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# Physical and Mechanical properties of materials for provisional crowns: 3D printed vs Milled. A systematic integrative review.

**Yan Tsiukhai**

**Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)**

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Gandra, **maio de 2024**

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Trabalho realizado sob a Orientação da Prof, Dra.

**Catarina Calamote**

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Os trabalhos desta dissertação foram apresentados em formato de comunicação oral nas XXXII Jornadas Cientificas de Ciências Dentárias - IUCS-CESPU realizadas no Porto em 09 de abril de 2024 (comprovativo em anexo)

Tsiukhai Y, Tsiukhai T., Braz M. P., Costa J.A. Dental Digital Projects: guidelines from digital treatment planning to execution. XXXII Jornadas Cientificas de Ciências Dentárias – IUCS-CESPU. Porto; 2024 Apr.

# Agradecimentos

First, I would like to extend my heartfelt gratitude to CESPU for providing an enriching and supportive academic environment. The resources and opportunities offered have been instrumental in the completion of this dissertation.

I am profoundly thankful to my professors and mentors at CESPU. Their guidance, insights, and encouragement have been invaluable throughout my academic journey. In particularly, I would like to acknowledge Catarina Calamote, whose expertise and support have been critical to the success of this research.

I would also like to express my appreciation to the beautiful country of Portugal. The cultural richness and academic excellence found here have greatly influenced my personal and professional growth. The experiences and friendships I have made in Portugal will always hold a special place in my heart.

To my family, your unwavering support and love have been my foundation. Thank you for always believing in me and for your endless encouragement. Your sacrifices and understanding have allowed me to pursue my dreams and achieve this milestone.

Finally, to all my friends and colleagues who supported me along the way, your companionship and encouragement have made this journey more rewarding. Thank you for being a part of this significant chapter in my life.

# RESUMO

**Introdução:** As restaurações provisórias são cruciais no tratamento protético fixo e devem apresentar boas propriedades físicas e mecânicas. O aparecimento da medicina dentária digital levou à introdução de vários materiais de impressão tridimensional (3D) e de fresagem no mercado.

**Objetivos:** O objetivo deste trabalho foi avaliar e comparar as propriedades físicas e mecânicas de materiais para coroas provisórias produzidas com diferentes tecnologias CAD/CAM (fresadas e impressas em 3D).

**Materiais e métodos:** Foi efectuada uma pesquisa na PubMed utilizando a estratégia de pesquisa avançada com a combinação das palavras-chave, "provisional dental"; "synthetic resins"; "cad cam"; "milling"; "physical phenomena"; "materials testing", utilizando os critérios de inclusão e exclusão.

**Resultados:** A pesquisa recuperou 2871 artigos, dos quais 22 foram considerados relevantes e forneceram dados para comparar e estudar as propriedades mecânicas e físicas dos materiais provisórios para ambas as tecnologias.

**Discussão:** A comparação das propriedades físicas e mecânicas das duas técnicas permitiu obter índices satisfatórios das propriedades físicas e mecânicas dos materiais para estruturas provisórias e a maioria dos dados obtidos permite concluir que as propriedades dos materiais provisórios impressos em 3D são semelhantes ou inferiores aos materiais fresados.

**Conclusão:** A impressão 3D e a fresagem são duas tecnologias completamente diferentes com as suas próprias vantagens e desvantagens. A grande variabilidade dos resultados oferece-nos oportunidades para desenvolver mais as tecnologias CAD/CAM.

**Palavras-chave:** *“provisional dental”; “synthetic resins”; “cad cam”; “milling”; “physical phenomena”; “materials testing”.*

# ABSTRACT

**Introduction:** Provisional restorations are crucial in fixed prosthodontic treatment and should show good physical and mechanical properties. The emergence of digital dentistry has led to the introduction of various three-dimensional (3D) printing and milling materials in the market.

**Objectives:** The aim of this work was to evaluate and compare the physical and mechanical properties of materials for provisional crowns produced with different CAD/CAM technologies (milled, and 3D-printed).

**Materials and methods**: A search was performed on PubMed using the advanced search strategy with the combination of the keywords, “provisional dental”; “synthetic resins”; “cad cam”; “milling”; “physical phenomena”; “materials testing”, using the inclusion and exclusion criteria.

**Results:** The search retrieved 2871 articles, of which 22 were found relevant and provided data to compare and study the mechanical and physical properties of temporary materials for both technologies.

**Discussion**: Comparing the physical and mechanical properties of the two techniques obtained satisfactory indices of physical and mechanical properties of materials for temporary structures and most of the obtained data lead us to conclude that properties of 3D-printed provisional materials are similar, or inferior compared to milled ones.

**Conclusions:** 3D printing and Milling are two completely different technologies with their own advantages and disadvantages. Wide variability in the results provides us with opportunities to further explore and develop CAD/CAM technologies.

**Keywords:** *“provisional dental”; “synthetic resins”; “cad cam”; “milling”; “physical phenomena”; “materials testing”.*

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## List of abbreviations and acronyms

↑↑ = Significant Increase,
↑ = Increase,
↔ = No Significant Change,
↓ = Decrease
↓↓ = Significant Decrease,

CAD/CAM: Computer-Aided Designing/Computer-Aided Manufacturing;
FDP: Fixed Dental Prosthesis;
SM: Subtractive Manufacturing;
AM: Additive Manufacturing;
SLA: Stereolithography;
SLS: Selective laser sintering;
DLP: Digital light processing;
PMMA: Polymethyl Methacrylate;

FS = Flexural Strength;
FR = Fracture Resistance;
EM = Elastic Modulus;
PS = Peak Stress;
SR = Surface Roughness;
WR = Wear Resistant;
FL = Fracture load;
KH = Knoop Hardness;
CS = Color Stability;
WS = Water Sorption;

MP: Mechanical Properties;
PP: Physical Properties;
TC: Thermocycling;
VH: Vickers Hardness.

# 1. Introduction

The emergence of computer-aided design and manufacture (CAD/CAM) in dentistry streamlines the production of crowns and fixed dental prostheses (FDPs) (1). Provisional restorations play a crucial role in fixed prosthodontic treatment, enhancing aesthetics and function while evaluating treatment effectiveness. Various clinical scenarios need provisionalization, including full mouth rehabilitation and crown lengthening cases (2,3).

A well-fabricated provisional crown or FDPs is essential for achieving a high-quality definitive prosthesis, ensuring tooth position maintenance, pulp protection, periodontal relationship preservation, and establishing function and aesthetics (4). Provisional restorative materials intended for longer-term provisionalization should possess excellent properties. Here are some of the criteria that are usually evaluated in articles to understand and obtain the results of the analysis of mechanical and physical properties of provisional restorations: flexural strength, elasticity module, durable, hard, wear resistance, biocompatible, color stability, surface and fracture resistance (5).

