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Derleme/Review

In-Office Aligner Fabrication

Ofis-İçi Şeffaf Plak Üretimi

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ÖZET: Ofis içi şeffaf plak üretimi, ortodontik tedaviye devrim niteliğinde bir yaklaşım sunarak ortodonti alanında hızla dönüşüm sağlamaktadır. Bu derleme, üretim sürecini ve süreçte yer alan ana adımları ele alarak, üç boyutlu(3B) tedavi planlaması, üç boyutlu baskı ve baskı sonrası işlemler üzerinde durmaktadır. Şeffaf plakların doğrudan basımı da önemli bir üretim teknolojisi ilerlemesi olarak incelenmektedir. Ofis içi şeffaf plak üretimi, gelişmiş hasta memnuniyeti, diş hekimleri için daha fazla kontrol ve maliyet tasarrufu gibi pek çok avantaj sunmaktadır. Şeffaf ve neredeyse görünmez bir tedavi seçeneği olarak şeffaf plaklar, ortodontik tedavi olmak isteyen hastalar arasında önemli bir ilgi görmektedir. Bu plaklar, düzgün ağız hijyenini ve sınırsız gıda seçimine izin vererek, cazibelerini daha da artırmaktadır. Plak tedavisi, geleneksel diş tellerine kıyasla daha az rahatsızlık ve daha kısa randevu süreleri ile ilişkilendirildiğinden, ortodonti pratiğinde popülaritesi ve etkisi giderek artmaktadır. Plakların doğrudan basımı, diş hekimlerinin 3B baskı teknolojisi kullanarak plakları ofislerinde üretmelerine olanak tanıyarak daha da büyük verimlilik ve kişiselleştirme potansiyeli sunmaktadır. Bu yöntem, birden fazla adımı ortadan kaldırır ve dış laboratuvarlara olan bağımlılığı azaltarak süreci basitleştirir ve tedaviyi hızlandırır. Sonuç olarak, özellikle doğrudan basım yoluyla ofis-içi şeffaf plak üretimi, ortodontik bakımı devrim niteliğinde dönüştürme potansiyeline sahiptir. Üretim sürecini basitleştirerek ve daha rahat, estetik bir tedavi seçeneği sunarak, bu yenilikçi yaklaşımın diş hekimliği topluluğu içinde giderek daha fazla ilgi görmesi ve hastaların deneyimini dönüştürmesi muhtemeldir.

Anahtar Kelimler: Şeffaf plak, 3B baskı, tedavi planlama yazılımı, şeffaf plak malzemeleri, doğrudan basılabilir şeffaf plak

ABSTRACT: In-office aligner fabrication is rapidly transforming the orthodontic landscape, offering a revolutionary approach to orthodontic treatment. This review discusses the fabrication process, focusing on the key steps involved: three-dimensional(3D) treatment planning, three-dimensional(3D) printing, and post-processing. The direct printing of clear aligners is also explored, as it presents a significant advancement in aligner production technology. In-office production of clear aligners presents numerous advantages, including enhanced patient satisfaction, greater control for dental practitioners, and cost savings. As a discreet and virtually invisible treatment option, clear aligners have garnered significant interest among patients seeking orthodontic care. These aligners permit proper oral hygiene and unrestricted food choices, further increasing their appeal. Aligner therapy is generally associated with less discomfort and reduced chair time in comparison to traditional braces, contributing to its growing popularity and impact on the orthodontic industry. Direct printing of aligners offers the potential for even greater efficiency and customization, as it enables dental professionals to fabricate the aligners in-office using 3D printing technology. This approach eliminates the need for multiple steps and reduces reliance on external labs, streamlining the process and accelerating treatment. In conclusion, in-office aligner fabrication, particularly through direct printing, is poised to revolutionize orthodontic care. By streamlining the production process and offering a more comfortable, discreet treatment option, this innovative approach is likely to continue gaining traction within the dental community and transform the patient's experience.

