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Comparison of strength among different resin-matrix interim prostheses manufactured by traditional chairside and CAD-CAM: an “integrative review.”

Margarida Marques da Silva

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

Gandra, 30 de julho de 2021

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Trabalho realizado sob a Orientação de Mestre Carolina Coelho e Co-Orientador Professor Doutor Júlio Souza

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Eu, Margarida Marques da Silva, declaro ter atuado com absoluta integridade na elaboração deste trabalho, confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores foram referenciadas ou redigidas com novas palavras, tendo neste caso colocado a citação da fonte bibliográfica.

Agradecimentos

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RESUMO

Objetivo: O objetivo principal deste estudo foi realizar uma revisão integrativa sobre a resistência de diferentes próteses provisórias de materiais à base de resina fabricadas por CAD-CAM ou pela técnica tradicional.

Método: Uma revisão bibliográfica foi realizada no PUBMED usando uma combinação dos seguintes itens de pesquisa: "resina" OR "polímero" AND "prótese provisória" OR "prótese provisória" AND "CAD-CAM" ou "força". Artigos publicados na língua inglesa, de fevereiro de 2011 a fevereiro de 2021, relatando a resistência de diferentes materiais à base de resina para próteses provisórias. Estudos in vitro, meta-análises, ensaios clínicos randomizados e estudos de coorte prospetivos também foram avaliados.

Resultados: Dos 563 artigos identificados, 24 artigos foram selecionados para esta revisão integrativa. Diferentes materiais à base de resina fabricadas por CAD-CAM apresentaram valores maiores de força, variando de 31 a 142 MPa, quando comparados aos materiais fabricados pelo método tradicional pó/líquido para próteses provisórias que apresentaram valores de força variando de 15 a 133 MPa. Os materiais fabricados por CAD-CAM, possuem alto grau de conversão e baixa percentagem de poros e monômeros livres que proporcionam maiores valores de resistência. As tensões e fraturas ocorreram tanto na zona do pôntico quanto nas regiões de espessura fina dos materiais protéticos.

Conclusão: As próteses provisórias de matriz de resina e materiais fabricados por CAD-CAM apresentaram maior resistência quando comparadas às próteses produzidas pelo método tradicional pó/líquido. A baixa percentagem de defeitos como poros e um alto grau de polimerização podem fornecer propriedades mecânicas aprimoradas de próteses provisórias.

Palavras-chave: *Resina; Polímero; Prótese provisória; CAD-CAM; Força*

ABSTRACT

Purpose: The main aim of this study was to perform an integrative review on the strength of different interim resin-based prostheses manufactured by CAD-CAM or traditional chairside techniques.

Method: A bibliographic review was performed on PubMed using a combination of the following search items: “resin” OR “polymer” AND “interim prosthesis” OR “provisional prosthesis” AND “CAD-CAM” or “strength”. Articles published in the English language, from February 2011 up to February 2021, reporting the strength of different resin-based materials for interim prostheses. *In vitro* studies, meta-analyses, randomized controlled trials and prospective cohort studies were also evaluated.

Results: Of 563 studies identified, 24 studies were selected for this integrative review. Different resin-based materials manufactured by CAD-CAM showed the highest strength values ranging from 31 up to 142 MPa, when compared to the materials manufactured by traditional chairside powder/liquid methods that showed strength values ranging from 15 up to 133 MPa. Materials manufactured by CAD-CAM, revealed a high degree of conversion and a low percentage of pores and free monomers that provided the highest strength values. The stress and fractures occurred the pontic zone as well as at the thin thickness regions of prosthetic materials.

Conclusion: Interim resin-matrix prostheses and materials manufactured by CAD-CAM reveals a higher strength when compared to prostheses produced by traditional chair side powder/liquid methods. The low percentage of defects such pores and a high degree of polymerization can provide enhanced mechanical properties of interim prostheses.

Keywords: *Resin; Polymer; Interim prosthesis; Provisional prosthesis; CAD-CAM; Strength*

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%	Percentagem
MPa	Mega Pascal
GPa	Giga Pascal
N	Newton

1. INTRODUCTION

Interim restorations are subjected to chewing forces and require specific mechanical properties that allow them to survive the repeated functional forces of the oral environment, therefore, to predict the behavior of a material, it is important to understand its mechanical properties. (1–3) A well-crafted restoration allows for better control of the bacterial plaque, helping to keep the gingival tissue healthy and with the ideal shape, position, and emergence profile for the installation of a permanent prosthesis. Also, it re-establishes the vertical dimension of occlusion (DVO), centric relationship and occlusal/incisal plane. An optimal provisional restoration must therefore meet certain mechanical, biological and aesthetic criteria. (1,4–8)

