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Review

The Use of 3D Printers in Orthodontics - A Narrative Review

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Main Points

- The use of 3D printers and intraoral scanners eliminate the need for dental impressions and processes such as gypsum casting for some orthodontic workflows, providing a fully-digitalized workflow.
- A large percentage of the articles focused on the accuracy and precision of 3D-printed orthodontic models.
- There is limited information about the production of devices such as removable appliances with metal hooks consisting of multiple materials.
- The ability to produce completely patient-specific designs from 3D printers has allowed doctors to develop new solutions (customized chain for impacted tooth, replica tooth etc.).

ABSTRACT

Developments in computer-aided design and three-dimensional (3D) printing have revolutionized the workflow for orthodontic applications. The purpose of this review article is to provide information about 3D printer history and types, appliances manufactured using 3D printers, and new designs that can be used in different cases. Articles published between January 2010 and November 2020 were reviewed on PubMed, MEDLINE, ScienceDirect, Elsevier, and Google academic resources, and 69 were identified as appropriate for the study. It was seen that bracket and archwires, nasoalveolar molding devices, orthognathic surgical splints, removable appliances, expansion appliances, clear aligner, retainers, auxiliary attachments, and working models can all be made with 3D printers. The 3D printer is now a technology that is easily accessible to orthodontists, increasing the production of different customizable appliances and promising a transition to a digital clinical workflow in the future.

Keywords: Printing, three-dimensional, stereolithography, 3D printer

INTRODUCTION

Technological advances have affected dentistry in various ways, one of which is the utilization of three-dimensional (3D) printers and the additive manufacturing principle for producing appliances. This new system, unlike subtractive manufacturing, is based on building the desired product layer by layer, making it possible to produce more precise and complex objects. Particularly over the last decade, studies indicate that the demand for 3D printers has significantly increased in orthodontics.[1] The American Society for Testing and Materials defines 3D printing as: “the creation of an object from 3D model data by adding layer upon layer, unlike subtractive manufacturing techniques”.[2] Each of these layers can be viewed as a thinly sliced horizontal cross-section of the object made.

The foundation for 3D systems were laid by Charles Hull in 1986, when he launched a Stereolithographic 3D printer.[3] A few years after the first 3D printer’s release, Scott Crump developed the fused deposition modeling (FDM) (3), and in 1995, Prof. Ely Sachs invented the inkjet printer system, which could be used in metal materials and coined the term “3D printing” for the first time.[4]

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A file format STL, was developed by Charles Hull, to define the surface geometry of three-dimensional models through triangles and ensure their transfer to the printer.[5] It is available on almost all computer-aided design (CAD) and 3D printers due to its simplicity, open-source code, and universal format.[5] STL, which does not have any color scale and prints items in one color, is one of the most widely used file extensions even 30 years after its creation.[5]

The most commonly used types of 3D printers in orthodontics include stereolithography (SLA), FDM, digital light procession (DLP), Polyjet photopolymer (PPP), and selective laser sintering (SLS).[3] SLA is the first developed type of 3D printer.[4] The production process begins by sending an ultraviolet laser beam to the liquid photo-curable resin pool. The laser contact resin is cured and solid, and after the first layer is cured, the moving structure platform goes down until a layer thickness, creating space for the new layer to cure.[3,6] After the production of the object is finished, some post-curing processes are required to clean the non-polymerized resin and increase the degree of polymerization of the product. Although this process increases the cost and duration of the method, the high resolution and quality of the produced objects ensure the continued demand for SLA today.[6] In orthodontics, stereolithographic 3D printers have been reported to be used in surgical guides, clear aligners, occlusal splints, retraction hooks, removable appliances such as activator, nasoalveolar molding (NAM) devices, aligner attachments, and craniofacial - dental tissue engineering.[1,7-9] DLP is the same as SLA except for the light source. Unlike the spot laser on the SLA, light is projected as a plane to cure an entire layer immediately.[3] This difference allows DLP to produce in less time than the SLA. DLP and SLA are vat polymerization type (liquid chamber) printers.

