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Printing Orientation and Post-Curing Time effect on Fracture Resistance and Marginal accuracy of 3D-Printed Interim Fixed Dental Prostheses: A Narrative Review

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Abstract

Interim fixed dental prostheses (IFDPs) are essential for protecting prepared abutments and maintaining function during the provisional phase. Additive manufacturing, especially vat-photopolymerization, has become a viable alternative to milled PMMA for IFDPs fabrication. However, 3D-printed resins exhibit anisotropic mechanical behavior, and their fracture resistance and marginal accuracy are strongly influenced by printing parameters. This narrative review synthesizes current literature on how printing orientation and post-curing time (PCT) affect the performance of 3D-printed interim fixed dental prostheses, and summarizes the types of printers and resin materials used. Evidence indicates that a 90° build orientation yields the lowest fracture resistance, whereas a 45° angle optimizes the balance between mechanical strength and marginal adaptation. Fracture resistance increases with PCT up to 90–120 min, but marginal accuracy declines beyond 30–40 min due to polymerization shrinkage. SLA, DLP, and LCD are the main dental printing technologies, using urethane methacrylate or acrylic ester resins. Optimizing orientation and PCT allows clinicians to improve clinical outcomes of 3D-printed IFDPs. Further in-vivo validation and material standardization are needed.

Keywords: 3D printing; interim fixed dental prostheses; printing orientation; post-curing; fracture resistance; marginal accuracy.

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1. Introduction

Tooth loss from caries, periodontal disease, trauma, or congenital defects remains a global health burden. Beyond impaired mastication and speech, missing teeth reduce esthetics, self-confidence, and quality of life. Fixed dental prostheses (FDPs) are a definitive solution, but the period between tooth preparation and final cementation requires interim fixed dental prostheses (IFDPs) to protect abutments and maintain oral function [1-2]. IFDPs fulfill biological and mechanical roles. Biologically, they shield prepared dentin from thermal/chemical stimuli, guide gingival healing, and prevent microleakage. Mechanically, they maintain inter-abutment distance, prevent supraeruption/tilting of adjacent or opposing teeth, and restore esthetics and phonetics. In complex rehabilitations, orthodontic cases, or lab delays, IFDPs may serve for weeks to months. During extended temporization, fracture and marginal discrepancy are the two most frequent failures [3-5].

2. Methods of IFDPs fabrication

Traditional fabrication uses direct chairside bis-acryl composites or indirect PMMA. Direct methods are fast and inexpensive but suffer from polymerization shrinkage, exothermic heat, air voids from hand-mixing, and inconsistent marginal adaptation. Digital fabrication of IFDPs includes subtractive manufacturing (milling) and additive manufacturing (3D printing) [6]. Subtractive CAD/CAM milling of pre-polymerized PMMA blocks improved strength and marginal fit, but produces material waste, requires costly mills, and is limited by bur diameter for internal geometries [7-8]. Additive manufacturing, or 3D printing, has emerged as an alternative. Vat-photopolymerization builds restorations layer-by-layer from liquid photopolymer resin. Benefits of 3D printing include minimal waste, ability to fabricate complex internal geometries, lower equipment cost, and rapid production. Figure 1 shows a 3D printed three unit fixed dental prosthesis. Unlike isotropic milled PMMA, 3D-printed parts are anisotropic: mechanical and dimensional properties depend on layer thickness, printing orientation, and post-processing, especially post-curing time (PCT). This review examines how orientation and PCT influence fracture resistance and marginal accuracy of 3D-printed IFDPs, and describes printer types and resin materials reported in the literature [9-12].

3. Types of 3D Printers Used in Dentistry

Table 1 illustrates advantages and disadvantages of 3D printers used in dentistry. Vat-photopolymerization dominates dental additive manufacturing due to high resolution and surface quality. Three technologies are most relevant: stereolithography (SLA), digital light processing (DLP), and liquid crystal display/masked the SLA (LCD/MSLA) [13].

