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(Review Article)

Flexural strength of 3D printed posterior dental restorations: A Narrative review of the literature

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Abstract

The objective of this narrative review was to compare and analyze published articles on the mechanical properties of 3D printed fixed dental restorations compared to restorations fabricated with CAD/CAM and/or conventional milled composite and/or acrylic resins and to answer the following research question: Do 3D printed posterior restorations have increased flexural strength compared to restorations made of composite resin and/or acrylic resin? Articles were searched using the following electronic databases: PubMed, GOOGLE SCHOOLAR. This literature review was structured based on the guidelines given by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The PICO/PECO (Participant, Intervention/Exposure, Comparison, Outcome) focused question was: "Do restorations printed on 3D printers (I) for the posterior sector (P) have higher flexural strength (O) compared to restorations made of composite resin and/or acrylic resin (C)?". Of the two hundred and thirty-five titles, which were recognized after a primary search, fourteen articles were included in the analysis. The evidence available after performing this narrative review indicates that 3D-printed posterior fixed restorations have comparable mechanical behavior to CAD/CAM-engineered posterior fixed restorations in terms of flexural strength.

Keywords: Temporary dental resins; PMMA; 3D printing; CAD/CAM; Temporary crowns; Temporary fixed dental prosthesis; Mechanical properties; Fracture resistance; Wear resistance; Flexural strength; DLP digital light processing; SLA stereolithography

1. Introduction

In the field of dentistry, are dental restorations procedures that seek to restore the function, shape and aesthetics of a damaged or lost tooth, these can be performed with various materials [1]. Thus, several different resins are used in dentistry, according to their composition and processing method according to their purpose, all types of dental resins have a satisfactory aesthetic and functional effect, in addition to the ease and functional stability in the management of their process, however, they have negative aspects due to the volumetric and optical changes that originate in the oral cavity [2].

Currently, the field of dentistry has undergone a significant change in recent years, especially in the way dental restorations are fabricated, compared to traditional methods of dental restoration, new methods such as three-dimensional [3D] printing that offers the ability to create highly detailed designs and a greater variety of material options, so it is considered as dental restoration of the future [3]. In this way, 3D printing technology has recently opened new horizons in the method of molding and composite materials, from this approach, objects have been

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generated from a preset digital program by adding materials layer by layer in additive manufacturing technology, this has benefited a number of areas, especially dentistry, thus models and dental restorations have been adapted, which has led to the precise formation of complex structures and customized production [4]. Accordingly, this technology currently provides a wide range of dental treatments ranging from simple orthodontics, dental implants, jaw reconstructions, prosthetic rehabilitation, surgical and non-surgical endodontics, all of which have embraced 3D printing technology [5]. Printed restorations today are indicated as provisional restorations, but are gradually being indicated for definitive restorations.

In this sense, it has been shown that 3D printing is one of the most popular tools in the field of dentistry, due to the great benefits it generates for the professional, since it allows the elaboration of precise dental prostheses, as well as crowns, bridges and implants, favoring together, patients who have complex or unique oral anatomy, who need customized solutions due to injuries or other conditions [6].

In this regard, 3D printing technology has become a useful and efficient tool in the production of customized dental restorations, allowing dental professionals to create accurate, high-quality restorations faster and at lower cost. Compared to traditional methods of dental restoration, 3D printing also offers the ability to create highly detailed designs and a wider variety of material options. Under this approach, it is considered as the objective of this narrative review to compare and analyze published articles on the mechanical properties of 3D printed fixed dental restorations compared to restorations made with CAD/CAM and/or conventional milled composite and/or acrylic resins and answer the following research question: Do restorations printed on 3D printers for the posterior sector have higher flexural strength compared to restorations made of composite resin and/or acrylic resin?

1.1. Research question

Do restorations printed on 3D printers for the posterior sector have higher flexural strength compared to restorations made of composite resin and/or acrylic resin?

