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DIRECT PRINTED ALIGNERS: A PARADIGM SHIFT IN DIGITAL ORTHODONTICS

Orthodontics

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ABSTRACT

Direct Printed Aligners (DPAs), manufactured via stereolithography (SLA)/digital light processing (DLP) 3D printing directly from digital models, represent a major advance in clear aligner therapy. By eliminating thermoforming, they offer enhanced precision, speed, and customization using UDMA resins for controlled tooth movement. Key benefits include chairside fabrication and waste reduction. However, limitations persist around material biocompatibility, anisotropic behavior, surface roughness, and torque control. Future breakthroughs in smart materials, AI prediction, and multi-material printing are expected to address these challenges and drive the personalization of orthodontics.

KEYWORDS

Direct Printed Aligners, Stereolithography(SLA), Digital Light Processing(DLP)

INTRODUCTION

Orthodontic care has experienced a fundamental transformation during the last twenty years, transitioning away from conventional braces toward clear aligner therapy (CAT). This shift is primarily motivated by growing patient expectations for improved aesthetics, greater comfort, and enhanced treatment convenience. The standard method for producing clear aligners involves an indirect, multi-phase manufacturing sequence: digital intraoral scanning captures tooth anatomy, computer-aided design (CAD) software plans tooth movements, three-dimensional printing creates physical dental models, and thermoplastic sheets are thermoformed over these printed models. Although this established approach is clinically effective, its indirect nature introduces significant drawbacks: the process consumes substantial time, demands considerable manual labor, and is vulnerable to dimensional inaccuracies that accumulate across each intermediary production stage[1].

Progress in additive manufacturing (AM), especially innovations in high-resolution 3D printing techniques like DLP and SLA, has made feasible the direct fabrication of aligners using biocompatible, flexible photopolymer resins[2]. This direct 3D printing methodology removes the necessity for physical model creation and thermoforming steps, thereby offering prospective benefits including heightened dimensional precision, accelerated production cycles, and expanded capacity for appliance customization[3]. Nevertheless, the direct 3D printing of aligners presents substantial obstacles concerning the optimization of material characteristics, ensuring adequate mechanical performance, establishing biocompatibility for prolonged intraoral use, and securing necessary regulatory approvals[4].

Clinical research is essential to evaluate the therapeutic effectiveness and biological safety of directly printed aligners compared to thermoformed ones. As digital dentistry evolves, the practicality and merits of direct printing undergo increasing scrutiny, signaling an impending change in orthodontic appliance design and fabrication fundamentals.

History

- **1945:** Dr. Harold D. Kesling pioneered the tooth positioning appliance, establishing the foundational concept of incremental tooth movement achieved through a sequence of removable devices[5].
- **1964:** Dr. H.I. Nahoum devised vacuum-formed plastic appliances, initially utilized mainly as retainers, representing one of the earliest applications of plastic materials within orthodontics[6].
- **1997:** Align Technology debuted Invisalign®, the inaugural commercial clear aligner system integrating digital intraoral scanning, computer-aided design,3D printing of dental models, and thermoforming processes[6].
- **2017:** Graphy unveiled the first directly 3D-printed aligner, manufactured from a shape-memory resin capable of recovering its original form post-deformation. This innovation streamlined treatments by decreasing the required number of aligners per case[7].
- **2021:** Companies such as LuxCreo secured FDA clearance for their directly printed aligners, marking advancements in both clinical precision and material characteristics[7].

Direct Printed Aligner

Direct Printed Aligners constitute a groundbreaking advancement in orthodontics, utilizing high-resolution 3D printing technologies specifically DLP and SLA to manufacture clear aligners directly from digital patient models. This approach eliminates the conventional steps of physical model printing and thermoforming, resulting in a fully digital, streamlined, and contact-free production workflow. Graphy pioneered the first commercial DPA system in 2017, which employed a shape-memory photopolymer resin capable of reforming its original structure upon exposure to warm water. This innovation substantially decreased the number of aligners required per treatment and enhanced precision in controlling tooth movements[8].

