Yıldırım *et al. BMC Oral Health* (2025) 25:82
https://doi.org/10.1186/s12903-025-05470-z

BMC Oral Health

RESEARCH

Open Access

Effect of different 3D-printing systems on the flexural strength of provisional fixed dental prostheses: a systematic review and network meta-analysis of in vitro studies

Ömer Yıldırım[1], Zeynep Yeşil[1,2] and Ömer Hatipoğlu[3*]

Abstract

Objectives The aim of this systematic review and network meta-analysis was to compare the flexural strength of provisional fixed dental prostheses (PFDPs) fabricated using different 3D printing technologies, including digital light processing (DLP), stereolithography (SLA), liquid crystal display (LCD), selective laser sintering (SLS), Digital Light Synthesis (DLS), and fused deposition modeling (FDM).

Materials and methods A comprehensive literature search was conducted in databases including PubMed, Web of Science, Scopus, and Open Grey up to September 2024. Studies evaluating the flexural strength of PFDPs fabricated by 3D printing systems were included. A network meta-analysis was performed, using standardized mean differences (SMDs) and 95% confidence intervals (CIs) to assess the effects of each system on flexural strength.

Results A total of 11 in vitro studies were included, with 9 studies contributing to the network meta-analysis. SLS (77.70%) and SLA (63.82%) systems ranked the highest in terms of flexural strength, while DLP ranked the lowest (23.40%). Significant differences were observed between SLS and multiple other systems, including DLP (-14.58, CI: -22.67 to -6.48), LCD (-14.65, CI: -25.54 to -3.59), FDM (-12.87, CI: -23.30 to -2.52), SLA (-11.41, CI: -18.74 to -4.01), and DLS (-10.89, CI: -21.23 to -0.67). Direct comparisons were limited, with DLP vs. SLA having the most data. Other comparisons were predominantly indirect.

Conclusions SLS and SLA systems exhibited superior flexural strength compared to other systems. However, the limited number of direct comparisons and reliance on indirect evidence suggest that further research is necessary to confirm these findings.

Clinical significance

The superior flexural strength of SLS and SLA 3D printing systems ensures enhanced durability and resistance to fracture in provisional fixed dental prostheses. This makes them preferable for clinical applications where long-lasting temporary restorations are critical, reducing the need for premature replacements and improving patient outcomes during the restorative phase.

---

*Correspondence:
Ömer Hatipoğlu
omerhtp@gmail.com

Full list of author information is available at the end of the article

Keywords 3D printing technologies, Flexural strength, Network meta-analysis, Provisional fixed dental prostheses

Introduction

The fabrication of provisional fixed dental prostheses (PFDPs) is a critical aspect of restorative dentistry, as these prostheses provide protection, function, and esthetics during the interim period before the placement of definitive restorations [1]. Despite their temporary nature, the performance of provisional restorations significantly influences the success of permanent restorations. Failures in provisional restorations can arise due to factors such as insufficient flexural strength, wear, discoloration, marginal leakage, and fracture, which not only compromise clinical outcomes but also impact patient satisfaction [2].

Fractures are among the most frequently reported failures in provisional restorations, often caused by inadequate flexural strength that renders the material unable to withstand functional loads. Dislodgement, resulting from poor retention or occlusal stress, can lead to discomfort and additional clinical interventions [3]. Furthermore, general structural failures, including deformations or wear, can reduce the effectiveness of the restoration in maintaining occlusal stability and protecting the underlying dentition [4]. These issues emphasize the importance of selecting materials and fabrication techniques that can minimize such failures and enhance the overall performance of provisional restorations.

Traditionally, PFDPs have been fabricated using polymethyl methacrylate (PMMA) and bis-acryl resins. These materials are applied using manual, time-intensive methods that may result in variability in material properties and clinical outcomes [5]. PMMA-based restorations are known for their strength and durability but can be brittle and prone to fractures under high functional loads. Conversely, bis-acryl resins are less time-consuming to work with but may lack the mechanical strength required for extended use. These limitations underscore the need for more precise and efficient fabrication techniques that improve mechanical properties while maintaining clinical reliability.

With advancements in digital dentistry, three-dimensional (3D) printing technology has emerged as a promising alternative for the fabrication of provisional prostheses. 3D printing offers several advantages, including high precision, repeatability, and customization based on digital scans [6]. Various 3D printing systems, such as digital light processing (DLP), stereolithography (SLA), liquid crystal display (LCD), selective laser sintering (SLS), Digital Light Synthesis (DLS), and fused deposition modeling (FDM), have been utilized to fabricate PFDPs [7]. These systems aim to overcome the limitations of traditional methods by offering better control over material properties, including flexural strength.

Flexural strength is a critical property for PFDPs, as it determines a material's resistance to deformation and fracture under functional loads. Provisional restorations with insufficient flexural strength are prone to failure during mastication, leading to premature replacements and increased clinical chair time [8]. Numerous in vitro studies have investigated the flexural strength of PFDPs produced using different 3D printing systems [9–19]. However, these studies often report inconsistent findings due to differences in experimental conditions, materials used, and testing protocols. This inconsistency creates uncertainty regarding the relative effectiveness of different systems in achieving optimal flexural strength for provisional restorations.

This systematic review and network meta-analysis aim to synthesize the available evidence from in vitro studies to compare the flexural strength of PFDPs fabricated using different 3D printing systems. By evaluating and ranking these systems, the study seeks to provide evidence-based insights that can guide clinicians in selecting the most appropriate 3D printing technology for fabricating durable and reliable provisional prostheses. The null hypothesis is that there is no significant difference in the flexural strength of PFDPs fabricated using various 3D printing systems.

Methods

Guidance and eligibility criteria

This systematic review and network meta-analysis followed the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Network Meta-Analyses (PRISMA-NMA). PRISMA-NMA provides a structured approach to ensure transparency and consistency in reporting the findings of systematic reviews that involve indirect comparisons across multiple interventions.

The eligibility criteria were defined using the PICOS framework as follows: Population included in vitro studies that evaluated PFDPs fabricated using various 3D printing technologies. Intervention focused on 3D printing systems, including DLP, SLA, LCD, SLS, and FDM. Comparator involved direct or indirect comparisons between these 3D printing systems, explicitly excluding conventional fabrication methods such as PMMA or bis-acryl resins. Outcome was the measurement of flexural strength (in megapascals, MPa) of PFDPs. Study Design was restricted to in vitro experimental studies to ensure consistency in the evaluation of mechanical properties and to minimize variability due to clinical conditions.

The inclusion criteria for this systematic review and network meta-analysis were defined to ensure the consistency and comparability of the included studies while maintaining a comprehensive approach. Only in vitro experiments evaluating the flexural strength of PFDPs fabricated using 3D printing technologies were considered. Eligible studies were required to use standard dental resins specifically designed for provisional restorations, excluding those that utilized unconventional, experimental, or non-dental materials to minimize variability in material properties. The analysis included studies examining 3D printing systems such as DLP, SLA, LCD, SLS, or FDM. To further ensure consistency in the results, only studies reporting detailed and comparable 3D printing parameters, including layer thickness, printing angle, and post-curing protocols, were included. Quantitative data on flexural strength, measured in megapascals (MPa), was required for inclusion. No restrictions were applied based on the language of publication, and both full-text and abstract-only studies were considered if they provided sufficient data for analysis. Exclusion criteria included studies that involved only conventional fabrication methods (e.g., PMMA or bis-acryl resins) as comparators, animal or human clinical studies, review articles, case reports, and studies lacking sufficient data on flexural strength outcomes.

Information sources and search strategy

A comprehensive literature search was conducted using multiple electronic databases, including PubMed, Web of Science, Scopus, and Open Grey, to identify the studies (Fig. 1). The search strategy was designed to comprehensively retrieve studies relevant to 3D printing technologies, provisional dental prostheses, and flexural strength while minimizing unnecessary heterogeneity. Specific keywords were selected to target the primary outcome ('flexural strength' OR 'mechanical properties'), the fabrication technology ('3D printing' OR 'three-dimensional printing' OR '3D-printed'), and the type of restoration ('interim' OR 'provisional' OR 'temporary'). Additionally, the strategy was tailored to align with the inclusion criteria by focusing on studies reporting essential parameters such as material composition, printing angle, layer thickness, and post-curing protocols. Boolean operators and advanced filters were applied to refine the search results, ensuring the retrieval of studies with well-defined and comparable conditions. The detailed search queries used for each database are provided in Supplemental Table 1.

To ensure the accuracy and reliability of the search process, two independent reviewers (O.Y. and O.H) screened the titles and abstracts of all identified records. Full texts of potentially eligible studies were then assessed independently by the same reviewers, and any discrepancies were resolved through discussion or consultation with a third reviewer if necessary (Z.Y). No language or publication status restrictions were applied, ensuring an inclusive and comprehensive review. Additionally, manual searches of reference lists from relevant articles and grey literature sources, such as conference proceedings and preprints, were performed to minimize the risk of publication bias. All searches were conducted up to September 2024, capturing the most recent studies available.