With the rise of digital dentistry, provisional materials are categorized by fabrication method into conventional or digital techniques (6). Digital technology facilitates the creation of temporary dental restorations, involving detailed scans of the patient mouth or cast, followed by engineering using CAD software and production using subtractive manufacturing (SM) milling or additive manufacturing (AM) 3D printing (7).

Subtractive manufacturing, exemplified by CAD/CAM milling, removes material from prefabricated blocks or discs but has drawbacks like material waste, limited tool uses due to wear, and precision limitations resulting in inferior fit and marginal adaptation for complex designs (7).

In contrast, AM technology, particularly 3D printing, overcomes milling disadvantages and continues to improve in quality, offering advantages like detailed internal geometries, reduced manufacturing time, and less raw material wastage, making it cost-effective for fabricating provisional crowns and FDPs (8,9). Various 3D printing methods, including stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM), digital light processing (DLP), polyjet, and bioprinting, are employed in dentistry

(10). Each method has distinct advantages and applications, contributing to the versatility of 3D printing technology (11–19).

The properties of 3D-printed provisional materials have been extensively studied, highlighting advantages such as tooth-color, high accuracy, shape fidelity, biocompatibility, and fast print performance (20–25).

While AM and milling manufacturing offer comparable results, especially with polymers, 3D-printed pieces may not withstand masticatory forces as long due to lower hardness and fracture load parameters (10). Hybrid materials combining 3D printing with traditional techniques present a novel perspective (26).

This systematic integrative review comparing fabrication methods and technologies for provisional crowns and fixed prostheses would provide valuable guidance for restorative dental professionals, offering an unbiased comparison between milling and 3D printing techniques, and save time and effort in daily clinical practice.

# 2. Objectives

This integrative systematic review has the following objectives:

## 2.1. Main objective:

To study and compare two technologies for the manufacturing of dental provisional protheses: milling and 3D printing.

## 2.2. Secondary objective:

Evaluate the physical and mechanical properties of provisional crowns made using both methods.

- Mechanical properties: flexural strength, fracture resistance, elasticity modulus.
- Physical properties: surface roughness, wear resistance, color stability.

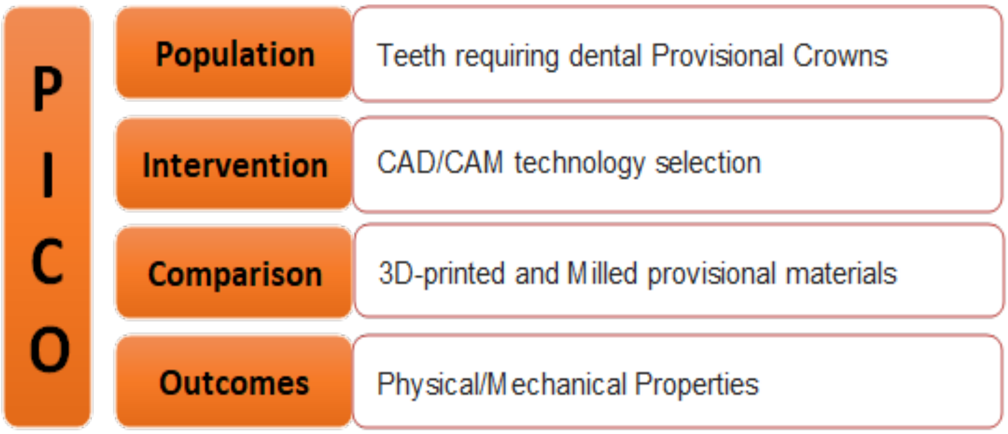
# 3. Materials and methods

## 3.1. Protocol Development

For the elaboration of this integrative systematic review, a detailed protocol was developed in accordance with the PRISMA 2020.

## 3.2. Focus of the PICO question

The criteria applied to the PICO question was presented in Figure 1:



| | | |
|---|---|---|
| P | **Population** | Teeth requiring dental Provisional Crowns |
| I | **Intervention** | CAD/CAM technology selection |
| C | **Comparison** | 3D-printed and Milled provisional materials |
| O | **Outcomes** | Physical/Mechanical Properties |

***Figure 1*** *- strategy PICO*

## 3.3. Question PICO

Focus question of the presented review and underlying population, intervention, comparison, and outcome (PICO) question was:

*Within the available studies in the literature, do 3D-printed provisional materials have Physical and Mechanical properties comparable to milled provisional materials to be used in temporary dental rehabilitations?*

### 3.4. Search strategy

The bibliographic search was carried out using PubMed (via the National Library of Medicine) with the combinations of "Mesh Terms" and “Title/Abstract”: *“synthetic resins [MeSH Terms]”; “cad cam [MeSH Terms]”; “physical phenomena [MeSH Terms]”; “materials testing [MeSH Terms]”; “provisional dental [Title/Abstract]”; “milling [Title/Abstract]”.*

### 3.5. Search Terms

The advanced data search was carried out using PubMed (via the National Library of Medicine) between the 22 of February and the 14 of march of 2024. A period of 10 years and English language was defined for the inclusion of studies (2014-2024).

The initial search resulted in the identification of 2871 articles (Table 1).

***Table 1**– Results obtained by search expression*

| Base | Search strategy | Total articles |
|---|---|---|
| **PubMed** | ((provisional[Title/Abstract]) OR (synthetic resins[MeSH Terms])) AND ((cad cam[MeSH Terms]) OR (milled[Title/Abstract])) AND ((physical phenomena[MeSH Terms] ) OR (materials testing[MeSH Terms])) | 871 |
| **PubMed** | (Computer-Assisted Designing / Computer-Assisted Milling[Title/Abstract]) OR ((cad cam[MeSH Terms]) AND (materials testing[MeSH Terms])) | 2000 |

### 3.6. Inclusion and exclusion criteria

All the articles included were individually read and assessed according to the inclusion and exclusion criteria (Table 2).

***Table 2** – Inclusion and exclusion criteria*

| Inclusion criteria | Exclusion criteria |
|---|---|
| Literature in English language | Literature in a language other than English |
| In vitro studies | Letters to the editor, case reports, technical reports, cadaver studies, dissertations, incomplete trials, unpublished abstracts, reports, commentaries, and review papers. |
| Studies evaluating the properties of 3D-printed fixed provisional materials compared to milled provisional fixed materials | 3D-printed material used for removable prostheses such as occlusal/night guard prosthesis, non-dental uses of 3D-printed material |
| Studies comparing properties of 3D-printed provisional crowns materials with other materials and methods used for the fabrication of provisional crowns. | Studies discussing properties of only 3D-printed provisional materials but do not compare them with other types of provisional materials |

### 3.7. Selection of studies

After eliminating duplicate articles, the initial stage of article selection was done by reading their titles and abstracts. Studies that did not meet the eligibility criteria were discarded. In the second selection phase, the same eligibility criteria were applied to the remaining full-text studies.