FDM is separated from SLS and DLP by using a thermoplastic polymer. The head part called the Nozzle is preheated and melts the thermoplastic material during its passage and sends it to the platform in semi-liquid form, and the polymer begins to solidify as soon as it spreads to the surface. The product consists of layers and overlapping of the melting filament. The shrinkage of the material during hardening and the limited materials that can be used in production creates disadvantages, while the advantage is that they do not require post-processing after printing and produce quickly.[6] FDM, which is one of the most widely used 3D printer types in the world, has been used for production in orthodontic models, retainer, aligner, surgical guide, and bioprinting studies.[10,11]

PPP creates a model by spraying the photopolymer resin layer by layer on the table and curing it with ultraviolet radiation at the same time. High-end PPP printers can print multiple materials on a single model.[3] PPP printers typically waste more material than other technologies, which increases the cost of use.

SLS-selective laser melting (SLS-SLM), developed by the University of Texas in 1989, is a system where layers of powder material are melted with a CO_2 laser to create 3D objects.[6] Layers of powder material are applied to the surface via a cylinder, and a new layer of dust is added after each melting process. The selective structure of the laser allows complex geometries to be obtained. It also enables the use of various materials including polymers (such as polyamide, polycaprolactone), hydroxyapatite, glass, ceramics and metal powders such as Co-Cr, titanium, and stainless steel.[3] Due to the mechanically strong structure of printed objects, it has been used to fabricate rigid metal structures such as implants,[12] retainers,[13] or maxillary expansion appliance[14] used in orthodontic and oral surgery.

The current article examines the areas in which 3D printers can be used in orthodontics by conducting a review of the current literature. A review of the literature published between January 2010 and November 2020 was conducted on MEDLINE, ScienceDirect, Wiley Online Library, Google Scholar, and PubMed. The keywords "3D printing, orthodontics", "SLA, and orthodontics" were used. The articles were scanned by one researcher (T.E). The search results are presented in Table 1. Mendeley desktop software (Mendeley Desktop, version 1.19.8, Mendeley Ltd., Elsevier Inc., NY, USA) was used as a reference manager to manage the search results. Using this tool, 169 duplicate studies were removed. Books, book parts, editorial letters, generics, dissertations, non-English articles, and articles that cannot be viewed even their abstract were excluded. Additionally, articles non-associated with orthodontics, and those that do not focus on the use of 3D printers were excluded. The most recent 69 articles that meet our criteria were included in the review.

Orthodontic Models

Many studies have evaluated the precision, accuracy, and reproducibility of orthodontic models produced from 3D printers. Most studies have shown that models made from 3D printers are suitable for clinical use[15-21] except for the study of Nurazreena et al.[22] (Table 2). Various methods have been used to create digital models for 3D printers, such as intraoral scanning, re-scanning existing plaster models, or referencing a typodont model. In 2017, Dietrich et al.[15] examined models produced from SLA and Polyjet printing for accuracy and precision, and found that both were clinically suitable for use. Measurements taken on Polyjet models were more accurate than those on SLA models, while the SLA models had higher precision than the Polyjet models.[15] Kim et al.[23] evaluated accuracy and precision digitally by scanning models made with DLP, fused filament fabrication (FFF), SLA, and Polyjet rinting. Models produced with Polyjet and DLP were found to offer more accurate results than

Table 1. Distribution of the articles by database and keywords

	3D printing and orthodontics	Stereolithography and orthodontics
PubMed	226	67
ScienceDirect	275	193
MEDLINE	62	2
Elsevier	12	-
Google Scholar	374	593