3.1. Stereolithography SLA

SLA uses a UV laser to trace each layer in the x-y plane while the build platform steps down in z. It achieves accuracy of ± 25–50 µm and smooth surfaces, but is slower than projection-based systems because the laser must scan every vector. Formlabs Form 3B is commonly used in dental labs for surgical guides, models, and provisional restorations. SLA provides uniform energy per layer, which may reduce internal residual stress compared to DLP [14-15].

3.2. Digital Light Processing DLP

DLP projects an entire layer simultaneously using a digital micromirror device and UV projector. This parallel exposure makes DLP faster for large builds. Resolution depends on pixel size, typically 50–100 µm. Most dental crown-and-bridge printers, including Asiga Max and Envision TEC Vida, use DLP. The trade-off is "pixelation" or staircase effect on curved surfaces and potential non-uniform light intensity across the build area [16-18].

3.3. LCD/MSLA

LCD printers use an LCD screen as a mask with a UV LED array. They are low-cost and fast, but resolution is fixed by screen pixel density and light uniformity can vary. LCD is widely adopted for dental models but less so for definitive restorations due to accuracy concerns. For IFDPs, SLA and DLP remain preferred because they consistently maintain marginal discrepancies within clinically acceptable 120 µm limit proposed by McLean and von Fraunhofer [19-21].

4. Materials Used for 3D-Printed Interim FDPs

Interim resins are photocurable methacrylate-based polymers that solidify when exposed to UV light [22].

4.1. Chemical composition

Most interim resins are based on urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA). UDMA provides toughness and flexibility; TEGDMA reduces viscosity to improve flow and interlayer adhesion. Inorganic fillers such as silica or zirconia nanoparticles at 1–20 wt% improve wear resistance and reduce polymerization shrinkage. Photoinitiators like camphorquinone absorb UV at 385–405 nm to initiate radical polymerization [23-25].

4.2. Commercial interim resins

The NextDent C&B resin is a methacrylate-based material classified for crown and bridge use. Published in-vitro work reports peak fracture strength when printed at 45° orientation. DentaTOOTH: Acrylic ester resin marketed for long-term provisionals up to 12 months. Some studies report better marginal fit at 0° orientation compared to NextDent.
Formlabs Dental LT Clear: Biocompatible resin primarily for surgical guides but used off-label for short-term provisionals.
SprintRay Crown: Urethane methacrylate resin with manufacturer claims of high fracture toughness [10-26].

4.3. Comparison with milled PMMA

3D-printed resins typically show lower flexural strength than milled PMMA blocks: 80–110 MPa vs 140–160 MPa for PMMA. However, printed resins offer superior esthetics and enable chairside fabrication. The key weakness is anisotropy from layering, absent in milled PMMA. Material behavior also interacts with printer type: DLP cures faster but may retain more residual monomer if PCT is insufficient, while SLA provides more uniform curing per layer [12-15-18].

5. Parameters influencing 3D printed IFDPs

While parameters like energy distribution, printing velocity, and curing depth are typically automated by the manufacturer, operators must manually configure pre-processing variables. These variables include layer thickness, build orientation, support structure geometry, object itself, and object placement on the build platform. Furthermore, the operator has control over post-processing procedures such final cleaning, and washing and curing which may impact component accuracy. Modifications to the pre- and post-processing phases may have an impact on the precision as well as the finished product's mechanical properties [27].

6. Printing Orientation: Definition and Biomechanical Rationale

Printing orientation is defined as the angle between the long axis of the restoration and the build platform. Common angles evaluated are 0° (Figure 2), 45° (Figure 3), and 90° (Figure 4). Orientation determines support structure placement and the direction of layer lines relative to occlusal loading [28-29]. Dental resins are weakest along the z-axis because interlayer bonding relies on diffusion of partially cured resin at interfaces. Within a layer, polymer chains are densely cross-linked, but between layers adhesion depends on uncured monomer penetration. When occlusal load is applied parallel to layer lines, stress concentrates at interfaces, promoting delamination. When load is perpendicular to layers, stress distributes through stronger intra-layer bonds. Thus, orientation directly governs fracture resistance of IFDPs [30-31].