### 3.8. Data extraction

A data extraction table was developed. This table (Table 4) contains information such as articles, criteria under analysis, methods/experiment, quantity and type of samples, technique of fabrication/material used, results/conclusion.

# 4. Results

## 4.1. Search results

The initial search resulted in the identification of 2871 articles.

***Table 3*** *- Final article selection*

| Base | Search strategy | Total articles | Articles for Full Analysis After Removal of Duplicates and Exclusions | Articles selected |
|---|---|---|---|---|
| **PubMed** | ((provisional[Title/Abstract]) OR (synthetic resins[MeSH Terms])) AND ((cad cam[MeSH Terms]) OR (milled[Title/Abstract])) AND ((physical phenomena[MeSH Terms] ) OR (materials testing[MeSH Terms])) | 871 | 35 | 10 |
| **PubMed** | (Computer-Assisted Designing / Computer-Assisted Milling[Title/Abstract]) OR ((cad cam[MeSH Terms]) AND (materials testing[MeSH Terms])) | 2000 | 59 | 12 |

Of the remaining 2871 articles were selected in the advanced data search in PubMed using the combinations of "MeshTerms" and Title/Abstract. Of these, 661 were eliminated due to duplicity using the Mendeley Citation Manager. 2116 were eliminated by reading the title and abstract, as they did not meet the eligibility criteria. Only 94 articles were selected by evaluating the full text. After reading all the articles, only 22 articles were selected by applying the content defined by the inclusion and exclusion criteria.

The selection resulted in 22 articles (Figure 2)

### 4.2. Flowchart

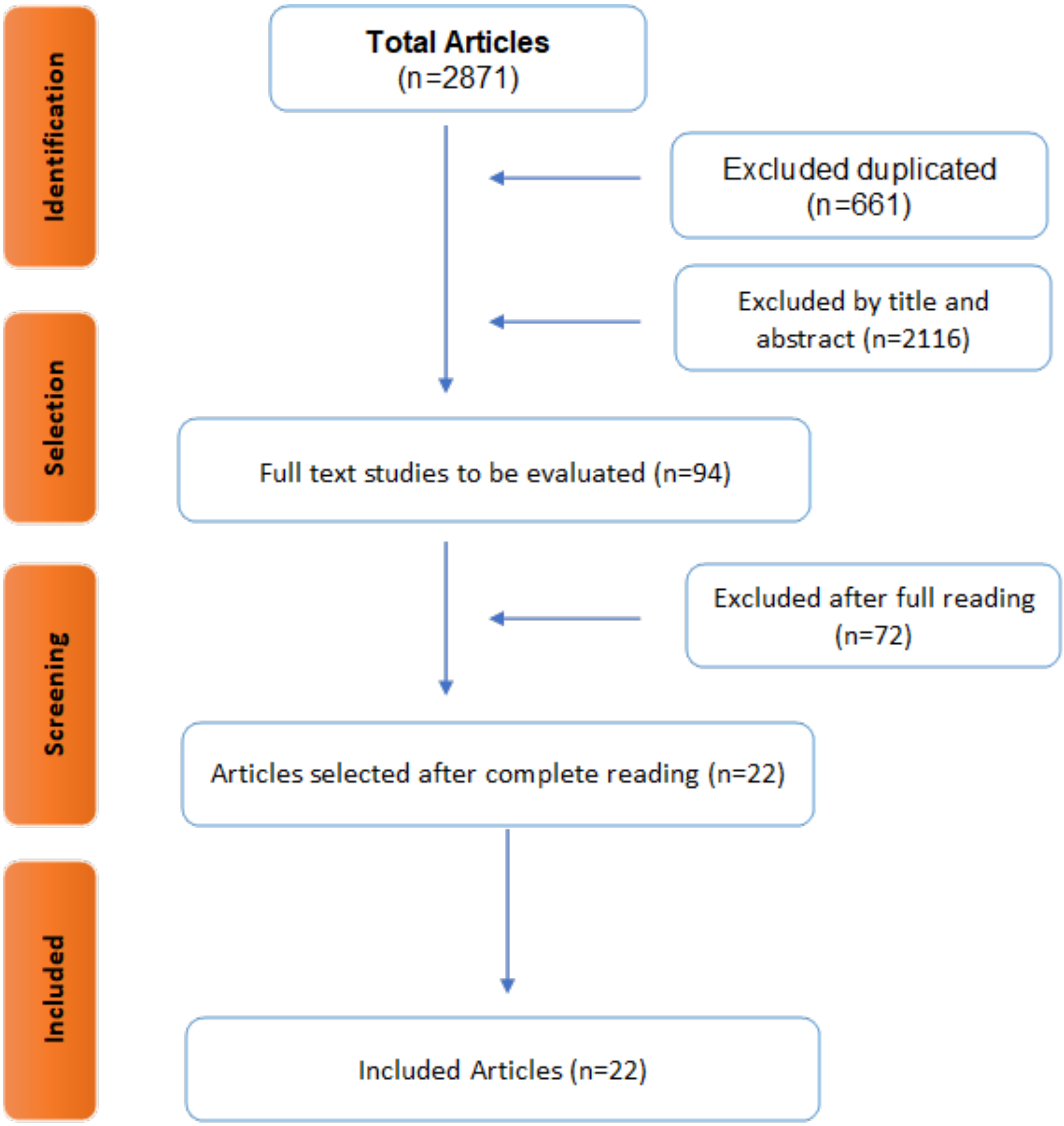


***Figure 2*** *– flowchart of the research strategy used in this work*

### 4.3. Results Table and data extraction

***Table 4*** *- Table of results and data extraction*

| **Reference** | **Criteria under analysis (FS, FR, EM, SR, WR, CS)** | **Method/experiment** | **Type and Quantity of Specimens** | **Technique of fabrication/material used** | **Results/Conclusions** |
|---|---|---|---|---|---|
| Sadek HMAA. *et al.*, 2023 (34) | MP<br>FS | The samples stored in various media were incubated at 37°C for a duration of 4 weeks, after which they were subjected to 60,000 simulated chewing cycles. Subsequently, a biaxial flexural strength test was performed. The results were analyzed using a two-way analysis of variance (ANOVA). | Discs (n=**60/ each** material group),<br>size: 10 × 2 mm | Milled:<br>- PMMA (VITA CAD-Temp$^{®}$)<br>-PMMA (breCAM.multiCOM$^{®}$)<br>Printed:<br>- NextDent C&B (Nextdent B.V$^{®}$ | MP<br>FS: printed ↑ than milled |
| Yao *et al.*, 2021 (49) | PP<br>CS | The study divided the samples into four subgroups based on different surface treatments: Control, Polish, Optiglaze, and Skinglaze. Shade measurements were taken using a digital spectrophotometer both before and after thermocycling to compare color stability. The effects on interim prostheses were analyzed using ANOVA and Tukey's honestly significant difference (HSD) test (α = 0.05). | Discs (n=**40/** each material group),<br>4 subgroups (n=10**/** each subgroup),<br>size: 98.5×16 mm | Milled:<br>-Temp Esthetic 98<br>Printed:<br>- NextDent C&B (Nextdent B.V$^{®}$) | PP<br>CS: printed ↓↓ than milled |