Keywords: Clear aligner, 3D printing, Treatment-planning software, Aligner materials, Direct printable aligner

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INTRODUCTION

Clear aligners have become a popular alternative to traditional orthodontic appliances due to their esthetic appeal and ease of use (1). Patients seeking orthodontic treatment are increasingly drawn to clear aligners as they offer a discreet solution that is virtually invisible, making them more aesthetically pleasing than metal braces. Additionally, clear aligners are removable, allowing patients to maintain proper oral hygiene, enjoy a wide range of foods without restrictions, and participate in social events with greater confidence. Furthermore, aligner therapy typically involves less discomfort and reduced chair time, as patients require fewer in-office adjustments compared to traditional braces. This patient-centered approach has propelled clear aligners into the mainstream, making them a highly sought-after treatment option for both teens and adults seeking orthodontic care.

Dr. Harold Kesling introduced dental positioning appliances in 1945, paving the way for clear aligners (2). Align Technology launched Invisalign in 1997, utilizing three-dimensional (3D) imaging technology and computer software to create a series of clear, removable aligners. Over time, advancements in digital dentistry, materials, and manufacturing techniques, such as CAD/CAM, led to improvements in aligner production and patient comfort (3).

In recent years, the orthodontic landscape has witnessed yet another groundbreaking development: in-office aligner production (3–6). This innovation has enabled dental practitioners to take full control of the aligner design and fabrication process, reducing reliance on off-site manufacturing facilities. By harnessing cutting-edge technology, such as intraoral scanners, computer-aided design and manufacturing (CAD/CAM) software, and 3D printing, dental professionals can create high-quality, custom aligners within their own practice (7).

In-office aligner production has garnered significant interest within the dental community due to its potential to revolutionize orthodontic treatment (6). It offers several benefits, including faster treatment times, improved patient satisfaction, increased control for dental practitioners, cost savings (8). In this review article, we will examine the fabrication steps involved in in-office aligner production, such as 3D treatment planning, 3D printing, and post-processing, emphasizing its potential to transform the orthodontic landscape.

1.Fabrication Stages

1.1. Intraoral Scanners and Lab Scanners

According to Jedliński et al (9) and Christopoulou et al. (10) intraoral scanners and lab scanners are commonly used in dentistry for various purposes, including the production of aligners (11). Intraoral scanners are used chairside by dental professionals to capture precise digital impressions of the patient's teeth.

Popular intraoral scanners for aligner production encompass a variety of advanced models, such as the TRIOS 3 (3Shape, Copenhagen, Denmark), iTero (Align Tech, San Jose, CA, USA), CEREC Omnicam and Primescan (Dentsply Sirona, York, PA, USA), Medit i700 (Medit, Seongbuk-gu, Seoul, Korea), and CS 3600 and CS 3700 (Carestream Dental, Atlanta, GA, USA). These scanners enable efficient and accurate digital capture of dental structures, streamlining the aligner manufacturing process.

In addition to intraoral scanners, lab scanners can also be utilized in aligner production, as they transform physical dental impressions or plaster models into digital models. Some examples of lab scanners for this purpose include E series (3Shape,

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Copenhagen, Denmark), T series (Medit, Seoul, Korea), and Vinyl UXD (Smart Optics, Bochum, Germany). By combining both intraoral and lab scanning technologies, dental professionals can optimize their workflow and customized aligners to their patients.

1.2. Treatment-Planning Software for Making Aligners

Orthodontic CAD software for aligner fabrication enables dental professionals to design custom clear aligners, plan treatments, and simulate virtual tooth movements for patients. Some common CAD software options for in-office aligner production include 3Shape Clear Aligner Studio (3Shape, Copenhagen, Denmark), Blue Sky Plan (Blue Sky Bio, Illinois, USA), Orchestrate 3D (Park Dental Research Corp., OK, USA), uLab (uLab Systems, Inc., Memphis, USA), Maestro Dental Studio (Maestro 3D, Pisa, Italy), DentOne (Diorco, Gyeonggi, South Korea), and Deltaface (Coruo, Limoges, France).