7. Effect of Printing Orientation on Fracture Resistance

Alkhateeb et al. [10] fabricated 3-unit IFDPs from NextDent C&B and ASIGA DentaTOOTH at 0°, 45°, and 90° using DLP technology. Using universal testing machine loading at the pontic, they reported highest fracture load at 45°, followed by 0°, with 90° significantly lower. The authors attributed this to 45° distributing occlusal forces over more layers and reducing stress concentration at connectors. Conversely, Diken Turksayar et al. tested similar 3-unit IFDPs at 0°, 30°, 45°, 90°, and 150° after artificial aging and found highest fracture strength at 0°, then 30°, with 90° weakest. They explained that when layers are perpendicular to load at 0°, each layer bears load independently, minimizing interlayer shear [32]. Nold et al. [33] simulated 1 year of oral function in an artificial mouth and found diagonal orientation superior to occlusal, vertical, and palatal orientations for temporary FPDs. Reymus et al. [34] also reported that build direction significantly affected fracture load, with occlusal and buccal orientations outperforming distal orientation. The consensus across studies is clear: 90° orientation should be avoided for IFDPs. The discrepancy between 0° and 45° as optimal likely depends on resin composition, filler content, and printer technology [10-32-33].

8. Effect of Printing Orientation on Marginal and Internal Accuracy

Marginal gap refers to the shortest distance from the restoration's edge to the tooth preparation margin, which affects cement film thickness and longevity. internal accuracy refers to adaptation at axial and occlusal walls. Both determine cement film thickness and clinical longevity. McLean and von Fraunhofer's landmark study established 120 µm as the upper limit for clinically acceptable marginal gap. Gaps exceeding this threshold increase risk of cement dissolution, plaque accumulation, recurrent caries, and periodontal inflammation [21-35]. Alharbi et al. [19] used SLA to print full-coverage crowns at various build angles and found 120° build angle provided highest dimensional accuracy with minimal support contact at margins. For IFDPs, Park et al. [16] tested 3-unit implant-supported prostheses printed with DLP and concluded that 45° or 60° build angles produced minimal internal gap and highest fit accuracy. Material differences are important. Al-Dulaijan et al. [36] compared NextDent and ASIGA resins at 0°, 45°, and 90°. For ASIGA, 0° orientation showed better fit than 45° and 90°. For NextDent, performance was consistent across angles, suggesting resin viscosity, filler content, and shrinkage behavior interact with orientation. Yang et al. [20] investigated marginal fit of 3-unit resin prostheses with different build orientations and layer thicknesses and found orientation significantly affected marginal gap, with oblique angles outperforming vertical. Son et al. [18] compared intaglio surface trueness of crowns fabricated by SLA, DLP, and milling, and found 3D printing demonstrated better accuracy than milling when orientation was optimized. For clinical practice, 45°–60° appears optimal for marginal accuracy, but this must be balanced against strength requirements [16-23].

9. Post-Curing Time: Mechanism and Importance

Post-curing is the final polymerization step after printing and washing in isopropyl alcohol. During printing, UV exposure penetrates only 50–100 µm, leaving underlying resin under-cured. Post-curing units use high-intensity UV-A light 385–405 nm combined with heat 40–60°C to drive polymerization to completion [37-38]. Post-curing completes polymerization by activating remaining radicals, which form additional cross-links between methacrylate monomers and increase the degree of conversion. This increases degree of conversion from ~50–60% in the green state to >90% after adequate curing. Higher degree of conversion directly correlates with flexural strength, hardness, wear resistance, and biocompatibility, because unreacted monomers can leach and cause cytotoxicity. However, polymerization is accompanied by 2–7% volumetric shrinkage. As chains cross-link and pack closer, the material contracts, creating internal stress and dimensional change that can warp the restoration and increase marginal gap [39-41]. Therefore, PCT must balance two competing outcomes: long enough for mechanical properties, short enough to limit shrinkage distortion [42].

