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A Review of the Flexural Strength of 3D-Printed and Milled Temporary Crowns in Dentistry

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Abstract **- Traditional methods of producing temporary crowns, such as traditional manufacture, have concerns with accuracy, material waste, and clinical efficiency. Recent advances in additive manufacturing, particularly vat photopolymerization methods such as stereolithography (SLA) and digital light processing (DLP), have enabled the creation of temporary crowns that are more durable, accurate, and visually appealing. This study examines information from research publications on 3D-printed temporary crowns, with emphasis on printing technology, material types, mechanical qualities, and accuracy. Current research suggests that 3D-printed temporary crowns perform as well as regular crowns.**

Keywords - 3D printing, provisional crowns, additive manufacturing, SLA, DLP, digital dentistry

I. INTRODUCTION

Provisional restorations safeguard prepared teeth while maintaining aesthetics. Traditional chairside and laboratory procedures employ polymethyl methacrylate (PMMA) or bis-acryl composites, however these materials are susceptible to polymerization shrinkage, poor marginal adaptability, and waste production. The use of computer-aided design and manufacturing (CAD/CAM) introduced milled PMMA blocks, which increased uniformity but needed subtractive processing, resulting in substantial material loss. Additive manufacturing, notably stereolithography (SLA) and digital light processing (DLP), allows for layer-by-layer manufacture directly from digital scans, lowering turnaround time and material usage. We examined how resin composition, build orientation, and post-curing impact physical and mechanical results in these printed provisionals [1]. The integration of digital technology into dentistry has resulted in the use of CAD/CAM milling and 3D printing to fabricate temporary restorations. CAD/CAM milling is the subtractive machining of restorations from pre-polymerized resin blocks, whereas 3D printing uses layer-by-layer photopolymerization. Although both approaches increase accuracy and efficiency, mechanical behavior particularly flexural strength is still a crucial determinant of clinical effectiveness [2].

II. LITERATURE REVIEW

Xiaoxu Liang et. al. (2025) [1]This article discussed current improvements in employing 3D printing technology to create temporary dental crowns and bridges from resin materials. These interim restorations were vital because they protected the teeth and gums while the permanent crowns or bridges were being created. According to the analysis, 3D printing allows dentists to make temporary dental pieces faster and with more precision than traditional methods. The resin materials used in 3D printing have greatly improve. They are now stronger, more lasting, and more visually appealing, making patients feel more comfortable. It also covered several uses for 3D-printed dental prosthesis, such as their usage in difficult situations or in clinics with digitized processes. Furthermore, the review discussed the remaining hurdles, such as making the materials even stronger while also assuring their safety and biocompatibility. Overall, 3D printing with resin materials is a promising and emerging area of dentistry that improves patient care by providing faster, more accurate, and more visually appealing temporary dental restorations.

Dixit santosh et.al (2025) [2] The author conducted an in vitro investigation to compare the flexural strength of a milled temporary crown material to two distinct 3D-printed temporary crown materials. The study sought to determine whether additively built materials might have mechanical qualities similar to traditionally milled temporary repairs. Standardized specimens were manufactured using CAD-CAM machining and two 3D printing processes, followed by flexural strength testing using a universal testing machine under controlled laboratory settings.

Jeong, Radomski, Lopez, and Liu (2024) [3] The author gave a detailed literature assessment on the materials and uses of 3D printing technology in dentistry, emphasizing its expanding importance in digital dental workflows. The authors discussed major additive manufacturing techniques such as stereolithography (SLA), digital light processing (DLP), fused deposition modeling (FDM), selective laser sintering (SLS), and selective laser melting (SLM), emphasizing their suitability for various dental applications in terms of accuracy, surface quality, and material compatibility. The review thoroughly examined dental 3D printing materials such as photopolymer resins, thermoplastics, ceramics, and metal alloys. The review noted that 3D printing improves customisation, minimizes material waste, and increases treatment efficiency when compared to traditional production processes. However, impediments to wider adoption have been noted, including expensive equipment costs, a lack of long-term clinical evidence, and regulatory issues. Overall, the study found that 3D printing technology represents a substantial improvement in modern dentistry, with ongoing research aimed at increasing material characteristics, biocompatibility, and clinical dependability in order to enable wider clinical use.

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Dinesh Rokaya et. al. (2023) [4] Address unusual materials that may change shape when prompted by heat, light, or other signals before returning to their original form. Because of this unique property, SMPs (shape memory polymers) are extremely beneficial in medicine.The authors discussed how shape memory polymers (SMPs) function and why they are significant in healthcare. For example, SMPs (shape memory polymers) can be used to create devices that fit within the body and change shape once inside, such as stents that open blood channels or scaffolds that aid tissue growth.Recent advancements include mixing shape memory polymers (SMPs) with microscopic particles known as nanomaterials, which makes these materials stronger and more sensitive. This improves the performance of shape memory polymers (SMPs) in a variety of medical devices.However, there are still hurdles, such as ensuring that SMPs (shape memory polymers) are safe to use in the body for an extended period of time, do not produce adverse responses, and are simple and inexpensive to manufacture. Overall, the report emphasizes the intriguing potential of SMPs (shape memory polymers) in medicine and calls for greater research to tackle present difficulties and put these smart materials into routine clinical use.

