ISSN- O: 2458 - 868X, ISSN–P: 2458 – 8687
Index Copernicus Value: 68 . 16
PubMed - National Library of Medicine - ID: 101731606

International Journal of Medical Science and Innovative Research (IJMSIR)
IJMSIR : A Medical Publication Hub
Available Online at: www.ijmsir.com
Volume – 4, Issue – 6, December - 2019, Page No. : 32 - 40

3D Technology: The Third Dimension In Orthodontics

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Type of Publication: Original Research Article

Conflicts Of Interest: Nil

Abstract

The advancements in the field of dentistry are increasing rapidly mainly in the field of digital imaging and 3D printing. It makes the treatment procedures easy and time saving. Though the initial cost may be high the subsequent procedures are faster and comparatively cheaper with the conventional technique. In this article digital imaging techniques, various machineries available for 3D printing and the applications are the 3 D printing procedure have been discussed.

Keywords: Intraoral scanning, Digital imaging, 3D printing,

Introduction

Dentistry has evolved a lot for the past years more importantly in clinical and laboratory workflows with a progression from an analogous, manipulation of materials manually to a systematic, digitally verifiable process. The field of orthodontics has advanced greatly in the technological perspective.[1]

The 3D printing in orthodontics has made the procedures easier, time saving, cost-effective apart from the initial investments. Based on the data obtained from CT or MRI or any other imaging techniques the models are fabricated. Many methods have been incorpotrated for the fabrication of a physical prototype. These methods can be divided into two categories: subtractive and additive. The process starts with the processing of the image obtained from Ct or MRI and then using the CAD software for making the model.[2] A three-dimensional (3-D) printing is also known as additive manufacturing or desktop fabrication[6]. The future of 3D in orthodontics will come with the improvement in the 3D printers, working in conjunction with intraoral scanners[9]. Rapid prototyping (RP) is a relatively new class of technology used for building physical models and prototype parts from 3D CAD data. It is a process where the additive material is added layer by layer. This process uses additive technology for the creating model and prototype parts where the material is laid down layer by layer on the one another to form a physical model[10]. The subtractive technique used is the conventional numerically controlled (NC) machining, generally milling (Petzold et al., 1999). In this case, the shape of the model is milled from a block of polyurethane or other foam.

3D printing technologies are not new; many of which have been developed and used from the late 1980s and 1990s. Now 3D printing has become coming that too in the field of dentistry.

The 3D printer are simple robotic devices with a CAD CAM which enables the physical models to be created in a virtual environment and also plan the treatment accordingly. There are many advantages which includes the low cost, easier fabrication, it is also possible to create surgical models to work on[2]. This method has limitation which results from milling machines, which have restricted motion capability. Complex geometries are difficult to programme and can result in tool/workpiece collisions, and they are often the cases in medical application (Potamianos et al., 1998).

Materials and Methods

A literature survey was done by using the following databases: PubMed, EMBASE, Cochrane library, google scholar and Web of science. A combination of keywords were used to collect all the articles about the 3D printing technology, intraoral scanning, digital models, lasers, MRI, CBCT in 3D imaging. The search includes all the publications up to the present date.

Data extraction

The data on the studies included in the review were extracted and they were compared . The following data were collected from the selected articles - 3D printing technology, intraoral scanning, digital models, lasers, MRI, CBCT in 3D imaging

Study selection

After removing all the duplicates from the databases, the title and abstract of each publication were reviewed

The inclusion criteria were:

i. Relevance: papers were required to report first hand on the use of 3D technology, 3D printing, digital imaging and scanning.

ii. Language: only papers written of translated into EWnglish were included in the review.

After taking into account the inclusion criteria , 30 articles were selected and the data gathered were compiled to give a proper knowledge about the 3D technology including the scanning, digital imaging ., printing and also about the various newer technologies available. All of them were compared and their further prospects were discussed.