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| Bergamo *et al.*, 2022 (32) | MP<br>FS, EM | Half of the specimens underwent 5000 thermal cycles, alternating between 5°C and 55°C. Three-point bending tests were then conducted using a universal testing machine, set to a crosshead speed of 0.5 mm/min. From the data collected, flexural strength and elastic modulus were determined. The results were analyzed using ANOVA and Tukey's honestly significant difference (HSD) test, with a significance level of α = 0.05. | Bar-shaped specimens (n=**10/** each material group) size: 25×2×2 mm | Milled:<br>-PMMA (TelioCAD®)<br>Printed:<br>-CosmosTemp-DLP (Yller®) | MP<br>EM: 3D printed ↔ to milled before and after TC<br>FS: 3D printed ↔ to milled and ↓↓ than milled after TC. |
| Digholkar *et al*, 2016 (43) | MP<br>FR, WR | The Universal Testing Machine was employed in this study, utilizing a three-point loading system to apply the load at a speed of 3 mm/min over a span of 20 mm. The loading process continued until the specimens fractured, at which point the breaking load was recorded. | Bar-shaped specimens (n=**20/** each material group) size: 25×2×2 mm | Milled:<br>-PMMA (Ceramill®)<br>3D-printed:<br>-E-dent 100 (Envision TEC®) | MP<br>FR: printed ↓↓ than milled<br>WR: Printed ↑↑ than milled |
| Kessler *et al.*, 2019 (48) | MP<br>WR | Three-body wear was simulated using an ACTA machine. The resulting data were statistically analyzed using ANOVA and a post hoc Tukey test, with a significance level of $p < 0.05$. The worn surfaces of the specimens were then examined to assess the wear characteristics. | Specimens (**n=8**/ each material group) | Milled:<br>-PMMA (Telio CAD®)<br>Printed:<br>-3 Delta temp (Deltamed®)<br>-NextDent C&B (Nextdent B.V®)<br>-Freeprint Temp (DETAX GmbH®) | MP<br>WR: ↑ filler content of printed Materials showed ↑ WR |

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|---|---|---|---|---|---|
| Ellakany *et al.*, 2022 (28) | MP<br>FS, EM | Samples were fabricated on a mandibular right second premolar and second molar using the specified materials. These samples were studied using the Kruskal–Wallis test, followed by multiple pairwise comparisons with Bonferroni-adjusted significance levels. Flexural strength and elastic modulus were calculated for each sample. | three-unit fixed dental prostheses (n=**10**/ each material group) | Milled:<br>-PMMA (TelioCAD®)<br>Printed:<br>- NextDent C&B (Nextdent B.V®)<br>-ASIGA (Denta Tooth®) | MP<br>FS: printed SLA ↔ to milled. printed DLP ↓↓ than milled.<br>EM: printed SLA ↓↓ than milled |
| Mayer *et al.*, 2021 (27) | MP<br>FR, WR | Chewing simulation was conducted under a vertical load of 50 N, corresponding to 480,000 cycles at 5°C/55°C. Two-body wear and fracture load were quantified as part of the analysis. Data were subjected to comprehensive statistical analysis, including global univariate ANOVA with partial eta squared, Kruskal-Wallis H test, Mann-Whitney U test, and Spearman's rho test, with a significance level set at $p < 0.05$. | Shape congruent three-unit FDPs were prepared (n=**16**/ each material group). | Milled:<br>-PMMA (Telio CAD®)<br>Printed:<br>-Temp PRINT (GC Europe®)<br>- NextDent C&B (Nextdent B.V.®)<br>-Freeprint Temp (DETAX GmbH®) | MP<br>WR: Printed ↑↑ than Milled.<br>FR: Printed ↓↓ than Milled. |
| Fouda *et al.*, 2023 (31) | MP<br>FS, EM | The flexural strength and elastic modulus of the specimens were determined through a 3-point bending test, while surface hardness was assessed using the Vickers hardness test. Scanning electron microscopy examined the surface morphology of the fractured specimens. Mean values and standard deviations were calculated for the obtained data. Subsequently, one-way ANOVA and Tukey's post-hoc test were conducted with a significance level of $\alpha = 0.05$ to analyze any significant differences among the groups. | Specimens (n=**20**/ each material group)<br>2 subgroup (n=10/ each)<br>size: 64×10×3.3 ± 0.2 mm | Milled:<br>-PMMA (Avadent®, IvoCad®)<br>Printed:<br>-NextDent C&B (Nextdent B.V®) | MP<br>FS, EM: Printed ↓↓ than milled |

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|---|---|---|---|---|---|
| Tahayeri *et al.*, 2018 (41) | MP<br>EM | The elastic modulus was derived from the slope of the initial linear segment of the load-deformation curve. Samples were loaded using a universal testing machine (MTS Criterion, Eden Prairie, WI) at a crosshead speed of 0.5 mm/min. | Bar-shaped specimens (n=**6/** each material group)<br>size: 25×2×2 mm | Milled:<br>-PMMA (Jet®)<br>Printed:<br>-NextDent C&B (Nextdent B.V®) | MP<br>EM: Printed ↔ to PMMA<br>PS: Printed ↑↑ than PMMA. |
| de Castro *et al.*, 2022 (30) | MP<br>FS, EM | The dimensions of bar samples were measured and the mean percent errors were compared to the reference (digital) values to obtain "accuracy" (n = 20). Samples were then aged in distilled water at 37 °C and half were submitted to a three-point bend test in a universal testing machine after 24 h and the other half after 1 year. FM and FS to three way-ANOVA, followed by Tukey's tests (α = 0.05). | Bar-shaped specimens (n=**20/** each material group)<br>size: 25×2×2 mm<br>+<br>Disc-shaped specimens (n=**10/** each material group)<br>size: 15×2.5 mm | Milled:<br>-PMMA (Vita®)<br>Printed:<br>-CosmosTemp-SLA (Yller®)<br>-CosmosTemp-DLP (Yller®)<br>-PriZma-Bioprov (Makertech®)<br>-Nanolab 3D (Wilcos®) | MP<br>After 24-h load:<br>FS and EM: ↓↓ all printed than milled<br>After 1-year load:<br>FS: ↓↓ Nanolab and DLP than milled.<br>↓↓ DLP at printing orientation 45° than 0°,and 90°↔ SLA(45°) to milled,<br>↑ SLA(90°) than milled<br>EM: ↓↓ all printed than milled |