2. Material and methods

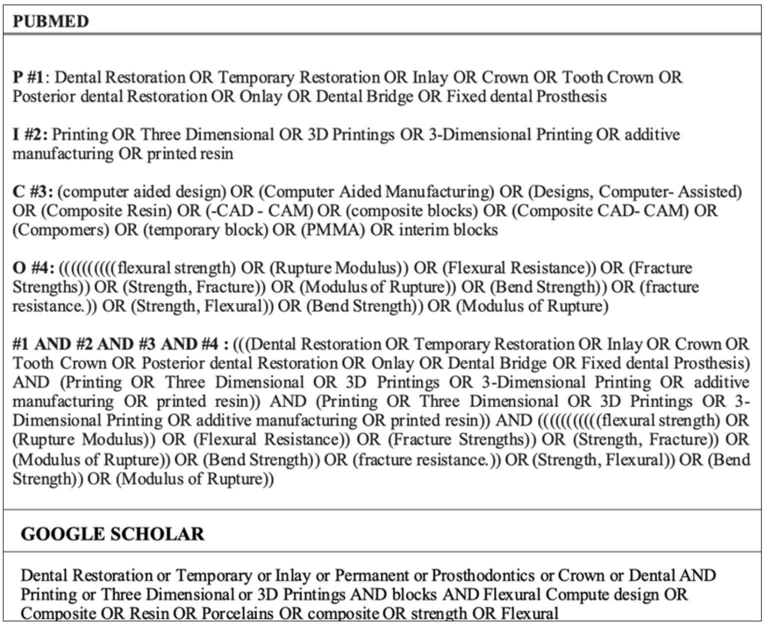
This literature review was structured based on the PICO question format. The focused PICO/PECO (Participant, Intervention/Exposure, Comparison, Outcome) question was: "Do restorations printed on 3D printers (I) for the posterior sector (P) have higher flexural strength (O) compared to restorations made of composite resin and/or acrylic resin?".

- P: Dental restorations for the posterior sector;
- I: 3D printed technique
- C: CAD/CAM or conventional technique (composite resin and/or acrylic resin)
- O: Flexural strength.

2.1. Search strategy

Two independent authors (J.O and S.G) systematically searched the indexed English literature using the following electronic databases: MEDLINE-PubMed, Google Scholar. The search for articles was performed in December 2022. Combinations of medical subject heading (MeSH) terms and non-MeSH terms along with Boolean operators were used to perform the search. Details of the search strings used for the systematic search are mentioned in Table 2. The reference lists of relevant articles were manually screened for supplementary relevant articles that were not detected during the electronic search. The search strategy was modified according to the requirements of the database searched.

Table 1 Electronic databases and research strategies.



PUBMED
P #1: Dental Restoration OR Temporary Restoration OR Inlay OR Crown OR Tooth Crown OR Posterior dental Restoration OR Onlay OR Dental Bridge OR Fixed dental Prosthesis **I #2:** Printing OR Three Dimensional OR 3D Printings OR 3-Dimensional Printing OR additive manufacturing OR printed resin **C #3:** (computer aided design) OR (Computer Aided Manufacturing) OR (Designs, Computer- Assisted) OR (Composite Resin) OR (-CAD - CAM) OR (composite blocks) OR (Composite CAD- CAM) OR (Compomers) OR (temporary block) OR (PMMA) OR interim blocks **O #4:** ((((((((((flexural strength) OR (Rupture Modulus)) OR (Flexural Resistance)) OR (Fracture Strengths)) OR (Strength, Fracture)) OR (Modulus of Rupture)) OR (Bend Strength)) OR (fracture resistance.)) OR (Strength, Flexural)) OR (Bend Strength)) OR (Modulus of Rupture) **#1 AND #2 AND #3 AND #4 :** (((Dental Restoration OR Temporary Restoration OR Inlay OR Crown OR Tooth Crown OR Posterior dental Restoration OR Onlay OR Dental Bridge OR Fixed dental Prosthesis) AND (Printing OR Three Dimensional OR 3D Printings OR 3-Dimensional Printing OR additive manufacturing OR printed resin)) AND (Printing OR Three Dimensional OR 3D Printings OR 3-Dimensional Printing OR additive manufacturing OR printed resin)) AND (((((((((((flexural strength) OR (Rupture Modulus)) OR (Flexural Resistance)) OR (Fracture Strengths)) OR (Strength, Fracture)) OR (Modulus of Rupture)) OR (Bend Strength)) OR (fracture resistance.)) OR (Strength, Flexural)) OR (Bend Strength)) OR (Modulus of Rupture))
GOOGLE SCHOLAR
Dental Restoration or Temporary or Inlay or Permanent or Prosthodontics or Crown or Dental AND Printing or Three Dimensional or 3D Printings AND blocks AND Flexural Compute design OR Composite OR Resin OR Porcelains OR composite OR strength OR Flexural

2.2. Eligibility criteria

The inclusion and exclusion criteria are listed in Table 2.