Procedure of 3D printing

The procedure of 3D printing was taken from the article by Andrew Dawood, British dental journal 2015

The acquisition of 3D patient model is done by intraoral scanning or scanning of the physical model. Then the appliance is designed in a CAD CAM software. After the appliance is designed using the software, the structure is sliced to create a stack of layers. The sliced data is then sent to the printer, where material is laid down layer by layer using the 3D printing technology. Then sandblasting, jet washing and grinding is done followed by infiltration and heat treatment (if it is metal objects) The intraoral scanning method is given below:

Intraoral Scanning

The replacement of alginate and polyvinyl siloxane material was brought about by the intraoral scanners[7]. Intraoral scanners capture the image of the dental arch perfectly[16]. The images of the all the dental and gingival tissues (as well as the implant scanbodies) captured by imaging sensors are processed by the scanning software, which generates point clouds. These point clouds are then triangulated by the same software, creating a 3D surface model (mesh)[12]. The subsequent image obtained is then printed using rapid prototyping. There were many advantages with the intraoral scanners over traditional impressions that had problems such as pulls, tears, bubbles, voids, tray-to-tooth contact, separation from the impression tray, temperature sensitivity, limited working time, material shrinkage, inaccurate pouring, model overtrimming [7,12]. Improved diagnosis and treatment planning, increased case acceptance, faster records submission to laboratories and insurance providers, fewer retakes, reduced chairtime, standardization of office procedures, reduced storage requirements, faster laboratory return, improved appliance accuracy, enhanced workflow, lower inventory expense, and reduced treatment times were some of the advantages of the intraoral scanners[7].

Scanning Technology

IOS is a medical device which has three major components: a wireless mobile workstation to support data entry; a computer monitor to enter prescriptions, approve scans, and review digital files; and a handheld camera wand to collect the scan data in the patient's mouth [7,17]. The goal of IOS is to record with precision the three-dimensional geometry of an object. The most widely used digital format is the open STL (Standard Tessellation Language) [17].

Light Projection and Capture

Within the 3D reconstruction field, there is a clear distinction between passive and active techniques. Passive techniques use only ambient lighting to illuminate intraoral tissues and are reliant on a certain level of texture of an object. Active techniques use white, red, or blue structured lights projected from the camera onto the object that is less reliant on the real texture and color of tissues for reconstruction[17]

Distance to Object Technologies

1. Triangulation: Triangulation is based on a principle that the position of a point of a triangle (the object) can be calculated knowing the positions and angles of two points of view. These two points of view may be produced by two detectors, a single detector using a prism, or captured at two different points in time.[7]
2. Confocal: Confocal imaging is a technique based on acquisition of focused and defocused images from selected depths. This technology can detect the sharpness area of the image to infer distance to the object that is correlated to the focal length of the lens. A tooth can then be reconstructed by successive images taken at different focuses and aperture values and from different angles around the object.[7]
3. Active wavefront sampling: AWS is a surface imaging technique, requiring a camera and an off-axis aperture module. The module moves on a circular path around the optical axis and produces a rotation of POI. Distance and depth information are then derived and calculated from the pattern produced by each point.[1,7]
4. Stereophotogrammetry: Stereophotogrammetry estimates all coordinates (x, y, and z) only through an algorithmic analysis of images. As this approach relies on passive light projection and software rather than active projection and hardware, the camera is relatively small, its handling is easier, and its production is cheaper.

5. Reconstruction technologies: One of the major challenges of generating a 3D numerical model is the matching of POI taken under different angles. Distances between different pictures may be calculated using an accelerometer integrated in the camera, but a similarity calculation is more often used to determine the point of view of the image. Using algorithms, similarity calculation defines POI coincident on different images. These POI can be found by detection of transition areas, such as strong curvatures, physical limits, or differences of grey intensity ("Shape from Silhouette"). A transformation matrix is then calculated to evaluate similarity between all images such as rotation or homothety. Extreme points can also be statistically eliminated to reduce noise. Each coordinate (x, y, and z) is extracted from the projection matrix, and a file is then generated.[4.7]

MRI imaging

This new technology is particularly helpful with orthodontic concerns such as root length, bone structure and root angulation. In contrast to CBCT imaging, MRI uses non ionizing electromagnetic radiation.[17] Magnetic resonance uses magnetic energy and radio waves rather than Xrays to create cross sectional images or slices of the human body.[16] MRI allows for repetitive 3D imaging of dental structure in any age group without worrying about potential harmful radiation exposure.[17] MRI is mostly used for upper airway analysis and 3D imaging of TMJ morphology.