Martin Rosentritt et. al. (2022) [5] Eleven resin-based CAD/CAM materials were examined utilizing instrumented indentation testing according to ISO 145771. Due to variations in the energy-converting characteristics of the examined materials, certain CAD/CAM resin-based composites may have higher stress-breaking capabilities than others. The subsequent decrease in stress buildup may be useful, particularly for implant-retained restorations or individuals suffering from parafunctions.

Passent Ellakany et. al. (2022) [6] This study assessed mechanical properties of 3-unit interim fixed dental prostheses (IFDPs) after thermomechanical aging of CAD/CAM milling and 3D-printing fabrication methods. Calculations of the flexural strength and elastic modulus were done in (MPa) in accordance with the International Organization for Standardization (ISO10477-2018 standard). The surface micro hardness of fractured IFDPs (Fixed Dental Prostheses) was measured using a hardness tester machine. The results showed that there was a significant difference in micro hardness between the studied materials, with the highest mean reported in milled and the lowest in conventional.

Reem Abualsaud et. al. (2022) [7] The goal of this research is to comparedthe physiomechanical and surface characteristics of 3D-printed zirconia to milled zirconia. There was no significant difference between groups in terms of density, porosity, or micro hardness ($p>0.05$). The slanted group showed considerably higher surface acuteness than the milling group. The vertical group provided the highest connection side that differed greatly from the machined and listed. The milling group had a much higher BFS (Biaxial Flexural Strength) than all other groups, although perpendicular and slanted had a significantly lower BFS than vertical.

Yura Cho et. al. (2022) [8] Investigated the effects of specific components on 3D printer resin characteristics. The mechanical and physical properties of Bis-EMA (Bisphenol A ethoxylated dimethacrylate), TMPTMA (Trimethylolpropane trimethacrylate), and urethane oligomers were investigated, and it was discovered that the monomer content ratio influenced the physical and mechanical properties of the resin.The three test patterns demonstrated acceptable printer output resolution.

Yousif A. Al-Dulaijan et. al. (2022) [9] The study looked at the printing parameters (orientation and post-curing time) for two distinct 3D-printed resins. There was no change or influence on surface roughness in either 3D-printed DBR (Denture Base Resin) due to printing orientations or post-curing time effects. In contrast, the printing orientation has no effect on the hardness, although the post-curing duration does. Increasing the post-curing period by 120 minutes enhanced surface hardness. The 3D-printed denture base resins that were post-cured for 120 minutes had comparable hardness to heat-polymerized DBRs (Denture Base Resin). Finally, increasing the post-curing time enhanced the hardness of the 3D-printed denture base material, but changing the printing orientation did not.

Jain S et al. (2022) [10] This study conducted a systematic review and meta-analysis to compare the physical and mechanical qualities of 3D-printed temporary dental resins to those produced using CAD/CAM milling and traditional techniques. It discovered that 3D-printed resins have equivalent or enhanced strength, hardness, and wear resistance compared to conventional materials. The study emphasized the advantages of 3D printing in terms of precision and personalization, but it also noted variations based on printing method and resin type. Overall, 3D printing is a promising option for both interim and permanent dental prosthetics.

Hiroto Nakai et. al. (2021) [11] Used Weibull dissection to statistically absorb biaxial flexural energy. The phase compositions of the Zirconia grades generated additively and subtractively were similar. The residual porosity of the SLA 3Y-TZPs and ATZ (Stereolithography, 3 mol% Yttria-Stabilized Tetragonal Zirconia Polycrystal, and Alumina-Toughened Zirconia) was comparable to that of subtractively produced 3Y-TZP. The biaxial flexural energy of the subtractively created LAVA Plus was comparable to that of the additively formed 3Y-TZPs (3 mol% yttria-stabilized tetragonal zirconia polycrystal), with the additively formed ATZ outperforming the subtractively formed 3Y-TZP. Additively created 3Y-TZP (3 mol% yttria-stabilized tetragonal zirconia polycrystal) exhibited comparable crystallography, microstructure, and flexural energy to subtractively formed zirconia.

Barenghi L, et. al. (2021) [12] This investigation examined at how CAD/CAM technology helps lower infection risks in dental clinics during COVID-19. It emphasizes how digital impressions, in-house milling, and fewer patient visits reduced the risk of viral transmission. Benefits included improved cleanliness and speedier processes. However, the report also identified certain disadvantages, such as the high cost, technological complexity, and training requirements. The authors concluded that CAD/CAM is a useful technology for safer and more effective dental treatment, especially during pandemics.