Study selection and data collection process

Two expert researchers (O.H, O.Y) screened the titles and abstracts of the studies independently and blindly. Each study was thoroughly evaluated, and full texts were accessed when necessary. To prevent discrepancies, reference management software (EndNote® X9, Thomson Reuters, Philadelphia, PA, USA) was utilized to eliminate duplicates efficiently. Following the removal of duplicate studies, the researchers applied the predefined inclusion and exclusion criteria, reaching a consensus on the final selection of candidate studies.

To maintain consistency and accuracy throughout the measurement and analysis processes, operator calibration was conducted. All operators involved in the study underwent a standardized training protocol to calibrate their assessment techniques and ensure uniformity in data collection. The calibration included training sessions on the use of measurement instruments, practice runs to establish proficiency, and periodic evaluations to maintain consistent performance during the entire study period.

For data extraction, two reviewers (O.H, O.Y) worked independently and in duplicate using pre-designed data extraction forms. The extracted information covered various study characteristics, including: (1) the year the study was published, (2) the specific resins used, (3) the 3D printing systems employed, (4) the printing angle, (5) sample shape and size, (6) the aging procedure applied, (7) the flexural strength testing machine used, and (8) the load and speed parameters reported.

Assessment of the risk of bias within the studies

The risk of bias in the included studies was assessed using the ROBDEMAT (Risk of Bias in Dental Materials Testing) tool, which evaluates biases across multiple domains specific to in vitro studies. The assessment focused on four key domains. The first domain, bias in planning and allocation, evaluated whether a control group was included and if the samples were randomized appropriately. The second domain, bias in sample/specimen preparation, focused on the justification and reporting of sample size, standardization of materials, and consistency in experimental conditions across groups. The third domain, bias in outcome assessment, examined the adequacy and standardization of testing procedures,

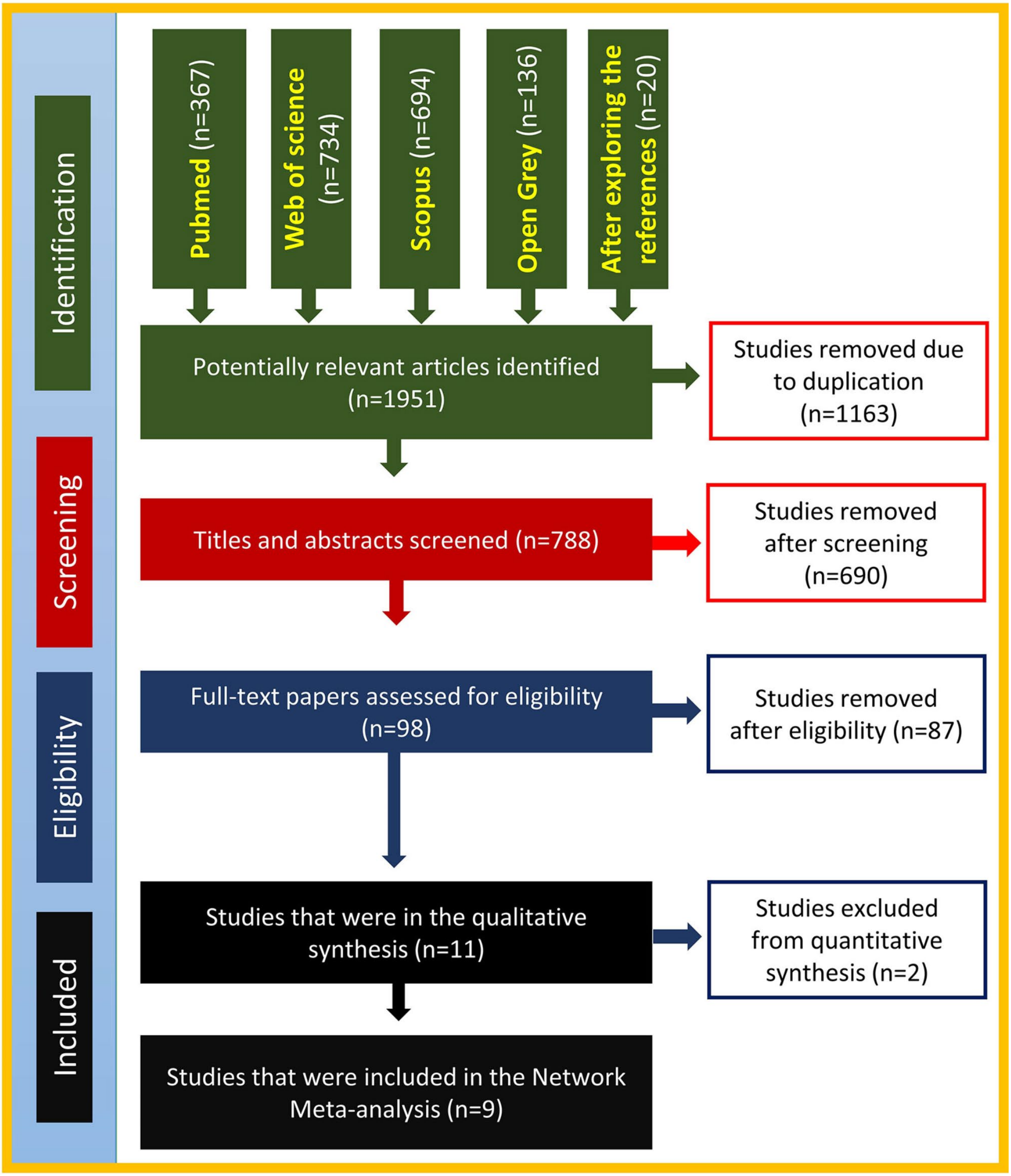


Fig. 1 PRISMA flow diagram for study selection process

the use of operator blinding, and the appropriateness of statistical methods. Lastly, bias in data treatment and outcome reporting assessed whether statistical analyses were suitable and if the study outcomes were reported accurately.

The overall inter-rater agreement (O.H with O.Y) for the risk of bias assessment was high (kappa > 0.80), and discrepancies were resolved through discussion or consultation with a third reviewer (Z.Y) when necessary.

Publication/Reporting bias

To evaluate publication and reporting bias in this network meta-analysis, the ROB-MEN (Risk of Bias due to Missing Evidence in Network meta-analysis) tool was employed. This tool is specifically designed to assess the impact of missing studies and potential biases in network meta-analyses. ROB-MEN examines the consistency of the network and the presence of small-study effects, providing a more comprehensive evaluation tailored to the structure of indirect and direct comparisons within the analysis. As part of this assessment, the ROB-MEN tool analyzed the network structure to detect any inconsistencies that could indicate the presence of publication bias. The tool's algorithms were used to assess whether smaller studies or studies with extreme results were disproportionately influencing the network's overall effect estimates.

Data synthesis

The primary outcome of the study was measured in megapascals (MPa), a continuous variable representing the flexural strength of the provisional fixed dental prostheses. To estimate the effects for both direct and indirect evidence within the network meta-analysis, standardized mean differences (SMDs) and their respective 95% confidence intervals (95% CIs) were utilized.

The analysis was conducted using a random-effects model and implemented in BUGSnet and JAGS, facilitating a Bayesian approach to estimate and interpret the SMDs for each comparison. The model parameters included a burn-in of 1,000 iterations, a total of 10,000 iterations, and a thinning factor of 1 to ensure convergence and the robustness of the estimates. The network's consistency was evaluated to confirm coherence between direct and indirect evidence, and any inconsistency detected was explored using diagnostic tools available in BUGSnet.

The results were presented in a league table format, ranking the 3D printing systems based on their estimated effects on flexural strength. Additionally, SUCRA (surface under the cumulative ranking curve) values were calculated to provide a probabilistic ranking of the systems, indicating their likelihood of being the most effective.

Assessment of confidence in network meta-analysis

CINeMA (Confidence In Network Meta-Analysis) is a web-based tool designed to assess the level of confidence in network meta-analysis results. In this project, CINeMA was used to systematically evaluate the six key domains that impact confidence in network meta-analysis: within-study bias, reporting bias, indirectness, imprecision, heterogeneity, and incoherence. These domains were examined based on the framework proposed by Papakonstantinou, et al. [20] and implemented in the CINeMA software, which offers a transparent and structured approach to evaluating the strength of evidence.

The CINeMA process began with the configuration of the network meta-analysis data, where the necessary outcome data were uploaded in .csv format, ensuring it contained the study-level assessments of bias and indirectness. After specifying the effect measures and modeling choices (random-effects models), the software computed the NMA results and produced visual outputs, such as network plots and contribution matrices. These were used to guide the evaluation of the six domains.

For each domain, the contributions from individual studies were reviewed, focusing on their respective risk levels. CINeMA offers automated judgment rules for summarizing these risks, but manual adjustments were made where necessary, especially in cases of high within-study bias or indirect evidence. Ultimately, CINeMA helped to assign a confidence rating ("high," "moderate," "low," or "very low") to each treatment comparison, providing a comprehensive assessment of the evidence that will enhance the transparency and rigor of this network meta-analysis.

