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Review

Rapid prototyping: A future in orthodontic

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Abstract: The term "rapid prototyping" (RP) refers to a variety of methods for creating "physical models based on computer-aided design and computer-aided manufacturing". With the aid of RP technology, practically any variation of the surface and interior anatomical structure may be replicated in a medical model that is constructed layer by layer. To create the physical model, layer-by-layer construction is carried out using a variety of processes, including stereolithography, selective laser sintering, inkjet printing, and fused deposit modeling. Data for RP is received from magnetic resonance imaging and computed tomography scans, which are then turned into digital images and then into standard triangulation language files. The use of this computerized programming in orthodontics incorporates "diagnosis and treatment planning", the creation of removable "orthodontic appliances", "impression trays" for indirect bonding, "3D printed occlusal splints and aligners", prototype models used in various orthognathic surgeries, and the production of a distractor for distraction osteogenesis. It increases a crucial understanding at the time of preoperative treatment planning and raises the effectiveness of the therapy, yet, clinical judgment is still essential. Applications of RP for an orthodontist vary, and if we utilize it creatively, the future appears more hopeful. This article briefly reviews key advancements, challenges, and prospects in the integration of rapid prototyping and 3D printing, shaping a promising future for orthodontics.

Keywords: digital technologies; orthodontics; rapid prototyping; additive manufacturing; 3D printing

1. Introduction

Rapid prototyping (RP) is the process of making a three-dimensional (3D) model quickly from a computer-aided design (CAD), which is typically constructed layer by layer from a 3D input [1]. The method was initially utilized in mechanical engineering, and its primary application is to assess how simple it will be to assemble and build specified objects before they are ever produced. The scope of applicability has recently expanded to include other industries, such as medicine and dentistry [2]. The fusion of three separate technologies—medical imaging, computer graphics/CAD, and RP—has made a variety of medical applications conceivable. Additive manufacturing (AM), sometimes referred to as rapid prototyping, solid freeform fabrication, or 3D printing, is a process that uses layer-by-layer material deposition to build intricate, multifunctional, and multi-material components straight from CAD files [3–6]. One such technique is 3D printing, which offers the chance to make an object that is customized to the patient and the intended site [7,8]. By adjusting design and fabrication settings, this technology allows for the development of objects with precise dimensions, complexity, and microstructural environments [9,10]. Over the past forty years, this technology has advanced steadily, and it has lately been used in the clinical setting to create innovative 3D-printed biodegradable scaffolds and other medical devices [11–13].

More versatility in object development is provided by 4D (four dimensional) printing an inventive method of using 3D printing to create intelligent and dynamic structures [14]. Furthermore, 4D printing follows the same processes as AM but adds the capability of material attributes modifying or changing over time [15–17]. It is quick, improves design communication, and makes finding faults simple [18]. In both industry and/or medicine, subtractive and additive methods have been used to create physical prototypes (models) [19]. In most cases, the subtractive process is carried out using computer numerically controlled (CNC) machining, most often milling [20]. On the other hand, additive technologies may create complicated forms with voids, which is typically the case in the architecture of the human anatomy. The main concept behind this ground-breaking technique, also known as “layered manufacturing” rather than solid free-form fabrication, is that thing appears to be a solid 3D CAD model is divided into cross-sectional depictions of layers, and these cross-sectional layer representations are then quickly built up physically in an automated fabrication machine to create the prototype [21]. Before the 3D model is generated, a variety of tasks related to fast prototyping must be completed. With the use of these “3D” printers, designers can swiftly produce physical prototypes of their creations as opposed to only two-dimensional images. The capacity of contemporary imaging technologies, like spiral computed tomography (CT) or magnetic resonance imaging, to provide sets of continuous volumetric data, which serve as the data needed for model input construction, helped this progress [22]. Apart from orthodontics, oral surgery, implantology, operative dentistry [23], prosthodontics, and orthodontics are just a few of the dental disciplines that employ RP. These technologies are now commercially available with shorter clinical procedures thanks to significant improvements [24]. Recent years have seen a sharp growth in demand for speedy product development cycles, lower prices, and higher-quality products, which has propelled the rapid prototyping trade. Additionally, the market is growing due to factors including the increased use of 3D printing technology across a range of industries, including healthcare, automotive, and aerospace, as well as the growth in demand for customized objects. This review’s main goal is to concentrate on the most recent developments in RP and how they apply to the practice of orthodontics.