10. Effect of Post-Curing Time on Fracture Resistance

Alkhateeb et al. divided 3-unit IFDPs into five groups: green state control, 30, 60, 90, and 120 min PCT. Using standardized loading at the pontic, they found fracture load increased significantly with PCT, $p<0.05$. The 90 and 120 min groups showed highest fracture loads, while green state samples fractured at much lower forces. The difference between 90 and 120 min was not statistically significant, suggesting a plateau [10]. Reymus et al. [34] examined 3D-printed IFDPs with different build directions and PCTs and concluded that longer post-curing time was linked to higher fracture resistance across all orientations. This was attributed to increased cross-linking density and reduced plasticization from residual monomer. Kim et al. [38] focused on post-curing effects on mechanical and color properties of 3D-printed crown and bridge materials and reported flexural strength and hardness improved with increasing PCT. Hossain and Steinmann's polymer physics model supports this: curing transforms viscoelastic liquid into viscoelastic solid, increasing elastic modulus and strength [39].

11. Effect of Post-Curing Time on Marginal Accuracy

While PCT improves strength, it worsens marginal accuracy due to shrinkage. Mostafavi et al. [37] investigated post-processing procedures on accuracy of additively manufactured dental model resin and found highest manufacturing accuracy under dry conditions at 10 and 40 min. Beyond 40 min, trueness decreased, likely due to accumulated shrinkage stress. Hossain and Steinmann [39] explained that during curing, polymer chains come closer together, reducing specific volume and causing dimensional change. This volume reduction is not uniform in complex FDP geometries, creating internal stress that warps the restoration and increases marginal discrepancy. Al-Dulaijan et al. [26] noted that for NextDent crowns, marginal fit remained consistent across PCTs, while ASIGA showed worse fit with extended curing. This material dependence means universal PCT recommendations are difficult.

12. Clinical Recommendations

No single setting fits all clinical scenarios. The literature suggests:For maximum fracture resistance: Avoid 90° orientation. Use 0° for short spans, 45° for long spans or high occlusal load.Post-cure for 60–90 min for maximum strength, especially for bruxers or long-span FDPs.Expect 3D-printed resins to have lower flexural strength than milled PMMA [10-32-34-43]. F For best marginal accuracy:Use 45°–60° orientation to minimize marginal gap.Limit PCT to 30–40 min to reduce shrinkage distortion. Use dry post-curing rather than water-submerged for better trueness [16-23-37]. Practical compromise: For typical 3-unit provisional bridges in patients without parafunction, a 45° build angle combined with 30–40 min of post-curing appears to balance strength and marginal fit. For extended temporization >1 month or patients with heavy occlusal load, increase PCT to 60–90 min and compensate for marginal gap by increasing cement space in CAD design by 20–30 µm [10-37-44]. Material choice matters. With ASIGA DentaTOOTH, 0° orientation may give better fit. With NextDent C&B, orientation is less critical for fit but 45° still improves strength [10-26]. Figure shows printing orientation on slicing software (0°,45°,90°).

Figure 1: Showing a 3D printed three-unit fixed dental prosthesis.

