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3D PRINTING IN ORTHODONTICS

Dr. Anuj Yadav[1], Dr. Tarun Kumar[2], Dr. Namrata Dogra[3]
[1]*Post Graduate (2nd Year), Department of Orthodontics and Dentofacial Orthopedics, SGT Dental College*
[2]*Head of Department, Professor, Department of Orthodontics and Dentofacial Orthopedics, SGT Dental College*
[3]*Professor, Department of Orthodontics and Dentofacial Orthopedics, SGT Dental College*

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ABSTRACT

3D printing, or additive manufacturing, is an evolving technology that enables the precise fabrication of customized orthodontic appliances by layering and curing photosensitive resin with a light source such as a laser. Its adoption is growing rapidly in orthodontic practices as it provides a more efficient and streamlined alternative to traditional techniques like dental impressions and plaster models.

Although incorporating 3D printing into a digital workflow can present challenges – such as the need for specialized equipment and staff training – the advantages are substantial. These include greater accuracy, fewer errors, quicker production times, and long-term cost savings. When proper materials and standardized protocols are followed, 3D printing proves to be a reliable and effective tool for contemporary orthodontic care.

INTRODUCTION

Technological advancements have significantly impacted dentistry, with one notable innovation being the integration of three-dimensional (3D) printing and additive manufacturing for the production of orthodontic appliances. Unlike subtractive methods, which remove material to create an object, additive manufacturing builds items layer by layer, allowing for the creation of highly detailed and complex structures. This revolutionary approach has opened new possibilities in orthodontics, and over the past decade, studies have shown a marked increase in the adoption of 3D printing within the field.

3D printing, as defined by the American Society for Testing and Materials, involves producing a physical object by successively layering material based on a digital 3D model. This method contrasts with subtractive manufacturing, which removes material to create the final shape. Every layer represents a finely sliced cross-section of the final object, contributing to the precision of the build. The foundation of modern 3D printing was laid in 1986 when Charles Hull introduced the first stereolithographic printer. Subsequent advancements included Scott Crump's invention of fused deposition modeling (FDM), a key breakthrough in additive manufacturing. Later, in 1995, Professor Ely Sachs developed a technique using inkjet technology to print metal-based objects and was the first to use the term "3D printing" to describe the process.

Today, 3D printing plays a pivotal role in the fabrication of clear aligners, which serve as a viable alternative to traditional fixed appliances for selected malocclusions. These aligners offer advantages such as enhanced aesthetics and improved oral hygiene. The digital design process, made possible by 3D printing, enables the production of transparent aligners with finely finished edges and consistent, precise fits across an entire treatment set. However, direct 3D printing of aligners remains technically complex, particularly in achieving uniform thickness throughout each appliance.

TYPE

In orthodontics, the primary types of 3D printers utilized are stereolithography (SLA), fused deposition modeling (FDM), digital light processing (DLP), PolyJet photopolymer (PPP), and selective laser sintering (SLS). Of these technologies, SLA holds the distinction of being the earliest form of 3D printing to be introduced.

HISTORY

Orthodontics is currently undergoing its fourth significant transformation since it was first recognized as a dental specialty in the early 20th century. In its early stages, the treatment of malocclusion involved the use of metal bands that were cemented around the teeth, which served as anchors for wires delivering corrective pressure. However, this method often resulted in a high incidence of dental caries due to the difficulty in maintaining oral hygiene—caused both by the bulkiness of the bands and the limited availability of effective dental hygiene tools at the time.

In the 1960s, these bands were replaced by the first stainless steel brackets, which supported orthodontic wires more efficiently. This innovation marked a significant technological leap, offering benefits like enhanced strength, increased durability, minimized friction, better stimulation of salivary flow & easier oral hygiene maintenance. This advancement was made possible by the development of dental materials that allowed brackets to be directly bonded to teeth.

