the microstructure of printed object without any cracks or porosities (15). Customized dental implants printed using Selective laser melting (SLM) method showed increased density, strength and adequate dimensional accuracy. SLM is an efficient means for printing fully dense customized implants with increased strength and sufficient dimensional accuracy (16). In cases where conventional implants cannot be used 3D printed customised subperiosteal implants can be used. It also avoids the requirement of an extra oral donor tissue or bone and the use of allografts (17).

SURGICAL GUIDES

A study was done to evaluate the accuracy of 3D printed implant templates.8 implants were placed using stereolithographic templates. Using a 3D computer model created by reformatted CT data, preoperative implant simulation was done. The implants were placed on the most favourable position. The templates were replicating the exact spatial position of the implants within the bone as simulated by the computer during treatment planning. Results showed that the dimensions and angulations of all abutments were accurate and as planned (18). Using implant drilling guides for the placement of implants has been proved to be more accurate and predictable when compared with non-guided surgery. Based on the individual anatomical structures the implant drilling guide will be either tooth supported or mucosa supported or bone supported (19).

Lefort III surgery is a surgery which is done to treat craniofacial synostosis. Considering the challenges associated with the surgery a new approach based on 3D surgical guide for fronto-nasal-ethmoidal-vomer osteotomy was done on a 9 year old Apert craniosynostosis patient.3D CT of the skull was done and 3D reconstruction was done using software, saved under STL format and skull was 3D printed. PMMA resin was moulded around the osteotome and the nasal bones. Surgery was then performed with bi-coronal and intra-oral access. Osteotome was then positioned in the flat groove inside the 3D guide and inserted into the bone using the orientation provided by 3D guide until it reached the marked depth. Hence this approach could help the surgeons and avoid complications in the patient.3D guide gives information on impact point for osteotome, orientation in 3D space and depth of insertion of the osteotome (20).

ORTHOGNATHIC SURGERY

Traditional orthognathic surgery consists of two stages-cephalometric planning (radiographic simulation) following which jaw movements are transferred by physical manipulation of the dental models. This process establishes the post-operative occlusion as planned before It is then transferred to the surgical episode by the use of surgical wafer (21). The success of orthognathic surgery primarily rely on exact planning based on accurate diagnosis. CT and CBCT are gaining more importance in pre-operative planning compared with conventional radiographic imaging techniques providing the 3 dimensionality of the acquired dataset. Digital study models prove to be a better alternative to conventional plaster study models in the treatment planning for malocclusion patients (22).

A new technique for fabrication of surgical wafers involve simulated repositioning of digital model images using intra-oral scanners and then fabrication of a computer-generated wafer using orthodontic software package which are linked to 3D printing technology for dental model fabrication. It is possible to perform orthognathic surgical planning by the manipulation of digital orthodontic models without the use of a facebow recording and physical model surgery or by virtual planning from a CBCT – based approach. Subsequently computer-generated 3D printed surgical wafers are produced. The wafer fabrication stage involves virtual filling in void between the upper and lower digital dental models in the final occlusal positions. After the virtual wafer design has been approved by the technician and clinician, using a 3D printer the surgical wafers are printed and the surgery is done (21).

Dental splints used in orthognathic surgery with conventional plaster study models, inspite of being an established and accepted method, theoretically it suffers from several errors and inaccuracy, as detailed analysis of the technique reveals. In plaster model surgery there is no proper control of movements such as rotation and translation with regard to the whole cranial situation. With the help of virtual blanks within the preoperative 3D planning, the information obtained from repositioning can be transformed into a dental splint after printing (22).

DIGITAL ORTHODONTICS

Invisalign System realigns the patient teeth digitally to make a series of 3D printed models for construction of aligners, where the patient will be receiving a new set of aligners every 2 weeks and reposition the teeth over a period of time. This technology will be time saving, patient data set can be digitally saved, printed when needed and minimises the physical storage requirement (1). With the help of CAD/CAM technology two separate processes of bracket production and bracket positioning are fused into single unit. In this method the need for maximum individuality with reduced space requirements is put into practise (13).