CBCT

CBCT data can be used to produce 3D digital study models without the need for alginate impressions. These models are of higher diagnostic value than other digital models because it includes not only the tooth crowns but also roots, impactions, developing teeth and alveolar bone. CBCT provides more specific anatomic imaging than 2D radiographs and it is more effective than CT and MRI in detecting osseous changes. According to Lai et al CBCT improves exact localisation of the impacted canines, assessment of the proximity to other structures and teeth, determining the existence of any pathology and root resorption associated with treatment planning of the impacted teeth and adjacent teeth.

CAD CAM

Computer based technologies play an important role in all aspects of our daily life as well as in dentistry. Computers are used to collect data, design and manufacture a wide range of products in CAD CAM systems. CAD CAM systems consists of three components:

1. A scanner to transform the geometry of real object into digital data
2. Software for data processing
3. A production technology able to realize the desired product.

CAD CAM technologies has been used to 3D print orthodontic appliances and surgical splints for orthognathic cases.

3D printing

Common technologies which are used in medicine are selective laser sintering (SLS), fused deposition modelling (FDM), stereolithography (SLA) and inkjet-based system[2].

Stereolithography

The first process of this type of RP was patented by Hull (1984), for the production of 3D models from photopolymer resins[10]. The build tray of an SLA printer is immersed in a liquid resin that is curable by a concentrated ultraviolet laser light (Fig. 1).The laser draws a cross-section of the object to form each layer.

After the layer is cured, the tray descends by a distance equal to the layer thickness,allowing uncured resin to cover the previous layer.

This process is repeated hundreds of times as the printed object takes shape[9].

Selective Laser Sintering

SLS is a process of fusing together layers of specified powder material especially nylon, elastomer, and metal into solid objects into a 3D model by a computer-directed laser (Fig – 2). [10,11]

Fused Deposition Modeling

This is the second most common method after stereolithography.(11) A plastic / wax filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic/wax to form each layer. The plastic/wax hardens immediately after being squirted from the nozzle and bonds to the layer below. The entire system is contained within a chamber which is held at a temperature just below the melting point of the material (Fig- 3) [10]. Fused deposition modeling is the quickest and cheapest method of RP. Prototypes of different colors are possible to make. It is an easy and convenient building process involving less wastage of material with no exposure to toxic chemical materials.[11]

Digital light processing

DLP is identical to SLA except for the light source. a projector is used to cure an entire layer at a time, in contrast to the SLA laser, which must draw the entire layer to cure it (Fig -4). Similar to the difference between stamping and drawing an object, this results in significantly faster print times.[9]

PolyJet Photopolymerization

Liquid materials such as liquid photopolymer resin are filled into the jetting heads which squirt tiny droplets of the material from hundred nozzles as they move in X-Y plane into the desired pattern to form the layer of the object and immediately cured with ultraviolet light (Fig – 5). The build platform moves vertically to accommodate subsequent layers.[9,11] Advantages of inkjet printing are a fine resolution, accurate surface finish, and minimal material consumption.[11]

Application in orthodontics

3-D printing is revolutionizing the orthodontic process, providing digital advantages over the traditional workflow process [6].

1. **Diagnosis and treatment planning:** The main thing in this is the CT scan or the intra oral scanning which helps in the fabrication of the 3D model that can be used for diagnosis and treatment planning. [1] CT slice images were overlapped one on other in 0.5 mm layers. CT files were imported into CT image processing software (Vworks 5.0, Cybermed, Seoul, Korea) and then opened in a prototyping software which is then sent to the rapid prototyping machine which formulates the 3D model.[11]
2. **Fabrication of trays:** Rapid prototyping helps in the fabrication of indirect bonding trays with the accurate positioning of the brackets. Computer-aided technology is used to design the individualized trays, which are then produced with a rapid prototyping procedure. [5,11]
3. **Orthognathic surgery:** Recent advances in three-dimensional imaging have made an enormous breakthrough in the diagnosis and management of