3D, three-dimensional

Table 2. Details of 3D-printed model studies included in the review

Authors	Year	Model data source	3D printing system	3D printing material	Layer thickness (μm)	Postprocessing treatment	Modelbase shape	Assesment method	Advised printer type
Dietrich et al.[15]	2017	Patient ios 2 case	SLA Polyjet	Epoxy-based resin (Accura) Photopolymer resins	100 at base/50 tooth level	Unclear	Unclear	By software	Both types suitable
Rebong et al.[20]	2018	Plaster dental cast 12 case	SLA Polyjet FDM	Unclear	100 50 16	Unclear	Unclear	Digital caliper	FDM
Ledingham et al.[19]	2016	Typodont model 30 case	SLA	Calcium sulfate-based substrate	Unclear	High heat Low heat Epsom salt	Unclear	By Software	Epsom salt
Brown et al.[17]	2018	Paitent ios 30 case	DLP Polyjet	Unclear	Unclear	Unclear	Unclear	Digital caliper	Both types suitable
Camardella et al.[24]	2017	Paitent ios 10 case	SLA Polyjet	Light-curing methacrylic resin (E-Denstone; Envisiontec) Photopolymer resin (Full Cure 720; Stratasys)	100 16	Unclear	Regular base horseshoe-shaped horseshoe-shaped with bar	By software	Polyjet
Kim et al.[23]	2017	Typodont model, 14 case	SLA DLP FFF Polyjet	Unclear	50 75 100 16	Unclear	Unclear	By software	Polyjet DLP
Koretsi et al.[16]	2018	Plaster dental cast	Polyjet	MED620	Unclear	Unclear	Horseshoe-shaped	Digital caliper	Suitable
Hazeveld et al.[18]	2014	Plaster dental cast 6 case	DLP Polyjet Inkjet	Unclear	Unclear	Unclear	Unclear	Digital caliper	All replicas are accurate enough
Wan Hassan et al.[22]	2017	Patient impression 10 cast	FDM	High performance composite (Zp151; 3D Systems)	Unclear	Infiltrant modeling	Unclear	Digital caliper	Not suitable
Manuelli et al.[21]	2018	Patient impression 80 cast	Unclear	Unclear	Unclear	Unclear	Unclear	Digital caliper	Suitable
Favero et al.[25]	2017	Typodont model	SLA SLA DLP DLP Polyjet	Grey photopolymer resin (FLGPGR02; Formlabs), unclear	25, 50, 100 100 100 100 28	Immersion baths, unclear	Unclear	By software	All types suitable

Table 2. continued

Authors	Year	Model data source	3D printing system	3D printing material	Layer thickness (µm)	Postprocessing treatment	Modelbase shape	Assesment method	Advised printer type
Zhang et al.[26]	2019	Patient ios	SLA DLP DLP DLP	Dental model resin (Formlabs) Model Orthoresin (Union Tec) Enca-Model Resin (Encashape) E-Denstone Resin	25, 50, 100 50, 100 20, 30, 50, 100 50, 100	Unclear	Unclear	By software	Except of two groups all types suitable
Loflin et al.[27]	2019	Plaster dental cast 12 case	SLA	Gray photopolymer resin (FLGPGR03; Formlabs)	25, 50, 100	Unclear	Unclear	Aboriginal tool	100 um SLA
Scott et al.[38]	2019	Plaster dental cast 15 case	SLA	Gray photopolymer resin (GPGR03; Formlabs)	50	Immersion baths	Unclear	Hand-grading Suresmile	Need future research

IOS, intraoral scanner; SLA, stereolithography; FDM, fused deposition modeling; DLP, digital light procession; FFF, fused filament fabrication; Aboriginal, American Board of Orthodontics

models produced with SLA and FFF, but the highest accuracy was observed in the Polyjet models.[23] Although Polyjet models gave highly accurate results in some studies conducted,[15-17,23,24] there are studies that claim this is not the case.[20]

Print layer height is an important factor that affects the printing time and the precision and accuracy of models. Naturally, researchers have conducted studies on this issue.[25,26] Favero et al.[25] conducted a comparison by using SLA printing to produce models with print layer heights of 25, 50, and 100 µm. The 100 mm layer height group was found to be more accurate than the 50-µm and 25 mm layer height groups.[25] These results suggest that increasing the number of layers increases accumulated of errors and failures during printing, reducing the accuracy of the printed model.[26] Zhang et al.[26] compared models with different print layer heights (20, 30, 50, 100 µm) from 3 different DLP printers to models with different print layer heights (20, 50, 100 µm) from an SLA printer. The highest accuracy was observed in DLP models with a thickness of 50 µm, while SLA models with a thickness of 100 µm showed the lowest accuracy.[26] In contrast to Favero et al.[25], the researchers observed that when the SLA models were examined, the resolution increased with the reduction in the print layer height, the stair-stepping effect decreased, and the accuracy of the model increased.[26] Two studies used the American Board of Orthodontics Cast-Radiograph evaluation (ABO-CRE) rating system, which has proven to be an objective way to evaluate models produced from 3D printers.[27,28] Loflin et al.[27] evaluated the effect of print layer height on the accuracy of 3D printed models using the ABO-CRE system. The researchers compared models with print layer heights of 25, 50, and 100 µm produced from SLA printer, and ultimately concluded that all models are clinically acceptable.[27] Scott et al.[28] used the ABO-CRE system to compare SLA-printed 3D models with values measured manually and automatically by the software (Suresmile), and the software was found to have higher scores on some measurements. It is explained that the software can be used instead of manual measurements if properly scaled.[28]