Table 2 Inclusion and exclusion criteria

Inclusion criteria	**Exclusion criteria**
English literature	Literature in another language than English
Studies comparing the flexural strength of 3D printed fixed restorations with other materials and methods used for posterior dental restorations	Studies that compare properties other than physical and mechanical properties.
Literature since 2018	Literature prior to 2018
Clinical Trial, Meta-Analysis Randomized Controlled Trial Review Systematic Review, in vitro	Studies other than those indicated.
Articles that have an abstract available	Studies that discuss the properties of only 3D printed materials, but do not compare them to other conventional materials.
Full articles that can be opened freely or through sci-Hub	Incomplete articles that can NOT be opened freely or through sci -Hub
	Studies discussing the effects of 3D printing variables (print orientation, resin color setting, layer thickness, post-curing , degree of conversion, etc.) on the mechanical properties and precision of crown provisional restorative material and the 3D printed bridge.
	Studies comparing the accuracy, marginal and internal fit of 3D printed materials with other types of materials.

2.3. Screening and selection

Studies located in the searches were screened in duplicate, independently, by two investigators (JO and SG) to identify those with titles and abstracts that met the inclusion criteria. Articles in which both authors agreed were selected.

The full text of the selected articles was read over their titles and abstracts and the inclusion and exclusion criteria were applied. The references listed in all selected articles after reading the full text were reviewed manually and compared with the inclusion criteria. Disagreements regarding their inclusion were resolved by discussion with the third author (DAR).

2.4. Data extraction

A data extraction protocol was defined and evaluated by two of the authors (JO and SG). Data were extracted independently from the full-text articles selected for inclusion using a standardized form in electronic format (Office Excel 2011 software, Microsoft Corporation, Redmond, WA, USA). The authors categorized information on: authors, year, study design, Type of mechanical test, Flexural strength value in MPa or Nw, Experimental group (3d resin brand), Control group (cad/cam block), Conclusions.