Custom clear aligners are generated from digital scans of a patient's teeth using orthodontic CAD software. The stages include importing digital scans, creating virtual models, orienting and trimming scans, modifying teeth and gum structures, segmenting teeth, adjusting tooth axis, digitally planning and analyzing treatment, constructing attachments, and identifying and numbering modelsImporting Digital Scans: The process commences by importing digital scans of the patient's teeth, obtained from an intraoral scanner. These software programs are compatible with various scanners and accept files in multiple formats, such as STL, OBJ and PLY.

Virtual Model Creation: The software allows practitioners to generate a virtual model of the patient's dentition, offering tools for manipulation and editing. The model can be examined from different angles and displayed in various forms, including wireframe and solid renderings.

Scan Orientation: The initial step entails positioning the scans accurately and adjusting scan parameters as required. The software features tools for aligning scans with the occlusal plane and modifying scan resolution.

Dental Scan Trimming: After orienting the scans, practitioners can trim dental scans to eliminate extraneous parts of the image data. The software permits cropping scans to the desired dimensions, ensuring only relevant portions are included in the analysis.

Tooth and Gum Editing: Once trimmed, individual teeth and gums can be edited using an array of sculpting tools. Practitioners can adjust tooth shape, smooth rough surfaces, and edit teeth and gum structures to create an accurate digital representation of the patient's dental anatomy (Figure 1).

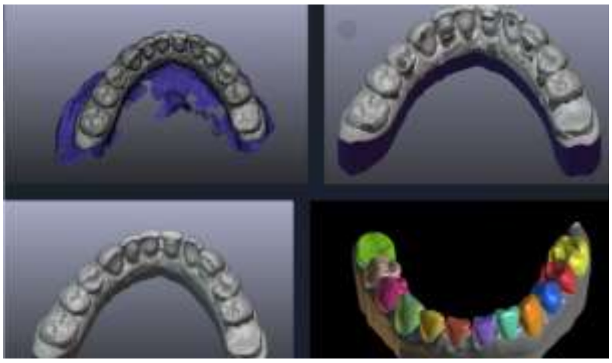

Figure 1: Editing with Blender and Teeth Segmentation using Blue Sky Plan

Teeth Segmentation: Post-editing, the software automatically segments teeth from the remaining image data. Practitioners can refine segmentation using advanced tools for improved precision and representation of teeth and gums. Certain software options offer semi-automatic teeth segmentation.

Tooth Axis Adjustment: The software supplies tools for adjusting tooth axes, enabling practitioners to position teeth more naturally. This is particularly beneficial when

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addressing rotated or tilted teeth or when correcting a patient's bite.

Digital Treatment Planning: Utilizing the virtual model, practitioners can develop digital treatment plans, including tooth movement prediction, clear aligner design, and orthodontic treatment simulation. The software incorporates advanced tools, such as virtual setups, arch length analysis, and smile design.

Visualizing and Analyzing Treatment Plans: The software provides functionality for visualizing and analyzing treatment plans, encompassing treatment simulations, overlaying virtual models onto original scans, and generating orthodontic measurements (Figure 2).

Figure 2: Adjusting Tooth Axis and Numbering Models with Autoalign (Diorco, South Korea)

Attachment Design: The software presents a variety of attachment shapes that can be dimensionally adjusted on teeth for clear aligners. Custom attachments tailored to the patient's individual needs can be created, allowing for increased precision and accuracy in tooth movement.

Adding Numbers and Names to Models: The software includes options for adding numbers and names to virtual models, which facilitates tracking individual teeth and aligners throughout treatment (Figure 3).

Figure 3: Adding Pontic Teeth to Spaces with Blender

Specialized dental software programs, such as Deltaface, Maestro Dental Studio and Blu Sky Plan offer comprehensive features for designing direct aligners. Open-source programs like Meshmixer (Autodesk, USA) or Blender (Blender Foundation, Netherland) can also be employed for creating clear aligners. Dental practitioners can customize the numbering and naming of teeth and treatment stages within these software programs, simplifying the identification of specific teeth and monitoring treatment progress.