According to their chemical composition, the interim materials can be composed of resins composed of Bis-acryl and Bis-GMA, which can be self- or dual-polymerized, and by acrylic methacrylate resins (PMMA, PEMA), which are self-curing. (1,5,6,9 – 13) Composite resins are formed by organic matrix, inorganic matrix and a bonding agent. These materials are dysfunctional capable of cross-linking with another chain of monomers. They have a polymeric structure created by the union of dimethacrylate monomers by linear bonds and are capable of cross-linking with another chain of monomers. Also, contain inorganic fillers (quartz, glass or silica) that increase their rigidity. (1,6,9,10) PMMA-based resins are organic compounds, presented in powder and liquid form. The powder is composed of polymer grains (PMMA), initiator (benzoyl peroxide), pigments, dyes, opacifiers, plasticizer, organic fibers (carbon, glass, polyethylene, nylon, and aramid) and inorganic fillers. Liquid contains monomer (methyl methacrylate), inhibitor, accelerator, and cross-linking agent. (14 – 17) They are monofunctional and linear molecules with low molecular weight that lead to reduced rigidity and greater shrinkage during polymerization. Filled materials give the material greater surface rigidity and greater resistance to compression and traction, increasing durability and clinical performance, reducing polymerization shrinkage and thermal shrinkage and expansion, controlling viscosity and handling characteristics, and even

decreasing water absorption. (1,7,9,10,12) With the advancement of technology, CAD-CAM materials based on PMMA appeared, which are highly crosslinked and with a more homogeneous structure, less free monomers, and less porosity. (1,2,18) Interim prostheses can be fabricated by using traditional chairside or computer aided design/fabrication. CAD-CAM systems are based on 3 main components, firstly an intraoral scanner, which collects data from the preparation and neighboring structures and then converts them into fingerprints. Then a software (CAD) processes the information obtained allowing the operator, in a virtual way, to study, apply and improve the design of the restoration according to the desired and required particularities, and finally a milling unit for the manufacture of the restoration (CAM) using subtractive methods, starting from a solid block or disk that is mechanically progressively cut by a drill, until the desired final restoration geometry is obtained, or by additive manufacturing that is processed by joining a powder or liquid material when deposited layer by layer, guided by the segmented image of the design obtained in the CAD software. (2,7,9,12,18 – 22) The traditional chairside fabrication of interim prostheses involves the auto-polymerization of a polymer powder and liquid monomer or of 2-part composite resin pastes. (12)

Temporary restorations manufactured by traditional chairside are associated with deficiencies in terms of mechanical strength. The difficulty in controlling air bubbles and porosity during manual mixing of resins can lead to compromised mechanical strength, as it leads to the incorporation of voids. It can be controlled through self-mixed cartridge systems (bis-acryl resins) however CAD-CAM based materials offer better conditions.

1.1. Objective and hypotheses

The purpose of this study was to perform an integrative on the strength of different interim resin-based prostheses and materials manufactured by CAD-CAM or traditional chairside techniques. It was hypothesized that prostheses and related materials produced by CAD-CAM reveal the highest strength values when compared to

the prostheses and related materials manufactured by traditional chairside. Also, the mechanical performance of interim prostheses is negatively affected by a low degree of polymerization and high percentage of defects such as pores.

2. METHODS

2.1 Information sources and search strategy

A bibliographic review was performed on PUBMED (via National Library of Medicine) considering such database includes the major articles in the field of dentistry and biomaterials. The present search of studies was carried out in accordance with previous integrative or systematic review articles. The following search terms were applied: "resin" OR "polymer" AND "interim prosthesis" OR "provisional prosthesis" AND "CAD-CAM" OR "strength". Also, a hand-search was performed on the reference lists of all primary sources and eligible studies of this systematic review for additional relevant publications. The inclusion criteria encompassed articles published in the English language, from February 2011 up to February 2021, reporting the strength of different resin-based materials for interim prostheses. The eligibility inclusion criteria used for article searches also involved: *in vitro* studies; meta-analyses; randomized controlled trials; and prospective cohort studies. The exclusion criteria were the following: narrative review; systematic review; papers without abstract; case report with short follow-up period; articles assessing other properties of the resin-matrix materials.

2.2. Study selection and data collection process

Studies were primarily scanned for relevance by title, and the abstracts of those that were not excluded at this stage were assessed. Two of the authors (JCMS, MF) independently analyzed the titles and abstracts of the retrieved, potentially relevant articles meeting the inclusion criteria. The total of articles was compiled for each combination of key terms and therefore the duplicates were removed using Mendeley citation manager. The second step comprised the evaluation of the abstracts and non-excluded articles, according to the eligibility criteria on the abstract review. Selected articles were individually read and analyzed concerning the purpose of this study. At last, the eligible articles received a study nomenclature label, combining first author

names and year of publication. The following variables were collected for this review: authors' names, journal, publication year, purpose, chemical composition, flexural

strength, three-point bending strength, tensile strength, elastic modulus, main outcomes. PICO question was adjusted to the issue where "P" was related to the patients or specimens while "I" referred to the methods of analyses. Data of the reports were harvested directly into a specific data-collection form to avoid multiple data recording regarding multiple reports within the same study (e.g., reports with different set-ups). This evaluation was individually carried out by two researchers, followed by a joint discussion to select the relevant studies.