2. Rapid prototyping and 3D printing

Prototyping is an outcome or final product of a manufacturing process, whereas additive manufacturing, or 3D printing, is the process.

2.1. Is rapid prototyping important?

However, the answer to this remains yes. In the current dynamic consumer market, companies must expedite the development and launch of new items to stay competitive. For a company to succeed, speedier product development and technological innovation are essential, making RP the most important component of new product development. A variety of RP/3D printing methods, notably fused deposition modeling, and bioprinting, have also seen rapid development and popularization over the past twenty years to facilitate the creation of biomaterial scaffolds that guide tissue regenerations [25,26].

2.2. 3D/4D bioprinting technology

Employing bio-ink functional materials, 3D bioprinting technology creates complex, 3D cell-filled tissue structures that resemble natural tissues. Many artificial soft tissues, such as skin, bone, and cartilage, are created using this method [27–29]. Extrusion-based, laser-based, and inkjet bioprinting are the three main methods used in bioprinting [30–32]. On the other hand, the idea of 4D bioprinting suggests that 3D printed materials can deform when stimulated externally [33]. To accomplish the desired result, a 3D-printed object also undergoes predetermined form modifications during post-printing. It enables precise and regulated tissue replication [34]. Additionally, it aids in achieving dynamic contact with native cells to a degree [35]. Artificial intelligence and machine learning can be combined with 3D/4D printing to create patient-specific medicinal technology [36].

2.3. Role of 4D printing: 3D printing of smart materials in orthodontics

Using the latest stimuli-responsive materials along with 4D bioprinting processes, dynamic 3D-printed living constructions are created [37]. A recent review paper by Osouli-Bostanabad et al. [38] provides statistical evidence for the trend of a notable rise in published articles about the 4D bioprinting of smart materials in recent years. Some essential bioactive smart materials used in 4D bioprinting are included in the following subsection.

2.3.1. Smart material

Stimuli-responsive materials (SMs) are divided into two main categories: materials that change stiffness, materials that change phase, shape-changing materials (SCMs), and shape memory materials (SMMs) [39–41]. Subclasses of these materials include shape-memory polymers (SMPs) and shape-memory alloys (SMAs) [42]. The range of SMs used in 4D bioprinting, such as hydrogels, shape memory elastomers, shape memory polymer composites (SMPCs), SCMs, SMAs, and SMPs [43–45]. Five different categories of smart features are represented by 4D-printed materials, which are self-assembly, self-sensing, shape memory, self-actuating, and self-healing systems [46]. External factors cause folding and assembly into preprogrammed shapes during self-assembly [47]. Self-sensing actions recognize and evaluate outside stimuli [48]. In shape memory, materials transform into predetermined geometry upon external stimuli [49]. On the other hand, external stimuli induce automatic actuation in materials in the self-actuating mechanism [50], and the biomedical industries, including tissue engineering (TE), wound healing systems, drug delivery systems (DDS), and 3D bioprinting, make substantial use of self-healing hydrogels [51,52]. Additionally, orthodontics uses specialty polymers for fundamentals, qualities, advancements, and applications [53].

3. Techniques used in rapid prototyping

RP has advanced significantly since being discovered. There are now more than 30 methods, some of which are used commercially and the others are in the development stage. But the precision has substantially increased. Dentistry typically employs four techniques, namely:

3.1. Stereolithography

It has become the most widely used RP method because of its precision and surface polish. Using a photosensitive liquid resin that solidifies when exposed to an ultraviolet (UV) laser, this approach creates 3D polymers. As the resin is subjected to UV light, the layers successively cure. A second layer of resin is exposed and cured after the first layer has dried and the resin platform has been lowered inside the bath by a predetermined amount. Repeatedly lowering the platform into the resin bath and curing the object until the entire model is finished. Its ability to construct parts with intricate geometries with excellent geometrical accuracy and surface quality are its standout features. Cuperus et al. [54] examined the validity and reproducibility of stereolithographic models for measuring dentition-wide distances. The term “quick cast” refers to recent software developments in stereolithography that are used to create parts with hollow interiors that can be used straight away as investment casting wax patterns. Additionally, a technique for selectively coloring areas of stereolithography models to highlight areas of interest has been developed.