| | | | | | |
|---|---|---|---|---|---|
| Taşın *et al.*, 2022 (33) | MP<br>FS | Each material was divided into 3 subgroups according to the applied thermocycling (5 °C to 55 °C) procedure: control (0 cycles), 2500, and 10 000 cycles. The sample size was determined by using a statistical power analysis software program (G*Power 3.1.9.3; HeinrichHeine-Universität Düsseldorf). Parameters of the materials were tested in a 3-point bend test. Data were statistically analyzed with the Shapiro-Wilk test followed by Kruskal-Wallis test, the Mann-Whitney test, the Friedman test, and Wilcoxon signed-rank test (α=.05). | Rectangular specimens (n=**30** for each material)<br>3 subgroups (n=10/ each) | Milled:<br>-PMMA (Duo Cad®)<br>Printed:<br>-Temporis (DWS system®) | MP<br>FS: Milled ↔ 3D-Printed |
| Diken Turksayar *et al.*, 2022 (40) | MP<br>FR | Samples were milled as the control group and with 5 different orientations (0°, 30°, 45°, 90°, and 150°) were printed by using (3D) printing (n = 10).<br>All specimens were cemented onto cobalt-chromium test models representing a maxillary first premolar and first molar tooth with a long-term temporary cement (DentoTemp), and subjected to thermomechanical aging (120,000 cycles, 1.6 Hz, 50 N, 5-55 °C). Then, all specimens were loaded until fracture by using a universal tester. The data were analyzed with nonparametric 1-way analysis of variance (Kruskal-Wallis) and Dunn's tests (α = 0.05). | 3-unit fixed dental prosthesis (n=**50)**<br>5 groups (n=**10**/ each group) | Milled:<br>-PMMA (Duo Cad®)<br>Printed:<br>-Temporary CB (Formlabs®) | MP<br>FR: printing ↓ than milled and with 45° and 150° ↓↓ milled PMMA. Printed with 0° and 30° ↔ printed with 150° and ↑ than 45°. |

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|---|---|---|---|---|---|
| Abad-Coronel *et al.*, 2020 (36) | MP<br>FS | The resistance to fracture was determined with a universal testing machine | **40** samples were manufactured and divided into two groups (n = **20**). | Milled:<br>-Vipiblock Trilux , (VIPI®)<br>Printed:<br>-PriZma 3D Bio Prov , (MarketechLabs®) | MP<br>FS: Printed ↓ than milled |
| Tasın *et al.*, 2021 (47) | MP & PP<br>CS, SR | A group of each material was divided into 2 groups as per the applied surface treatment procedure: conventional polishing (C) or coated with a surface sealant (B). Surface roughness values were measured with a profilometer. Each group of specimens was then divided into 4 subgroups and stored for 1 day, 7 days, and 30 days at 37 °C in different solutions: distilled water, cola, coffee, and red wine. Color parameters were measured with a spectrophotometer before and after each storage period, and color differences were calculated. Data were statistically analyzed with the Shapiro-Wilk test, Kruskal-Wallis test, and Mann-Whitney U test followed by the Friedman test (α=.05). | Specimens (n=**80**/ each material) was divided into 2 groups (n=**40**) Each group of specimens was then divided into 4 subgroups (n=**10**) | Milled:<br>- Duo Cad (FSM DENTAL®)<br>Printed:<br>-Temporis (DWS®) | MP & PP<br>CS, SR: Printed ↔ to milled |

| | | | | | |
|---|---|---|---|---|---|
| Angwarawong *et al.*, 2020 (42) | MP<br>FR | All cemented provisional crown were subjected to thermal cycling (5,000 cycles at 5°-55℃) and cyclic occlusal load (100 N at 4 Hz for 100,000 cycles). Maximum force at fracture was tested using a universal testing machine. | Provisional crowns (n=**10**/group) | Milled:<br>-PMMA (Brylic Solid®)<br>Printed:<br>-Freeprint Temp (DETAX GmbH®) | MP<br>FR: ↔ between the study group |
| Ribeiro *et al.*, 2023 (35) | MP<br>FS, SR | The specimens underwent thermocycling consisting of 10,000 cycles. Following this, the bars were subjected to a mini-flexural strength ($\sigma$) test with a speed of 1 mm/min, while roughness analysis was conducted on all the blocks. Statistical analysis was performed using both one-way ANOVA and two-way ANOVA, with Tukey's test employed for post-hoc comparisons, maintaining a significance level of $\alpha = 0.05$. | Bars n=**50**<br>Size: 8× 2×2 mm<br>Blocks n=**20**<br>Size: 8×8×2 mm | Milled:<br>-PMMA (ViPi®)<br>Printed:<br>- NextDent C&B (Nextdent B.V®) | MP<br>FS, SR: Printed ↔ to milled.<br>3D printed don't decrease in $\sigma$ after TC |

| | | | | | |
|---|---|---|---|---|---|
| Reymus *et al.*, 2020 (44) | MP<br>FR | FDP was prepared from different materials. The fracture load was measured after artificial aging (H2O: 21 days, 37 °C). In the second part, the impact of post-curing was tested.The measured initial fracture loads were compared with those after artificial aging. Data were analyzed using Kolmogorov-Smirnov test, one-way ANOVA followed by Scheffé post hoc test, t test, Kruskal-Wallis test, and Mann-Whitney U test ($p < 0.05$). | Specimens subgroup n= **15** | Milled:<br>-Telio CAD®<br>Printed:<br>- NextDent C&B (NextDent®)<br>- Freeprint temp (Detax®)<br>- 3Delta temp | MP<br>FR: Printed ↓ than milled |
| Alam M *et al.*, 2022 (46) | MP<br>FR | Recently extracted maxillary central incisors were handpicked.Tooth preparation followed standard principles. Provisional crowns were cemented using eugenol-free temporary luting cement (Templute, Prime Dental). Subsequently, all cemented provisional crowns underwent loading using a Universal Testing Machine. The maximum load required to induce fracture for each specimen was recorded in Newtons (N).. | provisional crowns<br>n = **10 (**each/ group) | Milled:<br>-PMMA (Dentsply Sirona®)<br>Printed:<br>- NextDent C&B (Nextdent B.V®) | MP<br>FR: Printed ↑↑ than milled |
| Srinivasan *et al.*, 2021 (37) | PP & MP<br>SR, EM, FS | Three-point bending and nanoindentation tests measured the mechanical properties. Surface roughness was evaluated using a high-resolution laser profilometer. ANOVA and post-hoc tests were used for statistical analyses ($\alpha = 0.05$) | 6 groups (n=**5**/each material group) of resin specimens were prepared | Milled:<br>-PMMA (AvaDent®)<br>Printed:<br>- NextDent C&B (Nextdent B.V®) | MP<br>EM, FS: Printed ↓ than milled<br>SR: Printed ↔ milled |