3. RESULTS

The literature search identified a total of 563 articles in PubMed, of which 155 duplicate articles were eliminated. Of the remaining 408 articles, 372 studies were excluded because they did not meet the inclusion criteria. The evaluation of titles and abstracts resulted in the selection of 36 potentially review articles of which 12 articles were excluded after full reading (**Figure 1**).

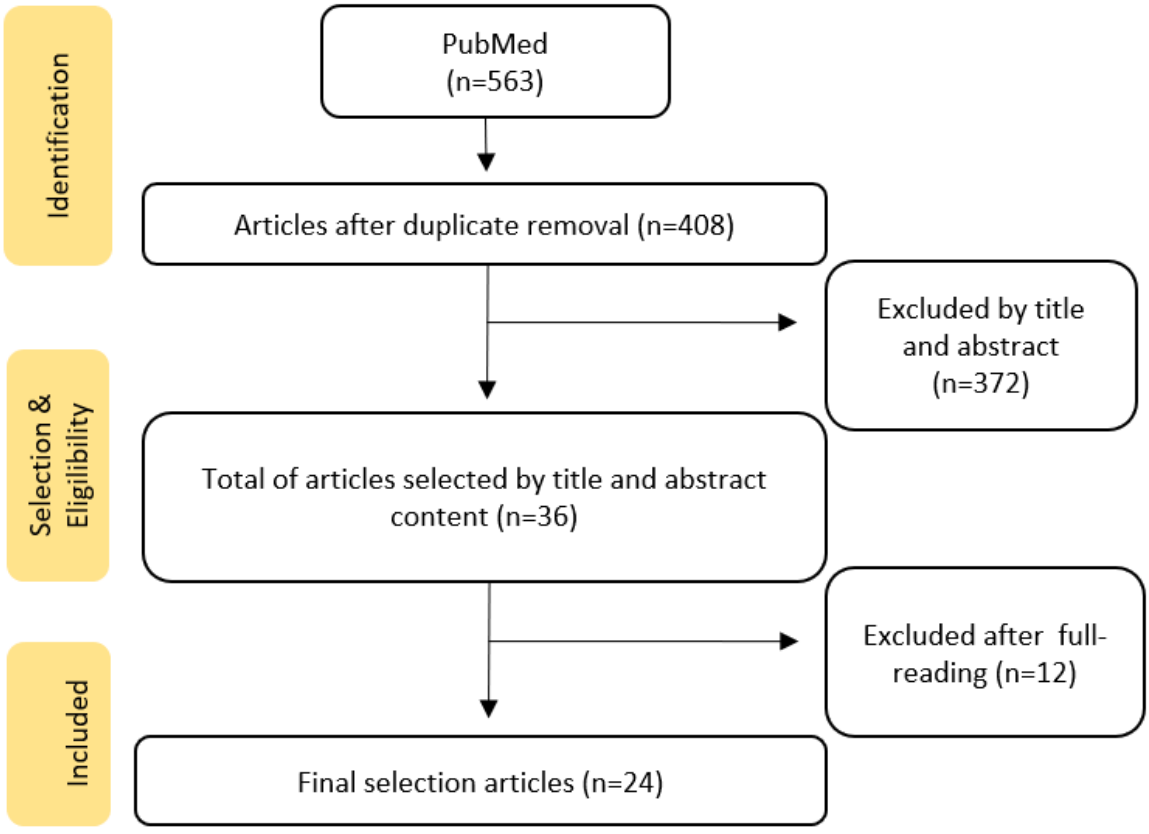


Figure 1. Flow diagram of the search strategy used in this study.

Of the 24 articles included in this review, 18 (75%) *in vitro* studies compared the interim resin-based prostheses manufactured by CAD-CAM or traditional chairside techniques. (1–3,5,7,9–12,18–26). Of which eleven studies assessed the mechanical performance of prostheses by compressive load tests (2,3,25,26,9,11,12,18–22) while, five studies assessed the prostheses by using 3-point bending test (1,7,10,23,24) and two studies using a 4-point bending test (5,27). Two studies performed further computational analyses using the finite element method following the experimental set up and results. (12,18) Regarding the design, five studies assessed three-unit interim prostheses (18–20,25,26) while one tested 4-unit interim prostheses (12). Six in vitro studies (25%) evaluated the fracture behavior of resin-based prostheses manufactured by the traditional chairside (4,6,8,13,27,28).

The retrieved data on the chemical composition, processing parameters, elastic modulus, strength (MPa), and mechanical assessment are provided in Table 1.