Despite offering significant benefits such as improved accuracy, shorter production cycles, and reduced waste, widespread DPA adoption is currently hindered by persistent challenges related to material biocompatibility, mechanical performance consistency, and compliance with regulatory standards.

Clinical Workflow Integration(Figure 1)

1. Digital Impression & Model Acquisition

An intraoral scanner obtains a digital 3D model of the patient's dental anatomy. Alternatively, conventional physical impressions may be created and digitized using a laboratory scanner.

2. Treatment Planning & Digital Setup

Clinicians use specialized orthodontic software (ClinCheck, uDesign) to plan tooth displacements. The software then produces a sequence of progressive digital models, each depicting the target tooth configuration for treatment phases.

3. Aligners Designed

The software autonomously generates the aligner's 3D geometry incorporating attachments, pressure zones, and gingival trim lines ensuring precise adaptation to every digital model.

4. 3D Printing Preparation (Slicing)

The STL file is loaded into printer software. This software segments the 3D geometry into layers and creates the machine code (.cws,.phz). Necessary support structures are auto-generated.

5. Direct 3D Printing

The processed file is transmitted to a vat photopolymerization 3D printer typically employing SLA or DLP. Technologies like Continuous Liquid Interface Production (CLIP/DLS) are frequently utilized for enhanced speed and isotropic properties. The printer constructs the physical aligner layer-by-layer through selective UV curing of a biocompatible, transparent, dental-grade photopolymer resin.

6. Post-Processing (Cleaning)

Printed aligners are detached. Residual uncured resin is eliminated via immersion in a solvent bath, typically >90% isopropyl alcohol using automated washer or ultrasonic cleaner.

7. Post-Curing

Cleaned aligners undergo controlled UV exposure in a post-curing chamber. This completes the polymerization reaction, optimizing the material's mechanical strength, elasticity, and biocompatibility.

8. Support Removal & Finishing

Support structures are meticulously detached. Aligners are examined, and any irregularities along the edges are polished using fine burs or polishing wheels for comfort and smooth fit.

9. Quality Control & Sterilization

Each aligner is inspected for fit, clarity, uniform thickness, and integrity. Qualifying aligners are cold sterilized and packaged for delivery[9].

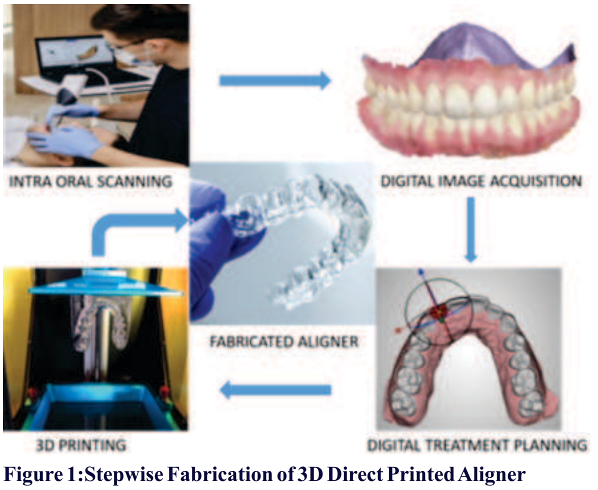

Figure 1:Stepwise Fabrication of 3D Direct Printed Aligner

Materials For Direct Printed Aligners

DPA are fabricated via DLP or SLA additive manufacturing. These techniques construct aligners layer-by-layer from liquid photopolymer resins, predominantly formulated with urethane dimethacrylate (UDMA). Each resin layer is selectively polymerized under UV/LED light.

Clinically Viable Resins Must Satisfy Stringent Criteria

- Compliance with ISO 10993-1 biocompatibility standards for intraoral safety.
- High optical transparency for aesthetic appeal and clinical monitoring.
- A tightly regulated flexural modulus (0.8–1.5 GPa) to generate controlled orthodontic forces.