| | | | | | |
|---|---|---|---|---|---|
| Zeidan *et al.*, 2023 (38) | MP<br>FS | The flexural strength was measured using a universal testing machine and three-point loading test. Data were collected and analyzed using one-way ANOVA and Tukey's pair-wise post hoc tests (α = 0.05). | Specimens (n=**10/** each group)<br>size: 65×10×3 mm | Milled:<br>-PMMA (AvaDent®,Polident®)<br>Printed:<br>- NextDent C&B (Nextdent B.V®)<br>-HARZ Labs Dental Sand (HARZ Labs®) | MP<br>FS: Printed ↓ than milled |
| Gruber *et al.*, 2021 (50) | PP<br>CS | Samples underwent four distinct aging procedures: thermal cycling, immersion in distilled water, exposure to red wine, and immersion in coffee. Color changes were assessed using a spectrophotometer, with measurements taken in two modes (specular component included and specular component excluded) recorded at day 30. ANOVA and post hoc tests were used for statistical analysis (alpha = 0.05). | Milled specimens n=**112**<br>Printed specimens n=**32** | Milled:<br>(pink shade^ WIMP, AVMP, MEMP, POMP, tooth-shade: AVMT, MEMT, POMT)<br>Printed:<br>pink: NDRPP ,tooth-shade: NDRPT) | PP<br>CS: Printed ↓ than milled |

| | | | | | |
|---|---|---|---|---|---|
| Martín-Ortega *et al.*, 2022 (45) | MP<br>FR | 2 anatomic contour crowns, a maxillary right central incisor (anterior group) and a maxillary right premolar (posterior group). Each group was subdivided into 2 subgroups depending on the manufacturing method: milled (milled subgroup) and additive manufacturing (additive manufacturing subgroup). Then, each specimen was cemented to an implant abutment by using composite resin cement (Multilink Hybrid Abutment HO) as per the manufacturer's instructions. A universal testing machine was used for fracture resistance analysis, and the failure mode was recorded. The Shapiro-Wilk test revealed that data were normally distributed. One-way ANOVA and Tukey multiple comparison were selected (α=.05). | Provisional crown (N=**40**/ each group – anterior and posterior)<br>2 subgroup n=**10**/ each material. | Milled:<br>-Vivodent CAD Multi (Ivoclar Vivadent AG ®)<br>Printed:<br>-SHERAprint-cb (Sher(A) ®) | MP<br>FR: Printed ↓↓ than Milled. |

### 4.4. Quantity characteristics

Figure 3 illustrates the quantitative evaluation of different grades of milling materials manufactured using subtractive technology. **793** specimens were produced in all analyzed articles for evaluation on the studied parameters (FS, EM, FR, CS, WR, SR), which are indicated in different colors.

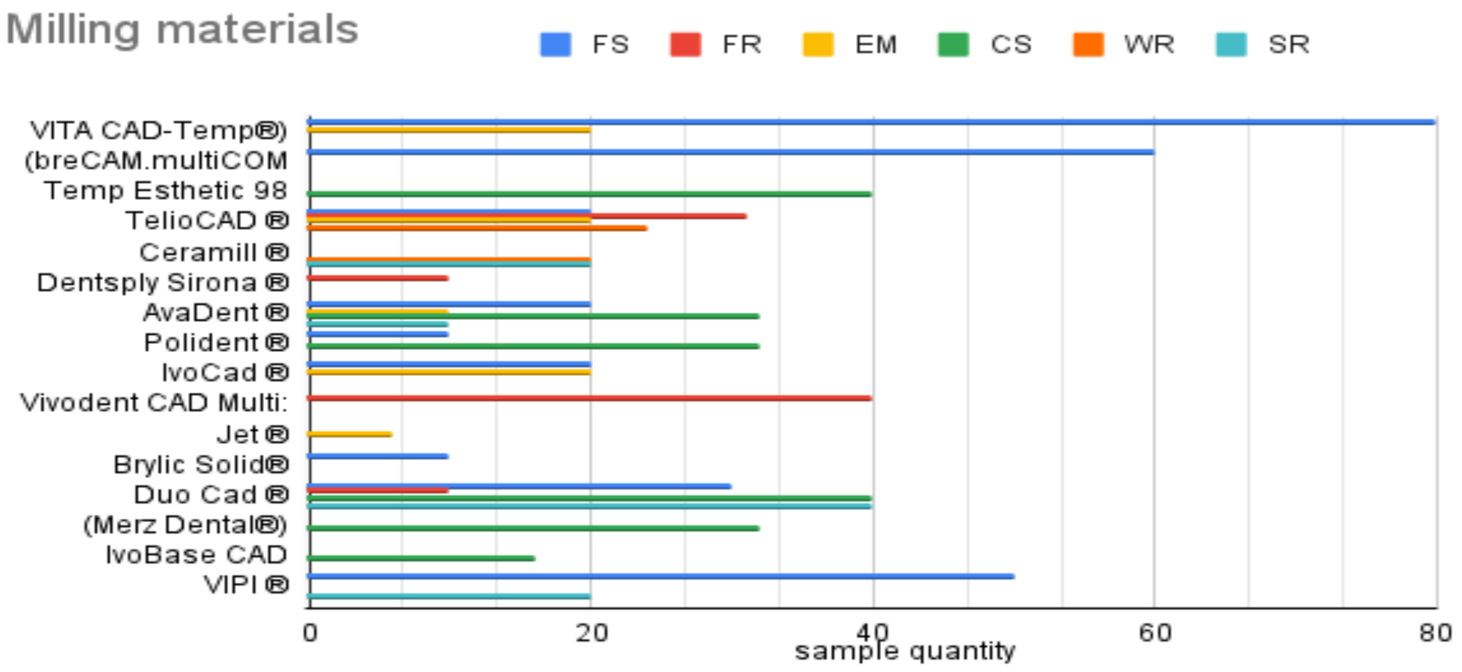

***Figure 3*** *- quantitative evaluation of different grades of milling materials*

Figure 4 quantifies the different grades of milling materials manufactured using additive technology. In all analyzed articles, **808** samples were produced for evaluation of the studied parameters (FS, EM, FR, CS, WR, SR), which are indicated in different colors.

