



3D Printing in Orthodontics: A Narrative Review.

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ABSTRACT

3D printing has revolutionized various fields, with orthodontics being a significant beneficiary of this technological advancement. The ability to convert digital designs into physical objects offers a transformative approach to patient care, treatment planning, and appliance fabrication in orthodontics. This review explores the applications, benefits, and challenges of 3D printing within the orthodontic landscape. Orthodontic practices traditionally relied on labor-intensive methods for creating space maintainers, retainers, and custom brackets. However, 3D printing enables the production of these devices with enhanced precision and efficiency. Utilizing digital impressions from intraoral scanners, orthodontists can design and fabricate orthodontic appliances that perfectly fit individual patient anatomies. This customization not only improves patient comfort but also shortens treatment times, enhancing overall satisfaction. One of the key advantages of 3D printing in orthodontics is its ability to produce complex geometries that are often difficult to achieve through conventional methods. For instance, personalized aligners, which require intricate shapes to ensure effective tooth movement, can be manufactured quickly and accurately. Additive manufacturing processes allow for the creation of lightweight, durable materials that meet the rigorous demands of orthodontic treatment. In addition to improve patient appliances, 3D printing has streamlined workflow efficiencies in orthodontic practices. The integration of digital technologies facilitates a smoother transition from diagnosis to treatment planning and final appliance creation. This efficiency not only reduces the lead time for patients but also minimizes the need for multiple appointments, thus optimizing the overall patient experience. Despite the numerous advantages, several challenges remain. The high initial cost of 3D printing equipment and materials can be a barrier for many practices. Furthermore, the regulatory landscape surrounding the use of 3D printed devices in orthodontics is evolving, and compliance with safety and quality standards is critical. Adequate training and education for orthodontists and technicians are paramount to harnessing the full potential of this technology. Present review of Literature aims to role of 3D Printing in orthodontics in detail.

Keywords: 3D Printing, 3D printed orthodontic devices, Orthodontics.

Introduction

In recent years, 3D printing technology has emerged as a groundbreaking innovation across various domains, including healthcare, engineering, and consumer products. Among these fields, orthodontics has significantly benefited from the adoption of 3D printing, fundamentally transforming patient care, treatment methodologies, and orthodontic appliance fabrication. Traditional orthodontic practices typically involved labor-intensive processes for creating appliances, which could lead to discrepancies in fit and require multiple adjustments. However, the advent of 3D printing has revolutionized this landscape, enabling orthodontists to harness the power of digital technology to enhance the accuracy, efficiency, and customization of orthodontic treatment.¹ At its core, 3D printing, or additive manufacturing, involves the layer-by-layer construction of three-dimensional objects from digital models. By converting virtual designs generated through computer-aided design (CAD) software into physical objects, orthodontists can now leverage this technology to create a wide array of devices, including aligners, retainers, brackets, and even model casts for diagnosis and treatment planning. The transition from traditional methods to 3D printing not only streamlines the workflow within orthodontic practices but also contributes to improved patient outcomes. One significant area where 3D printing has made an impact is in the fabrication of custom orthodontic appliances. Traditional methods often relied on impression materials and manual labor to create molds for aligners and retainers. These processes were susceptible to human error, resulting in appliances that did not fit accurately. With 3D printing, orthodontists can obtain high-resolution digital scans of a patient's dental anatomy using intraoral scanners or cone-beam computed tomography (CBCT) technology. This data can be processed to create highly precise digital models for the subsequent production of orthodontic appliances tailored specifically to each patient's unique anatomy.²⁻⁴

The high degree of customization offered by 3D printing leads to significant advantages, including improved patient comfort and satisfaction. Customized appliances fit better, minimize irritation to the oral tissues, and reduce the likelihood of adjustments, all of which contribute to a more favorable treatment experience. Furthermore, shorter lead times for appliance fabrication mean that patients can begin their treatment regimen much quicker, enhancing their overall experience in the practice.^{2,3}

Another notable aspect of 3D printing in orthodontics is the ability to produce complex geometries that are challenging, if not impossible, to create using traditional methods. For instance, the design of clear aligners requires intricate shapes to ensure effective tooth movement. 3D printing not only allows for the fabrication of these complex designs but also enables the incorporation of specific features to enhance the functionality of devices, such as anchors for attachments or optimized thickness for varying points of the appliance.

Beyond individualized appliance fabrication, 3D printing has revolutionized treatment planning and

communication between orthodontists and their patients. With 3D printed models, practitioners can provide their patients with visual representations of their treatment plans, enhancing understanding and buy-in. Moreover, these physical models can be instrumental in the demonstration of treatment progression and expected outcomes, increasing patient engagement and satisfaction.¹⁻³

Despite the numerous advantages that 3D printing brings to orthodontics, challenges persist. The cost of 3D printers and materials can be prohibitive for some practices, particularly smaller orthodontic offices. Additionally, the regulatory framework surrounding the use of 3D printed medical devices is still evolving. Orthodontists must navigate compliance with safety and quality standards to ensure that their printed devices are safe for patients. Continuous education and training for practitioners and lab technicians are essential to ensure that they can effectively integrate this technology into their workflows.

Research into the clinical effectiveness and efficacy of 3D printed orthodontic devices is continually growing. Numerous studies have demonstrated the accuracy of 3D printed appliances and their impact on treatment outcomes. As techniques and materials advance, there is potential for 3D printing to play an even more critical role in orthodontics, leading to more innovative treatment options and improved patient care.^{1,2}

Advantages Of Digital Over Conventional Methods¹⁻³

1. Accuracy
3. Efficiency
4. Customizable Treatment
5. Improved material properties
6. Storage and Organization
7. Improved patient 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 the 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 Mortadi described the 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 unmatched 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.⁹⁻¹¹

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.¹²⁻¹⁴

Future Prospective

The future of 3D printing in orthodontics holds exciting potential for enhancing patient care and treatment efficiency. Advances in materials will enable the production of even stronger, biocompatible appliances, fostering greater comfort and effectiveness. Innovations in digital scanning technology will streamline the design process, allowing orthodontists to create highly customized solutions with precision.

Integration of artificial intelligence could further refine treatment planning and predict outcomes more accurately. Additionally, 3D printing may facilitate the rapid prototyping of new appliances, enabling more frequent updates to treatment plans based on real-time patient feedback and progress.

Collaboration between orthodontists and engineers may lead to the development of multifunctional devices that combine orthodontic treatment with aesthetic enhancements. Overall, as regulatory frameworks adapt and technology advances, 3D printing is set to revolutionize orthodontic practices, ensuring improved patient satisfaction and transformative outcomes in the field.¹⁵⁻¹⁸

Conclusion

In conclusion, 3D printing represents a paradigm shift in orthodontics, providing unprecedented levels of

customization, efficiency, and precision in appliance fabrication. Its integration into clinical practice is shaping the future of orthodontic treatment, leading to enhanced patient experiences and outcomes. As the technology continues to evolve, orthodontists must stay informed about the latest advancements and implications for their practice, ensuring they harness the full potential of 3D printing for the benefit of their patients.

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