Results

Study selection

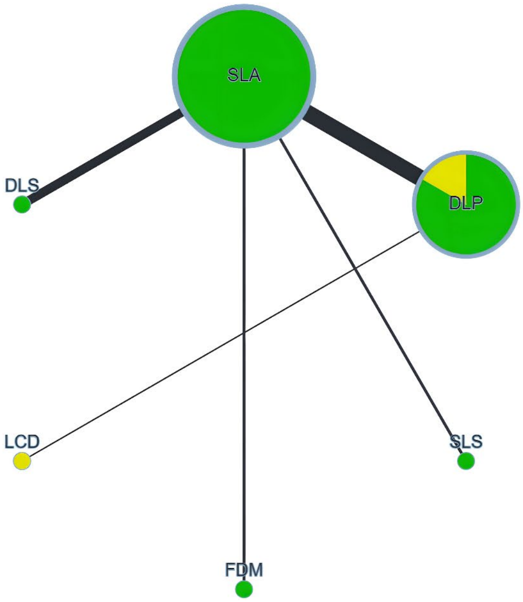
Reference lists of relevant studies were manually reviewed to ensure comprehensive coverage. After removing duplicates, the remaining records were screened based on titles and abstracts, followed by a full-text assessment of eligible articles. Ultimately, 11 studies were included in the qualitative synthesis, and 9 were further analyzed in the network meta-analysis. Two studies [11, 15] were excluded from the quantitative synthesis due to the insufficient clarity of the data presented (Fig. 1).

Summary of network geometry

The network geometry consists of 6 interventions and 9 studies, with the node sizes in the network plot representing the number of studies evaluating each intervention. The color of the nodes indicates the risk of bias associated with the studies, with green representing a low risk, yellow indicating moderate risk, and red denoting high risk. The edges between the nodes are proportional to the sample size for each pairwise comparison, where wider edges indicate larger sample sizes. The network is fully connected, meaning that there is a path linking all interventions, and all included studies are two-arm studies, with no multi-arm studies contributing to the network (Fig. 2).

Study characteristics

The characteristics of the included studies exhibited a variety of approaches regarding materials, 3D printing systems, sample preparation, and testing protocols



Characteristic	Value
Number of Interventions	6
Number of Studies	9
Total Number of Patients in Network	230
Total Possible Pairwise Comparisons	15
Total Number of Pairwise Comparisons With Direct Data	5
Is the network connected?	TRUE
Number of Two-arm Studies	9
Number of Multi-Arms Studies	0

Fig. 2 Network geometry of interventions

(Table 1). A total of 11 studies were included, each utilizing different types of resins specifically designed for dental applications. Alageel, et al. [15] used Crown & Bridge NextDent®, DentaTooth, and JamgHe Temporary Resin. Al-Mutairi [9] employed Form 3B + Crown and Bridge Resin, Dentca Crown and Bridge Resin, and Telio CAD. Other studies, such as Chen, et al. [11] and Cho, et al. [14], also explored various dental resins, including Enlighten AATemp, NextDent C&B MFH, and ZMD-1000B Temporary.

The studies utilized a range of 3D printing systems, with DLP being one of the most common. Alageel, et al. [15] used NextDent 5100 and Asiga MAX, while Ellakany, et al. [13] employed NextDent 5100 and Asiga MAX UV. SLA was another widely used system, as seen in Al-Mutairi [9] with Form 3B + and Cho, et al. [14] with Zenith U. Other printing technologies included FDM and SLS, which were utilized in some studies [10, 18].

Sample preparation followed a relatively standardized approach across the studies, with most using rectangular-shaped samples for flexural strength testing. Most of the studies [10, 11, 13–15] used rectangular samples measuring 2 mm × 2 mm × 25 mm. However, there were some variations, such as Park, et al. [19] which employed three-unit fixed dental prostheses as their sample shape, with connector sizes ranging from 4 mm to 5.5 mm.

Aging procedures were included in several studies to simulate long-term wear and durability under conditions that mimic the oral environment. Some studies [13–15] employed thermocycling procedures, whereas, some [17–19] used hydrothermal aging to assess the durability of the printed materials in a moisture-rich environment.

Most studies conducted flexural strength testing using universal testing machines. The Instron Universal Testing Machine was a common choice [9, 12–16, 19]. Testing protocols typically involved applying load to the samples at speeds ranging from 0.5 mm/min to 5 mm/min, with most studies using a rate of 1 mm/min. Load capacities varied, with some studies using a maximum load of 500 N [10, 11, 15], while Ellakany, et al. [13] applied up to 30 kN. Most studies printed samples at 0° or 90° angles [9, 10, 12–15]. However, some studies [17–19] used a 30° angle for their samples.

Risk of bias within studies

The assessment revealed that most studies provided sufficient reporting in several domains, including standardization of experimental conditions and sample materials, as well as the adequacy of testing procedures and outcomes (Table 2). However, one consistent area of weakness across studies was the randomization of samples, which was not reported (NR) in any of the studies.

In terms of blinding, none of the studies reported blinding of the testing operator (NR), introducing potential bias in outcome assessment. Similarly, the reporting of statistical analysis was insufficient in several studies [10, 11, 18]. Additionally, outcome reporting was inadequate in some studies [11, 15], where key results were either missing or insufficiently described.

Despite these limitations, most studies reported their outcomes clearly and had adequate control groups and standardized procedures, contributing to overall moderate confidence in the included studies.

Table 1 Characteristics of the studies included in the qualitative synthesis ($n=11$)

Study	Article type	Resin	3d printing system	Printing Angle	Sample shape and size	Aging procedure	Flexural strength testing machine	Load and speed
Al-lagael et al. (2023)	Research article	1. Crown & Bridge NextDent® (NextDent, Soesterberg, Netherlands) 2. DentaTooth (Asiga, Alexandria, Australia) 3. JamgHe Temporary Resin (JamgHe, Shenzhen, China)	1. NextDent 5100 (NextDent, Soesterberg, Netherlands) - DLP (Digital Light Processing) 2. Asiga MAX (Asiga, Alexandria, Australia) - DLP (Digital Light Processing) 3. Nova 3D Master (Nova3D, Shenzhen, China) - LCD (Liquid Crystal Display)	0° and 90°	Rectangular-2 mm × 2 mm × 25 mm	Tooth Brushing Simulation: 27,500 strokes at a brushing speed of 30 s/min with a vertical load of 200 g, Thermocycling: 3,500 cycles	Instron Universal Testing Machine (Instron Corp., Canton, MA, USA)	1 mm/min with a 500 N load cell
Al-mutairi et al. (2023)	Thesis	1.Form 3B + Crown and Bridge Resin: FormLabs, Sommerville, MA 2. Dentca Crown and Bridge Resin: Dentca, Torrance, CA 3. Telio CAD: Ivoclar Vivadent AG, Schaan, Liechtenstein	1. Form 3B + 3D Printer(FormLabs, Somerville, Massachusetts, USA)-SLA 2. Carbon Digital Light Synthesis™ (Carbon DLS™,Redwood City, California, USA)	0°	4-unit provisional fixed dental prostheses (FDPs)- 12 mm^2	none	Instron Model 5566 (Instron Corp, Canton, MA, USA)	increased until the sample fractured and 0.5 mm/min
Alzaid et al. (2022)	Research article	1. NextDent Denture 3D+ (NextDent, Vertex-Dental B.V., Soesterberg, Netherlands): 3D-printed resin for denture base fabrication. 2. FormLabs Denture Base LP (FormLabs Inc, Somerville, MA, USA): 3D-printed resin for denture base fabrication	1. NextDent 5100: A 3D printer used for fabricating denture bases with NextDent Denture 3D + resin. Manufacturer: Vertex-Dental B.V., Soesterberg, Netherlands - DLP 2. Form 2: A 3D printer used for fabricating denture bases with FormLabs Denture Base LP resin. Manufacturer: FormLabs Inc, Somerville, MA, USA - SLA	90°	Rectangular-64 × 10 × 3.3 mm	Immersion in artificial saliva with different pH levels (5.7, 7.0, and 8.3) at 37 °C for 90 days	Instron Model 8871 (Instron Corp, Canton, MA, USA)	5 mm/min with a 5 kN load cell
Chen et al. (2020)	Research article	1. Enlighten AATemp (Enlighten Materials, Taiwan) 2. NextDent C&B MFH (NextDent, Netherlands) Enlighten AA	1. MiiCraft Ultra 125(Taiwan)-DLP 2. Phrozen Sonic(Taiwan)- Mono-LCD	none	Rectangular-2 × 2 × 25 mm	none	Universal testing machine (QC-513B1; Cometech, Taiwan)	1 mm/min with a 500 N load cell
Cho et al. (2019)	Research article	1. ZMD-1000B TEMPORARY (Dentis, Daegu, Korea) 2. 3DCNB-500 (DIO, Busan, Korea)	1.ZENITH U(Dentis, Daegu, Korea)-SLA 2. ZENITH D(Dentis, Daegu, Korea)-DLP 3. PROBO(DIO, Busan, Korea)-DLP	0°	Rectangular-25 × 2 × 2 mm	Thermomechanical Aging (37 °C for 24 h)	Universal testing machine (Instron Co., Canton, Orange, CA, USA)	90° angle to the samples at a rate of 1 mm/min
Creen et al. (2022)	Research article	1. Polylactic acid (FDM, Nanovia, Louargat, France) 2. TemporaryCB®(Formlabs, Berlin, Germany)	1. Ultimaker 3®(Ultimaker, Utrecht, Netherlands)-FDM 2. Form 3(Formlabs, Berlin, Germany)-SLA	0°	Rectangular-25 × 2 × 2 mm	none	Universal testing machine (Autograph AGS-X, Shimadzu, Kyoto, Japan)	0.75 mm/min with a 500 N load cell