orthognathic surgery[3]. It provides an easy way to measure discrepancies due to asymmetry on the model directly, and an opportunity to study the bony structures of the patient and to manipulate them as required before the actual surgery. Surgical splints have also been produced using stereolithography as part of the computer-assisted orthognathic surgery.[11] Gandedkar et al presented a case with a mandibular prognathism where he takes the help of the virtual treatment planning and 3D orthognathic wafers for the surgery[3]. Vale et al did a study on a female patient with left craniofacial microsomia Pruzansky IIA associated with diminished left jugal soft tissues, a unilateral cleft lip and macrostomia, maxillary and mandibular retrusion and vertical maxillary excess, which required combined orthodontic-orthognathic surgery treatment. Intraoral scanning was done, surgical virtual models were created. Surgical splints were manufactured using CAD/CAM technology in order to transfer the virtual surgical plan to the operating room and the surgery was performed.[4]

4. **Surgical template for implant making:** The positioning of the mini implants on the site is determined by viewing the CBCT images. Data from the CT image are transformed by software for interactive segmentation of the images (Humobot, Seoul, Korea) into a format compatible with a SLA[11]. This apparatus used different laser intensities for segmentation of the tooth and the alveolus in the resin model. Surgical template for the proper positioning of orthodontic mini-implants are fabricated in this way on the replicas of the models; the surgical guides are used for precise placement of the mini-implant. [11]
5. **Lingual orthodontics:** Rapid prototyping can be used for the customization of the bracket and facilitating the technique of indirect bonding.[8] Silicone impression is taken. Noncontact scanning of the therapeutic setup is performed with a high-resolution optical 3D scanner. The outcome was a compound surface consisting of many thousands of minute triangles (STL surfaces) that can be turned, observed, and processed on a computer with an appropriate design software used high-end RP machines to convert the virtual bracket series into a wax analog and then into a final product.[11]
6. **Distraction osteogenesis:** Rapid prototyping machine is used in the fabrication of the distractor[4]

Discussion

The articles collected from the databases have been analysed and after getting to know their machinery, advantages and disadvantages we have considered its advantages over the conventional techniques, and found that the 3D dental models seem to have high level of accuracy and good reproducibility thus making it acceptable throughout the world. The 3D imaging techniques were also analysed and it was seen that all of the techniques have their own advantages and disadvantages. CBCT seems to have a better resolution for 2D osseous imaging than MRI and CT. Changes in the appearance of the face after tooth movement, orthognathic surgery or other craniofacial treatment can be detected with CBCT image. But it cannot be used for TMJ imaging, skeletal physiology, soft tissue swellings etc. since it has lesser soft tissue contrast.[20]

MRI has less radiation exposure because it uses non ionizing radiation. MRI operates by achieving a resonance signal from the hydrogen molecules. MRI is a gold standard for TMJ imaging. It gives detailed information about the intracapsular joint effusion, joint pain, adhesion and perforation of articular disc.[16,17]

After the advent of CAD CAM , its use in dentistry has become common. Whereas early approaches to scanning and the production of digitally manufactured restorations relied upon the use of centralised scanning and manufacturing facilities. Many laboratories now have their own laboratory scanners, and many also have their own milling units. In the dental practice environment, intra oral and CBCT scanners are becoming common. 3D printing offers another form of 'output' device for dental CAD software; making it possible to make intricate components and objects from a variety of different materials.

There are many other 3D printing technologies which exist, each of it has its own uses and limitations. Unfortunately, a common feature of the more functional and productive equipment is the high cost of the equipment, the materials, maintenance, and repair, often accompanied by a need for messy cleaning, difficult post-processing, and sometimes numerous health and safety concerns.

Though this method is adapted, better research is needed to define standards. Other shortcomings which has to be addressed is the delivery time and the total cost of manufacturing so that in future it can be used more widely.[5,10]

Conclusion

3D technology is the latest technology which is been widely used. The imaging is more precise. 3D printing reduces the fabrication time. Though these technology is popular everywhere, extensive research has to conducted to reduce its short comings including the cost and machinery. The challenge with 3D printing is that it is a static process. In order to change a static process into a dynamic appliance, the future of orthodontics is in 4D printing. 4D printing is a digital process that takes 3D printing materials and adds the 4th dimension of time.

