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Comparative Evaluation of Fracture Resistance/Strength of Interim Prosthesis for Crown and FDPs Using Conventional and Digital Methods: A Systematic Review and Meta-Analysis

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KEYWORDS

Fracture Resistance/Strength, Meta-Analysis

ABSTRACT:

Introduction: Interim prostheses play a vital role in protecting, stabilizing, and guiding treatment outcomes in restorative dentistry. The evolution of digital workflows, particularly 3D printing and CAD/CAM milling, has introduced new fabrication techniques for provisional restorations. However, there is ongoing debate over whether digital methods yield higher fracture resistance than conventional ones.

Objectives: This systematic review and meta-analysis aimed to compare the fracture resistance/strength of interim prostheses fabricated by 3D printing, CAD/CAM milling, and conventional methods.

Methods: A comprehensive literature search was performed across PubMed, Scopus, Web of Science, Google Scholar, and Cochrane Library databases for studies conducted from 2010 to 2024. Studies included in vitro or clinical human research directly comparing fracture resistance of 3D-printed, CAD/CAM-milled, and conventional interim crowns/FDPs. Risk of bias was assessed using Cochrane collaboration tools.

Results: Of 896 initial studies, 8 met the inclusion criteria. Meta-analysis showed that 3D-printed PMMA provisional restorations exhibited significantly higher fracture strength than conventional PMMA (SMD = 1.41 [0.74, 2.08], $p < 0.0001$, $I^2 = 87\%$). Comparisons between 3D-printed and CAD/CAM-milled PMMA revealed no significant difference in fracture resistance (SMD = 0.27 [-0.13, 0.66], $p = 0.18$, $I^2 = 93\%$). Similarly, while 3D-printed PMMA tended to outperform bis-acrylic resins, the difference was not statistically significant (SMD = 0.45 [-0.06, 0.96], $p = 0.12$, $I^2 = 85\%$).

Conclusions: 3D-printed PMMA-based interim prostheses demonstrate superior fracture resistance compared to conventional PMMA and bis-acrylic resins. However, evidence regarding their superiority over CAD/CAM-milled PMMA remains inconclusive.

1. Introduction

Interim prostheses play a foundational role in prosthodontic treatment, extending well beyond their traditional use as temporary placeholders. These restorations safeguard prepared teeth by preserving their integrity, preventing sensitivity, and shielding them from carious insults during the time between the preparation and placement of definitive restorations. Importantly, interim prostheses maintain occlusal and proximal stability, support gingival tissues, and provide ongoing comfort, thus ensuring that biological, functional, and esthetic demands are continuously met throughout often intricate or elongated treatment protocols. Their significance is further highlighted in comprehensive rehabilitations, such as full-mouth reconstructions, implant-supported cases, surgical procedures, and temporomandibular joint therapy, where they serve as therapeutic and evaluative tools. In these contexts, interim prostheses facilitate the assessment and fine-tuning of esthetic outcomes, occlusal schemes, and vertical dimension, and they enable both clinicians and patients to validate and adjust the treatment plan prior to final prosthesis delivery.

Historically, the evolution of interim prosthetic materials has mirrored advances in restorative dentistry. The earliest provisionals, fashioned from gutta-percha and zinc oxide eugenol, offered basic function but lacked esthetic appeal and mechanical resilience. The introduction of polymethylmethacrylate (PMMA) in the 1930s marked a significant leap forward, providing a durable, polishable, and affordable material that could be adapted to a range of provisional applications. PMMA's versatility—available in auto-polymerizing, heat-cure, and light-cure forms—cemented its place as the provisional standard for decades. Later, the advent of bis-acryl composite resins introduced adjunctive benefits, including improved marginal adaptation, color stability, and reduced polymerization shrinkage, making these materials especially advantageous for certain chairside uses. Additional advances in polymer chemistry have produced materials like polyethylmethacrylate (PEMA) and urethane dimethacrylate (UDMA), expanding the clinician's toolkit for specialized cases.