1.3. Exporting 3D File and Slicing Program

Upon completion of the digital treatment plan for clear aligners, specialized software generates 3D printable files in formats such as STL, OBJ and PLY. The exported files can then be sent to a 3D printer for fabrication. However, the success of the printing process is largely dependent on the used slicer software. The slicer program divides the 3D model into layers that can be printed with a resin printer and determines the optimal orientation and placement of the model on the build plate, layer height, and other printing parameters including exposure time and curing time. The parameters determined by the slicer program have a significant impact on the print quality; therefore, it is essential to choose a slicer program with reliable and customizable settings. Each printer may have its own specialized slicing software, but Chitubox (Chitubox, China), PrusaSlicer (Prusa 3D, Prague, Czechia) and Lychee Slicer (Mango 3D, France) have emerged as popular programs with distinct advantages and disadvantages. For optimum print quality, it is essential to consider personal preferences and project-specific requirements when selecting the most appropriate program (Figure 4).

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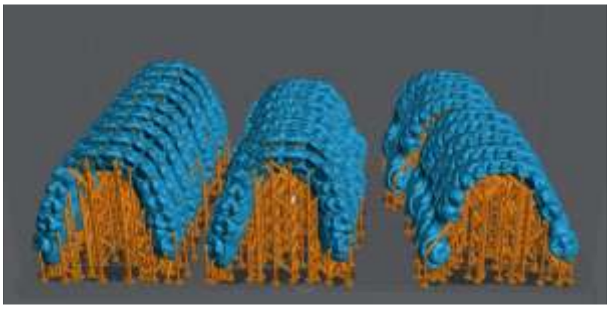

Figure 4: Lychee Slicer (5.1.8)

1.4. 3D Printers for Aligner Fabrication

Vat polymerization is a type of additive manufacturing (3D printing) process that utilizes a photopolymer resin that solidifies when exposed to a light source (12). This process is commonly used for creating highly detailed, complex, and intricate parts. There are three main types of vat polymerization: Stereolithography (SLA), Digital Light Processing (DLP), and Liquid Crystal Display (LCD). Each type has its own advantages and disadvantages.

Stereolithography (SLA): SLA is one of the oldest and most established vat polymerization techniques. It uses an ultraviolet (UV) laser to selectively cure (harden) the resin in a vat, layer by layer. The build platform moves upward after each layer is solidified, and the process repeats until the object is fully printed (13–15). SLA produces high-resolution parts with smooth surfaces and fine details. However, it can be relatively slow compared to other vat polymerization methods, as the laser has to trace the entire shape of each layer.

Digital Light Processing (DLP): DLP uses a digital light projector, which is essentially an array of micro-mirrors, to project an entire layer's image onto the resin at once. This allows for faster printing compared to SLA, as it cures an entire layer in one go, rather than tracing individual lines(15). DLP provides similar levels of accuracy and surface finish as SLA. However, the build size is limited by the resolution of the projector, and larger prints may require more expensive, high-resolution projectors.

Liquid Crystal Display (LCD): LCD-based vat polymerization is a relatively newer method that uses an LCD panel as the light source. The LCD panel selectively masks portions of the UV light to create the desired pattern for each layer, similar to how DLP operates (15–17).

Some popular 3D printers for aligner fabrication include the Formlabs Form 3B (Formlabs, Somerville, MA, USA), EnvisionTEC Vida (Dearborn, USA), SprintRay Pro (SprintRay, Los Angeles, CA, USA), Asiga Max UV (Asiga, Sydney, Australia), NBEE (Uniz, San Diego,CA, USA), Sol (Ackuretta, Taiwan), Phrozen Sonic Mini 8K (Phrozen Tech., Taiwan), ELEGOO Mars (Shenzhen Elegoo Technology Co., Shenzhen, China), and Anycubic Photon D2 (Anycubic Tech., Shenzhen, China). By choosing the right 3D printer for their needs, dental professionals can efficiently create custom clear aligners in-office, providing greater control, efficiency, and accuracy than traditional orthodontic treatment methods.

1.5. Thermoforming Machines for Aligner Production

Dental practitioners must first create, and 3D print dental models as a foundation for making clear aligners. However, a thermoforming machine is required to make the actual aligners. Heat and pressure are used to mold a thermoplastic sheet over a 3D-printed dental model, resulting in a custom-fitted aligner (18).