3. Results

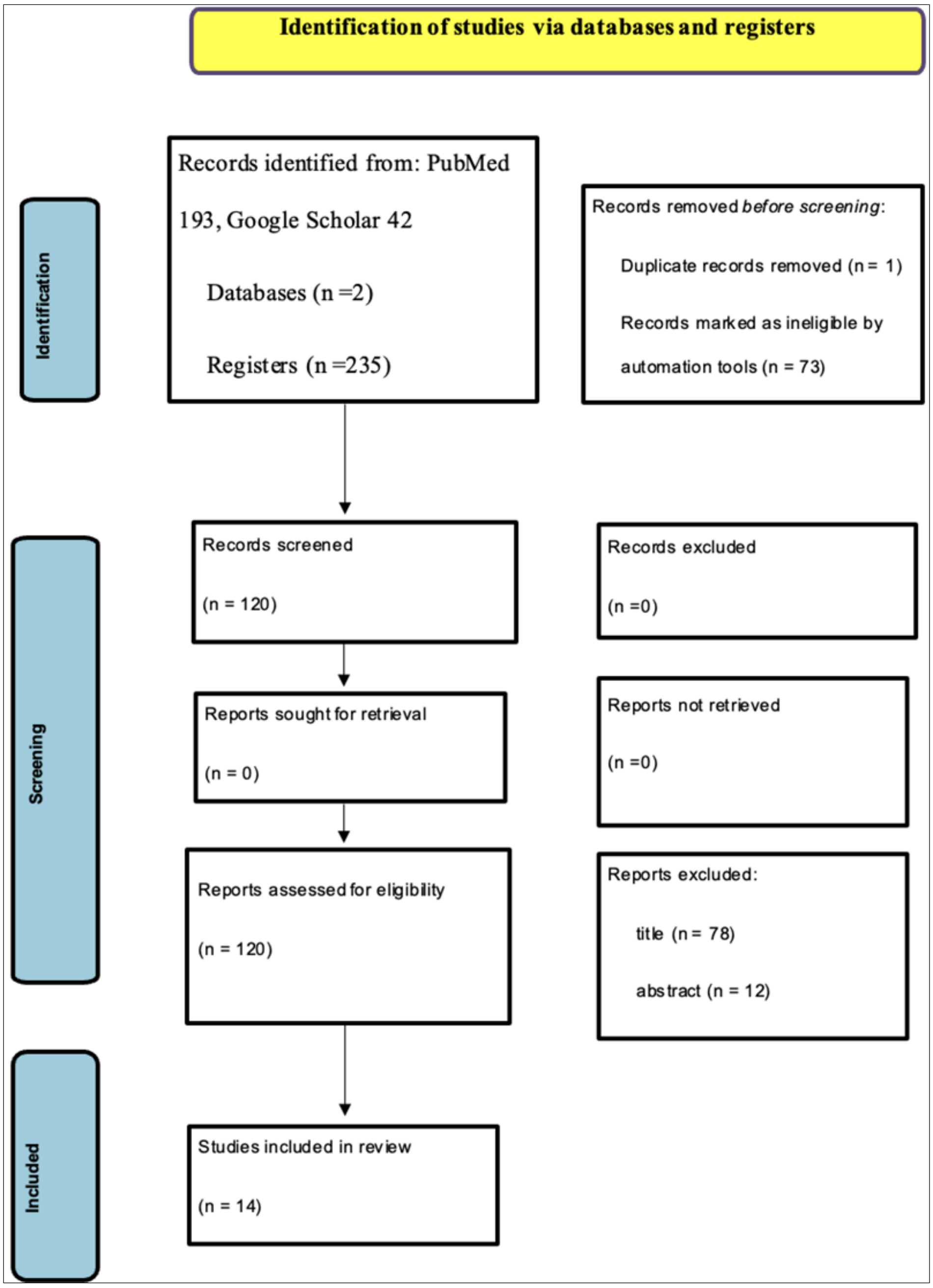


Figure 1 The PRISMA flow diagram.

*The search yielded 235 studies. 193 in Pubmed 42 in Google Scholar, of these, 1 duplicate was excluded. Another 114 studies were excluded because they did not meet the eligibility criteria. The remaining 120 studies were selected for full-text review, which resulted in the exclusion of 99 articles that did not meet the inclusion criteria, 78 articles were discarded by title, 12 by abstract, 16 by inclusion and exclusion criteria. *Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools. From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/*

The titles and abstracts of the identified articles were selected according to the pre-established inclusion and exclusion criteria (by J.O and S.G). Subsequently, the two authors (J.O and S.G), after reviewing the full texts, used self-developed tables to tabulate the relevant data. The extracted information was divided into several categories; Table 3 was a common table for all selected articles that provided information on: author's name, year of publication, type of study, type of mechanical test, value of flexural strength, experimental group, control group and conclusions. The details of these tables were related to the type of test, the results of the tested property for each type of group (experimental and control) and the authors' conclusions and suggestions.

Table 3 Characteristics of the articles included

Qualification	**Author/s**	**Year**	**item type**	**test type mechanics**	**Conventional group bending resistance value**	**Flexural strength value for CAD/CAM milling unit**	**Flexural strength value 3D printed group**	**Conclusions**
Flexural Strength of 3D-Printing Resin Materials for Provisional Fixed Dental Prostheses	Sang-Mo Park et al.	2020	IN VITRO	universal testing machine _	**Self curing PMMA powder / liquid (Jet tooth shade, Lang Dental Co).** 543N	**Milled PMMA (VIPI Co):** 1232N	**SLA: PMMA (Formlabs Co.):** 1323 N **DLP: PMMA (NextDent Co.)** 1189 N **FDM: Polylactic acid. (ColorFabb Co.):** N/A	The restorations for fixed prostheses of 3 units made with SLA, presented the highest resistance to fracture with a statistically significant difference in all the experimental groups. There was no statistically significant difference between the restorations made between SLA and milled PMMA. The FDM group showed considerably better flexibility than the other groups, it did not fracture.
Fracture Resistance of Three-unit Fixed Dental Prostheses Fabricated with Milled and 3D Printed Composite-based Materials	Karim Corbani et al.	2021	IN VITRO	Universal testing machine _	**N/A**	**Hybrid Ceramic /CAD/CAM (Amber, Creamed):** 1312.27 N **FRC: CAD/CAM glass fiber reinforced resin technopolymer (Trilor , Bioloren):** 839.07 N	**3DP: SLA Hybrid Composite: (Irix Max)** .1360.20N **MC: PORCELAIN CHROME COBALT SLM (Starbond CoS powder 30) :** 2390.87 N	Fixed dental prostheses of three units with materials such as SLM COBALT CHROMIUM PORCELAIN showed the highest fracture resistance, SLA Hybrid Composite and Hybrid Ceramic/CAD/CAM, showed better fracture resistance compared to technopolymer , epoxy resin reinforced by CAD/CAM glass fibers. where detachment of the veneering resin