The digital revolution has dramatically transformed interim prosthesis fabrication. Computer-aided design/manufacturing (CAD/CAM) heralded a shift toward subtractive milling of pre-polymerized PMMA blocks, which affords industrial-grade homogeneity and superior mechanical properties compared to hand-mixed materials. More recently, additive manufacturing, or 3D printing, allows clinicians to create highly precise, patient-specific interim prostheses with unmatched speed, design complexity, and minimal material wastage. This technology leverages advanced photopolymer resins, and ongoing research is exploring hybrid resin-ceramic and biocompatible materials, expanding the possibilities for clinical application.

Interim prostheses are categorized by fabrication technique (direct, indirect, or combined), material composition (PMMA, bis-acryl, etc.), expected duration of use (short- vs. long-term), and method of polymerization or digital manufacture (chemical, heat, light-cure, CAD/CAM, 3D printing). The move towards digital workflows (CAD/CAM and 3D printing) has further allowed more precise, iterative provisionalization, benefitting both clinical workflow and patient outcomes through improved accuracy, speed, and customization.

2. Objectives

The objective of this systematic review and meta-analysis is to *thoroughly evaluate and compare the fracture resistance/strength of interim prostheses for crowns and fixed dental prostheses (FDPs) fabricated using conventional, CAD/CAM-milled, and 3D-printed methods*. This study addresses a critical clinical question: whether advances in digital fabrication, particularly 3D printing, deliver superior or at least comparable mechanical performance—specifically fracture resistance—relative to more established techniques like conventional self/chemically-cured polymethyl methacrylate (PMMA), bis-acryl resins, and CAD/CAM-milled PMMA blocks.

Comparative Evaluation:
The review aims to compare multiple fabrication methods—namely conventional, CAD/CAM-milled, and 3D-printed. Each method's mechanical performance (especially regarding fracture resistance) is systematically assessed to delineate their relative strengths and weaknesses in a clinically relevant context.

Focus on Fracture Resistance/Strength:
Fracture resistance is chosen as the primary mechanical outcome because it is directly related to the longevity and clinical success of interim prostheses. Parameters analyzed include flexural strength, fracture load, and failure load as measured in both in-vitro and eligible in-vivo studies.

Systematic Literature Review:
The objective includes conducting a systematic search across multiple scientific databases (PubMed, Scopus, Web of Science, Cochrane Library, and Google Scholar) to comprehensively identify, screen, and synthesize relevant studies published up to 2024. The review follows PRISMA guidelines to ensure methodological rigor and transparency.

Meta-Analysis:
Where feasible, quantitative data from included studies are pooled using meta-analytic techniques. This allows for statistical comparison between groups and yields more robust, generalizable conclusions, highlighting statistically significant differences (if present) as well as overall trends.

Assessment of Study Quality and Bias:
A critical secondary objective is to assess the methodological quality and risk of bias of included studies using the Cochrane Risk of Bias tool. This evaluation ensures that subsequent clinical

recommendations are grounded in sound scientific evidence.

Clinical Applicability: Ultimately, the objective extends to informing clinical decision-making by identifying which fabrication technique offers the best balance of mechanical strength and practicality. The review aims to guide practitioners in selecting the most suitable approach for fabricating interim crowns and FDPs based on evidence of fracture resistance and durability.

PICO Framework Represented

- P (Population): Patients or sample specimens requiring interim prostheses (provisional crowns and FDPs)
- I (Intervention): Fabrication with 3D-printed resins
- C (Comparison): Fabrication with CAD/CAM-milled PMMA and conventional (self/chemically-cured PMMA, bis-acryl) methods
- O (Outcome): Fracture resistance/strength
- T (Time): Studies up to 2024

Methods

Study Design

This study is a systematic review and meta-analysis conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The aim was to comprehensively compare the fracture resistance/strength of interim prostheses fabricated by conventional, CAD/CAM-milled, and 3D-printed methods for crowns and fixed dental prostheses (FDPs).