The main results can be drawn as follow:

- The interim prostheses and materials produced by CAD-CAM showed higher strength values when compared to prostheses and materials produced by chairside powder/liquid methods. Regarding the design, three-unit interim prostheses manufactured by CAD-CAM revealed fracture loading values ranging from 644 up to 1339 N while traditional chairside powder/liquid methods revealed values ranging from 739.5 up to 946 N. Four-unit interim prostheses manufactured by CAD-CAM revealed fracture loading values ranging from 3136 up to 3126 N while traditional chairside powder/liquid methods revealed values ranging from 1287 up to 1320 N (1–3,5,7,9–12,18–26);
- Prostheses assessed using three-point bending test revealed fracture loading values ranging from 15 up to 131 MPa, while prostheses assessed using four-point bending test revealed values ranging from 70 up to 144 MPa (1,5,7,8,10,11,13,24,27,28);

- Regarding the chemical composition of the materials, PMMA showed higher fracture strength values than that recorded on bis-acrylic after manufacturing by CAD-CAM technique. (1,2,5,7,10,11,19 – 21,25) On the contrary, bis-acrylic prostheses revealed significantly higher strength values than that recorded for PMMA based prostheses after manufacturing by traditional chairside technique (1,2,10,21);
- On the design effect, the presence of cantilever negatively affected the strength of the test prostheses. However, the prostheses manufactured by CAD-CAM still revealed the highest fracture loading values (1634-2649 N) than those recorded for the group manufactured by traditional chairside powder/liquid technique (1268-1954 N) (12);
- Another study showed maximum powder/liquid values ranging from 644 up to 987 N for the interim prostheses without a screw channel and ranging from 493 N up to 951 N for the interim prostheses with a screw access. Thus, the fracture loading values of the interim prostheses depended on the type of material, but not on the restoration design (with or without screw) (19);
- One study reported that prostheses with 1 mm finish lines (chamfer or shoulder) provides a higher fracture strength when compared to prostheses with 0.6 mm finish lines. Bis-acrylic prostheses was found to have the lowest fracture strength. (20) The fracture spots were most noted at connector zone followed by pontic and abutment regions. Stresses were located at those regions that initiated the cracks and the catastrophic fracture of the prostheses (12,18,19);
- Materials with fillers in their chemical composition manufactured by CAD-CAM and the traditional chairside powder/liquid methods showed higher fracture loading values when compared those without fillers (7,19);
- The flexural strength and the elastic modulus increased from 20% up to 50% when of reinforcing fibers were embedded in their organic matrix (6,11,26);
- Regarding the environment testing set up, the flexural strength decreased significantly for all materials after the thermal cycling effect (3,7);

Table 1. Relevant data gathered from the retrieved studies.

Author (Year)	PURPOSE	Study design	Chemical composition	Processing parameters	Elastic modulus (GPa)/strength (MPa)	Mechanical assessment	Main outcomes
Abdullah et al. (2016)	Comparison the marginal gap, internal fit, fracture strength, and mode of fracture of CAD-CAM provisional crowns with that of direct provisional crowns	• *In vitro* • First premolar was prepared for full ceramic crown, they were cemented to the master die using TempBond NE (Kerr, CA, USA)	A. PMMA within 14% (wt) inorganic filler **(Vita CAD-temp; VITA Zahnfabrik, Germany)** B. 100% Polyetheretherketone **(PEEK; Invibio Biomaterial Company, UK)** C. 99.5% PMMA, pigments **(Telio CAD; Ivoclar Vivadent, Liechtenstein, Germany)** D. Bis-GMA, dimethacrylate polymer, zirconium particles, silica and silane, pigments **(Protemp 4; 3M ESPE, Germany)**	A/B/C: CAD-CAM (Sirona, Bensheim, Germany) D: Self-mixing	A. 2.8/ 80 B. 3.6/ 165-170 C. 2.9/ 115-130 D. 2.5/ 91-116	Compressive load test (Lloyd Universal Testing Machine, LRX 2K5, Hants, UK)	Maximum compressive load (N): A. 361.01 B. 802.23 C. 719.24 D. 416.40
Coelho et al. (2020)	Comparison the effects of CAD-CAM versus traditional chairside	• *In vitro* • Two types of 4-unit interim prostheses were fabricated with	A. PMMA within 14% (wt) inorganic filler **(Vita CAD-temp, Vita Zahnfabrik)**	A/B: CAD-CAM (CEREC 3; Dentsply Sirona)	A. 2.8/ 80-97 B. 2.9/ 115-130 C. 2.5/ 91-116	Compressive load test (TIRAtest 2705; TIRA GmbH) Finite element	Maximum compressive load: **Without cantilever:** A. 3136 B. 3126 C. 1287