Table 1 (continued)

Study	Article type	Resin	3d printing system	Printing Angle	Sample shape and size	Aging procedure	Flexural strength testing machine	Load and speed
Ellakany et al. (2022)	Research article	1. SLA ND resin (NextDent C&B MFH, produced in Soesterburg, Netherlands) 2. DLP AS resin (ASIGA DentaTooth, produced in Erfurt, Germany)	1. NextDent 5100(NextDent, Soesterburg, Netherlands)-SLA 2. Asiga MAX UV(ASIGA, Erfurt, Germany)-DLP	90°	Rectangular-2×2×25 mm	Thermo-mechanical aging(50,000 cycles of thermal cycling between temperatures of 5 °C and 55 °C)	Instron 8871: A universal testing machine(Instron Co., Norwood, MA, USA)	
Lim et al. (2021)	Research article	1. ZMD-1000B Temporary (Dentis, Daegu, Korea) 2. Detax Freeprint Temp (Detax, Ettlingen, Germany)	1. Zenith U (Dentis, Daegu, Korea)-SLA 2. Asiga Max UV (Asiga, Sydney, Australia)-DLP	none	Beam- 25 mm × 2 mm × 2 mm	none	Universal Testing Machine (UTM): Instron 5848 (Instron, Canton, USA)	2 mm/min with maximum load
Pantea et al. (2022)	Research article	1. NextDent C&B MFH (NextDent by 3D Systems, Vertex B.V., Soesterberg, The Netherlands) 2. HARZ Labs Dental Sand (HARZ Labs, Riga, Latvia)	1.NextDent 5100 (NextDent by 3D Systems, Vertex B.V., Soesterberg, The Netherlands)-DLP 2.Phrozen Sonic Mini 4 K (Phrozen Technology, Xiangshan Dist., Hsinchu, Taiwan)-LCD	30°	Rectangular-80 mm length × 20 mm width × 5 mm thickness	hydrothermal aging	The Universal Testing Machine (Walter + Bai LFV 300, Walter + Bai AG, Löhningen, Switzerland	5 mm/min
Park et al. (2020)	Research article	1. C&B NextDent (NextDent Co., Soesterberg, The Netherlands) 2. Standard (GPGR04) (Formlabs Co., Somerville, Massachusetts, USA) 3. PLA (ColorFabb Co., Belfeld, The Netherlands)	1. NextDent 5100 (NextDent Co., Soesterberg, The Netherlands)-DLP 2. Form 2 (Formlabs Co., Somerville, Massachusetts, USA)-SLA 3. Creator Pro (FlashForge Co., Zhejiang, China)-FDM	30°	• Shape: Three-unit fixed dental prosthesis • Size: The connector between the premolar and the molar was 5.5 mm wide and 5.5 mm tall, while the connector between the two premolars was 4 mm wide and 5 mm tall	hydrothermal aging	Instron 8871 (Instron Co., Norwood, OH, USA)	1 mm/min- 10 kN
Simoneti et al. (2022)	Research article	1. SLS Nylon 12 PA2201 (Stratasys Direct Manufacturing, Valencia, California, USA) 2. Gray Resin (Formlabs Inc, Somerville, Massachusetts, USA)	1. SLS 3D Printer(• Stratasys Direct Manufacturing, Valencia, California, USA)-SLS 2. Form 2 (SLA 3D Printer) (Formlabs Inc, Somerville, Massachusetts, USA)-SLA	30°	Rectangular-4 mm x 2 mm x 10 mm	hydrothermal aging	DL500 Universal Testing Machine(São José dos Pinhais, Paraná, Brazil)	0.5 mm/min- A 1000-N load cell

Synthesis of results

The SUCRA plot results demonstrate a clear ranking among the 3D printing systems in terms of flexural strength. The SLS system stands out with the highest SUCRA value of 77.70%. Following closely, the SLA system ranks second with 63.83%. The DLS system achieves a moderate performance with 59.95%, while the FDM system ranks lower at 46.27%. On the other hand, both LCD and DLP systems demonstrate lower performance, with 28.85% and 23.40%, respectively, positioning DLP as the system with the weakest flexural strength among the compared technologies (Fig. 3).

The league table further confirmed these findings. Significant differences were observed between SLS and multiple other systems, including DLP (-14.58, CI: -22.67 to -6.48), LCD (-14.65, CI: -25.54 to -3.59), FDM (-12.87, CI: -23.30 to -2.52), SLA (-11.41, CI: -18.74 to -4.01), and DLS (-10.89, CI: -21.23 to -0.67). These large negative SMD values indicate that SLS performed significantly better in terms of flexural strength compared to all other systems. In contrast, the differences between other systems such as DLP, LCD, FDM, and SLA were much smaller and mostly statistically non-significant, as

Table 2 Risk of bias assessment of included studies based on ROBDEMAT

	D1: Bias in Planning and Allocation			**D2: Bias in Sample/Specimen Preparation**		**D3: Bias in Outcome Assessment**		**D4: Bias in Data Treatment and Outcome Reporting**	
Author/Year	**Control Group**	**Randomization of Samples**	**Sample Size Rationale and Reporting**	**Standardization of Sample Materials**	**Identical Experimental Conditions across Groups**	**Adequate and Standardized Testing Procedures/ Outcomes**	**Blinding of the Testing Operator**	**Appropriate Statistical Analysis**	**Reporting Study Outcomes**
Cho et al. (2019)	SR	NR	NR	SR	SR	SR	NR	SR	SR
Park et al. (2020)	SR	NR	NR	SR	SR	SR	NR	SR	SR
Simoneti et al. (2020)	SR	NR	NR	SR	SR	SR	NR	IR	SR
Chen et al. (2020)	NR	NR	NR	SR	SR	SR	NR	IR	IR
Lim et al. (2021)	SR	NR	NR	SR	SR	SR	NR	SR	SR
Crenn et al. (2022)	SR	NR	SR	SR	SR	SR	NR	IR	SR
Ellakany et al. (2022)	SR	NR	SR	SR	SR	SR	NR	SR	SR
Pantea et al. (2022)	SR	NR	NR	SR	SR	IR	NR	NR	SR
Allgeal et al. (2022)	NR	NR	SR	SR	SR	SR	NR	SR	IR
Al-Mutairi et al. (2023)	SR	NR	NR	SR	SR	SR	NR	SR	SR
Alzaid et al. (2023)	SR	NR	SR	SR	SR	SR	NR	SR	SR

IR: Insufficiently reported; NR: Not reported; SR: Sufficiently reported

evidenced by SMD values close to zero and confidence intervals crossing zero (Fig. 4).

The forest plot visually confirmed these findings, illustrating that the largest differences in flexural strength were seen between SLS and other systems, particularly DLP and LCD. The plot highlighted the substantial advantage of SLS, with large negative standardized mean differences compared to other systems. Meanwhile, the comparisons between DLP, LCD, FDM, and SLA were much closer to the zero line, indicating minimal differences in flexural strength (Fig. 5).

Publication/Reporting bias

Comparisons such as DLP vs. SLA, DLS vs. SLA, FDM vs. SLA, and DLP vs. FDM showed no contribution from evidence with suspected bias, and these comparisons were evaluated as having a low risk of bias. Furthermore, the small-study effect evaluations did not reveal significant concerns in these comparisons (Supplemental Table 2).

However, some concerns arose in a few specific comparisons. The comparison between DLP and LCD showed that 100% of the evidence contributing to this comparison came from pairwise comparisons with suspected bias, raising some concerns. Additionally, the comparison between LCD and SLS/FDM/DLS also had 33.3% of evidence with suspected bias favoring LCD. Moreover, certain comparisons, such as DLS vs. LCD and FDM vs. LCD, were flagged with high risk of bias, primarily due to suspected bias in a portion of the contributing evidence. In these cases, the bias assessment suggested favoring LCD over DLS and FDM, although the impact of small-study effects was minimal (Supplemental Table 2).