Protocol and Registration

A study protocol was developed in accordance with the Centre for Evidence-Based Medicine's PICOTS framework, with clearly defined inclusion/exclusion criteria, data extraction strategy, and risk of bias assessment

Eligibility Criteria

Inclusion Criteria:

- Peer-reviewed studies published in the English language.
- In vitro or clinical human studies.
- Studies directly comparing fracture resistance/strength of 3D-printed interim crowns/FDPs with those fabricated by conventional (self/chemically-cured PMMA or bis-acryl) and CAD/CAM-milled PMMA methods.
- Studies evaluating at least one of the following outcomes: flexural strength, fracture load, or failure load.

Exclusion Criteria:

- Non-English literature, animal, cadaveric, or case report studies.
- Studies not making direct comparisons between 3D-printed and other fabrication techniques.
- Articles focusing on properties unrelated to fracture strength (e.g., accuracy, marginal adaptation).
- Reviews, editorials, technical notes, dissertations, or unpublished work.
- Studies focused exclusively on permanent restorations.

Literature Search Strategy

A comprehensive electronic search was performed using the following databases: PubMed, Scopus, Web of Science, Google Scholar, and Cochrane Library. The search covered articles published up to December 2024. Both Medical Subject Heading (MeSH) terms and free-text keywords were used in combination with Boolean operators. The main search terms included:

- "restoration, temporary" OR "Tooth Crown" OR "Dental Prosthesis" OR "provisional crown" OR "interim resin" OR "Temporary dental restoration" AND

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- "3D print" OR "Rapid prototyping" OR "additive manufacturing" AND
- "CAD/CAM" OR "Computer-Aided Design" OR "polymethyl methacrylate" OR "bis-acryl".

Duplicates were removed, and additional studies were identified through screening reference lists of relevant reviews and included articles.

Study Selection

Two independent reviewers screened titles and abstracts for relevance. Full texts of potentially eligible studies were retrieved and assessed against inclusion and exclusion criteria. Any discrepancies were resolved through discussion or consultation with a third reviewer.

Data Extraction

Data were independently extracted by two reviewers using a standardized data collection form, capturing:

- Author(s) and year of publication
- Study design (in vitro or clinical)
- Sample size and group allocation
- Material type (3D-printed, CAD/CAM-milled, conventional)
- Fabrication technique
- Fracture resistance/strength values (flexural strength, fracture load, failure load)
- Main outcomes and findings

Assessment of Risk of Bias

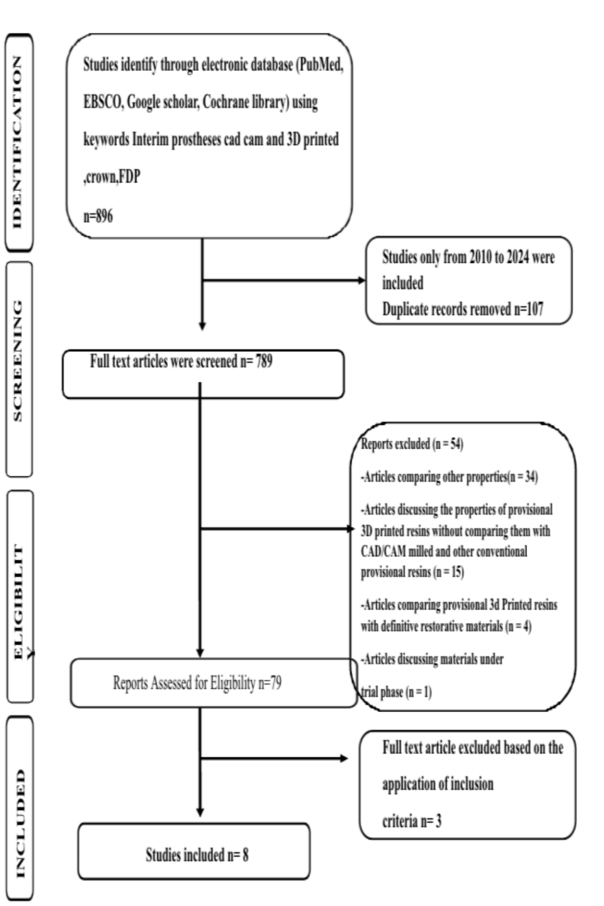
Risk of bias was assessed for all included studies using the Cochrane Risk of Bias tool for randomized trials and the ROBINS-I tool for non-randomized studies. Each study was evaluated for:

- Random sequence generation
- Allocation concealment
- Blinding of participants/personnel and outcome assessment
- Incomplete outcome data
- Selective reporting
- Other biases

Judgments were categorized as 'low risk,' 'high risk,' or 'unclear risk' for each domain.

Data Synthesis and Statistical Analysis

Meta-analysis was conducted where appropriate, using Review Manager (RevMan) 5.4 software. Continuous data (e.g., fracture strength) were summarized as mean difference (MD) or standardized mean difference (SMD) with 95% confidence intervals (CIs). Heterogeneity was assessed using the Chi^2 and I^2 statistics, with $I^2 > 30\%$ and $p < 0.05$ indicating significant heterogeneity. A random-effects model was used in the presence of considerable heterogeneity. Results were presented as forest plots, and findings were further discussed in relation to identified methodological weaknesses and heterogeneity among studies.



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Author & Year	**Study Type**	**Studied Characteristics**	**Studied Property**	**Sample Size (n)**	**Trade Name & Manufacturer**	**Main Chemical Composition**	**Fabrication Technique**	**Shape & Dimension of Tested Samples**	**Layer Thickness & Orientation of Printing**
Reeponmaha et al., 2020	In vitro	Fracture Strength	MP	n = 40 (10 per group)	(A) Unifast Trad (GC Chemicals) (B) Protemp 4 (3M ESPE) (C) Brylic Solid (Sagemax Bioceramics) (D) Freeprint Temp (Detax GmbH)	(A) Methyl methacrylate resin (B) Bis-acryl resin (C) Highly polymerized PMMA resin (D) Photopolymerized Methacrylate-based resins	(A) & (B): Conventional (C) CAD/CAM Milling (D) 3D Printing	Provisional crowns cemented on prepared epoxy die replicated from prepared tooth	Layer Thickness: N/M Orientation: N/M
Ibrahim et al., 2020	In vitro	Fracture Resistance	MP	n = 16 (8 per group)	(A) Telio CAD disc (Ivoclar Vivadent) (B) NextDent C&B resin (NextDent B.V)	(A) PMMA (B) MMA	(A) CAD/CAM Milling (B) 3D Printing	Provisional crowns cemented on prepared epoxy die replicated from prepared tooth	Layer Thickness: 50 µm Orientation: N/M
Suralik et al., 2020	In vitro	Fracture Strength	MP	n = 45 (15 per group)	(A) Jet (Lang Dental Inc.) (B) Zirlux Temp (Henry Schein) (C) Free Print Temp (DETAX GmbH)	(A) PMMA (B) PMMA (C) Methacrylate-based resins	(A) Conventional (Self-cured) (B) CAD/CAM Milling (C) 3D Printing	Provisional 3-unit fixed dental prosthesis (FDP) attached to implant abutments of the master metal typodont, with no luting agent.	Layer Thickness: 50 µm Orientation: 0°
Reymus et al., 2020	In vitro	Fracture Load	MP	n = 195 (15 per group)	(A) Luxatemp (DMG) (B) Telio CAD (Ivoclar-Vivadent) (C) Experimental (GC Europe) (D) NextDent C&B (NextDent) (E) Freeprint Temp (Detax) (F) 3Delta Temp (Deltamed)	(A) Bis-acryl Methacrylate (B) PMMA Polymer (C) Methyl Methacrylates (D) Methyl Methacrylates (E) Methyl Methacrylates (F) Methyl Methacrylates	(A) Conventional (B) CAD/CAM Milling (C), (D), (E), and (F): 3D Printing	A full-anatomic three-unit FPD attached to a steel abutment model with no luting agent.	Layer Thickness: N/M Orientation: N/M Long-axis positioned either occlusal, buccal, or distal to the printer's platform.
Abad-Coronel et al., 2021	In vitro	Fracture Resistance	MP	n = 40 (20 per group)	(A) Vipiblock Trilux (VIPI) (B) PriZma 3D Bio Prov (Markertek Labs)	(A) PMMA (B) Light-Curing Micro Hybrid Resin	(A) CAD/CAM Milling (B) 3D Printing	A 3-unit FDP fitted on a 3D-printed resin master typodont without any fixing agent.	Layer Thickness: N/M Orientation: N/M
Mayer et al., 2020	In vitro	Fracture Load & Two-body Wear	MP	n = 152 (48 per group for 3D-printed and 8 for CAD/CAM milled)	(A) Telio CAD disc (Ivoclar Vivadent) (B) Freeprint Temp (Detax) (C) GC Temp PRINT (GC Europe) (D) NextDent C&B MFH (NextDent)	(A) PMMA (B) Methylmethacrylates (C) UDMA (D) Methylmethacrylates	(A) CAD/CAM Milling (B), (C), and (D): 3D Printing	A full anatomic three-unit FDP fixed on a steel abutment model with a dual-cure self-adhesive resin composite cement	Layer Thickness: N/M Orientation: N/M
Martín-Ortega et al., 2022	In vitro	Fracture Resistance	MP	n = 40 (10 per group) (10 each anterior and posterior, CAD/CAM milled and 3D-printed)	(A) and (C): Vivodent CAD Multi (Ivoclar Vivadent AG) (B) and (D): SHERAprint-cb (SHERA)	(A) PMMA (B) Photopolymer interim dental resin	(A) CAD/CAM Milling (B) 3D Printing	Full anatomic crowns (20 anterior and 20 posterior) cemented on implant abutment with autopolymerizing composite resin cement	Layer Thickness: 50 µm Orientation: 45°