A study was done to compare the orthodontic appliances fabricated using 3D printing and milling machine.6 patients with malocclusion were made to wear aligners fabricated using 3D printing and milling. It was concluded from the study that to get the best clear and removable orthodontic aligner, it is important to consider various factors mainly the staircase effect, layering thickness, accuracy of system, duration of treatment and the transparency of aligners. On comparing milling and 3D printing, the disadvantage of Milling was that it required longer duration of machine period, whereas 3D printing is efficient without needing much human input and models are fabricated quickly (23).

RESTORATIVE DENTISTRY

Since photo-polymerisation has been used in dentistry for long time UV or Visible light-based approaches in 3D printing are among the first to be implemented. Hence resins are commonly used material in 3D printing but it has shown some degree of shrinkage due to its mechanical and light activated polymerisation properties. Hence 3D printable resins need further evaluation (24).

A study was conducted to assess the fit of interim resin crowns fabricated using photopolymer jetting, milling and compression moulding methods (3 groups).12 study models were fabricated using an impression of a metal model of mandibular 1st molar. The virtual crown designed using a 60 micrometer cementation space was reutilised for all the three groups. Design files were transformed to a Polyjet 3D printer and was printed in a biocompatible photopolymer with a layering thickness of 5 micrometer. The study results showed that proximal and marginal regions in both Polyjet and Milling produced Interim crowns that were more accurate than those in molding group. Milling and Polyjet showed no significant difference($p<0.001$). The study concluded that 3D printing can produce temporary crowns with greater accuracy than the conventional methods. Even though it is documented in literature that 3D printed resins used for restorative purpose is clinically acceptable, resins still have the disadvantage due to shrinkage (25).

GUIDED ENDODONTICS

A novel treatment approach for root canal treatment of teeth with pulp canal calcified and apical pathology using special drills and surgical templates were introduced. In a 15 year old male patient with history of pain in upper right central incisor which showed signs of apical pathology and canal calcification it was anticipated that because of pulp canal calcification root canal location would be difficult and there was a high chance of perforation. CBCT and Intra-oral scan was done and combined using virtual implant planning software. A special drill was designed for root canal location. Its position was planned, virtual template was designed, exported as STL file and sent to a 3D Printer. The template was placed on the anterior maxillary region, a special drill was used to penetrate through the obliterated portion of the root canal and obtain minimally invasive access to apical portion. Root canal was accessible at 9mm distance from apex and further root canal preparation was done using endodontic rotary instrumentation system. After 15 months patient was examined and there were no signs of pain on percussion and radiographs showed no signs of apical pathology. This study concluded that guided endodontic approach seems to be a secure, clinically possible method to locate root canal and avoid perforation in teeth with pulp canal calcification (26).

Using the same method, root canal treatment was done in a 61 year old woman who presented with pain in upper left posterior teeth region (27,28), which showed signs of apical periodontitis. This method proved to be quick and more predictable and can be preferred as best option for location of calcified canal and thus preventing failures in these cases (27).

In a similar case 51year old male patient with history of pain and dental trauma over 30 years ago in mandibular central incisors (31,41). It was tender to percussion and yellowish discolouration was seen. Radiographs showed severe pulp canal calcification and signs of apical periodontitis. Using 3D printed template guides and specific drill access to the orifice of the root canal and negotiation of root canal was done and conventional root canal treatment was done. This case report demonstrates that guided endodontics is minimally invasive and apically extended access cavities are feasible.

Challenges associated with this technology is the space required for the template and difficulty in placement of instrument in the posterior region. It can be used only in straight canals and up-to the straight portions of apically curved canals. CBCT exposure have to be carefully justified. Micro-guided endodontics require a considerable amount of technical effort but nowadays CBCT and intra-oral scanners are becoming more common among dentists because of rapidly increasing trends combination of these two data sets are used for other purposes such as implantology. It might become standard in future and hence it is more favourable that micro-guided endodontics may also become established in clinical practise (28).