Assessment of confidence in network meta-analysis

For comparisons of DLP vs. SLA, DLS vs. SLA, FDM vs. SLA, DLP vs. DLS, DLP vs. FDM, DLS vs. FDM, and LCD vs. SLS, the confidence was rated as high. These comparisons showed no major concerns across most domains. Specifically, there were no concerns regarding within-study bias, indirectness, imprecision, or heterogeneity. However, for all these comparisons, major concerns were raised regarding incoherence, yet this did not significantly affect the high confidence rating due to the robustness of the evidence in other domains (Table 3).

In several comparisons, the confidence was rated as moderate, primarily due to concerns in specific domains. For example, in the comparison between DLP vs. LCD, there were some concerns related to within-study bias and reporting bias, along with major concerns about incoherence, which lowered the overall confidence to a moderate level. Similarly, the comparison of SLA vs. SLS showed some concerns regarding reporting bias and heterogeneity, leading to a moderate confidence rating despite no significant issues in other domains (Table 3).

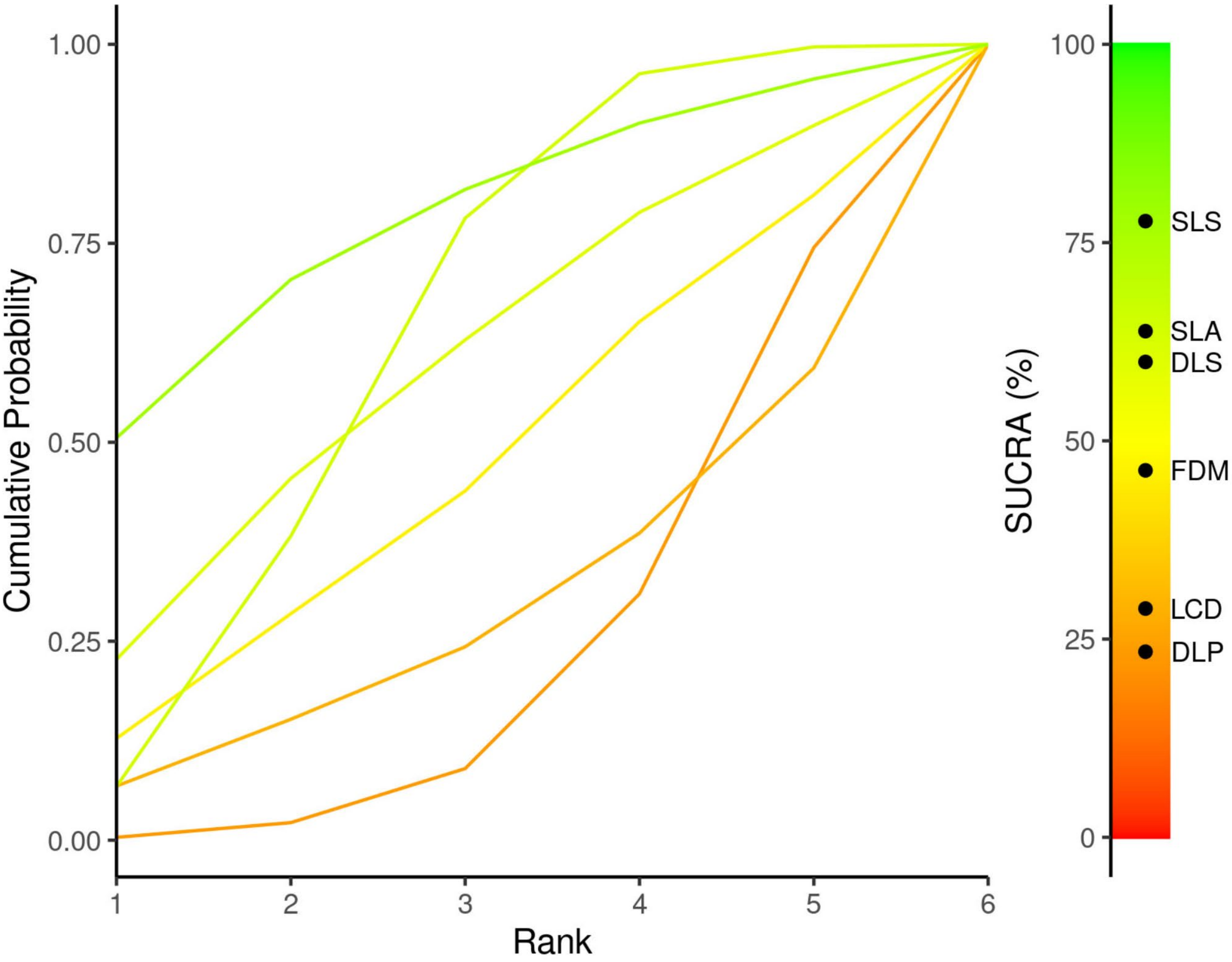


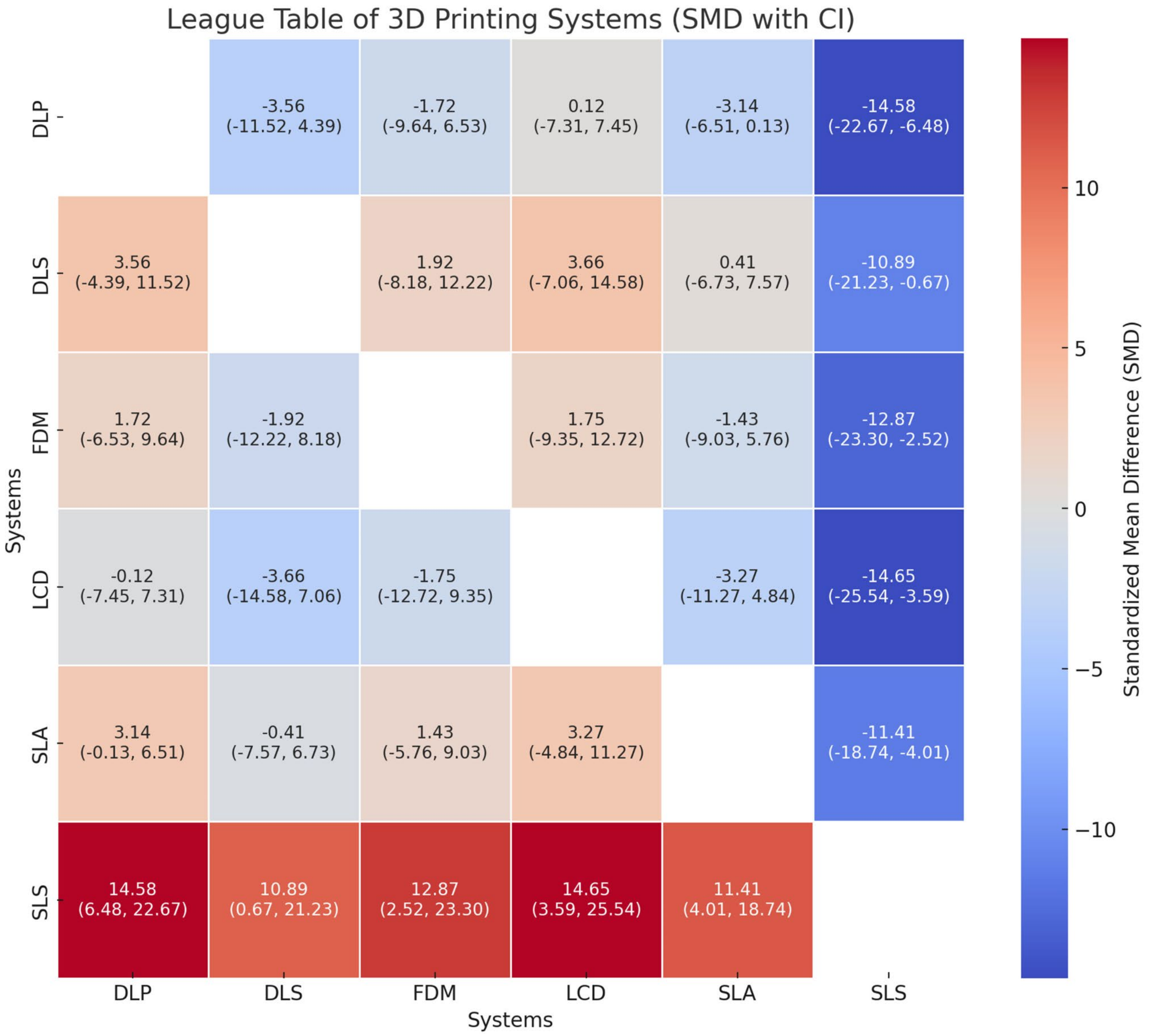
Fig. 3 SUCRA (Surface Under the Cumulative Ranking Curve) plot

Other comparisons that received a moderate rating include DLP vs. SLS, DLS vs. SLS, FDM vs. SLS, and LCD vs. SLA. In these cases, the primary issues were related to heterogeneity and incoherence, both of which were flagged as areas of concern. For instance, in the DLP vs. SLS comparison, some concerns about heterogeneity and major concerns regarding incoherence contributed to the moderate confidence rating. Similarly, in DLS vs. SLS and FDM vs. SLS, concerns about heterogeneity, coupled with incoherence, led to the reduction in confidence (Table 3). Certain comparisons, such as DLS vs. LCD and FDM vs. LCD, were assigned a low confidence rating. The main reason for this low rating was the high risk of reporting bias combined with major concerns regarding incoherence (Table 3).