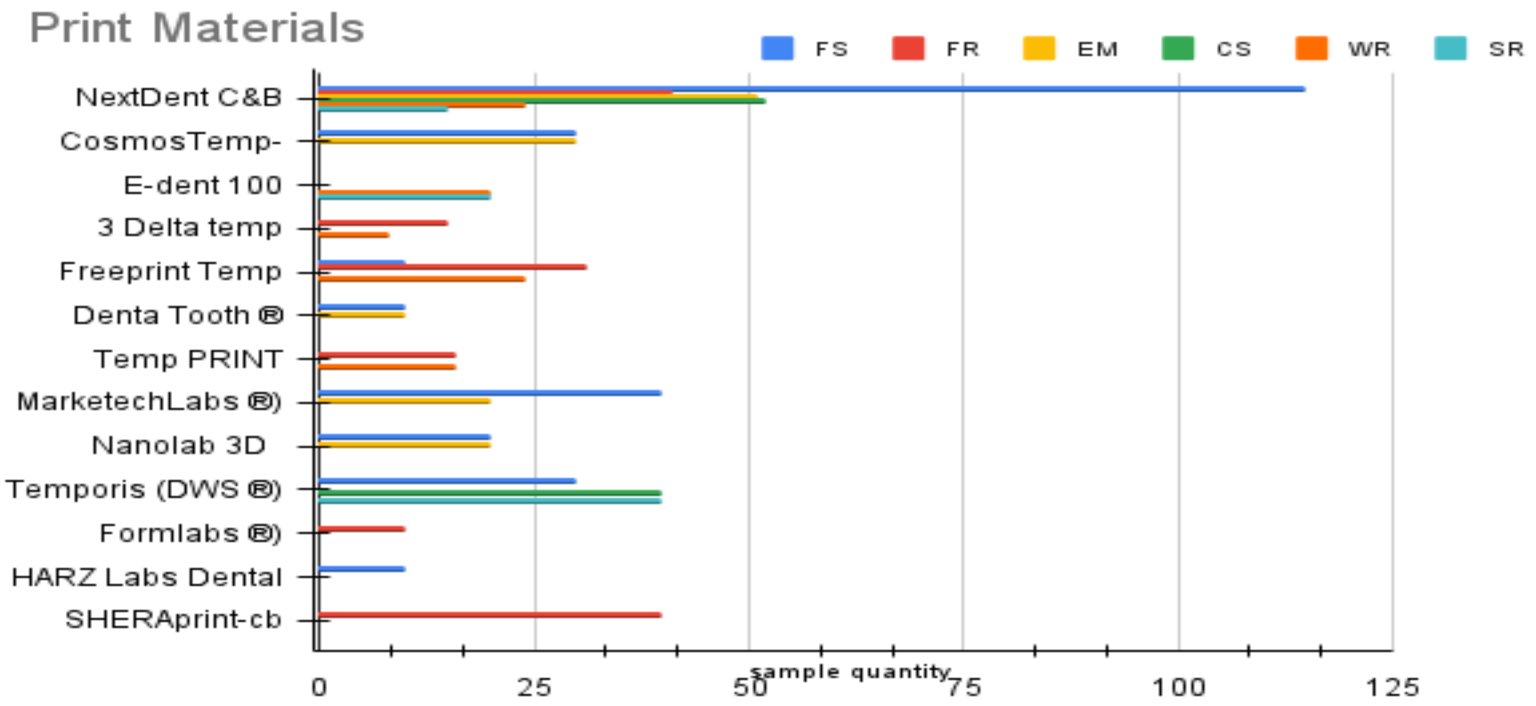

***Figure 4*** *- quantitative evaluation of different grades of printing materials*

## 4.5. Summary and compilation of results

***Table 5 -*** *Compilation of results*

| Property | Printed ↓↓ Milled | Printed ↓ Milled | Printed ↔ milled | Printed ↑ milled | Printed ↑↑ milled |
|---|---|---|---|---|---|
| FS | 28 (DLP), 30 (DLP), 31, 32 (after TC) | 36, 37, 38 | 28 (SLA), 30 (SLA 45°, DLP 90°), 32 (before TC), 33, 35 | 30 (SLA 90°), 34 | |
| FR | 27, 43, 45 | 40, 44 | 42 | | 46 |
| EM | 28 (SLA), 30, 31 | 37 | 32 (before and after TC), 41 | | |
| SR | | | 35, 37,47 | | |
| WR | | | 48 | 48 (Add filler) | 27, 43 |
| CS | 49 | 50 | 47 | | |

# 5. Discussion

Provisional materials have shown significantly different mechanical and physical properties. Furthermore, 3D-printed resin material showed comparable results to milled provisional materials.

The milled materials have higher fillers packed under higher temperatures and pressure, which result in lower porosity, voids, and residual monomers compared to 3D printing resins (27).

Mechanism of the printing technique, where in successive layers are printed under the controlled penetration of a UV laser beam (28), involves the presence of several factors that were identified as influencing the physical and mechanical properties of 3D-printed materials. These include the thickness of the printed layer, post-curing techniques, shrinkage between layers, curing speed and intensity, angle, post-polymerization time and temperature, and printing direction (29). Technology selection (SLA, SLS, DLP) also can show different results (30–32).

## 5.1 Mechanical properties

### Flexural strength

Ten studies provided data to compare the flexural strength between 3D-printed PMMA resin and CAD/CAM milled PMMA resin and had shown contrasting results (28,30–38).

Every study assessing flexural strength included in this work reported results exceeding 50 MPa, surpassing the minimum flexural strength requirement outlined in ANSI/ADA specification no. 27 for recommended fixed provisional prostheses (39).

Toughness, resilience, and microhardness are notably poorer in 3D-printed composite-based resins compared to CAD/CAM milled PMMA resins (27,28,30–32,34) a crucial consideration for long-term provisional restorations where higher resiliency is essential to prevent failures. The dense cross-linking and homogeneous structure of CAD/CAM milled PMMA resins make them less susceptible to hydrolytic degradation compared to conventional and 3D-printed resins (35).

Despite significant variability in the studies assessing FDP flexural strength concerning post-curing processes and cementation, milled FDPs exhibited greater flexural strength compared to DLP (digital light processing) FDPs when employing the same cleaning agent, isopropanol (27). Additionally, differences in composition and manufacturing techniques contribute to 3D-printed resins exhibiting inferior properties compared to milled provisional (36–40).

However, Sadek *et al.* noted that 3D-printed polymethylmethacrylate provisional material presents with both greater biaxial flexural strength and increased durability against chemical and mechanical aging compared to conventional and CAD-CAM milled provisional materials tested (34).