Today, different base designs can be used for model production. Camardella et al.[24] examined the effect that different model base designs have on the accuracy of models made with SLA and Polyjet printing. They used three different model base designs: regular base, horseshoe-shaped base, and horseshoe-shaped base with bar.[24] The 3D-printed models from the Polyjet printer were accurate regardless of their model base design, but the same cannot be said for the models from the SLA printer.[24] Transverse shrinkage was observed in models using the horseshoe-shaped base design; however, but there was no significant difference in measurements with the horseshoe-shaped base with bar and regular base models.[24]

Orthodontic models are sometimes required for constructing appliances. To prevent the deformation of polymer materials at high temperatures, Ledingham et al.[19] produced 3D-printed models based on calcium sulfate hemihydrate and subjected them to different post-processing treatments to increase their strength. They applied high heat (30 min.-250 °C), low heat

(30 min.-150 °C) and Epsom salt treatment. Epsom salt-treated models might be a viable alternative to the production of soldered orthodontic devices, as they produced statistically significant improvements in their mechanical properties.[19] A review study of 3D-printed orthodontic models was conducted in 2020 and it was noted that several different techniques, production parameters, materials, and evaluation protocols are used, making a meta-analysis impossible.[29] It is recommended that studies be conducted in accordance with a standardized reporting protocol that details all printing parameters, materials used, the post-processing protocol and evaluation time.

Clear Aligners

Aligners can be made with plaster and 3D-printed models using traditional techniques or by printing directly from 3D printers. Geometric inaccuracies are common and frequent due to the heat-forming process and decay of models during the traditional technique in which a thermoforming material is vacuum-formed.[30] Jindal et al.[30] compared 3D-printed aligners with thermoform aligners vacuum-formed from 3D-printed models through finite element analysis (FEA). Eliminating the thermoforming printing process with 3D-printed aligner increased accuracy, while the mechanical resistance and geometric accuracy of the 3D-printed aligner were also high. The next year, Jindal et al.[30] chose thermoplastic materials such as Duran and Durasoft for the vacuum-forming technique and dental LT Resin for direct 3D printing, then compared them using FEA under forces equivalent to a human biting force.[31] Researchers have shown that Dental LT Resin provides an alternative to the conventional materials for manufacturing clear dental aligner due to its compatibility with 3D printers.[31] Jaber et al.[10] used FDM and DLP printing to evaluate the reliability of aligner produced from different 3D-printed models. 3D-printed models produced with FDM and DLP did not show any significant differences compared with the original models. Both 3D-printed models produced were suitable for clinical use, but neither guaranteed the production of clear aligner.[10] In another study, the cytotoxicity of thermoform (SmartTrackInvisalign) aligner produced from 3D-printed models and aligners made directly from different types 3D printers was compared.[32] Dental LT resin was selected for stereolithographic 3D printer, while E-Guard clear material was used in DLP type 3D printer.[32] Post-curing processes that eliminate uncured resin after printing had reduced cytotoxicity. Meanwhile, SmartTrack (a polyurethane material) was considered the most biocompatible material.[32] There was no significant difference in cell viability between Dental LT and E-Guard material. Dental LT and E-Guard Clear, used in the production of aligners from a 3D printer, had slight cytotoxicity (expressing cell viability of 60%-90% after incubation) within the acceptable range compared to thermoforming retainers.[32] However, Edelmann et al.[33] compared the thickness of the aligner they designed digitally and produced with an SLA 3D printer using 2 different types of resin (Dental LT and Grey V4) to the thickness values originally planned. According to the results of this study, Dental LT aligner showed noticeable overbuilding across all intaglio regions. They found that producing aligners directly from a 3D printer can increase aligner thickness by 0.2 mm, thus damaging the functionality of the aligner.[33] Although the resin they use meets most of the requirements that should be in an aligner material, they reported that there is no resin on the market just for aligner production.[34,35] In another study, they found that the print orientation of 3D-printed aligners (with Dental LT resin) and heat exposure and UV curing duration after printing had little effect on overall dimensional accuracy, but considered that the effects of positional differences on 3D-printed aligner should be considered.[34]

