Journal of Advanced Medical and Dental Sciences Research

@Society of Scientific Research and Studies *NLM ID: 101716117*

Journal home page: www.jamdsr.com doi: 10.21276/jamdsr Indian Citation Index (ICI) Index Copernicus value = 100

(e) ISSN Online: 2321-9599; (p) ISSN Print: 2348-6805

Review Article

3D Printing In Orthodontics: A Narrative Review

Prakash Patel

Senior Lecturer, Department of Pedodontics and Preventive Dentistry, Triveni Institute of Dental Sciences Hospital and Research Centre, Bilaspur, Chhattisgarh, India

ABSTRACT:
3D printing, or Additive Manufacturing, has revolutionized orthodontics by offering advanced solutions for treatment planning and appliance fabrication. This technology enables the creation of precise, customized orthodontic devices such as retainers, aligners, and functional appliances, enhancing both treatment efficiency and patient outcomes. The workflow involves scanning, designing, printing, and post-processing, allowing for rapid production with high accuracy. Applications in orthodontics include digital models for diagnosis, removable appliances, pre-surgical nasoalveolarmoulding, and occlusal splints. Additionally, innovations in metal printing and orthognathic surgery are further expanding the scope of 3D printing in orthodontics. As digital technologies continue to evolve, 3D printing promises even greater customization, efficiency, and cost-effectiveness in orthodontic treatments.
Keywords: 3D Printing, Orthodontics, Application

Received: 19 February, 2025 Accepted: 22 March, 2025

Corresponding author: Prakash Patel, Senior Lecturer, Department of Pedodontics and Preventive Dentistry, Triveni Institute of Dental Sciences Hospital and Research Centre, Bilaspur, Chhattisgarh, India

This article may be cited as: Patel P. 3D Printing In Orthodontics: A Narrative Review. J Adv Med Dent Scie Res 2025; 13(4):1-3.

INTRODUCTION

It is 2024 and we are living through the “Digital Era”, which has expanded the horizons and opened the doors for new opportunities making our day to day lives and professions quite comfortably fast paced and hassle-free. Digital Fabrication Technology, also referred to as 3D printing or Additive Manufacturing, creates physical objects from a geometrical representation by successive addition of materials, is a fast-emerging technology. Three-dimensional (3D) printing is also known and referred to as Desktop Manufacturing and Rapid Prototyping.[1]

3D printing was developed in 1980s by Charles Hull, who created the first 3D printer and 3D printing technology, which was named by the founder as stereolithography. Moreover, Hull created the STL (standard tessellation language or stereolithography) file format. STL file is a triangular representation of an object’s surface geometry. Each object is built of many triangles and the peak of each triangle is represented by the coordinates system. STL is the most commonly used file format to edit and prepare the object for 3D printing.[1]

The 3D Printer Workflow: The printer workflow is outlined in Figure 1, but can be summarized in 4 key steps: **1. Scan** – A digital scan is recorded and sent to the lab as an 'STL' file. This file provides the 3D format for image manipulation in CAD programs. **2. Design** – The digital scan is imported into computer aided design (CAD) software, where the design is simulated. **3. Print** – The file is then sent to the printing 'slicing' software, where the object is made ready for printing. The slicing software involves setting up model supports, printing speed, determining material options, and printing size. **4. Prepare** – Post printing, the object must be washed, dried, and post-cured. Prints are washed in 99% isopropyl alcohol (IPA) and cured using heat and ultraviolet light.[2]

Advantages Of Digital Over Conventional Methods

1. Accuracy
2. Efficiency
3. Customizable Treatment
4. Improved material properties
5. Storage and Organization
6. Improved patience experience

3d Printing in Orthodontics: The Present: Orthodontics is rapidly embracing new materials and advanced technologies, making the fully equipped 3D orthodontic office a reality. With involvement of recent developments and introduction of intraoral and facial scanners, digital radiology, cone beam computed tomography (CBCT), and additive manufacturing; the efficiency, accuracy, consistency, and predictability of the treatment outcomes has been enhanced by multiple folds.[2]

3D Printing in Orthodontics: Applications

Orthodontic Models: Diagnostic measurements performed on digital models represent high validity, reliability, and reproducibility, and thus may be regarded as an equal alternative to conventional plaster models.Rapid prototyping technology allows attainment of many identical copies of a digital model without any risk of distortion or deformation, available at any time. Printed models can be used for diagnosis and treatment planning, as well as to manufacture removable orthodontic appliances, expansion appliances, indirect bonding trays, or thermoformable orthodontic aligners and retainers.[3]