	material processing on the fracture and biomechanical behavior of 4-unit interim prostheses with and without a cantilever.	abutments on the first premolar and first mandibular molar. • Ni-Cr model • Distilled water bath at 37ºC for 30 days	B. 99.5% PMMA, pigments **(Telio CAD, Ivoclar Vivadent AG)** C. Bis-GMA, dimethacrylate polymer, zirconium particles, silica and silane, pigments **(Protemp4, 3M ESPE)** D. P: PMMA, L: n-butylmethacrylate/ urethanacrylate/ ethylmethacrylate **(Dentalon Plus, Kulzer GmbH)**	D/C: Self-mixing	D. 2.4/ 58-75		D. 1390 **Presence of a cantilever:** A. 1634 B. 2649 C. 1954 D. 1268
Larissa et al. (2021)	Evaluation the effect of interim restorative materials on the stress distribution of a posterior three-unit FDPs	• *In vitro* • Three-unit fixed partial denture (First Molar, Second Premolar and First Premolar) • Zinc oxide-based cement)	A. UDMA, Bis-GMA, Bis-EMA, TEGDMA, Silica and fillers **(Resin composite)** B. 100% Polyetheretherketone **(PEEK)** C. Polymethyl methacrylate, diethyl phthalate, benzoyl peroxide, titanium dioxide **(Acrylic resin)**	A/B: CAD-CAM (Rhinoceros 5.0 McNeel North America, Seattle, WA, US) C: Self-mixing	A. 8/14.7 B. 4/90 C. 2.2/90	Compressive load test Finite element (FEA)	Stress peak Mpa (occlusal/cervical): A. 7/14 B. 21/12 C. 21/13 The connectors showed the highest tensile stress magnitude
Yao et al. (2014)	Investigation the FS and marginal accuracy of 2 traditional bis-acryl composite	• *In vitro* • Models of a prepared left maxillary first molar	A. 99.5% PMMA, pigments **(Telio CAD, Ivoclar Vivadent)**	A/B: CAD-CAM (Optispray; Sirona Dental	A. 2.9/ 115-130 B. 2.9/ 115-130	3-point loading test (Easy Test EZ20; Lloyd Instruments Ltd)	Mean flexural strength values (before/ After thermal cycling): A. 124.10/95.35MPa B. 96.84/77.27

	resin interim materials and 2 CAD-CAM interim materials.	• Water bath at 37ºC for 24 hours and termocycled 5000 cycles (5 to 55ºC)	B. PMMA within 14% (wt) inorganic filler **(Vita CAD-temp, VITA)** C. Bis-GMA, dimethacrylate polymer, zirconium particles, silica and silane, pigments **(Protemp 4,3M ESPE)** D. Bis-GMA, BHT, amines, benzoyl peroxide, dimethacrylates, glass particles **(Structur 2 SC/QM, VOCO)**	Systems GmbH) C/D: Self-mixing	C. 2.5/ 91-116 D. 1.8/90		C. 103.13/92.97 D. 107.85/84.85
Karaman et al. (2020)	Investigation the impacts of finish line type and width on the fracture resistance of provisional crowns, and to determine the suitable type of crown material to use	• *In vitro* • Three element bridges • Zinc oxide-based provisional cementation (Cavex Provisional Cement, Cavex, Holland) • 37 °C deionized distilled water for 24 h	A. PMMA **(Tempo-CAD, Ondent Tıbbi Malz. /Izmir, Turkey)** B. Bis-GMA, UDMA, aromatic polyvinyl ester resin, Barium glass, Silica, BHT, Self-Healing and Pigment Starters (Iron Oxide and Titanium Dioxide) **(Acrytemp, Zhermack S.p.A./via Bovazecchino, Italy)** C. Polyfunctional methacrylates (48 wt.%), inorganic fillers (47 wt.%), additives, initiators,	A: CAD-CAM (7 Series, Dental Wings, Montreal, Quebec, Canada) B/C: self-mixing	A. 2.9/ 78 B. 2.5/ 65 C. 2.9/ 115-130	Compressive load test (INSTRON 8801, Instron, Ltd., England)	Maximum compressive load with 1 mm finish lines (shoulder/chamfer): A. 1339/1160N B. 739.5/964.5 C. 829.5/914

			stabilizers, and pigments (5 wt.%) **(Telio CS, Ivoclar Vivadent, Schaan, Liechtenstein)**				
Alp et al. (2019)	Comparison the flexural strength of different computer-aided design/ computer-aided manufacturing (CAD-CAM) PMMA based polymers and conventional interim resin materials after thermocycling.	• *In vitro* • The specimens were prepared in accordance with ISO 10477:2004 (Dentistry-Polymer-Based Crown and Bridge Materials) • Stored in distilled water bath at 37°C for 24h • Thermocycling (10,000 cycles, 5 to 55°C)	A. 99.5% PMMA, pigments **(Telio CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein)** B. PMMA, colourants, peroxide as dibenzoyl peroxide and MMA **(M-PM-Disc, Merz Dental GmbH, Lutjenburg, Germany)** C. PMMA, dimethacrylates and pigments **(Polident PMMA, Polident d.o.o, Volcja Draga, Slovenia)** D. Bis-GMA, dimethacrylate polymer, zirconium particles, silica and silane, pigments **(Protemp 4, 3M ESPE, St. Paul, MN)** E. PMMA **(Art Concept ArtDentine, Merz Dental GmbH, Lutjenburg, Germany)**	A/B/C: CAD-CAM (3Shape, Copenhagen, Denmark) D/E: Self-mixing	A. 2.9/ 115-130 B. 2,7/ 96.6 C. 2.7/ 114 D. 2.5/ 91-116 E. 1.7/90	3-point flexural strength (MIN 100; Moddental)	Mean flexural strength values: A. 106.2 MPa B. 131.9 C. 113 D. 85.2 E. 66.1
Karaokutan et al. (2015)	Evaluation the effect of the fabrication	• *In vitro* • A master model with one crown	A. Yttrium Trioxide, Foil Dioxide, Aluminum Trioxide, Silica Dioxide,	A: CAD-CAM ((Yenamak D50,	A. 1.2/210 B. 1.2/130 C. 2.5/140	Compressive load test (LS 500; Lloyd	Maximum compressive load (N): A. 1106