Retainers

The retention stage after orthodontic treatment has long been of great importance in maintaining occlusion. With models made from 3D printers, problems such as patient losing their retainer or the retainer degrading have been eliminated with the possibility of easily producing a replacement. In 2014, Nasef et al.[13] designed a virtual Essix retainer, obtaining a digital model from cone beam computed tomography (CBCT) images and producing it with SLS 3D printing. The compatibility of the retainer that was produced was good in the controls, but the opaque white was a disadvantage.[13] In 2017, Nasef et al.[35] compared Essix retainers made from 3D printers via CBCT scans with vacuum-produced thermoforming retainers, examined their accuracy, and found no significant difference between them. 3D-printed retainers have been found to be accurate and reliable compared to traditional vacuum-produced ones.[35] Cole et al.[36] compared 3D-printed Essix retainers, traditional vacuum-formed Essix retainers (TVF), and a group of commercial vacuum-formed retainers (CVF). Models for the CVF group were digitally scanned using an intraoral scanner and sent to Invisalign (AlignTechnology) for retainer production. In the printed group, the models were digitally scanned using a 3Shape TRIOS scanner and the retainers were produced with a 3D printer. Compliance was measured with software that superimposed digital images of Essex retainers and reference models. The TVF retainer group showed minimal deviation from the original reference models.[36] The printed group showed deviation at some points, but its results were similar to those of the TVF group.[36]

A more interesting study was conducted by Jiang et al.[11] to prevent problems that may arise because of patients forgetting their drug intake. They made Essix retainers from a 3D printer, designing them to release constant, low doses of drugs into the mouth. To do this, they chose clonidine hydrochloride, which is used to keep the blood circulation stable as an antihypertensive and pain-relieving agent and extruded it in a hot melt state into the orthodontic retainer made using FDM printing. Although drug release remained high for the first three days in their simulation experiments *in vitro*, the fact that it became stable over time showed that 3D-customised retainers could be promising in the future of regular drug release applications.[11]

Removable Appliances

The first semi-automatic acrylic orthodontic devices were made with 3D printers by Sassani and Roberts[37] in 1996, who stated that it was possible to use digital systems to create orthodontic devices, but that wires and screws had to be pre-attached to the model. Salmi et al.[38] produced two soft removable appliances using SLA printing. One of the appliances applied minimum force and the other applied moderate force, for use in patients who had not previously undergone orthodontic treatment. Although the moderate force-applying device reduced patient comfort, both appliances were tolerated and comfortable to use.[38]

Al Mortadi et al.[7] used SLA printing's stop feature during production for their own designs, Andreasen designs, and sleep apnea devices. They added grooves to the areas where the wires would pass and seated manually bent wires of their choice into these grooves.[7] In 2015, they then conducted a new study to produce metal elements, including Adams clasps and labial arcs, with computer-aided design (CAD) software (version 12, Geomagic FreeformModeling Plus; 3D Systems, Rock Hill, SC) and additive manufacturing technology.[39] A Hawley appliance was printed and then clasps and wires were printed on another 3D printer and added to the base part.[39] This Hawley appliance was produced through intraoral scanning alone without any impressions, also gives hope for future designs.[39]

Orthodontic Auxiliaries

Various orthodontic auxiliaries have also been produced with 3D printers. Nagib et al.[40] produced a customized chain from a 3D printer for impacted canine teeth by taking CBCT images. The attachment was easily inserted during operations and offered increased compliance and good bonding.[40] Ahamed et al.[1] reported that the retraction hook, bite turbo, lingual retainer, and attachments of an aligner can all be produced with 3D printing technology.[2] After creating digital models by scanning dental arches or models, auxiliaries were designed with software, such as Netfabb, and manufactured using FDM or SLA printing.[1] The authors noted that the biggest advantage of 3D printers is the ability to produce customized devices, emphasizing that it will quickly replace older technologies.[1] Park et al.[41] produced a replica tooth with rapid prototyping technology from CBCT images to guide the autotransplantation process. To increase the success of the process by reducing the extraoral time of the tooth they were transplanting, they placed the replica tooth in the recipient socket area.[41] They then extracted the impacted tooth, applied root canal treatment, and placed it in the recipient socket area prepared for it. Additionally, case reports using custom-made 3D-printed miniscrews are also available in the literature.[42]