Discussion

The purpose of this systematic review and network meta-analysis was to explore and compare the flexural strength of PFDPs produced by various 3D printing technologies. The fabrication of temporary dental restorations plays a critical role in clinical practice, and ensuring their mechanical durability, particularly flexural strength, is essential for patient outcomes. While traditional methods such as PMMA have been widely used [21], recent advancements in 3D printing offer new opportunities for improving the mechanical properties of these restorations [6]. This study hypothesized that different 3D printing systems would exhibit varying degrees of flexural strength, which could influence their clinical application and reliability. Based on the findings, the null hypothesis that there is no significant difference in the flexural strength of PFDPs fabricated using various 3D printing systems was rejected, as notable variations were observed among the systems.

Our findings align with the results reported by Saini, et al. [22], who conducted a systematic review and meta-analysis focusing on the flexural strength of provisional restorations fabricated using different resins across various 3D printing techniques. Their study highlighted that


League Table of 3D Printing Systems (SMD with CI)

Systems	DLP	DLS	FDM	LCD	SLA	SLS
DLP		-3.56 (-11.52, 4.39)	-1.72 (-9.64, 6.53)	0.12 (-7.31, 7.45)	-3.14 (-6.51, 0.13)	-14.58 (-22.67, -6.48)
DLS	3.56 (-4.39, 11.52)		1.92 (-8.18, 12.22)	3.66 (-7.06, 14.58)	0.41 (-6.73, 7.57)	-10.89 (-21.23, -0.67)
FDM	1.72 (-6.53, 9.64)	-1.92 (-12.22, 8.18)		1.75 (-9.35, 12.72)	-1.43 (-9.03, 5.76)	-12.87 (-23.30, -2.52)
LCD	-0.12 (-7.45, 7.31)	-3.66 (-14.58, 7.06)	-1.75 (-12.72, 9.35)		-3.27 (-11.27, 4.84)	-14.65 (-25.54, -3.59)
SLA	3.14 (-0.13, 6.51)	-0.41 (-7.57, 6.73)	1.43 (-5.76, 9.03)	3.27 (-4.84, 11.27)		-11.41 (-18.74, -4.01)
SLS	14.58 (6.48, 22.67)	10.89 (0.67, 21.23)	12.87 (2.52, 23.30)	14.65 (3.59, 25.54)	11.41 (4.01, 18.74)	

Fig. 4 Detailed league table of Standardized Mean Differences (SMD) with 95% Confidence Intervals (CI) for pairwise comparisons of 3D printing systems

the mechanical properties, including flexural strength, are significantly influenced by resin composition and polymerization processes. The key findings of this analysis indicate that among the evaluated 3D printing systems, SLS and SLA systems consistently demonstrated higher flexural strength compared to other technologies. These results are clinically significant as flexural strength is a critical property for the durability of provisional dental prostheses [17]. The superior performance of SLS and SLA systems suggests that these technologies are more suitable for producing restorations that can withstand functional loads, reducing the likelihood of fractures during the provisional phase. Therefore, the findings of this study can inform clinicians in selecting the most appropriate 3D printing systems for the fabrication of durable and reliable provisional restorations, ultimately improving patient outcomes.

The results of this study align with several previous investigations that have highlighted the superior flexural strength of SLS and SLA systems in dental applications. Numerous studies have demonstrated that SLA systems exhibit significantly higher mechanical durability compared to DLP [13, 14, 16, 19] and FDM [10] technologies. However, some discrepancies exist in the literature regarding the performance of SLA systems. Al-Mutairi [9] and Alzaid, et al. [12] found no significant difference between SLA, DLS, and DLP systems. While there is substantial evidence supporting the high performance of SLA systems, only the study of Simoneti, et al. [18] has demonstrated that SLS systems surpass SLA in flexural

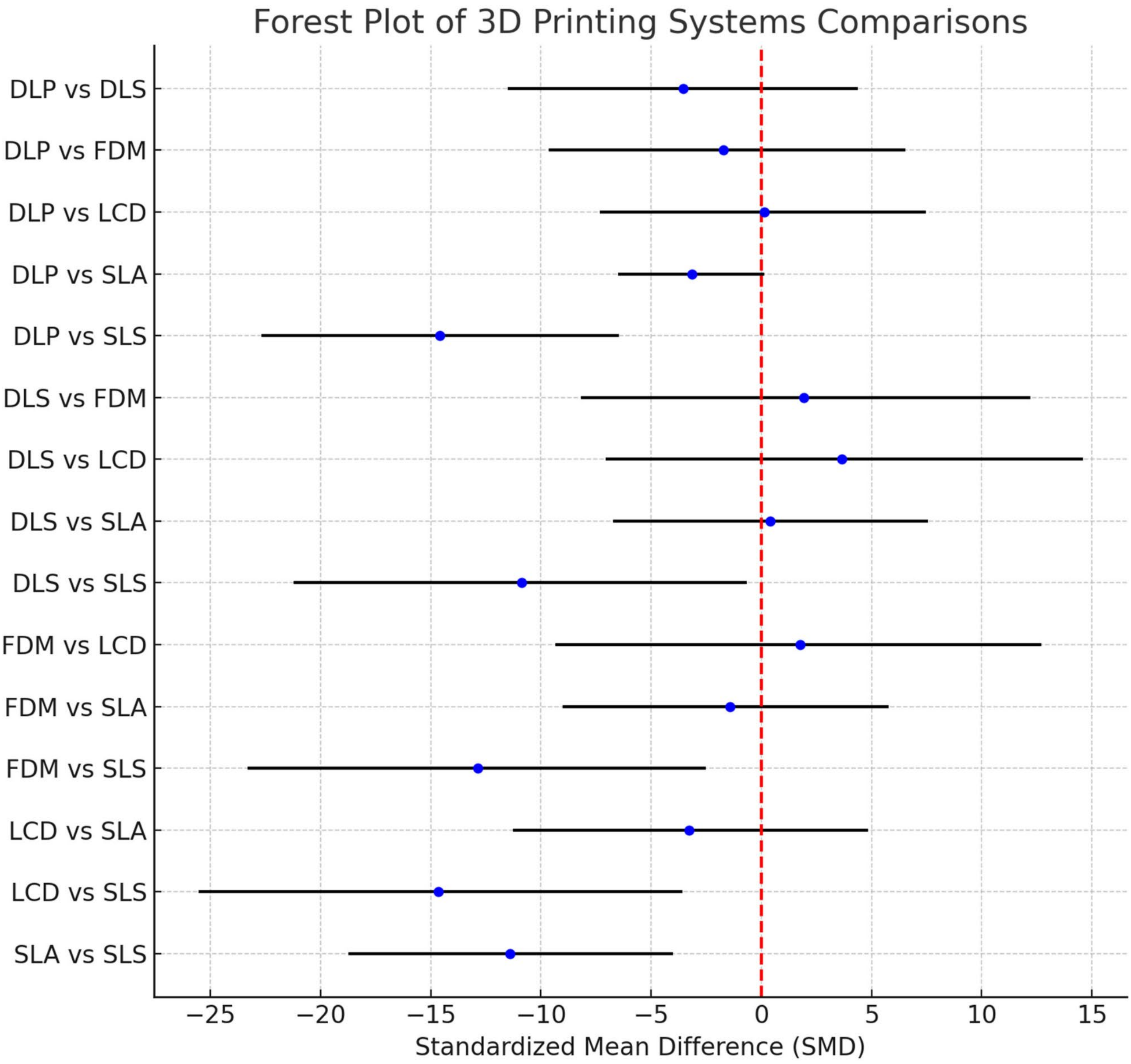


Fig. 5 Forest plot of Standardized Mean Differences (SMD) for pairwise comparisons of 3D printing systems based on flexural strength measurements

strength. Most comparisons involving SLS in our network analysis are therefore indirect, relying heavily on the findings from the aformentioned study. These variations may be attributed to differences in experimental conditions, such as resin composition, aging procedures, or the angle at which samples are printed. Thus, while our findings contribute to a growing body of evidence supporting the use of SLA and SLS systems, further research may be needed to explore the conditions under which other printing technologies could offer comparable mechanical performance.