	method and material type on the fracture strength of provisional crowns	(2.5) was manufactured from Cr-Co alloy • Distilled water at 37ºC for 24 hours • Thermocycled (5000 cycles, 5 to 55°C)	Sodium Oxide, Iron Trioxide, Zirconium Dioxide **(Cercon base, DuguDent GmbH/Hanau, Germany)** B. Polymethyl methacrylate **(Imident, Imicryl Dis Malzemeleri/Konya, Turkey)** C. Methacrylates, amines, terpenes, benzoyl peroxide and BHT **(Structur premium, VOCO GmbH/Cuxhaven, Germany)** D. Polyfunctional methacrylates (48 wt.%), inorganic fillers (47 wt.%), plasticizers, initiators, stabilizers and pigments (5 wt.%), **(Systemp c&b II, Ivoclar Vivadent AG/Schaan, Liechtenstein)** E. Bis-GMA, UDMA, aromatic polyvinyl ester resin, barium glass, Silica, BHT, Self-Healing and pigment Starters (Iron Oxide and Titanium Dioxide)	Yenadent Ltd, Istanbul, Turkey) B/C/D/E/F: Self-mixing	D. N/A/ 90 E. 2.5/65 F. N/A	Instruments, West Sussex, UK)	B. 843.71 C. 1392.1 D. 1009 E. 910 F. 711.09

			(Acrytemp, Zhermack spA/Via Bovazecchino, Italy) F. Highly cross-linked methyl methacrylate **(Takilon BBF, WP GmbH/Barmstedt, Germany)**				
Çakmak et al. (2020)	Evaluation the flexural strength of different CAD-CAM PMMA based polymers and conventional interim resin materials, auto polymerized bis-acrylate composite resin and PEMA with and without a surface sealant after thermocycling	• *In vitro* • Specimens were fabricated from each material according to ISO 10477:2018 (Dentistry-polymer-based crown and veneering materials) • Thermocycled (10 000 cycles in distilled water (Buchi 461 Water Bath; Fisher	A. PMMA and cross-linked polymers based on methacrylic acid esters; colorants; residual peroxide as dibenzoyl peroxide; MMA contained as residual monomer up to max. 1% **(M-PM-Disc, Merz Dental GmbH)** B. PMMA, pigments 1% **(Polident-PMMA, Polident d.o.o)** C. 99.5% PMMA, pigments **(Telio CAD, Ivoclar Vivadent AG)** D. Bis-GMA, UDMA, aromatic polyvinyl ester resin, Barium glass, Silica, BHT,	A/B/C: CAD-CAM (Dental System Software; 3Shape A/S) D/E: Self-mixing (Elite HD; Zhermack SpA)	A. 2,7/ 96.6 B. 2.7/ 114 C. 2.9/ 115-130 D. 2.5/65 E. N/A	3-point bend test (Lloyd LRX; Lloyd Instruments Ltd)	Mean flexural strength values (Mpa): • CAD/CAM PMMA (31.11-34.8) • Conventional materials (15.79-15.92)

		Scientific), 5 to 55ºC)	Self-Healing and Pigment Starters (Iron Oxide and Titanium Dioxide) **(Acrytemp, Zhermack SpA)** E. L: isobutyl methacrylate, dibutyl phthlate, dimethyl-p-toluidine; P: dibenzoyl peroxide 5%, cadmium (nonpyrophoric) <2%, titanium dioxide 1% **(Trim, Bosworth Co, Keystone Industries)**				
Bauer et al. (2020)	Evaluation the performance and fracture load of resin anterior implant-supported interim fixed partial dentures.	• *In vitro* • Three element bridges • Interim cement (Telio CS Link; Ivoclar Vivadent AG) • Thermocycling (2×1500 cycles, 5º to 55ºC)	A. 99.5% w/ PMMA, pigments **(Telio CAD, Ivoclar Vivadent AG)** B. DMA, 14% w/ inorganic filler **(Vita CAD-temp, VITA Zahnfabrik, H. Rauter, GmbH & Co KG)** C. DMA, 27 % w/ inorganic filler **(Structur CAD, VOCO GmbH)** D. DMA, 86.6% w/ inorganic filler **(Gandio blocs, VOCO GmbH)** E. DMA, >30% w/ inorganic filler **Structur premium, VOCO GmbH)**	A/B/C/D: CAD-CAM (CEREC Omnicam; Dentsply Sirona) E: Sel-mixing (Turbosil; Klasse 4 Dental GmbH)	A. 3.2/ 130 B. 2.8 / 80 C. 4.4/ 136 D. 18/ 330 E. 2.5/ 140	Compressive load test (1446; Zwick)	Maximum compressive load (N): A. 871 B. 644 C. 742 D. 987 E. 0 Fracture located: connector area (55%) or was a mixed fracture (23%)