PROSTHODONTICS

Bibb et all conducted a study to assess the effectiveness of a method which combined CAD and 3D Printing using Selective laser melting method (SLM). A 3D scan of the partially edentulous patient cast was performed which subsequently allowed the digital designing of the RPDs components. In the first experiment stainless steel was chosen because of its excellent corrosion resistance making it suitable for dental application and in the second experiment cobalt chromium alloy was selected. Using Selective laser melting a same RPD framework design was printed using 2 different metals for comparative purpose. On comparing both the RPD frameworks, both showed accurate fit on the patients cast, but the retentive component(clasp) of the stainless-steel framework showed deformation after repeated insertion and removal. The cobalt chromium alloy framework exhibited perfect fit on the cast and patient with no signs of deformation. Thus Cobalt-Chromium alloy framework proved to be more efficient than stainless steel. Compared to manual investment and casting procedures, time taken for preparation, and probability for errors this study shows result in favour of using 3D printing to construct RPD frameworks (29).

Silva et al in a review article discussed the utilisation of the method of “ROBOCASTING” to fabricate fixed partial dentures. Robocasting is a 3D printing fabrication method in which an object is printed in a layer by layer fashion onto a flat substrate directly from digital file. The paste used in robocasting is composed of ceramic part and typically 47% solid and 1-2 % organic material. This paste is capable of producing fine filaments and drying with minimal shrinkage (30).

Ebert et al conducted a study with an aim to develop a customised direct inkjet printing process which can be used to build up high strength zirconia ceramic prosthetic restorations. A customised additive system was developed which allowed printing of suspension of high solid content of zirconia powder by combining direct inkjet printing technology with conventional drop on demand inkjet print heads. They tested that it is possible to overcome the major issues of CAD/CAM milling system limited accuracy, wastage of raw materials and possible occurrence of microscopic cracks by the direct inkjet printing technology. The study concluded that it is capable of producing crown with required size, shape and morphological features. Even though they exhibited some microscopic cracks, it exhibited density of 96.9% which can provide the strength and physical properties required for oral function (31).

DRILLING AND CUTTING GUIDES

Drilling and cutting guides printed using 3D printing technology results in less destructive, more rapid and predictable surgery. These tools should be strong enough, accurate and sterilisable . Using a software, virtual 3D planning can be done and transferred to the operative site. It also acts as an interface between the real patient and virtual planning. Using a 3D printed Selective Laser Sintering (SLS) drill guide a case of fibrous dysplasia was sculpted and removed successfully (1).

MAXILLOFACIAL PROSTHESES:

3D printed implants are used for replacement and reconstruction of zygomatic bones, temporal bones including ear ossicles, calvarial bones and mandibles. They are also used in soft tissue reconstruction of head and neck. These are more suitable following a trauma or a tumour resection. After a tumour resection of ameloblastomas there is a requirement of considerable bone and soft tissue reconstruction. With the help of 3D implants cosmetic defects associated with these surgeries has been reduced significantly (1).

CONCLUSION

With the help of 3D Imaging and CAD/CAM Technology 3D printing is in the forefront position hugely impacting on all aspects. It enables to create a complex geometrical form using a variety of materials from digital data in specific patients. With the increased use of intra-oral scanning system, it is already applied practically in orthodontics by high resolution printing resin, printing models for restorative dentistry and lost wax process pattern. In craniofacial and implant surgery 3D printed anatomical model is becoming more essential as it guides in treatment planning of complex surgeries. It is also widely accepted that the surgery becomes less invasive, more predictable and accurate with the help of surgical guides made from resins. Even though 3D printing is becoming cost effective in the present but still the cost of running, materials used and maintenance of the machines are still areas of concern. The demand for well trained operators, post processing, adherence to strict health and safety measures should be considered. As the technology evolves, it is important for the dentist to be alongside the advances that may have the future to benefit both the dentist and the patient.3D printing is emerging as a promising technology, with innate curiosity and creativity of the dentist, makes this an extremely exciting time to be in the industry.

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