								composite was the most common type of failure.
Printable and Machinable Dental Restorative Composites for CAD/CAM Application-Comparison of Mechanical Properties, Fractographic, Texture and Fractal Dimension Analysis	Wojciech Grzebieluch et al.	2021	analytical	universal testing machine _	N/A	**CAD/CAM nano-hybrid ceramic composite (Grandio Blocs):** 186.02Mpa **CAD/CAM reinforced hybrid composite** **(Brilliant Crios)** :170.29 Mpa **CAD/CAM hybrid ceramic (Enamic):** 118.96 MPa	**LCD light-curing fluid resin (VarseoSmile Crown plus):** A(PRINTED **vertically)**: 119.85 Mpa B(PRINTED **rotated at 45 degrees)**: 143.39 Mpa	The highest resistance to bending was demonstrated by (Grandio Blocs) and (Brilliant Crios) and the minor by (Enamic) and (VarseoSmile Crown plus) (PRINTED vertically) group A -The resistance to bending of (VarseoSmile Crown plus) depends on the orientation of the layers. -Due to the low filler content, the flexural modulus of the printed material is the lowest among the materials tested and lower than that of dentin.
Surface Properties of Polymer Resins Fabricated with Subtractive and Additive Manufacturing Techniques	Amal S. Al-Qahtani , et al	2021	analytical	universal testing machine _	**(PMMA) powder/liquid self-curing material (Jet Tooth Shade™):** 93.68 MPa	**PMMA CAD/ CAM (Ceramill Temp):** 116.09MPa	**Photopolymerizable resin , biocompatible for 3D printing (Freeprint Temp) SLA:** 113.16MPa	comparable flexural strength and microtoughness to CAD-CAM-fabricated samples. 3D technology for the fabrication of temporary resin restorations is potentially applicable for clinical use.

Comparison of fracture strength after thermo-mechanical aging between provisional crowns made with CAD/CAM and conventional method	tanapon Reeponmaha et al	2020	analytical	universal testing machine _	**PMMA powder/liquid self-curing material (UNIFAST TRAD):** 769.81 N **biacrylic resin dispensed with a gun (PROTEMP 4):** 1338.51 N	**PMMA CAD/CAM (BRYLIC SOLID):** 1084.46 N	**Photopolymerizable resin , biocompatible for 3D printing (Freeprint Temp) SLA:** 1149.05 N	Self-curing PMMA powder/liquid (Unifast Trad) represented the lowest fracture strength of all groups. biacrylic resin (Protemp 4), and PMMA CAD/CAM (Brylic Solid) and 3D-printed light-curing resin (Freeprint Temp). The results indicated that the CAD/CAM fabricated provisional restoration could be used as a promising long-term provisionalization .
Mechanical Properties of Additively Manufactured and Milled Interim 3-Unit Fixed Dental Prostheses	Juan Legaz et al.	2022	analytical	universal testing machine _	**biacrylic resin dispensed with a gun (PROTEMP 4):** 147.6N	**PMMA CAD/CAM (Telio CAD LT):** 656.2N	**Methacrylate, filler: SLA (P Pro C &B, Straumann):** 266.9N **Methacrylate SLA (SHERAprint C&B)** :895.8N **Methacrylate, DLP filling (P Pro C &B, Straumann):** 245.2N **methacrylate (SHERAprint C&B):** 805.3N	In the present study, AM manufacturing procedures showed statistically significantly lower survival and higher complication rates compared with the other groups. The proven manufacturing methods, the type of resin selected, and the impression mode used have all influenced the mechanical stability and fracture resistance of provisional fixed dental prostheses. The evaluated AM technology did not show an impact on the mechanical properties of the AM fixed dental prostheses made with different resins tested.

Physical and Mechanical Properties of 3D-Printed Provisional Crowns and Fixed Dental Prosthesis Resins Compared to CAD/CAM Milled and Conventional Provisional Resins: A Systematic Review and Meta-Analysis	Jain S et al	2022	Systematic review - Meta-analysis	universal testing machine _	N/A	PMMA-based 3D printed resins	Milled CAD/CAM resins based on PMMA	Taşın et al. reported higher values of resistance to flexing of composite-based 3D printed resins compared to conventional PMMA and conventional bis-acrylic-based resins.
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	Passing Ellakany et al	2022	In vitro studies	universal testing machine _	Control group: CAD-CAM: 174.42 ± 3.39 MPa CONVENTIONAL: 98.02 ± 6.11 MPa experimental group: DLP: 103.79 ± 8.93 MPa SLA: 167.25 ± 6.92 MPa	3D-printed composite resins : Methacrylate, printed in 3d SLA (NextDent) 3D-printed composite resins : Methacrylate , , 3d printed DLP (ASIGA)	CAD-CAM: PMMA blocks milled technique (Telio CAD). self-curing PMMA resin conventional technique (unifast trad)	flexural strength and hardness were higher in milled IFDPs compared to conventional SLA ND, DLP AS, and IFDPs.
Compressive and Flexural Strength of 3D-Printed and Conventional Resins Designated for Interim Fixed Dental Prostheses: An In Vitro Comparison	Pantea M et al	2022	In vitro studies	universal testing machine _	Control group: CAP: 88 ± 10Mpa CHP: 76 ± 7Mpa Experimental group: 3DCS 143 ± 15 MPa 3DOS 141 ± 17 MPa	3DCS NextDent : DLP 3D printed PMMA (NextDent) 3DOS HARZ: LCD 3D printed PMMA (HARZ)	CAP Duracyl : self-curing PMMA liquid/powder acrylic resin (SpofaDental) CHP Superpont : self-curing PMMA liquid/powder acrylic resin (SpofaDental)	The tested 3D printed provisional resins performed better than conventional resins in both compression and flexural tests.