The superiority of SLA and SLS systems over DLP and DLC systems in terms of flexural strength can be attributed to several factors. First, SLA and SLS technologies produce more homogeneous and high-resolution prints, which reduces the number of microstructural defects within the material, thereby enhancing mechanical strength [23]. In SLA systems, the photopolymerization process enables stronger interlayer bonding, which contributes to improved fracture resistance [24]. In SLS systems, laser sintering creates a denser bond between material particles compared to traditional additive manufacturing techniques, minimizing internal voids and resulting in higher mechanical durability [25]. On the other hand, DLP and DLC systems may suffer from microvoids and surface roughness during layer-by-layer production, which can negatively affect their mechanical properties [26]. Additionally, differences in resin

Table 3 CINeMA tool table

Comparison	Number of studies	Within-study bias	Reporting bias	Indirectness	Imprecision	Heterogeneity	Incoherence	Confidence rating
DLP: LCD	1	Some concerns	Some concerns	No concerns	No concerns	No concerns	Major concerns	Moderate
DLP: SLA	5	No concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	High
DLS: SLA	1	No concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	High
FDM: SLA	1	No concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	High
SLA: SLS	1	No concerns	Some concerns	No concerns	No concerns	Some concerns	Major concerns	Moderate
DLP: DLS	0	No concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	High
DLP: FDM	0	No concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	High
DLP: SLS	0	No concerns	Low risk	No concerns	No concerns	Some concerns	Major concerns	Moderate
DLS: FDM	0	No concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	High
DLS: LCD	0	No concerns	High risk	No concerns	No concerns	No concerns	Major concerns	Low
DLS: SLS	0	No concerns	Low risk	No concerns	No concerns	Some concerns	Major concerns	Moderate
FDM: LCD	0	No concerns	High risk	No concerns	No concerns	No concerns	Major concerns	Low
FDM: SLS	0	No concerns	Low risk	No concerns	No concerns	Some concerns	Major concerns	Moderate
LCD: SLA	0	Some concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	Moderate
LCD: SLS	0	No concerns	Low risk	No concerns	No concerns	No concerns	Major concerns	High

properties and material curing processes may also contribute to the performance gap. Parameters such as resin viscosity, curing speed, and the intensity of the light source in each technology play a crucial role in determining internal stresses during printing, which directly impacts flexural strength [27].

Each 3D printing system evaluated in this study offers unique advantages and limitations that can influence their suitability for fabricating provisional fixed dental prostheses. SLA systems are known for their high precision and superior surface finish, which enhance the mechanical properties of printed restorations. However, SLA systems require thorough post-curing to achieve optimal flexural strength, adding time and complexity to the workflow [28]. SLS systems demonstrated the highest flexural strength, attributed to their ability to create dense, homogeneous structures without the need for support materials. Despite this, SLS systems are cost-intensive and involve complex powder-handling procedures, limiting their accessibility [29]. DLP systems offer faster printing speeds and good detail resolution but may exhibit lower mechanical performance due to potential microvoids and weaker interlayer bonding [29]. LCD systems are a cost-effective alternative; however, their prints tend to have reduced durability compared to SLA and SLS [30]. FDM systems, while the most affordable and widely available, produce restorations with lower surface quality and flexural strength, making them less suitable for demanding clinical applications [31]. These distinctions highlight the importance of carefully selecting the printing technology based on clinical requirements, budget constraints, and desired material properties.

The comparison between additive manufacturing (3D printing) and subtractive methods, such as CAD/CAM milling, provides valuable context for interpreting the findings of this study. Ribeiro, et al. [32] emphasized that CAD/CAM PMMA resins consistently exhibit superior mechanical properties, such as higher flexural strength and lower porosity, compared to 3D-printed resins, due to their homogeneous structure and lack of layer-by-layer fabrication. Similarly, Gad, et al. [33] highlighted that while 3D printing offers unmatched precision and customization capabilities, subtractive techniques remain advantageous for producing materials with higher resistance to mechanical stress, particularly for long-term provisional restorations. The versatility and cost-effectiveness of 3D printing, however, make it an attractive option for cases requiring rapid fabrication or unique geometries.

The heterogeneity observed among the included studies likely influenced the overall results of this network meta-analysis. One notable factor previously considered was the variation in printing angles. While most studies used a 0° or 90° printing angle, some utilized a 30° angle, which may have affected the flexural strength of the printed prostheses. A 30° angle could introduce anisotropy in the printed layers, making certain regions more susceptible to mechanical stress and reducing overall strength [34, 35]. However, recent evidence suggests that printing orientation (e.g., 0° vs. 90°) does not significantly influence the flexural strength or elastic modulus of 3D-printed resins, as demonstrated by Espinar, et al. [36]. Nevertheless, this difference in layer orientation may explain the variability in the mechanical performance of similar systems across different studies. Furthermore, the type of resin used in each study likely played a significant role in the results. Different resin formulations vary in their polymerization behavior, mechanical properties, and compatibility with specific 3D printing technologies. For instance, resins designed for DLP systems may not perform as well in SLA systems due to differences in curing mechanisms [24]. This could lead to inconsistencies in flexural strength measurements across studies that used different resin materials, even if they employed the same printing technology.

Another consideration is that while this analysis focused on comparing 3D printing technologies, different brands of printers within the same technology may yield different results. For example, SLA systems from one manufacturer might outperform those from another due to differences in hardware precision, light source quality, or resin compatibility [37]. These brand-specific variations could contribute to discrepancies in mechanical performance observed within the same technology group. Additionally, some studies tested rectangular samples, while others used fixed dental prostheses, which could have influenced the flexural strength results. Rectangular samples provide a more standardized and reproducible testing format, whereas fixed dental prostheses introduce more complex geometries that may better mimic clinical conditions but also create more variability in mechanical performance. The complexity of the prosthesis design, such as connector thickness and the distribution of material stress points, could lead to differing results in flexural strength tests [33].

Another factor that influences the heterogeneity across studies is testing protocol, including the load and speed applied during flexural strength testing, which varies across studies [33]. Differences in loading rates or maximum forces can significantly impact the outcome, as faster loading rates may induce earlier failure, while higher load capacities can push materials beyond their expected functional limits [35]. These methodological variations highlight the importance of standardizing testing conditions when comparing 3D printing systems to ensure more consistent and comparable results.

One of the key limitations of this network meta-analysis is the relatively small number of direct comparisons available between the 3D printing systems. The highest number of direct comparisons occurred between DLP and SLA systems, with only five studies included in this category. For other comparisons, the available data were even more limited, with some being represented by only one direct comparison study. Furthermore, many of the comparisons in this analysis were derived indirectly, through the network structure, rather than from direct head-to-head studies. While indirect comparisons can still provide valuable insights, they are inherently less reliable than direct evidence due to the potential for confounding variables and differences in study designs.

The limited number of direct comparison studies raises concerns about the overall confidence in the results, particularly for comparisons that were based predominantly on indirect evidence. For example, while the DLP vs. SLA comparison is supported by a relatively higher number of studies, comparisons between systems such as FDM and SLS, or LCD and SLS, rely heavily on indirect data, reducing the confidence we can place in these results. The use of indirect evidence introduces additional uncertainty, as it combines results from studies that may differ in terms of materials, methodologies, or testing conditions, potentially amplifying any biases or inconsistencies present.

Another limitation lies in the exclusive reliance on in vitro data. While these studies provide controlled conditions to assess flexural strength, they do not fully replicate the complex oral environment, where factors such as temperature fluctuations, humidity, and dynamic mechanical loading may significantly influence the performance of 3D-printed provisional restorations. Future research should focus on standardizing testing protocols to reduce heterogeneity and improve comparability among studies. Moreover, clinical trials are needed to validate the findings from in vitro studies and explore the long-term performance of 3D-printed provisional restorations under real-world conditions. Investigating patient-centered outcomes, such as comfort and aesthetics, as well as the cost-effectiveness of different 3D printing systems, would further enhance the clinical applicability of this technology.

As a result, while the overall findings point to SLS and SLA systems performing better in terms of flexural strength, the strength of this conclusion is more robust for SLA than for others. Caution is warranted when interpreting the results of comparisons based on indirect evidence, and more direct comparison studies are needed to confirm the relative performance of other systems. Additionally, future research should explore strategies to enhance the mechanical properties of provisional restorations further. For instance, studies have demonstrated that glass fiber reinforcement can significantly improve the flexural strength of polymer-based dental materials [8]. Incorporating reinforcement techniques, such as embedding fibers or nanoparticles, may offer innovative solutions for increasing the durability and reliability of temporary restorations fabricated using 3D printing technologies. Until more high-quality, head-to-head studies are conducted to validate these approaches and provide stronger evidence, the reliability of some comparisons remains limited, and clinicians should consider these uncertainties when making decisions based on the available data.

Conclusion

This systematic review and network meta-analysis provides evidence that SLS and SLA systems, when employing appropriate resin materials and optimal machine settings, consistently demonstrate superior flexural strength compared to other 3D printing technologies, including LCD and DLP. These findings highlight the mechanical advantages of SLS and SLA systems in fabricating PFDPs under their respective optimal conditions.

However, the limited number of direct comparison studies and the reliance on indirect evidence for certain comparisons may influence the confidence in some of the results. Further studies are necessary to validate these findings under standardized and clinically relevant conditions, ensuring that each technology is evaluated using consistent parameters and materials.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12903-025-05470-z.