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Legends Figures

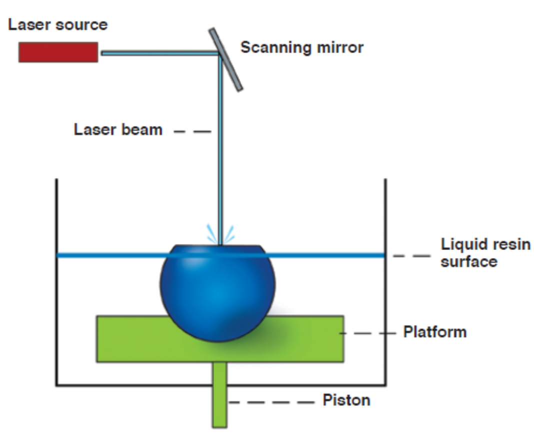

Fig. 1

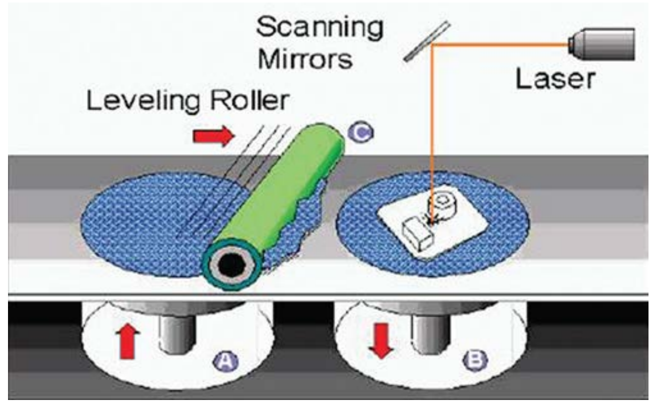

Fig. 2

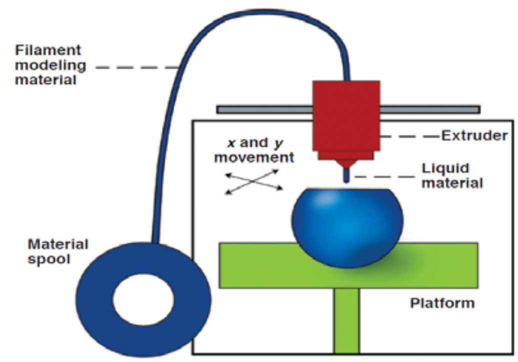

Fig.3

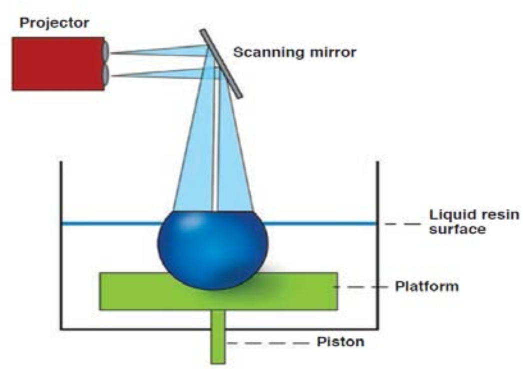

Fig. 4

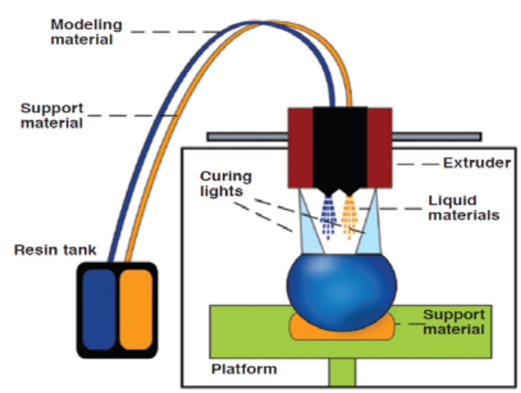

Fig. 5