Effect of material thickness on the fracture resistance and failure pattern of 3D-printed composite crowns	Corbani K et al.	2020	In vitro studies	universal testing machine _	Control group in thickness 519N (0.5mm) 932.1 (1.0mm) 1284 (1.5mm) Summary of fracture resistance of the experimental group in thickness: 1345N (0.5mm) 1945N (1.0mm) 2383N (1.5mm)	3D: SLA 3d printed nanocomposite (Irix Max)	CAD-CAD: resin blocks, CAD-CAM milled (Dentsply sirona)	Crowns fabricated in 3D showed significantly higher fracture resistance compared to those fabricated using CAD/CAM technology.
Comparison of material properties and biofilm formation in interim single crowns obtained by 3D printing and conventional methods	Simoneti DM et al	2022	In vitro studies	universal testing machine _	experimental group: SLA resin : 48.9 ±1.2MPa SLS resin : 77.3 ±3.1MPa Control group: Bisacryl resin : 75.0 ±8.2Mpa Acrylic resin: 69.2 ±8.8 MPa	SLA: 3d printed PMMA; (Formlabs Inc) SLS: 3d printed nylon; (Stratasys)	Bisacryl _ resin : Dimethacrylate conventional technique .(Yprov) Acrylic resin : PMMA conventional technique. (Dencor)	The SLS resin presented higher values of maximum flexural strength and maximum stress in the fracture load test than the conventional materials, while the SLA resin obtained worse results compared to all the materials evaluated.

Evaluation of intaglio surface trueness, wear, and fracture resistance of zirconia crown under simulated mastication: a comparative analysis between subtractive and additive manufacturing	Kim YK et al	2022	In vitro studies	universal testing machine _	N/A	**zirconia (4Y-PSZ):** N/A **CAD/ CAM zirconia (5Y-PSZ)** : N/A	**Zirconia with yttria 3D SLA (3 Y-TZP):** N/A **Zirconia with yttria 3D DLP (3 Y-TZP):** N/A	Additive manufacturing produced a precise single-unit zirconia prosthesis that was clinically acceptable, with the potential to compensate for the deficiencies of the subtractive technique. Additively fabricated zirconia crowns showed comparable or better properties in terms of fracture resistance and antagonist wear after simulated chewing, compared to crowns produced by subtractive fabrication using the latest generations of dental zirconia .
Flexural strength of aged and nonaged interim materials fabricated by using milling, additive manufacturing, and a combination of subtractive and additive methods	Giugovaz A et al	2022	In vitro studies	universal testing machine _	Control group: M: Nonaged 181 ±20 MPa Aged 178 ±20MPa, AM+M: Nonaged 114 ±10MPa Aged 105 ±12MPa, experimental group: AM: Nonaged 88 ±33MPa Aged 66 ±25MPa	AM: 3D Printed PMMA (FormLabs) AM+M: 3D Printed PMMA (FormLabs) + CAD/CAM	M: (PMMA) CAD-CAM (CopraTemp)	The milled specimens presented the highest flexural strength values of all the groups tested, while the additively manufactured specimens showed the lowest flexural strength values. However, the specimens manufactured by combining subtractive and additive methods presented higher flexural strength than the same material processed using only a subtractive technique.

Zirconia fixed dental prostheses fabricated by 3D gel deposition show higher fracture strength than conventionally milled counterparts	Rabel K et al	2022	analytical	universal testing machine _	Experimental group: Y-TZPSG_n : 5164 N Y-TZPSG_la:4507 N Control group: Y-TZPC_n:1923N Y- TZPC_la :2041 N Not artificially loaded and aged (n) and as artificially loaded and aged (la).	(Y-TZPSG): zirconia self-glazed manufactured using a 3D additive process (ErranTech Co)	Y-TZPC: Conventional zirconia ((Dentsply Sirona) manufactured using CAD-CAM technology	The fracture strength of the additively manufactured FDPs amounted to more than 4500 N and was therefore twice that of the CAD/CAM milled group.