Customised Brackets

Obviously, trends in the use of patient-specific devices have affected orthodontist's choice of bracket type. Wiechmann et al.[43] determined the bracket positions on digital models obtained from silicone impressions and designed the bracket bases in a tooth-compatible way. They applied the customized brackets created through rapid prototyping to the patient with indirect bonding.[43] Furthermore, in another study, they mentioned a Herbst appliance designed for use with customized lingual brackets.[44] To provide the strong anchoring required by the Herbst appliance, the upper first molar and canine brackets were designed in a band shape and produced as a single unit with pivots from a 3D printer.[44] Krey et al.[45] attempted to use an all-digital workflow to produce customized suspenders. Depending on the location of the customized brackets in the malocclusion model, the researchers created a transfer template and sent the dataset to the construction platform. The customized brackets were printed with DLP printing and then underwent post-processing, which improved biocompatibility.[45] Archwires were also produced according to a template.[45] Furthermore, Yang et al.[46] used DLP printing to convert virtual bracket models into wax patterns. In this study, 3D printing technology, lost-wax technology and selected glass-ceramic ingots were employed to fabricate a customized aesthetic ceramic bracket (CCB) system.[46] Duarte et al.[47] produced the transfer trays used in indirect bonding from a 3D printer for thirty-three orthodontists and investigated the effect they had on the reproducibility of bracket positions. They reported that the digitally-planned bracket and the bracket positions provided by the transfer tray were generally compatible. They also said that the orthodontist's previous experience and number of years of clinical practice had no significant effect on bracket positions with this technique. Plattner et al.[48] evaluated the production stages and durations of the digital and conventional indirect bonding tray and found that the digital laboratory process was longer, whereas the chair time per patient was shortened.

Occlusal Splints

Occlusal splints used for treating temporomandibular joint diseases have also been influenced by the development of 3D printers and digital workflows. Researchers have been able to use 3D printers to produce occlusal splints with adequate accuracy, and this development has shortened lab procedures, labor and patient waiting times compared to traditional manufacturing.Salmi et al.[38] designed an occlusal splint on a digital model obtained with a scanned plaster model and printed the splint using SLA printing.[8] They evaluated the wear and deformations on the splint by superimposing it with the digital model. Splints produced with a 3D printer were found to be as successful as splints produced with traditional methods and their use was recommended.[8] To assess the accuracy of 3D-printed splints, Ye et al.[49] conducted a study by placing digital splints that they designed with a Boolean operation on various offset models adjusted through CAD software (3D Systems, Rock Hill, SC). They produced an occlusal splint with DLP printing and measured the amount of impression material remaining in the airspace between the teeth and splint.[49] The results showed that 3D-printed splints generated from offset dental models can fit on teeth better.[49] 3D printers are used in surgery not only to produce surgical guides but also for the production of intermediate and final splints in serious operations, such as orthognathic surgery.[50-52] In 2014, researchers investigated the accuracy of splints by comparing traditional surgical splints and splints produced through rapid prototyping.[52] The error range of rapid surgical splints was shown to be wide, but they were acceptably accurate.[51] Shaheen et al.[51] supported the clinical use of 3D final occlusal splints after reporting a reduced error rate compared to previous studies. After a few years, Shaheen et al.[50] conducted a new study on 3D intermediate orthognathic splints. This gave acceptable clinical results and reproducibility, and they reported that this protocol can be used for 3D planning and fabrication of intermediate splints for bimaxillary orthognathic surgery.[50]