Leading commercial resins include Graphy's TeraHarz TC-85 (clear/white variants) and BASF's E-Guard Align. Post-printing, DPAs require:

1. Solvent washing to remove uncured residue.
2. Secondary UV curing to enhance mechanical properties and reduce cytotoxic residual monomers (<0.5%)[10].

Advantages of Direct Printed Aligners

- Permits in-office aligner production.
- Enhanced Clinical Efficiency
- Treatment Plan Control: Grants dentists superior oversight of therapeutic progress.
- Delivers safer, more comfortable, and efficient treatment.
- Streamlined Orthodontic Devices: Simplifies production of distalizers while improving accuracy.
- Small-Batch Economics: Cost-effective for limited runs due to minimal material waste[11].

Limitations of Direct Printed Aligners

- Lacks a universally optimal material balancing safety, clarity, printability, strength, and flexibility.
- Rougher than thermoformed aligners, causing opacity, crack susceptibility, and hygiene challenges.
- Rapid intraoral degradation (saliva/heat/bacteria) leading to brittleness.
- Cost-Intensive Processing: High equipment, material, and labor expenses
- Inadequate root control/torque application.
- Rapid force decay (>50% within hours/days in oral environment).
- Ineffective for complex movements (rotations, extrusion) or severe malocclusions.
- Unpredictable treatment outcomes.
- Hygiene Risks: Surface roughness promotes biofilm adhesion; materials lack inherent antimicrobial activity [11].

Biomechanical Considerations of Direct Printed Aligners (DPA)

Direct Printed Aligners (DPA) demonstrate significantly higher compressive strength than conventional thermoformed PETG aligners. Testing shows Graphy's TC-85 resin withstands forces up to 455 N at 700 µm compression depth nearly 4× greater than PETG (115 N). This enhanced strength enables clinically effective force delivery, such as posterior intrusion using integrated bite blocks.A key biomechanical advantage is precise control over localized stiffness through strategic variations in aligner wall thickness (e.g., Rectangular Pressure Areas/Customized Pressure Regions). Increased thickness dramatically elevates rigidity, generating targeted force spikes (>300 µm depth) for specific tooth movements while potentially reducing reliance on attachments. This thickness force correlation demands careful optimization to prevent excessive loading.Notably, DPAs exhibit anisotropic mechanical behavior: they excel under compression but show lower tensile strength. This allows rigid force zones to coexist with overall aligner flexibility. Although force decay occurs, DPAs maintain 30% greater force retention than PETG after 500 fatigue cycles, supporting their clinical longevity [12].

Clinical Applications

- **Thermoforming Elimination:** Directly printed from digital designs, bypassing physical model fabrication and vacuum-forming of plastic sheets.
- **Variable Thickness Design:** Permits localized thickening (e.g., for enhanced torque control) or thinning (e.g., for targeted flexibility) within a single aligner.
- **Rapid Refinement:** Enables same day in-office printing of mid-treatment correction aligners.
- **Complex Movement Capability:** Facilitates biomechanically optimized designs for root uprighting, extrusion, or asymmetric rotations.
- **Waste Reduction:** Eliminates disposable plaster models and thermoforming debris.
- **Streamlined Retainers:** Allows immediate printing of temporary retainers post bracket removal.
- **On-Demand Appliances:** Ideal for minor corrections (e.g., pre-prosthetic alignment) [12].

Future Perspective of DPAS

DPA will revolutionize orthodontics through smart materials like drug-eluting resins that combat inflammation and shape-memory polymers that deliver adaptive, precise forces. AI-driven personalization will slash refinement needs by predicting tooth movement with unprecedented accuracy, while same-day chairside production eliminates traditional wait times. Hybrid multi-material printing will enable complex root movements by strategically combining rigid and flexible resins within single appliances. Sustainable bio-resins will reduce environmental footprints without compromising clinical performance, and embedded micro-sensors will provide real time compliance monitoring tracking wear duration, pressure distribution, and biomechanical responses to optimize outcomes dynamically [14].