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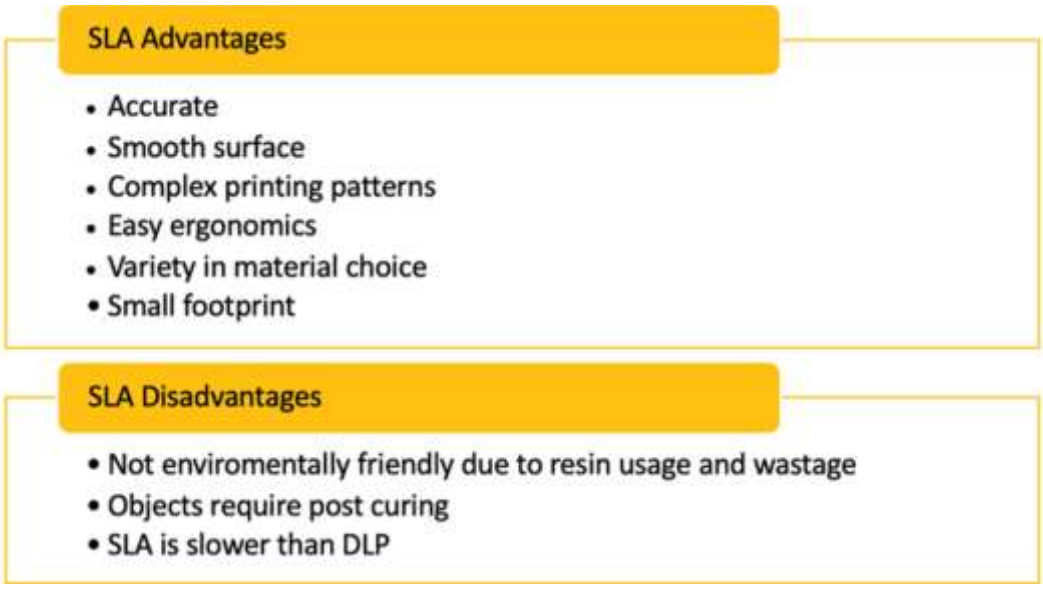
In the early 1970s, transparent or translucent non-metallic brackets were introduced, further enhancing aesthetics and patient comfort. Toward the end of the 20th century and into the early 2000s, clear aligners emerged as a new orthodontic option. This development was largely driven by patient demand for more comfortable, discreet, and less invasive treatment methods. Since their introduction, aligners have gained widespread popularity, motivating people across all age groups, including seniors, to pursue orthodontic care.

This review outlines the development of clear aligner production, beginning with traditional thermoforming approaches and moving toward contemporary direct 3D printing techniques. It also explores the benefits offered by 3D-printed aligners over earlier methods, provides an overview of current advancements in the field, and discusses ongoing challenges such as the limited availability of regulatory-approved printing materials and the scarcity of specialized design software. Finally, the review offers the authors' perspective on future directions and necessary developments in this field.

SLA

The 3D printing process begins by lowering the build platform into a tank filled with resin, maintaining a gap equal to the thickness of one layer between the platform and either the liquid resin or the previously solidified layer. A UV laser is then aimed at specific coordinates to selectively harden the resin. This laser guidance is facilitated by two mirrors, which control the direction and sequence of light exposure. Once a layer is cured and solidified, it detaches from the base of the resin tank and the build platform is incrementally raised to allow fresh resin to refill the gap. The next layer is then cured in the same manner, and this cycle continues until the entire model is complete.

The thickness of each layer can be adjusted—thinner layers generally result in higher resolution and more accurate prints. After the printing process is finished, the model is removed from the build platform and undergoes post-processing steps, which will be discussed later in this paper.



DLP

DLP printers work by lowering the platform into a resin tank, creating a gap that corresponds to the thickness of one layer between the platform and the resin. Light is then projected onto the resin through a screen, with mirrors directing the light to cure the material to the appropriate areas. Unlike other techniques, the curing process happens simultaneously across the entire surface. Once a layer is cured, the platform rises, allowing fresh resin to flow into the space, and the process repeats. This approach is more efficient than SLA printing, as the DLP projector cures the entire resin layer in one go, instead of curing it layer by layer based on individual coordinates.[9]

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DLP Advantages

- Accurate
- Complex printing patterns
- Faster than SLA printing
- Variety of material options
- Small footprint

DLP Disadvantages

- The surface finish is not quite as good as SLA
- Smaller build volume – due to digital projection (the larger the volume, the more voxel formation, so the build quality is reduced)
- Objects need post curing
- More expensive than SLA

3D printed Products Processing

Once printing is complete, three additional steps are necessary before the appliance or model can be used:

1. **Washing** – The appliance is typically cleaned using a washing station that submerges it in 99% isopropyl alcohol (IPA). Alternatively, an ultrasonic cleaner may be used with a tripropylene glycol monomethyl ether (TPM) solution instead of IPA, since IPA is flammable and unsuitable for ultrasonic cleaning.
2. **Support Removal** – Some intricate designs require support structures to remain stable during printing. These supports can be manually detached or removed with a flush cutter. Following this, sandpaper can be used to smooth the surface and improve the texture.
3. **Curing** – To finalize the material properties, the appliance is cured under ultraviolet (UV) light. The curing duration depends on the type of material and the manufacturer's specifications. This process is typically carried out using a specialized curing station, often provided by the printer manufacturer.[10]