Maiko Iwaki et. al. (2020) [13] This study compared the mechanical characteristics and molecular distribution of a polymethyl methacrylate (PMMA) block (Dry) to specimens manufactured conventionally and cured in a wet environment (Control). Two specimen kinds were created using heat-curing denture base resin. Dry specimens were polymerized under high pressure in a dry system, whereas control specimens were polymerized using a heat-curing process following the manufacturer's suggested protocols. Specimens from each group were tested for three-point bending, water absorption and solubility, and color change using gel permeation chromatography (GPC). The dry specimens had considerably higher mean values for flexural strengths and moduli than the control specimens.

Baroudi K, Ibraheem SN et. al. (2015) [14] This evaluation focused on chair-side CAD/CAM systems used in dentistry to create crowns, inlays, onlays, and veneers in a single visit. It summarizes research demonstrating that CAD/CAM repairs are accurate, durable, and time-saving. The paper cites benefits such as shorter treatment times, no need for temporary crowns, and patient comfort. It also identified several constraints, such as the high cost of equipment and the requirement for training. Overall, CAD/CAM technology increased efficiency and quality in dental care.

III. BEFORE STYLINGDIGITAL FABRICATION TECHNIQUES

The majority of the research listed utilize **vat-photopolymerization** methods, specifically SLA and DLP. SLA employs a focused laser to cure resin point-by-point, producing great precision but longer print times, whereas DLP projects a whole picture layer at once, enhancing efficiency Important process factors include layer thickness (25-100 µm), exposure energy, and print orientation [1]. **Pre-processing** in 3D-Printed Dental Crowns refers to all of the digital stages that occur before to printing.

Data collection : Intraoral scanners or laboratory scanners are utilized to get a digital imprint of the prepared tooth.

Digital design (CAD): The scanned data is imported into CAD software. Crown margins and anatomy are digitally designed.

File preparation: The design is converted to.STL (Standard Tessellation Language) format. The crown's orientation is selected in order to eliminate layer lines and increase strength. Support structures are used to support the crown when printing. Slicing software cuts the model into tiny layers dependent on the printer's resolution.

Processing in 3D-Printed Dental Crowns: The printing phase is when the crown is created.

Processing refers to the actual printing phase, where the crown is fabricated

Printing technology: Due to their excellent precision and flawless surface finish, SLA and DLP are the most regularly utilized methods for printing dental crowns. A light source selectively polymerizes biocompatible photopolymer resin, layer by layer.

Layer-by-layer fabrication: The crown is created using the sliced design.

Post-processing is crucial. Printed items are washed with isopropyl alcohol to remove any uncured resin before being UV-cured for full polymerization. Liang et al. found that proper post-curing greatly boosts flexural strength [1].

The study contrasted subtractive CAD/CAM milling and additive manufacturing (3D printing) processes for producing temporary crown materials. CAD software was used to produce digital designs, and standardized specimens were made from one milled PMMA material and two distinct 3D-printed resins. Milling entailed cutting crowns from pre-polymerized PMMA blocks, but 3D printing included layer-by-layer manufacturing, which provided exact control over crown shape. The computerized approach increased repeatability and decreased operator-dependent variability [2].

TABLE I.

Technique	Advantages	Disadvantages
Stereolithography (SLA)	• Quick production speed; •Precise and highly accurate; •Can accommodate complex designs; •Numerous material options.	•Production can be slower compared to other printers; •High post-processing requirements.
Digital light processing (DLP)	• High speed; •Precise and highly accurate; •Can accommodate complex designs; •Numerous material options.	•Arguably lower quality than other printers.
Fused deposition modeling (FDM)	•Cheaper technology; •Great layer bonding.	•Only thermoplastic materials.
Selective laser sintering (SLS) and selective laser melting (SLM)	•Can print polymers or metals; • Batch production; • No supports needed.	•Requires high printing infrastructure; •Use of fine powders can he hazardous.
Photopolymer jetting	•Extremely high resolution; • Can print with multiple colors on one single print.	•Low mechanical properties; •Limited heat resistance; •Costly maintenance of printer heads.
Powder binder printing	• Only option to print living cells and other biomaterials; • Completely unique.	• Costly; •Very specific conditions to produce viable biomaterials.

a. **Table 1.** Advantages and Disadvantages of 3D printing techniques [3].