PMMA: polymethyl methacrylate, 3 YZP : Third generation zirconium, SLA: stereolithography, DLP: digital light processing LCD: Masked Stereolithography FDM: Polylactic acid FRC: glass fiber reinforced resin Mpa: megapascals AM: additive manufacturing 3D: three dimensional. N/A: not applicable Y-TZPG: zirconia self-glazed Y-TZPC: Conventional zirconia 3DP: 3D printed hybrid Composite 4Y-PSZ: 4 mol% yttria-partially stabilized zirconia; 5Y-PSZ: 5 mol% yttria-partially stabilized zirconia. N: newton CAP: Duracyl self-curing PMMA CHP: Superpont self-curing PMMA 3DCS: digital light processing 3D printed PMMA 3DOS: Masked Stereolithography 3D printed PMMA.

4. Discussion

This narrative review aimed to compare and analyze published articles on the mechanical properties of 3D printed posterior fixed dental restorations compared to restorations fabricated with milled and/or conventional CAD/CAM methods. The fourteen included studies were in vitro studies, meta-analyses, and analytical articles, these studies compare restorations fabricated with PMMA and/or CAD/CAM composite resin using the subtractive and/or hand-mixing technique with restorations fabricated with the additive technique.

Five studies [5,7-10] reported that CAD/CAM posterior restorative materials have been shown to have superior flexural strength to restorations fabricated by 3D printing. Wojciech et al [7], in their study highlights that this result is due to the lower filler content of the 3D printing material. The relatively low filler content is forced by the need to maintain the liquid consistency required in the 3D printing process. Another reason is the influence of the angulation of the layers during 3D printing on the final flexural strength of the material. Vertical orientation of the layers relative to the longitudinal axis of the printed sample significantly decreases the flexural strength.

Juan Legaz et al.[8] and Giugovaz A. et al [10] attribute the better flexural strength of the CAD/CAM group, to the fabrication method, since in their study all catastrophic failures were found exclusively in the groups with additive technique, regardless of the type of technology (DLP digital light processing vs SLA stereolithography), furthermore Giugovaz A. et al [10] attributes a lower flexural strength associated with the surface roughness of the samples after thermocycling, finding that the samples milled by subtractive technique presented lower surface roughness values after thermocycling while the additively manufactured samples presented the highest surface roughness values after thermocycling, This could be explained by the higher water absorption of the additive material compared to the milled material, likewise, Passent Ellakany et al. [9] in their study relates the better results of the subtractive CAD/CAM method with the lower susceptibility to hydrolytic degradation of the milled blocks, this due to the manufacturing method of the blocks, which are industrially polymerized with high pressure and temperature, with a highly cross-linked structure, which makes them less porous materials, free of vacuum and residual monomer coated.

Another material widely used in dentistry is zirconia, currently monolithic zirconia restorations are characterized by their higher translucency and are processed by a subtractive fabrication method, however, two studies [12-14], (Kim YK et al [12] and Rabel K. et al [14]) documented the fabrication of zirconia restorations with additive technique through a technique called "precise additive 3D gel deposition". These materials showed better mechanical behavior than those fabricated with subtractive technique. This can be explained by the fact that the milled monolithic 3rd generation zirconia restorations have a higher yttrium content, which decreases their mechanical properties. In addition, it was observed that the presence of surface glaze is a potential weak point for the initiation and propagation of cracks that were created during the milling process, In contrast, the zirconia restorations fabricated with the additive technique were monolithic 3Y-TZP restorations formed by a gel deposition process (colloidal) resulting in restorations with few structural microscopic defects and reduced grain size, and without surface glaze, designated as "self-glazed" zirconia, which resulted in one of the factors leading to twice the fracture toughness compared to conventionally milled counterparts, one could therefore speculate that the difference in fracture toughness of imprinted zirconia and conventionally milled zirconia would have been less pronounced if the milled zirconias had not been glazed, however these new materials should be investigated under aging conditions that simulate situations closer to the reality of the oral cavity.