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Henderson et al., 2022	In vitro	Failure Load	MP	n = 180 (60 per group)	(A) 3M-Paradigm (3M Oral Care) (B) Solid Shade PMMA Disc (TD Dental Supply) (C) Dentca Crown and Bridge resin (Dentca)	(A) Bis-acryl resin (B) PMMA (C) Bis-acryl resin	(A) Conventional (B) CAD/CAM Milling (C) 3D Printing	3-unit interim FDP cemented onto 3D-printed resin dies	Layer Thickness: N/M Orientation: N/M

3. Results

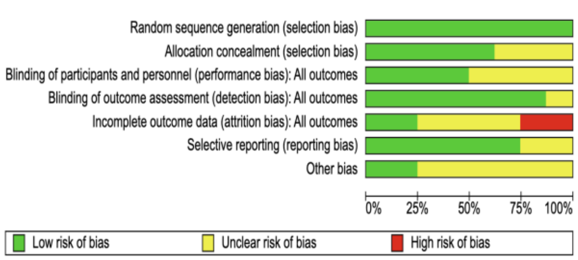
A comprehensive search of electronic databases including PubMed, EBSCO, Google Scholar, and the Cochrane Library was conducted using relevant keywords and Boolean operators such as “Interim prostheses AND CAD/CAM”, “3D printed crown”, and “3D printed FDP”.

The initial search yielded a total of 896 studies. After restricting the publication range to studies conducted between 2010 and 2024 and removing 107 duplicate records, 789 full-text articles remained for screening.