Two studies examined hardness, yielding divergent findings. It was presumed that hardness would be greater in milled provisional resin materials due to higher cross-linked monomers and filler loading, thereby increasing hardness compared to 3D-printed materials. However, the SLA printing technique produced comparable results to the milled technique (27,30).

**Elasticity module**

Six authors specifically analyzed the modulus of elasticity in their studies (28,30–32,37,41).

Tahayeri *et al.* and Bergamo *et al.* reported similar values for both milled and printed materials. Their findings suggest that with certain materials and under specific conditions, 3D printed samples can achieve comparable mechanical properties to those of milled counterparts (32,41).

This observation indicates potential for additive manufacturing to meet or even exceed subtractive methods in terms of elasticity, which is crucial for various applications requiring flexibility and durability. However, the remaining authors observed a distinct superiority of milled materials over printed samples, and results consistently demonstrated that milled materials possess a higher modulus of elasticity compared to their 3D printed equivalents (28,30,31,37).

### Fracture resistance

In seven studies, fracture resistance tested were conducted on the fabricated specimens (27,40–46).

The influence of several factors (print orientation, of cleaning methods, thermomechanical aging on marginal gap, impact of resin material, build direction, post-curing, and artificial aging) on printing technology has been studied in the following articles, where milled structures have an advantage (27,40,43–45). Also, Alharbi *et al.* discovered that the compressive strength of 3D-printed materials increased when the layers were printed perpendicular to the load direction (17). De Castro *et al.* observed this improvement after printing two different provisional materials at 0, 45, and 90-degree angles (30).

However, Alam *et al.*, 2022 reported inferior mechanical properties of CAD/CAM milled provisional resins compared to 3D-printed resins, attributing the presence of cement clearly improves the load resistance of printed materials in comparison with milled ones (46).

## 5.2 Physical properties

The studies showed that, regardless of composition, 3D-printed provisional crown and FDP materials exhibited different physical properties compared to CAD/CAM milled provisional restorative materials.

### Surface roughness

Several studies compared surface roughness and found comparable results, indicating no significant differences or advantages for either material or technology (35,37,47). In summary, the surface roughness of 3D-printed resins is influenced by the resin composition and printing orientation. Taşın *et al.* found that 3D-printed hybrid resins have lower surface roughness compared to CAD/CAM PMMA resins, suggesting that the milling and polishing processes may introduce additional surface defects that increase surface roughness (47).

### Wear resistance

Several investigations comparing the wear resistance of 3D-printed materials demonstrated reduced wear volume loss and smoother surfaces in comparison to milled provisional materials (27,43,48).

During printing, printers could deposit layers up to a tenth of a micromillimeter, which results in a product with a smoother surface and minimizes the polishing time in comparison to the milling (39). Mayer *et al.* noted that 3D-printed provisional resins consist of multiple methacrylate resins and additional additives, potentially explaining their superior wear resistance properties (27).

### Color Stability

Specifically, two studies comparing the color stability of 3D-printed PMMA resins found them to have poor color stability relative to CAD/CAM milled PMMA resins (49,50).

Additionally, Taşın *et al.* reported inadequate color stability of 3D-printed hybrid composite resins compared to CAD/CAM milled provisional resins. Immersed specimens in various staining solutions (coffee, grape juice, curry, black tea, cola, and red wine). Prolonged immersion durations led to increased discoloration of the tested specimens. These authors assessed the sorption and solubility of 3D-printed provisional resins, finding that the water sorption and solubility of 3D-printed PMMA and photopolymer provisional resins were higher than CAD/CAM milled PMMA (47).

## 5.3 Limitations and Futures:

Exploring the impact of cementation is crucial as it enhances the fracture resistance of fixed dental prostheses (FDPs) by uniformly distributing external forces across the specimen (45,46). This aspect holds greater clinical relevance compared to assessing flexural strength without considering cementation.

Several concerns persist regarding 3D-printed materials that could impact their mechanical properties. These include the challenge of cleaning residual uncured resin after printing. Reymus *et al.* observed that the degree of conversion is affected by the post-printing curing strategies, consequently impacting the mechanical properties of the material (27). Furthermore, thorough investigation into the maximum number of units for fabricating fixed dental prostheses (FDP) and cleaning solutions is essential before making any recommendations.

The endeavor to improve the flexural strength of printed polymers remains ongoing. Aati *et al.* undertook modifications by incorporating zirconia oxide ($ZrO2$) nanoparticles into the printable resin at varying concentrations. Their findings revealed superior mechanical properties compared to the unaltered printable resin (51).

# 6. Conclusions

3D printing and Milling are two completely different technologies with their own advantages and disadvantages.

Evaluating the physical and mechanical properties of the two techniques, we can consider that:

1- Two technologies showed satisfactory indices of physical and mechanical properties of materials for temporary structures.
2- This study demonstrated significantly different mechanical and physical properties and most of the obtained data lead us to conclude that properties (except WR) of 3D-printed provisional materials are similar, or inferior compared to milled ones. However, the wide variability in the results provides us with opportunities to further explore and develop CAD/CAM technologies.
3- The presence of factors such as print orientation, of cleaning methods, thermomechanical aging on marginal gap, impact of resin material, build direction, post-curing and artificial aging, thickness of the printed layer, shrinkage between layers, curing speed and intensity, angle, post-polymerization time and temperature) influencing the physical and mechanical properties of 3D-printed materials.

As more dental practitioners and technicians become interested in 3D-printed provisional materials, it is crucial to ensure that these materials have the best possible properties. Using 3D-printed and milled provisional materials shows great promise for creating provisional crowns and FDP.

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# Attachment

EVENTOS CIENTÍFICOS IUCS

JORNADAS CIENTÍFICAS AEIUCS

XXXII
JORNADAS CIENTÍFICAS
DE CIÊNCIAS DENTÁRIAS

**DIPLOMA**

O presidente das **XXXII Jornadas Científicas do Curso de Medicina Dentária do Instituto Universitário de Ciências da Saúde — CESPU**, com o tema **"Medicina Dentária Digital - uma Nova Era"** certifica que:

**Tsiukhai Y.**, Tsiukhai T. , Braz M.P., Costa J.A.

Apresentaram um trabalho científico sobre a forma de Comunicação Oral intitulada "Dental Digital Projects: guidelines from digital treatment planning to execution" realizadas no **Porto Palácio Hotel** no **dia 9 de abril de 2024**.

PROF. DOUTOR **JOAQUIM MOREIRA**
PRESIDENTE DAS XXXII JORNADAS CIENTÍFICAS DE CIÊNCIAS DENTÁRIAS

Sofia Lima Ferreira
SOFIA LIMA FERREIRA
PRESIDENTE DO NÚCLEO DE MEDICINA DENTÁRIA DA AEIUCS

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