There are various thermoforming machines on the market, and selecting the proper one is critical to achieving the required results. Scheu Dental's Drufomat Scan, Biostar, and Ministar machines, as well as Great Lakes Orthodontics' EZ-Align machine, are among the most common thermoforming machines for aligner manufacture.

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Dental professionals may make personalized clear aligners in-house with the correct thermoforming machine, improving patient outcomes and treatment control. Dental practitioners can monitor quality control and change clear aligners in-house to ensure they fit properly and achieve the desired results. This method reduces aligner production time, reducing patient treatment time.

1.6. Thermoplastic Materials for Aligner Fabrication

The mechanical performance of thermoplastic materials used in the production of clear orthodontic aligners is crucial in achieving successful results, particularly in complex tooth movements (19,20). To accurately evaluate the efficacy of orthodontic treatments based on these devices, it is essential to consider the mechanical properties of the materials utilized. Relying solely on the technical data supplied by the manufacturers may not be sufficient; instead, the materials should be experimentally assessed under various conditions to ensure their performance (21).

One important aspect to note is that the mechanical properties of thermoplastic polymers can change after thermoforming. This emphasizes the need for testing these materials after undergoing this technique. Moreover, the thickness of aligner material significantly impacts its physical and mechanical properties. Studies have shown that the thickness of orthodontic clear aligners changes after thermoforming and after 10 days of intraoral exposure, which in turn affects the properties of the thermoplastic materials used to create these devices (22).

Innovations in material chemistry and engineering, such as shape memory polymers, direct 3D-printed clear aligners, and bioactive materials combined with clear aligner materials, have contributed to the development of clear aligner materials for orthodontics. These innovations have the potential to bring about radical transformations in the therapeutic applications of thermoplastic aligners, reducing overall fabrication costs, the time required to correct complex malocclusions, and plastic consumption (7).

There are several popular thermoplastic materials used in the production of aligners, including Essix plastics (Densply Sirona, USA), Zendura (Bay material,USA), CA+plus (Scheu Dental, Germany), Taglus (Taglus, India), and Tristar Trubalance (Visivest Co., Malesia)

1.7. Aligner Trimming

After the thermoplastic material is molded over the 3D-printed dental model, excess material must be removed. Dental professionals should use precise cutting tools, such as dental scissors or a rotary cutting tool, to trim the aligner's edges following the gingival margin on the model. Proper trimming ensures a secure and comfortable fit for the patient while minimizing irritation to the gingival tissues.

Aligner Polishing: Once the aligner is trimmed, the edges may still be rough or sharp, potentially causing discomfort for the patient. Polishing the aligner edges using specialized tools, such as polishing burs, discs, or wheels, is essential to smooth out any irregularities and ensure patient comfort. Polishing also helps to maintain the clarity and aesthetics of the aligner, contributing to its discreet appearance.

2. Resins for Direct Fabrication of Aligners

Graphy's Tera Harz TC-85 DAC resin has emerged as a promising material for the direct fabrication of clear aligners using 3D printers due to its superior qualities (23,24). This photocurable resin demonstrates outstanding thermomechanical and viscoelastic properties, which are essential characteristics for clear aligners. Furthermore, the shape memory

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property and shape recovery ratio of this resin were assessed using a U-shaped bending test, highlighting its potential for direct 3D printing of transparent aligners (24).

A comparison study conducted by So Yeon Park and colleagues in 2023 used micro-computed tomography (micro-CT) to analyze the thickness, gap breadth, and translucency of 3D-printed clear aligners and thermoformed clear aligners (25). The study revealed significant differences in these parameters, with variations in regions of best fit depending on tooth type and location. Additionally, post-processing centrifugation was found to improve the translucency of 3D-printed aligners (25).