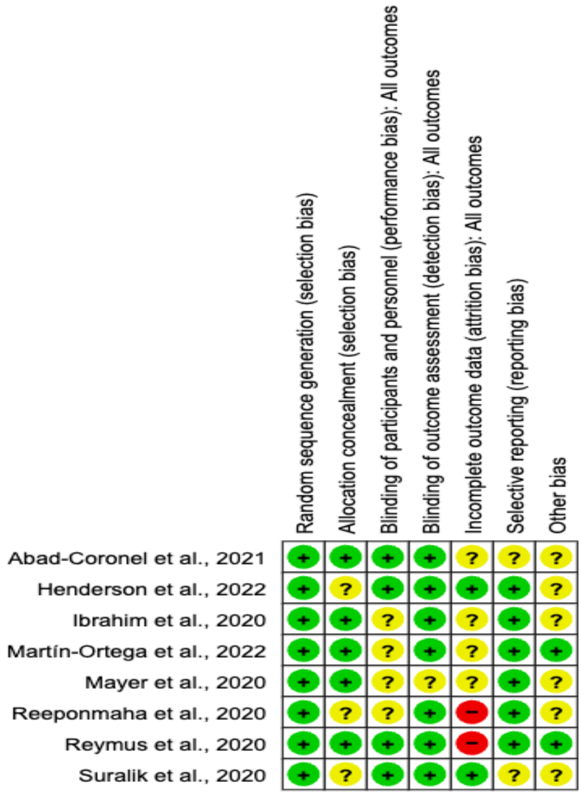
Upon screening, 54 articles were excluded for the following reasons: 34 articles discussed properties unrelated to fracture resistance, 15 studies investigated the properties of 3D-printed provisional resins without comparing them to CAD/CAM-milled or conventional provisional resins, 4 studies compared 3D-printed provisional resins with definitive restorative materials, and 1 study included materials still under the trial phase.

Further, 3 full-text articles were excluded for not meeting the predefined inclusion criteria.

Finally, a total of 8 studies were included in the qualitative synthesis and meta-analysis.



(Risk of bias graph - Judgment of review authors about each risk of bias in included studies presented as percentages)



(Risk of bias summary - Judgements of review authors about each risk of bias for all included study.)

Two studies (Reeponmaha et al., 2020; Reymus et al., 2020) had a high risk of bias from incomplete outcome data. Most studies had low risk for random sequence generation, except Henderson et al. (2022) and Suralik et al. (2020), which were unclear. Blinding of participants and personnel was uniformly rated as unclear due to the in vitro design, where blinding is typically not relevant

4. Discussion

This systematic review and meta-analysis critically examined the fracture resistance of interim prostheses fabricated by conventional methods, CAD/CAM milling, and 3D printing. The findings emphasize that the mechanical strength of provisional dental restorations is

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strongly affected by the choice of fabrication technique, intrinsic material properties, and specific processing parameters.

CAD/CAM-Milled PMMA

CAD/CAM-milled PMMA consistently demonstrated the highest fracture resistance among all examined methods. Its superior mechanical behavior results from industrial polymerization under controlled conditions, yielding a dense, homogeneous, and cross-linked structure with minimal defects. Such properties make milled PMMA especially suited for long-term provisional applications, including implant-supported prostheses and full-arch restorations, as corroborated by multiple included studies.

However, CAD/CAM fabrication necessitates expensive equipment and presents disadvantages such as material wastage and potential limitations in esthetics or marginal adaptation when compared to newer resin options.

3D-Printed PMMA

3D printing has revolutionized interim prosthesis fabrication by enabling rapid, customizable production and promising mechanical results. The results for 3D-printed PMMA were variable among studies, sometimes matching or exceeding milled PMMA, but not consistently so (SMD = 0.27

−0.13,0.66

−0.13,0.66; p = 0.18; high heterogeneity I^2 = 93%). Factors such as resin composition, printing orientation, and post-processing protocols influence the strength outcomes, indicating a need for standardization in 3D printing workflows.

The main advantage of 3D printing lies in its rapid prototyping capability and efficient use of materials. Innovations in resin development, including hybrid fillers and improved photoinitiators, are steadily enhancing both strength and biocompatibility. Still, inconsistencies in layer adhesion and mechanical anisotropy remain challenges.