Supplementary Material 1

Acknowledgements
This study is part of the specialization thesis conducted by Ömer Yıldırım at Recep Tayyip Erdogan University, which is currently in progress. This study has been supported by the Recep Tayyip Erdoğan University Development Foundation (Grant num-ber:02024011025179).

Author contributions

Z.Y supervised the project, Ö.Y wrote the article, Ö.H conducted analyses.

Funding
This study has been supported by the Recep Tayyip Erdoğan University Development Foundation (Grant number:02024011025179).

Data availability

The datasets generated and/or analyzed during the current study are not publicly available considering that we have not required consents to publish this data, but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

Author details
[1]Department of Prosthodontics, Recep Tayyip Erdoğan University, Rize, Turkey
[2]Department of Prosthodontics, Ataturk University, Erzurum, Turkey
[3]Department of Restorative Dentistry, Recep Tayyip Erdoğan University, Rize, Turkey

Received: 7 November 2024 / Accepted: 9 January 2025

References

1. Alzahrani SJ, Hajjaj MS, Azhari AA, Ahmed WM, Yeslam HE, Carvalho RM. Mechanical properties of three-dimensional printed provisional resin materials for crown and fixed dental prosthesis: a systematic review. Bioengineering. 2023;10(6):663.
2. Patras M, Naka O, Doukoudakis S, Pissiotis A. Management of provisional restorations' deficiencies: a literature review. J Esthet Restor Dent. 2012;24(1):26–38.
3. Hyde JD, Bader JA, Shugars DA. Provisional crown failures in dental school predoctoral clinics. J Dent Educ. 2007;71(11):1414–9.
4. Heboyan AG, Movsisyan NM, Khachatryan VA. Provisional restorations in restorative dentistry. World Sci. 2019;3(6):11–7.
5. Barqawi L, Kanot S. A comparative clinical performance of polymethyl methacrylate (PMMA) and urethane dimethacrylate (UDMA) materials in Provisional fixed prostheses. Cureus. 2024;16(6).
6. Dimitrova M, Vlahova A, Kalachev Y, Zlatev S, Kazakova R, Capodiferro S. Recent advances in 3D printing of polymers for application in prosthodontics. Polymers. 2023;15(23):4525.
7. Rezaie F, Farshbaf M, Dahri M, Masjedi M, Maleki R, Amini F, et al. 3D printing of dental prostheses: current and emerging applications. J Compos Sci. 2023;7(2):80.
8. Dimova-Gabrovska M, Uzunov T, Gusiyska A, Shopova D, Taneva I, Gerdzhikov I, et al. Exploring flexural strength variation in polymeric materials for provisional fixed prosthetic structures: comparative analysis with and without reinforcement through laboratory experimentation and statistical evaluation. Appl Sci. 2024;14(9):3923.
9. Al-Mutairi L. Evaluation of flexural strength of milled vs printed provisional 4-unit fixed dental prostheses. Tufts Univ Sch Dent Med. 2023.
10. Crenn M-J, Rohman G, Fromentin O, Benoit A. Polylactic acid as a biocompatible polymer for three-dimensional printing of interim prosthesis: mechanical characterization. Dent Mater J. 2022;41(1):110–6.
11. Chen H, Cheng D-H, Huang S-C, Lin Y-M. Comparison of flexural properties and cytotoxicity of interim materials printed from mono-LCD and DLP 3D printers. J Prosthet Dent. 2021;126(5):703–8.
12. Alzaid M, AlToraibily F, Al-Qarni FD, Al-Thobity AM, Akhtar S, Ali S, et al. The effect of salivary pH on the flexural strength and surface properties of CAD/CAM denture base materials. Eur J Dent. 2023;17(01):234–41.
13. Ellakany P, Fouda SM, Mahrous AA, AlGhamdi MA, Aly NM. Influence of CAD/CAM milling and 3D-printing fabrication methods on the mechanical properties of 3-unit interim fixed dental prosthesis after thermo-mechanical aging process. Polymers. 2022;14(19):4103.
14. Cho WT, Choi JW. Comparison analysis of fracture load and flexural strength of provisional restorative resins fabricated by different methods. J Korean Acad Prosthodont. 2019;57:225–31.
15. Alageel O, Alhijji S, Alsadon O, Alsarani M, Gomawi AA, Alhotan A. Trueness, flexural strength, and surface properties of various three-dimensional (3D) printed interim restorative materials after accelerated aging. Polymers. 2023;15(14):3040.
16. Lim J, Lee J. Comparative study of flexural strength of temporary restorative resin according to surface polishing and fabrication methods. J Dent Rehabil Appl Sci. 2021;37(1):16–22.
17. Pantea M, Ciocoiu RC, Greabu M, Ripszky Totan A, Imre M, Ţâncu AMC, et al. Compressive and flexural strength of 3D-printed and conventional resins designated for interim fixed dental prostheses: an in vitro comparison. Materials. 2022;15(9):3075.
18. Simoneti DM, Pereira-Cenci T, Dos Santos MBF. Comparison of material properties and biofilm formation in interim single crowns obtained by 3D printing and conventional methods. J Prosthet Dent. 2020;127:168–72.
19. Park SM, Park JM, Kim SK, Heo SJ, Koak JY. Flexural strength of 3D-printing resin materials for provisional fixed dental prostheses. Materials. 2020;13:3970.
20. Papakonstantinou T, Nikolakopoulou A, Higgins JP, Egger M, Salanti G. Cinema: software for semiautomated assessment of the confidence in the results of network meta-analysis. Campbell Syst Rev. 2020;16(1):e1080.
21. Jehan A. Effect of nanoparticles on mechanical properties of chemically activated provisional PMMA resin: an in vitro study. World J Dent. 2023;14(7):617–24.
22. Saini RS, Gurumurthy V, Quadri SA, Bavabeedu SS, Abdelaziz KM, Okshah A, et al. The flexural strength of 3D-printed provisional restorations fabricated with different resins: a systematic review and meta-analysis. BMC Oral Health. 2024;24(1):66.
23. Jacobs PF. Rapid prototyping & manufacturing: fundamentals of stereolithography. Soc Manuf Eng. 1992.
24. Stansbury JW, Idacavage MJ. 3D printing with polymers: challenges among expanding options and opportunities. Dent Mater. 2016;32(1):54–64.
25. Caulfield B, McHugh PE, Lohfeld S. Dependence of mechanical properties of polyamide components on build parameters in the SLS process. J Mater Process Technol. 2007;182(1–3):477–88.

26. Ngo TD, Kashani A, Imbalzano G, Nguyen KT, Hui D. Additive manufacturing (3D printing): a review of materials, methods, applications and challenges. Compos Part B Eng. 2018;143:172–96.
27. Tumbleston JR, Shirvanyants D, Ermoshkin N, Janusziewicz R, Johnson AR, Kelly D, et al. Continuous liquid interface production of 3D objects. Sci (New York NY). 2015;347(6228):1349–52.
28. Della Bona A, Cantelli V, Britto VT, Collares KF, Stansbury JW. 3D printing restorative materials using a stereolithographic technique: a systematic review. Dent Mater. 2021;37(2):336–50.
29. Chaudhary S, Avinashi SK, Rao J, Gautam C. Recent advances in additive manufacturing, applications and challenges for dentistry: a review. ACS Biomater Sci Eng. 2023;9(7):3987–4019.
30. Tsolakis IA, Papaioannou W, Papadopoulou E, Dalampira M, Tsolakis AI. Comparison in terms of accuracy between DLP and LCD printing technology for dental model printing. Dent J. 2022;10(10):181.
31. Chen H, Yang X, Chen L, Wang Y, Sun Y. Application of FDM three-dimensional printing technology in the digital manufacture of custom edentulous mandible trays. Sci Rep. 2016;6(1):19207.
32. Ribeiro AKC, de Freitas RFCP, de Carvalho IHG, de Miranda LM, da Silva NR, de Fátima L Dantas de Almeida, et al. Flexural strength, surface roughness, micro-CT analysis, and microbiological adhesion of a 3D-printed temporary crown material. Clin Oral Investig. 2023;27(5):2207–20.
33. Gad MM, Fouda SM. Factors affecting flexural strength of 3D-printed resins: a systematic review. J Prosthodont. 2023;32(S1):96–110.
34. Sood AK, Ohdar RK, Mahapatra SS. Parametric appraisal of mechanical property of fused deposition modelling processed parts. Mater Des. 2010;31(1):287–95.
35. Derban P, Negrea R, Rominu M, Marsavina L. Influence of the printing angle and load direction on flexure strength in 3D printed materials for provisional dental restorations. Materials. 2021;14(12):3376.
36. Espinar C, Pérez MM, Pulgar R, Leon-Cecilla A, López-López MT, Della Bona A. Influence of printing orientation on mechanical properties of aged 3D-printed restorative resins. Dent Mater. 2024;40(4):756–63.
37. Pham DT, Gault RS. A comparison of rapid prototyping technologies. Int J Mach Tools Manuf. 1998;38(10–11):1257–87.

Publisher’s note