Alternative resin materials, such as EnvisionTEC's E-ortholign (Envision Tech., USA) and 3Dresyn OD-Clear TF LTP - Rigid and LV versions from 3Dresyns(3)(Barcelona, Spain), are also promising options for direct fabrication of clear aligners. Although not as popular as Tera Harz TC-85 DAC (Graphy, Seoul,Korea) these resins possess similar properties and can serve as high-quality alternatives for dental professionals. In addition, Senertek Clear-A (Senertek, İzmir, Turkey) and ODS Clear (ODS, Yeonsu-gu, Korea) are emerging as potential options for clear aligner fabrication. While these new resin types have not been studied as extensively as some other resins, they hold promise and may offer valuable alternatives for dental professionals in the future. To ensure optimal results, dental professionals should thoroughly evaluate the properties and performance of each resin when fabricating clear aligners. Selecting the appropriate resin allows for the creation of comfortable, effective, and aesthetically pleasing clear aligners, providing patients with a personalized orthodontic treatment experience (Figure 5).

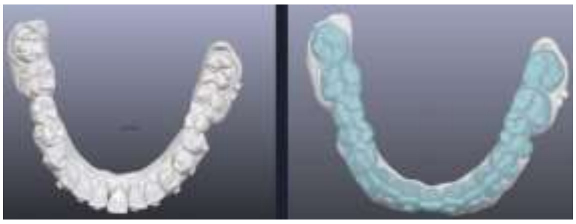

Figure 5: Designing a Directly Printable Aligner using Blender

3. Post-Print Process for Clear Aligner

After 3D printing clear aligners using specialized resins, dental professionals must perform post-print processing steps to ensure optimal fit, quality, and patient comfort. This section will outline the key stages of the post-print process for clear aligners:

Support Removal: Following the completion of the 3D printing, aligners may have support structures attached to the main aligner body, which are necessary for accurate printing. Dental professionals should carefully remove these supports using appropriate tools, such as pliers or cutters, without damaging the aligner.

Cleaning Post-Printing: After printing, it is crucial to clean the aligners thoroughly to remove residual uncured resin and support material from their surfaces. Proper cleaning ensures clarity and patient safety when using the aligners. This process typically involves submerging the aligners in isopropyl alcohol (IPA), ethanol, or another recommended cleaning solution (26). Some manufacturers do not recommend the use of cleaning solutions, as they may deteriorate the aligners' mechanical properties. Instead, these manufacturers suggest using a centrifuge to remove uncured resin effectively without compromising the material's integrity. By adhering to the specific recommendations provided by each manufacturer, dental professionals can maintain the quality and performance of their printed aligners.

Post-Curing: Aligners must be post-cured for biocompatibility and mechanical qualities.

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In a curing room, aligners are exposed to UV radiation for a specific time.

Inspection: After post-curing, dentists should inspect the aligners for cracks, warping, and uneven edges. Patient comfort and treatment success depend on product quality.

Trimming and Polishing: Aligner edges should be properly trimmed and polished to decrease gingival irritation and patient comfort. Dentists can polish aligner edges with scissors, burs, or polishing discs.

Quality Control: Aligners should be tested on the dental model. To ensure treatment success and patient satisfaction, dentists must verify aligner quality.

Sterilization and Packaging: To maintain safety and hygiene, the aligners should be autoclaved before being given to the patient. The aligners can be packaged and used after sterilization.

Aligner production requires a post-print process to ensure patient safety, comfort, and efficacy. Dental professionals can offer high-quality clear aligners that fulfill patient expectations and facilitate orthodontic treatment by following post-print procedures.

Direct-printed aligners outperform thermoformed ones in accuracy and precision (22). Direct 3D printing creates highly accurate transparent aligners with soft edges, digital design, and identical reproduction for a full treatment set, improving fit, efficacy, and repeatability (5). Direct 3D printing improves tooth movement force vector management by manipulating aligner thickness (5). Directly printing clear aligners allows for complete control over thickness, coverage, and attachments in an in-office aligner system. Eliminating intermediate steps in the thermoforming production process makes this method more accurate and resource-efficient (3).

CONCLUSION

In conclusion, the digital revolution in orthodontics has given patients access to efficient and individualized treatment options. Dental professionals can now construct customized clear aligners in-office using cutting-edge technology, such as intraoral scanners, CAD software, 3D printers, and specialized materials. By adopting these innovative tools and procedures, orthodontists can provide patients with a more streamlined and comfortable treatment experience.

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