3.2. Fused deposition modeling

After stereolithography, this technique is the second most used one. This method uses a moving tip in the X-Y plane to extrude heated thermoplastic filaments. A supporting structure with a low temperature is built by the extrusion head depositing a thin bead of materials on it. Similarly, the item is formed via layer-by-layer deposition and hardening. Materials such as polycarbonates, polyphenylsulfone, and investment casting wax are used in the fabrication process. For RP, fused deposition modeling is the most economical and fastest process. Color-different prototypes can be produced. It is a simple and practical building method that uses minimal materials and exposes users to no hazardous chemicals.

3.3. Selective laser sintering

Using this laser-beam-based technology, powdered materials such as metal, elastomer, and nylon can be transformed into solid forms through a process called selective fusion. Nylon composite, investment casting wax, metallic, ceramic, and thermoplastic composite are used in its fabrication. With a wide variety of materials, this innovative process can create the toughest parts. It processes quickly and results in less thermal distortion.

3.4. Inkjet printing

3.4.1. What is inkjet printing?

The jetting heads, which are filled with liquid materials like liquid photopolymer resin, spray the material in the required pattern in an X-Y plane, forming the object's layer. Micron-level detail, precise surface quality, and low material usage are benefits of inkjet printers. Models for prototypes are useful in many ways. These work great as visuals while explaining concepts to patients or other coworkers. Furthermore, in comparison to other 3D printing methods, this method offers low cell densities and rapid production speed [55]. Repeated verification can lead to better visualization, and the prototype design can be recycled. Cost is its primary disadvantage, and clinical judgment is still essential despite the digital nature of the procedure. Figure 1 show various techniques used in rapid prototyping.