Conventional PMMA and Bis-Acrylic Resins

Although easy to use and widely available, conventional PMMA and bis-acrylic resins displayed lower fracture resistance than their digitally produced counterparts. The reduced strength is attributed to chemical polymerization, increased porosity, and a less uniform structure. While bis-acrylics offer better handling and esthetics, their mechanical properties under long-term load are inferior.

Meta-analyses favored 3D-printed PMMA over conventional PMMA (SMD = 1.41

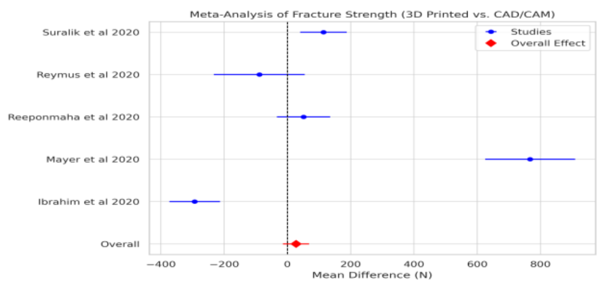
0.74,2.08

0.74,2.08; $p < 0.0001$; I^2 = 87%), signifying the advantages of digital fabrication in optimizing the structural integrity and longevity of interim restorations. Comparisons with bis-acrylics were less clear (SMD = 0.45

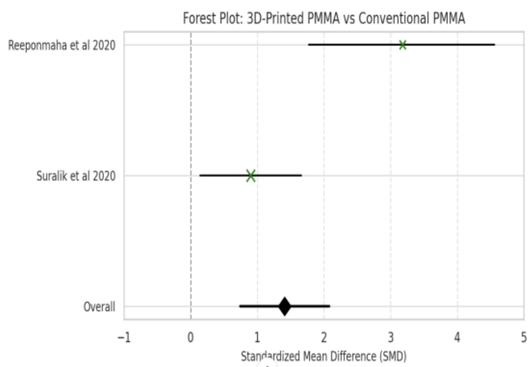
−0.06,0.96

−0.06,0.96; p = 0.12; I^2 = 85%) due to high variability in material composition and experimental parameters.

1) **Comparison of Fracture Strength between 3D-Printed PMMA Resin and CAD/CAM Milled PMMA Resin:**



2)Comparison of Fracture Strength Between 3D-Printed PMMA Resin and Conventional PMMA Resin



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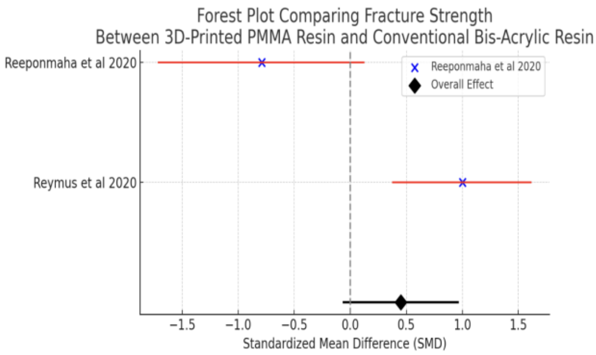
3)Comparison of Fracture Strength between 3D-Printed PMMA and Conventional Bis-Acrylic Resins



Clinical Implications

For cases requiring high durability and long-term provisionalization, CAD/CAM-milled PMMA remains the most reliable option. However, 3D-printed PMMA is emerging as a promising alternative for rapid customization and cost-effectiveness, especially as material science progresses. Conventional resins are likely best suited for short-term use or low-stress restorations.

Future Directions

To advance clinical applications, future studies must:

- Establish standardized testing and fabrication methodologies.
- Conduct long-term clinical trials under functional loading.
- Innovate resin formulations to further improve mechanical properties.
- Explore hybrid fabrication combining subtractive and additive techniques.

In summary, while digital fabrication methods are transforming interim prosthodontics, ongoing research is needed to ensure consistent, reproducible strength and durability across materials and platforms.

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