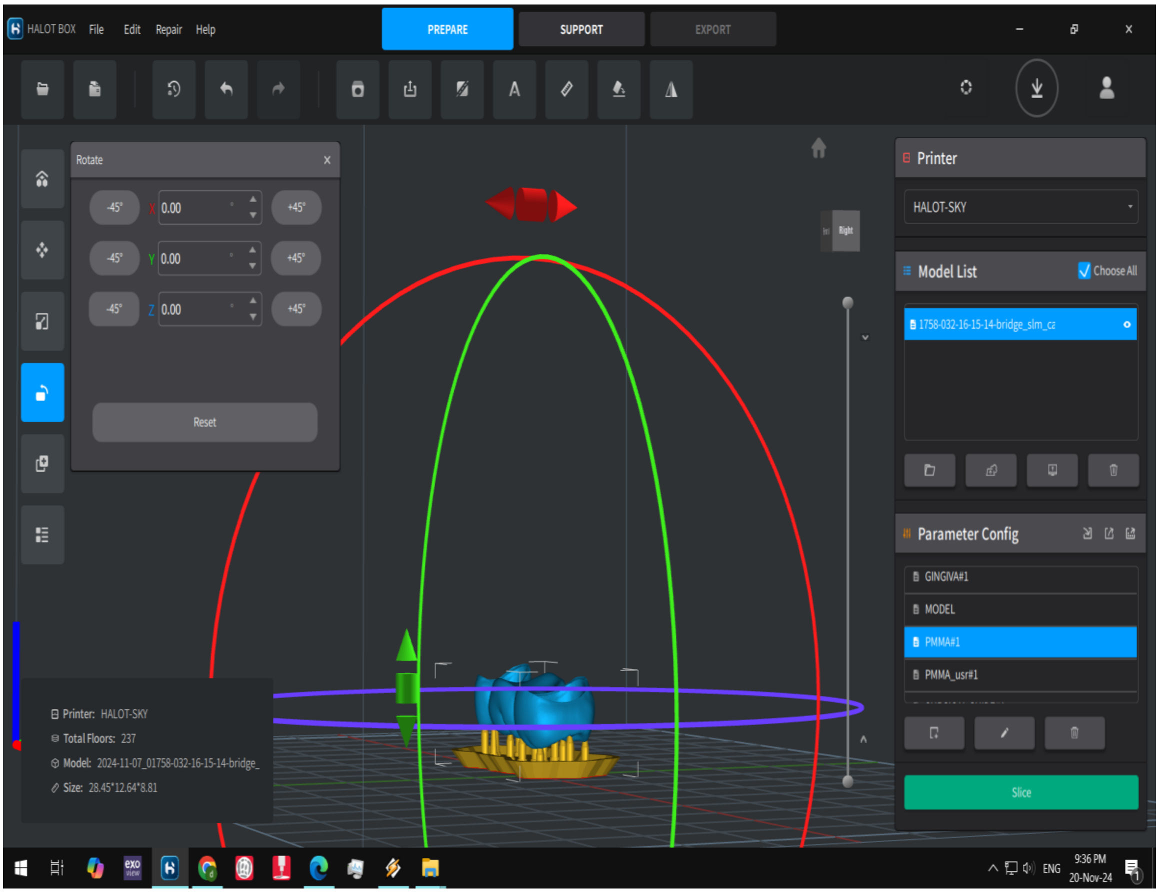

Figure 2: Showing a three-unit fixed dental prosthesis with an orientation angle 0° in a slicing software.

