Be your own manufacturer: 3D printing intraoral appliances

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Three-dimensional (3D) printing has revolutionized the world of orthodontic manufacturing. Orthodontists are no longer beholden to the limited specifications of traditional orthodontic manufacturing companies and now have a wide variety of customization options for their patients. In this paper, we will discuss orthodontic appliances that are currently 3D printed, many of which orthodontists can start printing in their offices today. Other available 3D printed appliances, which still require commercial printing options, will also be discussed. (Semin Orthod 2021; 27:184–188) © 2021 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

Introduction

Since the late 1970s, orthodontists have primarily depended on traditional manufacturing for production of their appliances. Currently, very few items are fabricated in-office. This manufacturer-dependent practice model allows for the treatment of more patients per doctor, but it has also led to less control over appliance customization, as well as significant increases in practice overhead. Traditional manufacturing has also contributed to the commoditization of orthodontic treatment.

On the other hand, additive manufacturing or 3D printing, allows custom designs to be directly manufactured and utilized in patient care. The simplified, “design to fabrication” nature of 3D printing has given orthodontists control over their treatment plans, providing patients with an efficient, safe, and a more comfortable experience. Also, 3D printed orthodontic appliances are becoming easier to fabricate in-office, with many requiring just computer software and a moderately-priced 3D printer system.

3D printed intraoral resin appliances

With the development of clear aligner technology in the 1990s, 3D printed resins have risen in popularity as a replacement for dental stone. While 3D printed dental models were among the first applications of 3D printing in orthodontics, they do not represent a true intraoral application of printed resin. Since the intraoral appliance is a thermoformed aligner, the 3D printed base model does not need to adhere to the same strict FDA requirements for intraoral use.

True intraoral resins must be approved by the FDA and undergo strict biocompatibility and cytotoxicity testing. These materials are dimensionally stable, color stable, and resistant to degradation in the oral environment. In addition, a separate, systematized process for washing and post-curing newly printed intraoral resins must be followed to ensure uniform quality and to avoid contamination with non-intraoral resins. Formlabs was the first company to offer affordable washing (FormWash) and curing (FormCure) units for in-office use (Fig. 1).

The ease and repeatability of 3D printing systems are instrumental in bringing this technology to in-office applications. Braces On Demand is the first company to allow orthodontists to choose from a wide variety of bracket prescriptions (Fig. 2A and B), elastic hooks (Fig. 3A and B), Class 2 correctors, and other fixed appliances (Fig. 4A and B), and then have these digital files sent directly to their in-office 3D printer. This exciting technology will continue to expand its capabilities,
Fig. 1. The Formlabs Form 3B, along with the FormWash and FormCure.

Fig. 2. A and B. A. Braces on Demand twin brackets. B. After 2 months. (Courtesy of Tom Shannon).

Fig. 3. A and B. A. Braces on Demand Caplin hooks used to help erupt the upper right canine. B. With aligners. (Courtesy of Tom Shannon).
allowing orthodontists to make even more custom 3D printed appliances in their office.

3D printed metal appliances

3D printed metal, also known as direct laser metal sintering or selective laser sintering, utilizes focused lasers to sinter metal in a powder form. Through the utilization of 3D metal printing, clinicians can easily design orthodontic appliances that were previously time consuming or impossible to fabricate with analog processes. Additionally, there is no need to place separators because 3D printed metal “bands” overlay on the occlusal surfaces and do not require additional interproximal space.

Currently, the most common 3D printed metal appliance is the hyrax-style RPE, but a wide variety of appliances can be printed (Fig. 5A-F). Although 3D printed metal appliances are currently more expensive than their analog counterparts, they can be less costly in other ways. Decreased number of appointments, reduced chair time, and increased patient comfort are just a few of the many advantages of 3D printed metal appliances.

3D metal printers are not currently cost effective for most orthodontic offices, as prices range from $100,000 to more than $300,000. As software improves and printers evolve, reducing the cost of equipment, it is possible that 3D metal printing technology will follow a similar path of resin printers over the last decade.

Customized 3D printed brackets

During the past century, orthodontic brackets have evolved from simple tooth attachments to highly variable fixed appliances with pre-adjusted prescriptions. Although anatomical averages are built into each pre-adjusted bracket, time-consuming wire bending is still necessary to finish the case. Despite its revolutionary step forward, pre-adjusted bracket technology is now more than 40 years old!

Customized, patient-specific orthodontic brackets are the next step in treatment efficiency. They utilize intraoral scanning and orthodontic simulation software to design brackets with ideal physical attributes to move teeth into the desired alignment. In the past, customized brackets were made of metal and fabricated using traditional techniques, but recently 3D printing has been utilized.

LightForce Orthodontics is the first company to 3D print customized, patient-specific orthodontic brackets (Fig. 6A and B). Polycrystalline alumina ceramic is 3D printed into twin brackets with idealized geometries, allowing for highly efficient tooth movement. In addition, an indirect bonding tray is fabricated to ensure accurate bracket placement.
LightForce only 3D prints brackets from second premolar to second premolar. Their brackets currently come in two colors—cloud and light. While customized ceramic brackets are expensive and require commercial labs for fabrication, traditional resins and ceramic-filled resins may be utilized in the future to print custom brackets in-office.

**3D printed resin aligners**

Align Technology pioneered mass production of clear aligners more than 20 years ago, with many other companies following in their footsteps. Recently, the low price of 3D printers and availability of 3D modeling software has allowed these processes to be brought into the orthodontic office. In-office aligners have become increasingly popular as they offer many advantages, including: control over the simulation, freedom to use a variety of aligner materials, superior logistics, and decreased cost.

Despite these advantages, 3D printed resin base models and the remnants of the thermoforming sheets are currently unrecyclable. To lessen the waste of traditional aligner fabrication, it is now possible to directly print aligners without a resin base model. While there is currently no FDA-approved resin for direct 3D printed aligners, several companies are in the late stages of development.

However, in order for them to become mainstream, several challenges must be resolved: the FDA-approved aligner resin must cost equal or less than the current combination of traditional 3D printed resin and thermoformed aligner material, the mechanical properties of the 3D printed aligner resin must be similar or better than

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**Fig. 6.** Previous comprehensive aligner treatment, but UR3 did not erupt fully. Braces On Demand Pivots™ were placed UR4-UR2 to erupt UR3 (courtesy of Dr. Tom Shannon).

**Fig. 7.** Examples of 3D printed metal appliances (courtesy of Motor City Lab Works).
current thermoformed polymers, and the resin post-processing must be simple and efficient.

EnvisionTec has developed a polycarbonate-based resin than can be directly printed into an aligner (Fig. 7). This proprietary resin requires no special equipment for post-processing, just the addition of nitrogen. Currently, 8 aligners can be printed in less than 2 hours using the EnvisionTec One 3D printer.

Conclusion

We are living in an exciting and increasingly digital era of orthodontics. 3D printing has allowed orthodontists to take control of their practice overhead and treatment planning individuality, and in many cases even become their own manufacturer for a wide variety of appliances. 3D printing technology has and will continue to revolutionize the patient and doctor experience, leading to a new era of digital treatment planning, customization, and efficiency.

References