Removable Orthodontic Appliances: The nomenclature covers a wide array of appliances including simplest appliances like Hawley, numerous functional appliances like activator, Twin block etc. and complex sleep apnea appliances to name a few. First trials to manufacture removable acrylic orthodontic appliances using Computer-Aided Design (CAD) and 3D printing were made and presented by Sassani. Al Mortadidescribed a procedure of Andresen activator and sleep apnea appliance fabrication using CAD and additive manufacturing technology. The next development in the field was Hawley retainer manufacturing using intraoral scans obtained with TRIOS™ (3Shape, Copenhagen, Denmark), eliminating the need of conventional impression taking and pouring plaster models.Another application of additive manufacturing was to fabricate soft customized, silicone removable appliances introduced by Salmi. Printing the appliance was done using stereolithography (SLA 350 machine – 3D Systems), which was preceded by creating the digital design. Manufactured silicone appliance was subjected to evaluation, which was conducted by scanning the appliance, creating its virtual model, and digital image superimposition on computer-aided design. Maximal deviation of 1 mm was observed on sharp edges and thin walls of the appliance. The technology used enabled faster production, limited the costs, and resulted in fabricating appliances with high accuracy.[4]

Retainers: There are various types of retainers used in orthodontic practice, but Clear/Essix/ thermoformed retainers are the currently trending and can be made with highest accuracy and ease using 3D printing. Fixed lingual bonded retainers are being 3D printed, too, which again provides unmatchable precision and effortless customization.[4]

Pre-Surgical Nasoalveolar Moulding: The development of digital technologies has also affected the treatment protocol in patients with cleft lip and palate. These developments, aimed at reducing the risk of material aspiration, by using a scanner, seem to allow the clinician to produce appliances with less labor in a shorter time. Shen designed orthopedic devices in accordance with Grayson and Cutting's treatment protocol using CAD software from scanning models obtained from patients with alginate impressions. These special plates were designed to close the gap between the alveolar bones by 1 mm per week and were manufactured using maxillary models printed from 3D printers. This new system, called Rapid-PNAM, automatically identifies the alveolar ridges with a graphical user interface and designs plates according to the growth data of healthy newborns, allowing plates to be produced in minutes.[5]

Occlusal Splints: Occlusal splints are contemporarily used for treatment of patients presenting with temporomandibular disorders (TMD) and/or asymmetries. Lauren and McIntyre were the first authors to describe digital workflow in occlusal splints manufacturing. They suggested digital protocol applied subtractive technology of splint fabrication, which was machined down from acrylic material block. On the other hand, there is still a need for further clinical and scientific examination of 3D printed occlusal splints concerning clinical use.[6]

Aligner Staging: Specific orthodontic CAD software can permit orthodontists to produce staging of in-house tooth movements for aligner production. Models are 3D-printed and then aligners are produced by vacuum forming around these models, or they can be printed directly. Direct 3D-printed models are in their infancy and more research must be carried out to ensure comparable material quality to conventional methods.[7]

Bracket Printing: Customized 3D printed brackets can reduce the debond or fracture rate, improving patient experience and reducing chair time. Brackets can be fully customized to individual tooth morphology, helping transfer the appropriate torque onto the tooth and could potentially improve treatment outcomes.[8]

Virtual Bracket Removal: After orthodontic treatment, attachments and brackets must be removed before fabricating retainers. There is a risk that the teeth can relapse slightly in the time taken to receive the new retainers. Virtual bracket removal via CAD programming has shown to be equally as accurate for the clinical use of orthodontic retainers. This method allows for instant debond and retainer fit, reducing the relapse risk.[8]

Transfer Brackets: Additionally, the transfer of brackets using transfer trays can be 3D-printed. This is known as 'digital indirect bonding'. Conventionally these are placed on a cast model and then carefully placed over the teeth to ensure the brackets are positioned to provide the correct tension and torque for tooth movement. 3D printing can achieve this with reduced labor intensity and chair time. Moreover, this decreases saliva contamination when bonding the bracket, reducing debonding and improving accuracy over conventional methods.[7]

Direct Aligner Printing: Direct aligner printing technology is in its early stages. Graphy was the first to develop a photocurable resin that would allow for direct aligner printing. CAD programmes (i.e. uLab, Delta Face) work by creating a 'shell' design for aligner construction. Retention can be controlled by blocking undercuts in the shell design, depending on the case needs. Lastly, support structures are required before printing because this shell design is more likely to distort. More research is required to ensure the material characteristics are as effective as conventional thermoformed aligners. This technology will undoubtedly grow in popularity and accuracy as more development and research is carried out. Direct aligner printing will significantly reduce environmental waste and speed up manufacturing.[8]

Orthognathic Surgery: 3D printing technology is used in orthognathic surgery. Currently, it can be used to print orthognathic wafers, cutting guides and models for treatment.[9]

Band and Loops: Conventionally, the band and loop system has been employed in orthodontic space maintenance to help with the early loss of deciduous teeth. However, there is a tendency for cement disintegration due to ill-fitting bands and increased chair time. 3D-printing technology allows the construction of personalized space maintainers, overcoming conventional methods' drawbacks.[9]

Metal Printing: Recent developments in the use of Selective Laser Melting (SLM) and Selective Laser Sintering (SLS) are being used to create metal appliances such as rapid palatal expanders (RPEs) and other metal-based appliances such as brackets/springs and screws. These processes are increasing the accuracy of appliances and the personalization of individual treatment plans.[10]

CONCLUSION

3D printing technology has become more widely used in orthodontics and the scope of possible applications is still expanding. Available literature gives many examples of various 3D printing techniques and materials in a wide range of applications.

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