CONCLUSION

DPAs represent a significant evolution in orthodontics, replacing thermoforming with direct digital manufacturing. By 3D printing aligners from biocompatible resins, DPAs offer superior compressive strength, targeted stiffness control, and shorter production times. They facilitate complex movement and same-day adjustments while minimizing waste. However, material drawbacks including rapid intraoral force decay, surface roughness, regulatory barriers, and suboptimal torque control limit widespread use. Future advancements in smart materials, AI-driven planning, and sensor-integrated aligners promise to overcome these hurdles. Resolving biocompatibility and biomechanical concerns through research will allow DPAs to redefine practice via chairside customization, predictive accuracy, and sustainable production.

REFERENCES

1. Ha DH, Ko DH, Kim JO, Im DJ, Kim BS, Park SY, Park S, Kim DP, Cho DW. Indirect fabrication of versatile 3D microfluidic device by a rotating plate combined 3D printing system. RSC advances. 2018;8(66):37693-9.
2. Nakano H, Kato R, Kakami C, Okamoto H, Mamada K, Maki K. Development of biocompatible resins for 3D printing of direct aligners. Journal of Photopolymer Science and Technology. 2019 Jun 24;32(2):209-16.
3. VAS NV, JAIN RK. An Update on 3D-printed Orthodontic Aligners. Journal of Clinical & Diagnostic Research. 2024 Apr 1;18(4).
4. Zinelis S, Panayi N, Polychronis G, Papageorgiou SN, Eliades T. Comparative analysis of mechanical properties of orthodontic aligners produced by different contemporary 3D printers. Orthodontics & craniofacial research. 2022 Aug;25(3):336-41.
5. Kesling HD. The philosophy of the tooth positioning appliance. American Journal of Orthodontics and Oral Surgery. 1945 Jun 1;31(6):297-304
6. Nahoum HI. The vacuum formed dental contour appliance. NY State Dent J. 1964;9:385-90
7. Panayi NC. Directly printed aligner: Aligning with the future. Turkish Journal of Orthodontics. 2023 Mar 21;36(1):62.
8. Tartaglia GM, Mapelli A, Maspero C, Santaniello T, Serafin M, Farronato M, Caprioglio A. Direct 3D printing of clear orthodontic aligners: Current state and future possibilities. Materials. 2021 Apr 5;14(7):1799.
9. Bichu YM, Alwafi A, Liu X, Andrews J, Ludwig B, Bichu AY, Zou B. Advances in orthodontic clear aligner materials. Bioactive materials. 2023 Apr 1;22:384-403.
10. Bhardwaj A, Mishra K, Pandey A, Kirtiwar D, Kharche A, Agaldiviti P. Mechanical Properties of 3D Printed Orthodontic Aligners Produced by Different Commercially Available Printers-An In-Vitro Study. Journal of Pharmacy and Bioallied Sciences. 2024 Apr 1;16(Suppl 2):S1431-2
11. Narongdej P, Hassanpour M, Alterman N, Rawlins-Buchanan F, Barjasteh E. Advancements in clear aligner fabrication: A comprehensive review of direct-3D printing technologies. Polymers. 2024 Jan 29;16(3):371.
12. Bae BG, Kim YH, Lee GH, Lee J, Min J, Kim H, Shin JW, Chae HS. A study on the compressive strength of three-dimensional direct printing aligner material for specific designing of clear aligners. Scientific Reports. 2025 Jan 20;15(1):2489.
13. Kasper FK. 3D printing applications in clear aligner fabrication. Embracing Novel Technologies in Dentistry and Orthodontics. 2020;56:7-21.
14. Migliorati M, De Mari A, Drago S. Direct-to-print aligners: An exploration of current knowledge, from software to printers, materials, and design variations. Seminars in Orthodontics 2025 Feb 1 (Vol. 31, No. 1, pp. 144-149). Elsevier.