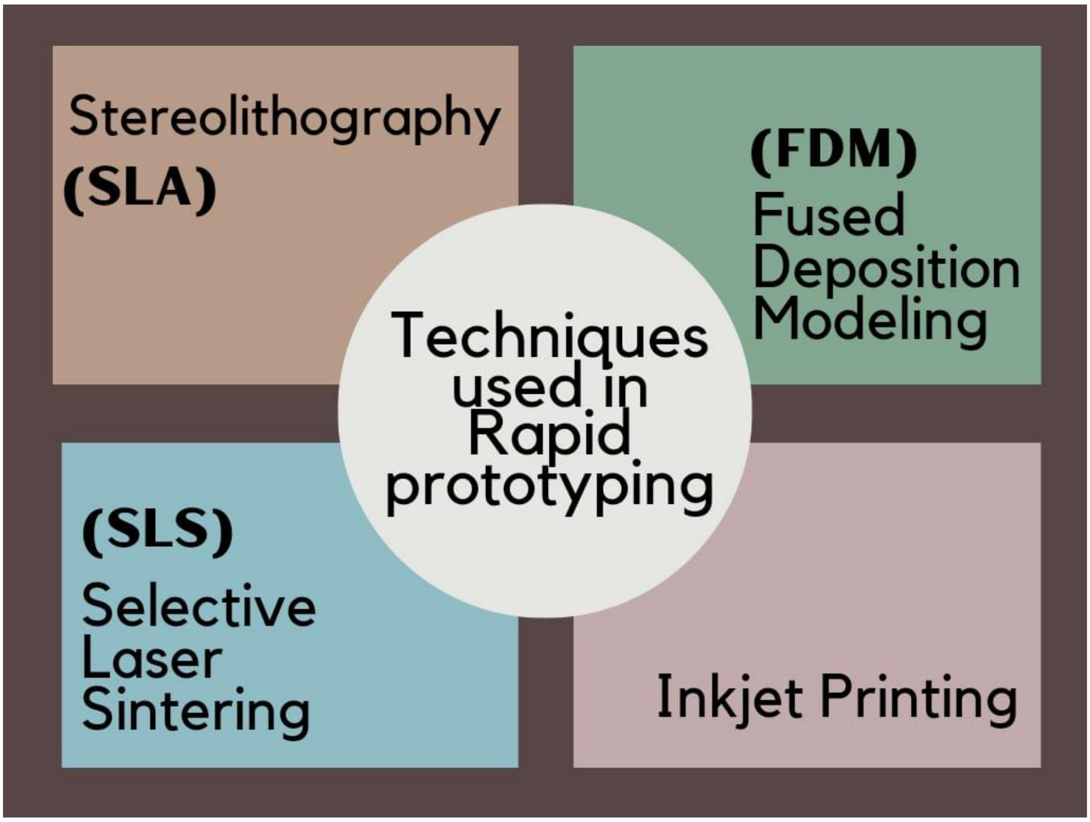

Figure 1. Schematic diagrams showing various techniques used in rapid prototyping.

3.5. A comparative analysis of different rapid prototyping techniques, highlighting their advantages and limitations in orthodontic applications

A tabular comparison below (Table 1) highlights the advantages and disadvantages of various rapid prototyping methods used in orthodontics.

Table 1. Highlighting advantages and disadvantages of different rapid prototyping techniques in orthodontic applications.

Techniques of rapid prototyping	Advantages	Disadvantages
Stereolithography (SLA)	• Excellent resolution: SLA is capable of obtaining incredibly fine details and quality. • Fast printing: Compared to some other resin-based 3D printing methods, SLA prints more quickly.	• Material restrictions: Less variety of materials in comparison to alternative technologies. • Post-processing: Post-curing and further post-processing procedures are usually essential to SLA prints. • Price: In comparison to FDM, SLA printers and resins may be more costly.
Fused Deposition Modeling (FDM)	• Affordable: Since FDM printers are often less expensive, small enterprises and amateurs may afford them. • The material variety: A range of thermoplastic products can be used with FDM. • Usability: FDM is comparatively simple to understand and apply.	• The layer lines: FDM prints often consist of visible layer lines, which change surface smoothness. • Minimal detail: In comparison to certain other technologies, this one achieves a lower resolution. • Support structures: After printing, supports that are required for overhanging structures must be eliminated.
Selective Laser Sintering (SLS)	• The material adaptability: SLS works with a broad variety of materials, such as polymers, metals, and ceramics. • Complex geometries: It is capable of creating complex geometries with moving pieces. • No need for support structures: Since unsintered material functions as a natural support, SLS doesn't require any.	• Surface smoothness: In comparison to other technologies, SLS products might have a rough and uneven surface quality. • Machinery costing: SLS devices can be pricey, which limits certain consumers' access to the technology.
Inkjet Printing	• Tremendous clarity: Inkjet printing is appropriate for applications requiring fine features because it can reach high levels of detail and resolution. • Colour printing: It is appropriate for producing authentic prototypes or models since it allows for full-color prints. • The material diversity: Powders, liquid photopolymers, and other materials can all be used with inkjet printing.	• Speed: The inkjet process's speed is typically less than that of certain other 3D printing methods. • Material limitations: Additionally, the materials that may be used with it are restricted in their range.

4. Application in orthodontics

4.1. Diagnosis and treatment planning

The tooth is considered impacted when its eruption is either halted or retarded. Diagnosis of impacted canines is based on clinical and radiographic findings that no spontaneous eruption can be expected [56]. Permanent maxillary canine impactions occur in 1% to 2% of the general population, second only to the impaction of third molars in frequency [57]. The ratio of impaction occurs twice as often in women than in men, and five times more often in Caucasians than Asians [58,59]. Palatal impaction is in about 85% of these cases, whereas 15% of these impactions are facially located [60,61]. Finding the precise location of a maxillary impacted canine is necessary for treatment. To diagnose and plan therapy for an impacted maxillary canine, Faber et al. [62] in his study employed the RP model where the CT slice pictures were layered in 0.5 mm intervals on top of one another. The models were created by superimposing the 0.016 mm layers of acrylic resin polymerized with UV light cure on top of each other using an RP machine and CT data uploaded into CT image processing. As a tool to expose the tooth during surgery using intraoperative guidance, the RP model demonstrated a precise anatomical link between the impacted tooth and the teeth around it. A metal attachment for the canine traction was made using the model, which was also utilized to interact together with the patients and parents.