Rayyan et al. (2015)	Comparison the color stability, water sorption, wear resistance, surface hardness, fracture resistance, and microleakage	• *In vitro* • Epoxy replicas were made from a prepared maxillary first pre-molar • Thermocycling (50 000 cycles, 5 to 60ºC) • Zinc oxide-based interim cement (RelyX Temp NE; 3M ESPE)	A. Yttrium Trioxide, Foil Dioxide, Aluminum Trioxide, Silica Dioxide, Sodium Oxide, Iron Trioxide, Zirconium Dioxide **(Base Cercon, DeguDent GmbH)** B. P: PMMA L: MMA, methanol dimetacrylate accelerant UV light absorber **(Alike, GC Europe)** C. Bis-GMA, UDMA, aromatic polyvinyl ester resin, Barium glass, Silica, BHT, Self-Healing and Pigment Starters (Iron Oxide and Titanium Dioxide) **(Acrytemp, Zhermack)** D. Polyoxymethlene Copolymer (Acetal Copolymer), pigments **(DurAcetal, Myerson LLC)**	A: CAD-CAM (S 50 Zenotec CAD; Wieland Dental) B/C/D: Self-mixing	A. 1.2/210 B. N/A C. 2.5/65 D. N/A	4-point bending test (Accuforce Elite test stand, Ametek)	Maximum compressive load (N): A. 1289 B. 996 C. 899 D. 1179 Mean flexural strength values (MPa): A. 142 B. 111 C. 118 D. 126
Peñate et al. (2015)	Comparison the marginal fit and fracture strengths of interim FDPs fabricated by using a direct	• *In vitro* • One maxillary first premolar and one molar were duplicated to produce a	A. 99.5% PMMA, pigments **(Telio CAD, Ivoclar Vivadent)** B. UDMA; Bis-GMA; benzoyl peroxide **(Structur 3, VOCO GmbH)**	A: CAD-CAM (CEREC Bluccam; Sirona Dental System) B/C/D: Self-mixing	A. 2.9/ 115-130 B. 2.5/500 C. N/A D. N/A	Compressive load test (Quasar 5 of 5kN; Galdabini SPA)	Maximum compressive load (N): A. 515,8 B. 208,9 C. 227,4 D. 340,7 Reinforced:

	technique with different materials with interim prostheses (Telio CAD) made with CAD-CAM system.	metal master model • Glass fiber was used to reinforce 10 interim FDPs: S3F; TMF; DLF • Stored in water bath at 37ºC for 24 hours • Thermocycling (2500 and 5000 cycles, 5 to 55ºC)	C. **P**: ethyl methacrylate prepolymers, benzoyl peroxide, pigments, titanium dioxide; **L**: isobutyl methacrylate, di-butyl phthalate, dimethyl-p-toluidine) **(Trim, Bosworth)** D. **P**: benzoyl peroxide, dialkyl phthalate, residual monomers, titanium dioxide, mineral pigment, pigment; **L**: methyl methacrylate), **(Duralay Crown & Bridge (Reliance))**				B. 475,2 C. 471,3 D. 531,1
Leila et al. (2020)	Investigated some mechanical properties of five CAD-CAM materials used for the fabrication of provisional restorations and tooth segments for digitally fabricated dentures	• *In vitro* • For each material, blocks were sectioned using a water-cooled diamond saw (Struers Secotom-50, Ballerup, Denmark) into equal bar-shaped. An autopolymerizing	A. PMMA **(L-Temp Multicolor, Degos Dental)** B. PMMA-based DCL material **(SR Vivodent CAD, Ivoclar Vivadent)** C. PMMA or polycarbonates-based resins with approx. 1% pigments **(Temp basic, Zirkonzahn)** D. PMMA or polycarbonates-based resins with approx. 1% pigments	A/B/C/D/E: CAD-CAM (SEM; JSM 5500, Jeol, Tokyo, Japan)	A. 2.1/80 B. 2/80 C. 1,8/70 D. 1,8/70 E. 2.2/100	3-point bending test (Model LRX, Lloyds Instruments, Hampshire, UK))	(Dry/Water): (Mpa) A. 102/108 B. 105/117 C. 74/64 D. 109/124 E. 96/131 (Gpa) A. 3/3,1 B. 3/3,7 C. 1.6/1.1 D. 2.2/2.7 E. 2.8/4