Advantages of 3D Printing

- As accurate and sometimes more accurate than conventional methods
- Quickly identify Scan defects
- Time Saving
- Reduced lab fees
- One Machine, multiple products
- High degreee of customisability of treatment
- Improved material properties
- Space Savings due to reduced need for storage of models
- Improved patient experience

Disadvantages of 3D Printing

- Print quality
- High upfront cost
- Staff training
- Implementation
- Ecological effects
- Health and safety
- Insufficient Expertise
- Space requirements
- Hardware Company Longevity

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Advantages of Digital over Conventional Methods

Accuracy

In orthodontics, both scanning and 3-dimensional printing can achieve the same level of accuracy as traditional impressions and models. One common application of 3D printing is the creation of orthodontic models. Traditional model production, however, is prone to technical errors at various stages, such as distortions from the impression process, prolonged alginate disinfection, or improper storage, all of which can impact the model's accuracy and outcome. 3D printing helps overcome many of these issues by streamlining the process, leading to more accurate models. Another application of 3D printing is in the creation of transfer trays for indirect bonding, which are used to position brackets accurately. Proper bracket placement is crucial, as it affects the treatment's effectiveness and duration. Traditional methods, which involve several stages, are more susceptible to inaccuracies, from distortion during the impression process to errors with the pick-up materials.[11]

Scan Defects

In traditional impression taking, clinicians inspect the impression for defects before sending it to the lab, but spotting defects or undercuts can be difficult. Scanning simplifies and accelerates the detection of issues, allowing for quick adjustments through rescanning or image editing. This minimizes the need for patient callbacks or returning lab work. Although not directly tied to 3D printing, this advantage stems from the overall workflow, providing a distinct benefit compared to traditional methods.[12]

Efficiency

3D printing saves time by streamlining the workflow. Clinicians no longer need to disinfect impressions, mail them, or wait for their return. Scans can be rapidly transmitted to the lab, and model adjustments are more efficient, with less need for trimming and processing. As a result, time is saved at every stage, enabling patients to experience shorter waiting times between appointments.

Reduced Lab fees

When the printing capacity is adequate, laboratory costs can be reduced, leading to lower expenses for patients. This provides the practice with a competitive edge over other orthodontists and enhances overall profitability.

One Machine, Multiple Products

Recent advancements in 3D printing have enhanced print quality, speed, and material options. Specialized resins designed for various applications, such as occlusal splints, retainers, brackets, and models, can be used with a single printer. This offers increased flexibility and customization in treatment while eliminating the need for additional equipment investments.[13]

Customisable Treatment

Each patient presents a unique malocclusion that requires an individualized treatment plan. 3- dimensional printing offers the ability to create fully personalized appliances. Recent case studies have highlighted the use of appliances like distillers, expanders, and brackets.

Improve Patient Experience

The taste of impression material can be unpleasant and may trigger a gag reflex in some patients. Scanning reduces discomfort, and when performed by experienced staff, it can be done rapidly and effectively, leading to a better patient experience. With quicker turnaround times, treatment can be finished more swiftly and with fewer visits, further enhancing the patient's overall experience.[14]

Disadvantages Of Digital Over Traditional Methods

Print Quality

Quality of print is determined by the printer model, the materials selected, and the calibration settings used. These factors can influence both the quality and cost of the prints. The initial expenses are significant, covering the cost of the printer, software, and post-processing equipment. Additionally, setting up an in-house lab may require plumbing, wiring, and the hiring of a technician to oversee its operations.

Staff Training

Investing in staff training is essential, but it can be time-consuming and inefficient in the beginning. This may result in more mistakes, leading to extra appointments, reduced earnings, and a poor experience for patients.

Insufficient Expertise

By incorporating 3D printing, When a practice assumes the role of a manufacturer, it must possess expertise across the entire process. It is essential to assess the skills of the staff and offer training for each phase of production.

Hardware Company Longevity

It's essential to investigate the printer manufacturer to assess whether they are a well-established industry leader or a newer start-up. Given the high cost of printers, it's essential to understand the warranties provided, especially in case the company goes out of business. Many start-ups initially offer lower prices to attract customers while securing investment, only to raise prices later for long-term profitability. If the company goes under and the printers lack warranties, sourcing replacement parts might become problematic, which could have a negative impact on the practice.[14]

Orthodontic Applications

Models

One use of 3D printing is in the development of models for treatment planning within a multidisciplinary approach. This enables the creation of models, stents, and guides that can be used to design final treatment prototypes and enhance communication between laboratories and various specialties. These methods can save time by allowing for pre-treatment measurements and analysis through CAD and 3D-printed models.