Pessa [63] performed a study on high-resolution stereolithography and concluded that how high-resolution stereolithography may be useful for face aging studies. The preoperative planning of complicated dentofacial abnormalities involves stereolithography. CT scans were taken of both Younger (mean age 20.2 years) and aged (mean age of 58.8 years) persons (n = 20). For each patient, the laser polymerization procedure created an identical duplicate of the face skeleton. The angles of the maxillary wall and the piriform aperture as specified by certain locations were measured about sella nasion. Changes in height, breadth, and depth were also assessed. Age-related angular alterations were discovered. With aging, from 69 to 56.8° on average, the maxilla's angle to the sella nasion is decreased. Similarly, the piriform's mean angle dropped from 65.1 to 55.7°. Age-related angular change shows that distinct growth rates may persist throughout life.

4.2. Fabrication of orthodontic removable appliances and impression trays

The newest high-tech orthodontic treatment approach, Invisalign, has received attention. Invisalign is manufactured with excellent precision and time savings using RP. A set of polyvinyl chloride impressions were employed by Lee et al. [64], who uploaded the impressions to a fully editable computer model in Stereolithography (STL) file format to OrthoCAD. An identical impression was delivered to Technology of Align for the creation of aligners when the 3D image model was finished. The practice of producing splints now practically ensures that no patient will ever receive an identical splint more than once. Compared to manual processes, digital production offers consistency, precise quantitative control, and speed. Direct digital manufacture of metal and plastic parts is offered by RP [65]. Contrary to earlier attempts, which required the patient's oral tissues to be digitized using a costly laser scanner, this method is straightforward since it regularly uses affordable cone-beam CT (CBCT) data [66]. The creation of removable orthodontic equipment involves the use of CAD and computer-aided manufacturing methods. Al Mortadi et al. [67] created a novel technique for integrating wire into a single construction. Class II Division 1 dental model were scanned, and the resulting three-dimensional pictures were shown on a two-dimensional computer display.

4.3. Orthognathic surgery

The cephalogram, dental study casts, and face photographs are common diagnostic and treatment-planning tools in orthognathic surgery. These have drawbacks, particularly when there is a face asymmetry, in precisely assessing the spatial connections of bone components. Typically, surgeons depend on their own perception and personal experience. In these situations, using a 3D RP model aids the surgeon in planning and carrying out surgical treatments to get better operational results. It offers a simple method for measuring asymmetry-related discrepancies on the model directly, as well as a chance to evaluate the patient's bone structures and adjust them as needed before the real operation. Pharmacologically, specific drug administration to bone marrow mesenchymal stromal/stem cells (BMSCs) could prevent proliferation and osteogenesis [68,69]. Stereolithography has also been used to create surgical splints as part of computer-assisted orthognathic surgery [70,71].

4.4. 3D-Occlusal splints

The primary treatment option for individuals with temporomandibular disorders (TMDs) with bruxism is occlusal splints [72]. These are removable appliances that are placed on either the lower or upper jaw and adjust the way jaws fit together. In 70%–90% of TMD situations, their use is successful [73]. Additionally, for those with bruxism, occlusal splints can prevent or minimize tooth wear. Modern dentistry has benefited from the use of additive (3D-printed) and subtractive (milling) technologies which are made possible by CAD/CAM; the digitally supported process of fabrication [74–78]. In contrast to milling production, 3D printing, or additive manufacturing, was initially introduced in 1986 and was not immediately adopted by the dental field [79,80]. One of the main benefits of additive manufacturing over milling in terms of producing specific products is reduced material waste. The capacity to construct complicated geometries, reproducibility, ease of usage and production, high productivity, and cost-effectiveness are its other benefits. At present, the two types of additive manufacturing technologies most commonly utilized for creating occlusal splints are SLA and digital light processing (DLP).