From a contrary perspective, several authors [2,5,6,11-15] have reached the consensus that 3D printing outperforms the mechanical properties of subtractive techniques mediated by CAD CAM technology, since additive 3D technology has been shown to have low brittleness, greater flexibility and the ability to absorb stress induced by the applied load, Moreover, the layer-by-layer polymerization creates strong chemical bonds in their restorations and finally they undergo a post-curing process, which increases the degree of conversion and releases less residual monomers, while the subtractive CAD CAM technique during the milling process will give a block a specific geometry, generating cracks and roughness detected along the thickness of the surface of the fabricated restoration, these defects depend on the contact angle between the milling cutter and block (downward or upward), the depth and speed of cutting, in addition it has been observed excessive generation of heat and noise, release of PMMA monomer in the case of temporary restorations after the aging process and higher percentages of carbon and oxygen, which results in lower mechanical properties due to weakening of the material and an increased risk of fracture [8-9] and to this is added the large waste of material during fabrication.

When considering the different 3D printing techniques, Sang-Mo Park et al [5], in this study, found that the flexural strength of the 3-unit provisional restoration was higher in the SLA (stereolithography) group compared to the DLP (digital light processing) group. The reason for the high flexural strength is explained by the surface morphology of the printed object. In the DLP principle, each segment projected onto the single screen from the micromirrors (DMD chips), polymerizes into lines, creating a rougher surface, so the surface roughness of the printed object will depend on the resolution (voxels) of the chipset. On the other hand, SLA (stereolithography) technology makes each layer as if drawing with a laser beam, making the surface of the printed object relatively smooth. Therefore, it is explained that fracture can occur more quickly if the surface is rough, as the specific bonding area between layers is weak. Another reason why the SLA (stereolithography) restorations presented better behavior was due to the presence of urethane methacrylate, which gives the material great fracture toughness.

Pantea M. [2] et al reported that temporary restorations made of printed PMMA showed better malleability, resilience and toughness, absorbing a greater amount of energy until reaching the breaking point, a detail that is important especially when masticatory forces are sharply applied on prosthetic restorations in comparison with the mechanical behavior in compression observed for conventional resins which was characterized by being brittle, non-homogeneous and failing without absorbing energy. However, the mechanical characteristics of 3D-printed PMMA can be affected by printing parameters, such as printing speed/layer thickness and number of printed layers; material shrinkage rate; position and angle of the restoration on the printing platform/build orientation; amount of support material and post-processing procedures, as well as the type of design software.

Jain S et al [15] reveals that the build orientation during impressioning affects the mechanical properties. The vertical orientation causes the layers to be deposited perpendicular to the direction of load application, therefore, these materials show superior mechanical properties compared to those printed in horizontal orientation, since in this case the layer deposition is parallel to the load direction, it is also indicated that the layer thickness during the printing process affects the mechanical properties of these materials. The smaller the thickness of the printing layer, the more layer-to-layer interfaces are available; thus, each layer will polymerize better, which will increase the mechanical properties of these materials. These risk factors inherent to the fabrication technology that are not present with additive technology could explain the higher fracture toughness found. It is important to highlight that the articles reviewed differ in the experimental methodology (single crowns and/or plural fixed prostheses), as well as in the materials employed, (PMMA CAD/CAM blocks and composite resin) which influences the final results of flexural strength.

The published scientific evidence has not reached a definite consensus, studies (Amal S. Al-Qahtani, et al [16] Tanapon Reeponmaha et al [17], Passent Ellakany et al [9] Simoneti et al [13] point out that fixed dental prostheses fabricated by block milling system through CAD/CAM has demonstrated mechanical properties (bending and/or fracture resistance) similar to fixed dental prostheses fabricated by 3D printing technology, but they highlighted that restorations made by the conventional method (PMMA powder/liquid and/or bisacryl) presented the lowest flexural strength of all the groups analyzed, as they are mixed manually or by using self-mixing units, and there is a high chance of incorporating air bubbles and porosities, which may be the reason for their poor mechanical properties. The best results observed in printed resins are attributed to material composition, type and amount of filler particles, polymerization light, processing temperature, 3D printing parameters and postpolymerization procedures influence the mechanical properties of the product.

Limitations

The satisfactory performance of a 3d-printed material is not solely based on its mechanical properties, but also on its interaction with the immediate environment, so other factors such as marginal adaptation, color stability, and pulp and gingival response need to be evaluated. For this reason, clinical studies should be performed to give further external validity to the present findings.

5. Conclusion

The evidence available after performing this narrative review indicates that 3D printed posterior fixed restorations have comparable mechanical behavior with CAD/CAM technology-based posterior fixed restorations in terms of flexural strength and showed superior mechanical behavior than restorations fabricated by conventional powder/liquid or bisacryl techniques.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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