Occlusal Splints and Retainers

3D printing can be employed for the direct production of retainers, which have shown adequate mechanical properties for functional use. Alternatively, models can be 3D printed, and retainers can be created from these models using the thermoforming process. Occlusal splints can be easily designed

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in CAD software and printed; however, careful consideration must be given to the type of resin used. Different resins have varying physical and chemical properties, and an occlusal splint must have sufficient fracture resistance to withstand occlusal forces (e.g., Sprint Ray NG Flex). Each printer manufacturer offers specific resins for these applications.

Aligner Staging
Orthodontic CAD software allows orthodontists to design and stage tooth movements for aligners in-house. 3D-printed models are created, and aligners are then made from vacuum forming over models, or can be directly 3D-printed. Direct 3D-printed aligners are still in the early stages, and additional research is necessary to ensure their material quality is on par with conventional methods.

Bracket Printing
Custom 3- dimensional printed brackets reduces the likelihood of debonding or fractures, leading to a better patient experience and less time spent in the dental chair. By being tailored to the specific shape of each tooth, these brackets help apply the correct torque, potentially enhancing treatment results.

Direct Aligner Printing
DAP technology is still in the early stages of development. Graphy pioneered the creation of a photocurable resin tailored for direct aligner printing. CAD software like uLab and Delta Face generates a "shell" design for the aligner, where retention is controlled by blocking undercuts within the shell according to the specific needs of the case. Since the shell design is more prone to distortion, support structures are necessary during printing. Further research is required to confirm that the material properties are on par with traditional thermoformed aligners. As the technology matures, it is expected to become more accurate and widespread. Additionally, direct aligner printing promises to reduce environmental waste and speed up the production process.[15]

Orthognathic Surgery
3-dimensional printing technology is employed in orthognathic surgery, where it is currently used to create orthognathic wafers, cutting guides, and treatment models.

Band and Loops
The band and loop system has been a standard method in orthodontics for preserving space after the premature loss of primary teeth. However, common drawbacks include cement failure due to poorly fitting bands and extended chair time. With 3D printing technology, customized space maintainers can be produced, addressing the limitations of traditional techniques.

Metal Printing
Advancements in Selective Laser Melting (SLM) and Selective Laser Sintering (SLS) are revolutionizing the production of metal appliances, such as rapid palatal expanders (RPEs), along with other components like brackets, springs, and screws. These technologies are enhancing the accuracy and level of customization for individual treatment plans. Although the initial cost of these printers is high, many practices find the investment worthwhile. As technology improves, it is expected that costs and print times will decrease, making it more accessible in the future.[16]

3D Printing- Future Advancements, Developments & Issues Surrounding It
Printer Hardware
As it becomes more widely adopted, advancements in print quality and material options will occur. Printers will achieve higher speeds, greater accuracy, and larger production volumes, while materials will be refined to offer improved properties, including better biocompatibility, eco-friendliness, and reduced shrinkage. This advancement will enable more tailored treatment solutions, including custom shade-matched brackets for patients seeking alternatives to clear aligners or lingual appliances.

Materials and the Environment
The selection of materials has significantly advanced and will keep evolving, improving biocompatibility, mechanical strength, and the range of printable materials. With growing awareness of environmental impact and the need for sustainability, new materials are being developed to make the technology more eco-friendly. One such material in development is nylon for orthodontic appliances. Nylon doesn't form chemical bonds during the curing process, allowing it to be recycled into pellets that can be used in non-cosmetic automotive parts and other machinery.

Brand Monopolies
A significant advancement is that specialist orthodontists now have the ability to compete with major brands dominating the clear aligner market. By creating their own aligners using 3D printing, practices can lower production costs, which can lead to more affordable prices for patients. This shift could encourage larger companies to improve customer service, reduce lab fees, and increase the overall value of their products.[17]

CONCLUSION
3D printing plays a pivotal role in the ongoing fourth industrial revolution, which blends advanced hardware with software and digital workflows. This technology is continually advancing due to strong commercial investment and an expanding base of scientific research validating its benefits. When used with suitable materials and optimized printing methods, 3D printing offers accurate, long-lasting dental models, effectively addressing the drawbacks of traditional impressions and plaster-based techniques. The move from manual fabrication to fully digital workflows has demonstrated clear benefits in terms of cost reduction and improved efficiency. A wide range of pricing models enables orthodontists to select from all-in-one systems or modular setups with separate components and software. Comprehensive packages like those from Sprint Ray or Formlabs simplify the process but come at a premium, whereas more customizable systems demand greater time and technical expertise. Orthodontic practices considering this shift should conduct a careful cost-benefit analysis to evaluate its practicality for their operations. As the dental field transitions from analog methods to digital solutions such as intraoral scanning and computer-aided workflows, 3D printing emerges

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as a natural progression. With its growing affordability, simplicity, and accessibility, it is set to become an essential tool in modern orthodontics.[18]

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