4.5. 3D printing and aligners

Orthodontic intervention is strongly associated with better quality of life at a time when advanced technologies are receiving a lot of attention [81]. More emphasis is being placed on esthetic-centered orthodontic appliances, to provide a more acceptable dentofacial look and comfort during the treatment, and not just after the treatment. Clear aligners are customized, removable appliances designed to effectively cure mild to moderate malocclusions with "comprehensive cosmetic orthodontic treatment" [82]. Through the use of subsequent sets of plastic aligner trays that are utilized and changed at predetermined intervals during treatment, the appliance gradually moves teeth. The clear retainer that Zia Chisti wore following the completion of his traditional braces treatment was designed by a multinational medical device company [83]. In 1997, using CAD/CAM, his group of Stanford University graduates established 'Align Technology,' a Silicon Valley start-up. It has now become a booming area of orthodontics as a result of patient interest growing over time and the entry of numerous firms [84].

4.6. Fabrication of surgical template for implant placement

A surgical template for the mini-implant was created utilizing rapid prototyping by Kim et al. [85] Viewing the CBCT pictures allowed the clinician to establish where to place the mini or small implants on the posterior part of the maxilla. Software for interactive image segmentation converts CT image data into a format that can be used with an SLA. This device segments the alveolus and the tooth in the resin model using various laser intensities. In this manner, using reproductions of the models, surgical templates for the correct positioning of orthodontic mini-implants were created; the surgical guides were then employed for the exact insertion of the mini-implant. To distinguish between teeth, an alveolus, and the maxillary sinus wall, color 3D RP was utilized. This 'surgical guide' was applied to the clinical site, enabling accurate mini-implant insertion and precise pilot drilling.

4.7. Lingual orthodontics

Additionally, RP is utilized to create personalized lingual brackets for later investment [86]. The desire for maximal originality in lingual appliances is met by the use of CAD/CAM technology. A typical two-phase silicone imprint was taken to begin the production process, according to Wiechmann et al. [87]. To create a specific target arrangement, molds made from this imprint are employed. An optical 3D canner with high resolution was used to do noncontact scanning of the treatment setup (GOM, Braunschweig, Germany). The result was a compound surface made up of a large number of tiny triangles (STL surfaces), which can be turned, observed, and processed using specialized design software. High-end RP machines were then used to transform the wax analog into the finished product, which was made of an extremely hard alloy with a high gold content.

Wiechmann et al. [88] with the help of the rapid prototyping method, attached Herbst to a lingual orthodontic (LO) appliance. He employed a LO appliance that was made with cutting-edge CAD/CAM software and premium RP methods. A CAD/CAM technology served as the location of the telescopes' interaction with the lingual orthodontic device. The bands of the maxillary molars and mandibular canines were attached to the individual labial pivot base. The precise and efficient operation of the telescope mechanism is guaranteed by the particular CAD portrayal of the interface, which guarantees an ideal 3D tube and plunger position.

4.8. Distraction osteogenesis

Salles et al. [89] accompanied a case report of a patient with aglossia who had abnormalities of the dentofacial region that had specifically damaged the mandible, demonstrating the fact of how important role the tongue plays in facial growth. To create an osteogenic distraction of the mandibular symphysis, a distractor was made with the help of RP jaw models. Figure 2 highlights various applications of rapid prototyping in orthodontics.