Stereolithography (SLA) :

offers high precision. Provides a smooth surface finish with fewer layer lines. Capable of producing complicated shapes with precise margin features. A wide selection of biocompatible dental resins are available. However, the printing speed is slower when compared to DLP. Requires substantial post-processing (cleaning and curing).Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

Digital Light Processing (DLP) :

Printing speeds are faster since complete layers are treated at once. Excellent dimensional precision, particularly for little dental components. Efficient for crown manufacture in batches. Produces consistent results with less printing time. However, resolution is determined on the size of the projector's pixels, which may restrict fine detail. Smaller build area than some SLA printers. Pixelation can occur on curved surfaces. Resin possibilities may be more restricted than SLA on some systems.

IV. MATERIAL SCIENCE AND MECHANICAL PROPERTIES

3D printing resins are generally methacrylate-based formulations that contain urethane dimethacrylate (UDMA) or bisphenol A-glycidyl methacrylate (Bis-GMA) oligomers. Filler particles (silica, zirconia, or nanoceramics) improve stiffness and wear resistance [1]. 3D printing materials include milled PMMA, 3D printed D Tech resin, and 3D printed Freeprint resin [2].Flexural strength is a fundamental mechanical attribute that measures a material's resistance to bending forces. Flexural strength values have been reported to vary from 60 to 90 MPa, with fracture resistance ranging from 1000 to 1200 N [1]. Milled PMMA has the highest mean flexural strength (114.74 ± 5.00 MPa) compared to resins such as Freeprint (91.32 ± 3.05 MPa) and D Tech (80.33 ± 5.48 MPa) [2]. The materials tested were CAD/CAM milled PMMA and two photopolymer 3D-printed temporary crown resins. Flexural strength tests found that milled PMMA has much better flexural strength due to its thick, homogenous microstructure. The 3D-printed materials had a reduced flexural strength, which was due to their layered structure and degree of polymerization. However, both 3D-printed materials showed clinically acceptable mechanical characteristics for temporary restorations [2].

V. DIMENSIONAL ACCURACY, FIT, AND ESTHETICS

Dimensional precision is one of the most significant advantages of 3D printing. Printed provisionals outperform milled PMMA and direct bis-acryl techniques, with marginal gaps ranging from 60 to 100 µm according to studies. Such accuracy is achieved using layer-by-layer polymerization, which reduces distortion [1]. Both manufacturing procedures produced crowns with a good fit. Milled PMMA crowns demonstrated outstanding marginal adaptability due to precision subtractive machining. 3D-printed crowns fit well, although marginal accuracy needed to be improved by meticulous post-processing. Esthetically, 3D-printed materials gave a nicer surface finish after polishing. From a sustainability standpoint, 3D printing has advantages over milling, such as less material waste and better resource usage. Milling generates substantial waste owing to the removal of superfluous material, whereas additive manufacturing utilizes only the necessary quantity of resin. Furthermore, 3D printing speeds up manufacturing and reduces energy usage for short-term interim restorations, promoting ecologically friendly dental procedures [2].

VI. CLINICAL OUTCOMES

From a clinical aspect, 3D printing enables the same-day supply of provisional crowns in 30-60 minutes. Digital procedures save technician time and chairside changes. Patients gain from esthetic predictability and increased comfort [1].

VII. ENVIRONMENTAL AND SUSTAINABILITY CONSIDERATIONS

The environmental effect of resin printing is still a problem. Liang et al. highlight how photopolymer resins create chemical waste that requires specialist disposal since cross-linked polymers are not recyclable [1]. From a sustainability standpoint, 3D printing has advantages over milling, such as less material waste and better resource usage. Milling generates substantial waste owing to the removal of superfluous material, whereas additive manufacturing utilizes only the necessary quantity of resin. Furthermore, 3D printing speeds up manufacturing and reduces energy usage for short-term interim restorations, promoting ecologically friendly dental procedures [2].

VIII. RESEARCH GAP

According to the above literature review, researchers have worked on NextDent C&B resin, Freeprint resin, Bis-acryl resin, ASIGA resin, and zirconia materials, with less work done on phorzen resin material used for 3D printing and calculating the flexural strength of the crown in dentistry. Despite substantial advances in dental technology, traditional crown fabrication processes remain time-consuming, labor-intensive, and prone to errors, resulting in suboptimal fit, patient pain, and increased clinical expenses. While 3D printing provides promise benefits in terms of precision, efficiency, and customisation, its use in restorative dentistry remains restricted due to factors such as costly initial investment, lack of standardization, and the need for specialized training. This emphasizes the importance of through research and development to optimize 3D printing technology for everyday dental use, particularly crown production.

IX. CONCLUSION

Liang et al. found that 3D-printed resin-based temporary crowns and bridges have become viable replacements to conventional materials. Examples include PMMA and bisacryl. They provide a better fit, comparable strength, and shorter production times while allowing for digital design integration. However, further study is required to enhance long-term safety and environmental friendliness. As digital dentistry advances, 3D printing is expected to become the preferred approach for creating interim restorations [1].

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