Nasoalveolar Moulding Devices

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 aspiration using a scanner, seem to allow the clinician to produce appliances with less labor in a shorter time. Shen et al.[54] designed orthopedic devices in accordance with Grayson and Cutting's treatment protocol[53] using CAD software (Rapid Form software, 2006; INUS Technology, Seoul, Korea) 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.[54] The results of the study were comparable to the results provided with traditional NAM treatment, while the number of visits to the clinic and device adaptation time decreased.[54] Grill et al.[55] investigated NAM devices using CAD/computer-aided manufacturing (CAD/CAM) technology (Geomagic® Studio 12, Morrisville, NC, USA) and devices that combine 3D printers with semi-automatic intraoral molding design (Rapid-NAM). This new system, called Rapid-NAM, 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.[55] At the end of treatment, both approaches narrowed the cleft line with leveling of the alveolar segments and produced successful results.[55] In Zheng et al.'s[9] 2019 study, devices designed with CAD software (Rhinoceros 5; Robert McNeel & Associates, Seattle, Wash) and printed from a 3D printer were manufactured independently of the nasal hook and were given the name "split type-NAM devices". In this technique, in which the two are separated to eliminate the negative effects of the nasal hook and NAM devices on each other, the nasal hook supports the nasal cartilage with a band that is supported from the forehead.[9] The resulting models were scanned (3Shape, Copenhagen, Denmark), designed with CAD software, and sent to a 3D printer in STL format.[9] The plates were replaced every week, and the patient was checked-up once a month.[9] With splint-type3D-PNAM treatment, the cleft distance was reduced, the form of the arch was improved, lip segments were brought closer together, and nasal morphology was significantly improved.[9] In 2019, Batra et al.[56] and the next year, Bous et al.[57] published a case series that combined the philosophy of clear aligners and presurgical infant orthopedics. Bous et al.[57] produced models using FFF printing for a patient with a unilateral cleft lip-palate with OrthoInsight 3D software (MotionView Software, Chattanooga, Tenn). This software could segment the alveolar crests and move them to a desirable position.[57] Researchers divided the total movement amount in the cleft line so that it could be digitally modeled with a sequence of 1-1.5 mm, then manufactured 3D-printed models from digital models and printed a clear aligner of 0.4 mm for each model.[57] They did not produce NAM plates directly from 3D printers as the FDA does not allow the use of 3D-printed plates on infants in the United States.[57] In their results, they reported that the clear aligner NAM plate succeeded at closing the segments but that a minor segment was in a more mesial position contrary to what was expected.[57]

There are studies in the literature related to the use of NAM devices manufactured directly from a 3D printer.[58-59] According to Abd El-Ghafour et al.[59], it is easier to treat patients with a full digital workflow, and the treatment results are successful compared to conventional methods. These findings also match the results found by other researchers.[58] Additionally, Gong et al.[58] reported, reduced patient visits and chairside thanks to its full digital workflow.

Surgical Guides

Customized surgical guides have been produced from 3D printers to ensure that miniscrews are positioned accurately, avoiding anatomical structures such as dental roots, the vascular-nerve pack, and thin bones during placement. To assess the accuracy of these guides, Liu et al.[60] determined suitable locations for the placement of miniscrews via CBCT and checked the locations of miniscrews after the use of guides via CBCT. They found that the guides produced with rapid prototyping have sufficient reliability.[60] Hard tissue (bone-teeth) images were provided to choose the appropriate area for the miniscrews, while tooth-bracket-mucous contours ensured that the surgical guide sat well in the mouth.[61] The surgical guide designed was sent in STL format and printed with FDM printing for use in clinical practice, helping ensure the accurate and safe placement of the miniscrews.[61] Some researchers preferred to place the miniplates on the models obtained from 3D printers in the appropriate position and to create a jig from the light-cured resin material.[61] Maino et al.[62] showed the effectiveness of the method they used for the placement of palatal miniscrews with a 3D-printed surgical guide called the MAPA system. In another study concentrating on a miniscrew-supported Hyrax appliance produced with CAD-CAM technology (3-Matic Medical v12.0 tools), a 3D-printed surgical guide was used for the placement of miniscrews.[63] In the literature, there are also studies in which surgical templates or computer-assisted piezocision guides have been produced from a 3D printer to guide a corticotomy carried out to accelerate orthodontic tooth movement.[64]

CONCLUSION

Having resolved storage and plaster model problems with scanners, and with the development of 3D printers, new-generation appliances are being produced cost-effectively and the workload caused by the traditional method is decreasing. This is transforming the traditional workflow into a digital one. While researchers focused more on 3D produced models in the first step, they now use 3D printers for the production of orthodontic appliances or attachments. Although one-stage production has not yet been achieved in the production of devices with acrylic parts and clasps, technological developments are promising.

Ethics

Peer-review: Externally peer-reviewed.

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