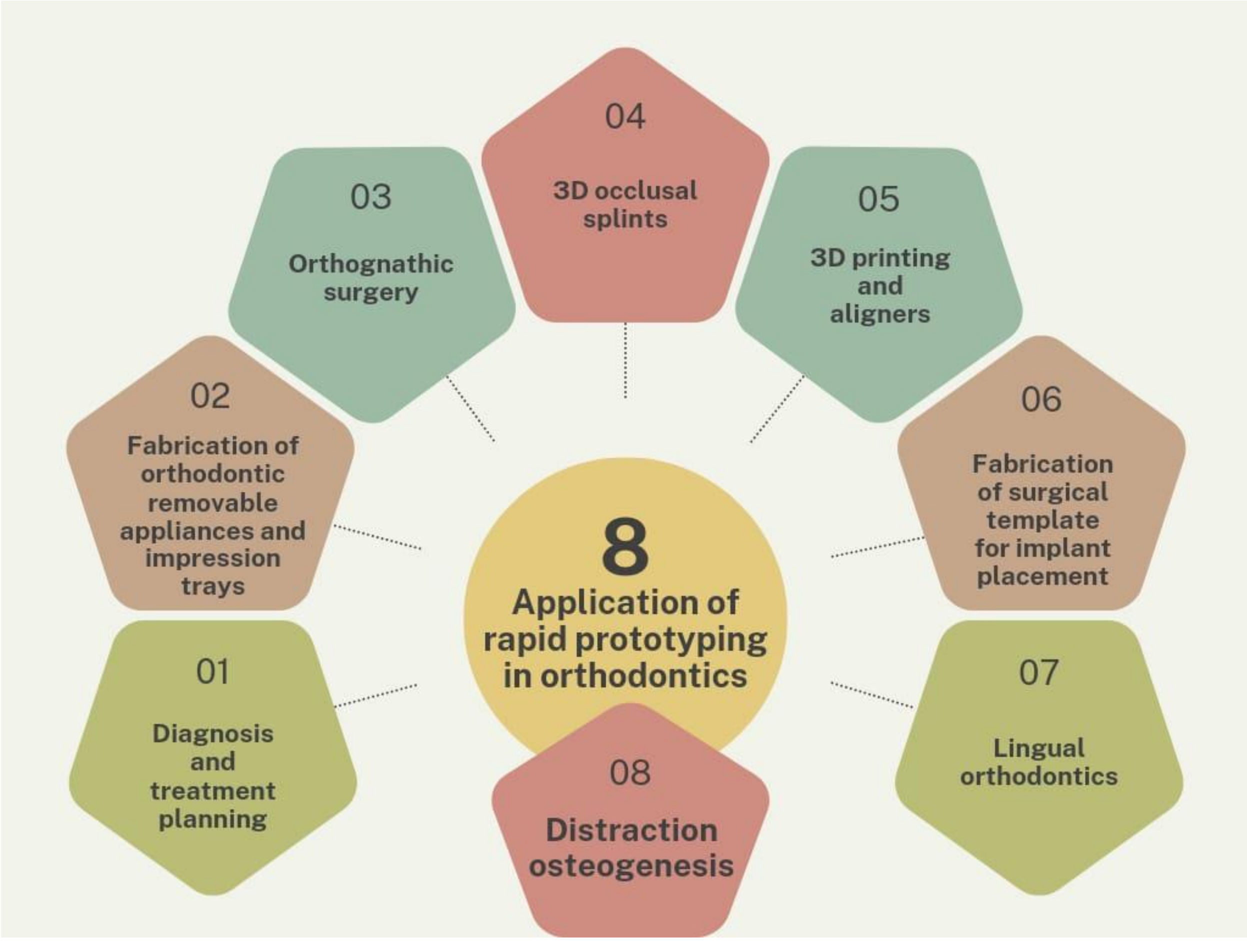

Figure 2. Schematic diagrams showing various applications of rapid prototyping in orthodontics.

5. Limitations and potential challenges in the adoption of rapid prototyping in orthodontics

To reduce the risk of upper incisor trauma, it is advised to address some malocclusions, such as class II division 1, at an early age [90]. However, the availability of well-known removable functional appliances is hindered by financial restraints and a shortage of experienced technicians. Finding workers is getting harder and harder, especially for dental technicians with orthodontic specialization. In addition, a lot of patients and offices experience financial difficulties, which means we need to look for an appropriate solution. Automation is one potential solution to the difficulties we must adapt to. This could make it possible for us to produce products like removable appliances for early orthodontic treatment more affordably and with fewer or no technician necessities. There are three ways to use removable functional appliances in the early treatment of Class II Division 1, these include

1. Fully customized appliances built by a skilled technician by set guidelines.
2. Prefabricated appliances with multiple functions (PMAs).
3. Digitally created and manufactured by 3D printing (CAD/CAM) technologies.

Even though 3D-printed appliances are practical, they still need to be improved.

1. Plug-ins are necessary for IT management because of software limitations. This requires software engineering expertise, and more intuitive and user-friendly modeling is needed to develop dental technician devices.

2. Further research on resins is required to improve their functioning and biocompatibility.

However, the system has many advantages as well. It allows practitioners to save time, money, and courier expenses by capturing impressions using conventional methods or intraoral scanning and emailing them to the destination organization. There is no requirement for a physical model if the impressions turn out to be unreliable; the procedure can be repeated at no additional cost. On the other hand, 3D bioprinting provides a way to create custom, therapeutically appropriate sized, hierarchical structures [91–96].