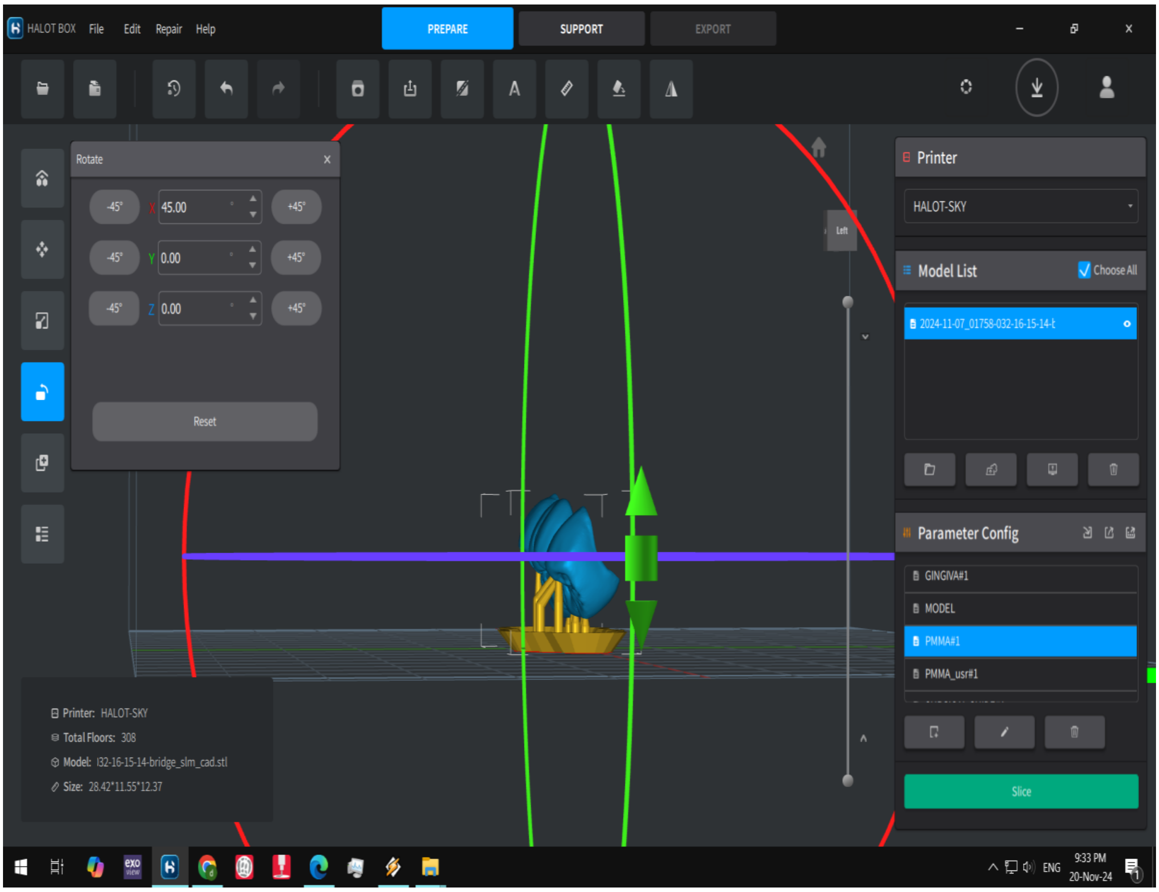

Figure 3: Showing a three-unit fixed dental prosthesis with an orientation angle 45° in a slicing software.

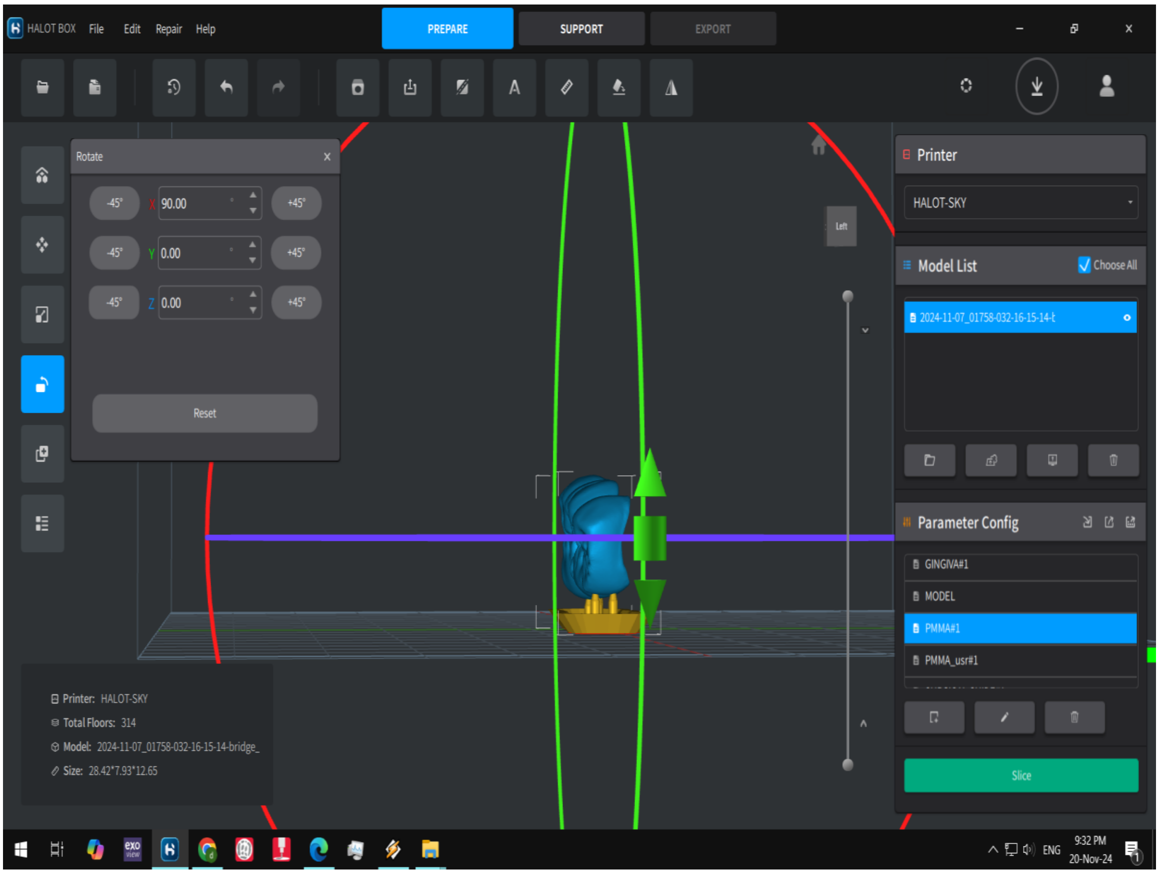

Figure 4: Showing a three-unit fixed dental prosthesis with an orientation angle 90° in a slicing software.

Table 1: Illustrating advantages and disadvantages of 3D printers used in dentistry.

Printer Type	Technology	Advantages	Disadvantages	Best dental uses
SLA	Stereolithography: UV laser traces each layer point-by-point	1. Highest accuracy: ±25-50 µm 2. Smooth surface finish with minimal layer lines 3. Uniform curing reduces internal stress 4. Excellent for fine details	1. Slowest print speed - laser must trace every vector 2. Higher cost per print and machine 3. Limited build volume on desktop units 4. Requires post-curing for full strength	Surgical guides, dental models, diagnostic wax-ups, custom trays
DLP	Digital Light Processing: Entire layer projected at once	1. Fast print speed - whole layer cures simultaneously 2. High resolution 50-100 µm pixels 3. Good for batch production of multiple units 4. Lower cost than SLA for same build size	1. "Pixelation"/staircase effect on curved surfaces 2. Light intensity varies across build platform 3. Resin vat wears out faster due to full-area exposure 4. Accuracy drops at edges of build area	Interim crowns/bridges, surgical guides, models, denture bases
LCD/MSLA	Masked SLA: LCD screen + UV LED array cures whole layer	1. Lowest cost printer + resin 2. Fast printing like DLP 3. Compact desktop size 4. Good entry option for dental labs	1. Fixed resolution set by screen pixels 2. Poor light uniformity causes inconsistent curing 3. LCD screen degrades and needs replacement 4. Lowest accuracy of the 3 types	Study models, diagnostic casts, splints, non-critical applications

13. Future research directions

Several research gaps remain. Most studies test 3-unit FPDs, but clinical need exists for 4-unit and full-arch provisionals. Long-term data >6 months is lacking. Standardized disclosure of resin composition would allow clinicians to predict behavior without testing every new material. In-vivo clinical studies correlating printing parameters with survival rates are needed, not just in-vitro fracture tests [45-46].

14. Conclusion

Printing orientation and post-curing time are clinical decisions, not minor printer settings. The data converge on avoiding 90° orientation and recognizing the strength vs. fit trade-off of PCT. A 45° build angle combined with 30–40 min post-curing represents a rational starting point for most 3-unit IFDPs. Understanding printer types and material composition allows prosthodontists to deliver interim restorations that are strong enough to function and accurate enough to protect abutment teeth [10-13-37-38].

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Conflicts of Interest

The authors declare no competing interests.

Ethics approval

Not applicable

Declarations

Data Availability and Visual Material Statement

All figures and tables presented in this manuscript are original, unpublished materials generated exclusively by the authors for this narrative review. No copyrighted third-party visual assets were utilized.

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