Resin shrinkage is a major source of dimensional errors in 3D printing. Several factors can affect the accuracy of 3D printed objects: the rate and power of the polymerizing energy source; the build's direction and orientation; the placement of 3D objects on the build platform; the quantity and arrangement of supporting structures; the number of layers and the material's shrinkage between layers; and postprocessing techniques.

- Certain RP techniques are still costly and inefficient.
- Diminished strength and surface smoothness of the material.
- Lack of skilled labor.
- Minimal material variety.
- Prototype testing is impacted when important features are ignored because they cannot be designed.
- Confusion among end users and clients misinterpreting it as the completed project or a developer's misinterpretation of the user's expectations.

6. The future perspective of biomedical 3D printing and rapid prototyping

Biomedical 3D printing is expected to see significant ongoing investment and innovation, if current research trends are any indication. We anticipate that the technology will extend further, and the idea of 3D printers being utilized in pharmacies is now highly probable. Hospitals must make a large financial commitment to biological 3D printing, but with careful planning, the advantages can easily exceed the disadvantages. As technology advances, a new regulatory framework that guarantees the efficacy and safety of biomedical 3D printing objects must be defined by the Food and Drug Administration, along with standardized terminology.

7. Future research directions and potential advancements in rapid prototyping relevant to orthodontics

Orthodontics in particular has benefited greatly from the rapid advancement of modern technologies in dentistry. One of the newest technologies in the manufacturing sector is 3D printing. Making dental casts was one of the very first uses of 3D printers in orthodontics. Dentists were now able to take dental impressions utilizing the intraoral scanner, without the patient discomfort that came with traditional impressions. An image that could be printed in 3D was produced by intraoral scanners [97–100]. Charles Hull unveiled the first 3D printer in 1986. Hull discovered SLA and created the first 3D printing technology in the same year [101–104]. Following another 4 years, Scott Crump [105] introduced FDM. SLA printing technique gained popularity in the dentistry industry due to its stiffness and accuracy. These days, liquid crystal display (LCD), direct light processing (DLP), and Laser-SLA are the three most widely utilized 3D printers. A VAT and building platform are included in those three categories of printers. To produce the printing model, liquid photopolymer resin is put on the VAT. Fused filament fabrication (FFF) is another type of printer that is gaining popularity. The extruder and the construction plate make up the majority of these printers. To construct the model on the plate, a plastic-based material is heated using an extruder. And last, the PolyJet photopolymer (PPP) is a highly well-liked 3D printing technology. Inkjet print heads, a build platform, and a material container make up the PolyJet printers [106–109]. With the advent of 3D printing technology, dentists could now send affordable appliances straight to patients, avoiding the dental lab. The objective of this paper is to conduct a thorough literature analysis, discuss the accuracy of various 3D printer types, and highlight other elements that may have an impact on the 3D printing of dental models for the orthodontic profession.

8. Conclusions

The integration of rapid prototyping and 3D printing technologies into orthodontics has marked a paradigm shift in the way practitioners approach treatment planning and appliance design. The ability to create patient-specific models with unprecedented accuracy has not only improved the precision of interventions but has also enhanced the overall patient experience. The efficiency of these technologies in producing customized orthodontic appliances, such as braces and aligners, has streamlined treatment processes and contributed to more predictable outcomes.

While the adoption of rapid prototyping and 3D printing in orthodontics has shown remarkable progress, challenges remain. Issues related to material selection, cost-effectiveness, and standardization need to be addressed to ensure widespread integration into orthodontic practices. Additionally, ongoing research and development are essential to refine techniques and explore new applications for these technologies in the evolving field of orthodontics.

Looking ahead, the future of orthodontics appears promising, with rapid prototyping and 3D printing set to play an increasingly pivotal role. As advancements continue, the technology is likely to become more accessible, cost-effective, and seamlessly integrated into everyday orthodontic workflows. This trajectory holds the potential to revolutionize the field, providing orthodontic professionals with powerful tools to deliver personalized and efficient treatments, ultimately improving patient outcomes and satisfaction.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

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