		acrylic resin (Palapress, Kultzer, Hanau, Germany) was used as a base material into which the CAD-CAM materials were embedded • Adhesive resin cement (Relyx Unicem, 3M ESPE)	**(Multistratum flexible, Zirkonzahn)** E. PMMA and pigments **(ZCAD Temp Esthetic, Harvestdental)**				
Reymus et al. (2019)	Investigated the impact of 3D print material, build direction, post-curing, and artificial aging on fracture load of FDPs	• *In vitro* • Steel abutment model imitating a second premolar and a second molar • Artificial aging, (H2O, 21 days, 37 °C)	A. MMA **(Experimental resin (EXP), GC Europe, Leuven, Belgium)** B. MMA **(NextDent C&B (CB), NextDent, Soesterberg, Netherlands)** C. Isopropylidenediphenol peg-2 dimethacrylate, 1,6-hexanediol dimethacrylate, 2-hydroxyethyl methacrylate,	A/B/C: 3Dprint (Rapidshape, Heimsheim, Germany) E: CAD-CAM (InLab 15.0, Dentsply Sirona, Bensheim, Germany) F: Self-mixing Post-cured:	A. N/A B. N/A/ 107 C. 2.3/100 D. N/A E. 2.9/ 115-130 F. 2/220	Compressive load test (Zwick 1445, Zwick, Ulm, Germany)	Maximum compressive load, after post-cured (LL/OF/PB): A. 585.4/746.4/874.3N B. 775.9/1050.4/871.5 C. 777.6/638.0/598.6 D. 609.6/868.2/678.4 E. 881.4 F. 551.7

			diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide, Hydroxy propyl methacrylate, (2,4,6-trimethylbenzoyl)-phosphine oxide **(Freeprint temp (FT), Detax, Ettligen, Germany),** D. MMA **(3Delta temp (DT), Deltamed, Friedberg, Germany)** E. 99,5% PMMA, pigments **(Telio CAD, Ivoclar-Vivadent)** F. Glass filler in a matrix of multifunctional methacrylates, catalysts, stabilizers, additives **(Luxatemp, DMG, Hamburg, Germany)**	Labolight DUO (GC Europe) Otoflash G171 with nitrogen atmosphere (NK Optik, Baierbrunn, Germany) LC-3DPrint Box (NextDent)			
Rosentritt et al. (2017)	Investigated the performance and fracture resistance of a temporary CAD-CAM and CAD-CAM-PMMA, material as implant or tooth-	• *In vitro* • All crowns were either permanently bonded ("P", Multilink Automix, Ivoclar Vivadent) or temporarily	A. 99.5% PMMA, pigments **(Telio CAD, Ivoclar Vivadent, Schaan, FL)** B. Bis-EMA, UDMA, Bis-GMA, TEGDMA, 20nm silica filer, 4 to 11nm zirconia filer, zirconia/silica cluster filer **(Filtek Supreme XTE flow,**	A: CAD-CAM (Cerec, MCXL, Sirona, G) B/C/D: Self-mixing	A. 2.9/115-130 B. 2.9/115-130 C. 1,2/160 D. 1.8/50	Compressive load test (1446, Zwick)	Maximum compressive load (N), "P/T": Tooth: 3034,3/1602,9 Labside (Telio CAD): 1510,5/963,6 Labside: 2691,1/2064,5 Chairside: 1609,4/1253,0

	supported single crown with respect to the clinical procedure	bonded ("T", Telio CS Link, Ivoclar Vivadent) • Thermocycling (2 × 3000 cycles, 5 to 55 °C distilled water)	**3M Oral Care, St. Paul, USA)** C. 55–56% DMA, ~43% inorganic fillers, catalysts, stabilizers, pigments **(Telio CS, Ivoclar Vivadent, Schaan, FL)** D. 32–33% DMA, HEMA, ~65% inorganic fillers (barium glass, ytterbium), Ba-Al-fluorosilicate glass, catalysts, stabilizers, pigments **(Multilinik automix, Ivoclar Vivadent, Schaan, FL)**				
Digholkar et al. (2016)	Evaluation and compare the flexural strength and microhardness of provisional restorative materials fabricated utilizing rapid prototyping (RP), CAD-CAM and conventional method	• *In vitro* • To fabricate the samples the specimens were designed as per the dimensions using the CAD software and computer file in STL format was prepared and kept ready to be utilized by the respective units	A. P: PMMA, PEMA, Dibenzoyl peroxide L: Methylmethacrylate, 2-Hydroxyethyl-Methacrylat **(Pattern resin, GC Corporation, Japan)** B. PMMA, transverse polymers based on satril acid, residual peroxide and MMA **(Ceramill TEMP, AmannGir rbach, AG, Austria)** C. Multifunctional acrylic resins and fillers of 0.04-	B: CAD-CAM A: Self-mixing C: RP (EnvisionTECs Perfactory® 4 Standard 3D)	A. 2/63 B. 2.7/91.5 C. 4.5/100	3-point bending test (Star Testing System, India. Model No. STS 248)	Mean flexural strength values: A. 95.58MPa B. 104.20 C. 79.54

		for milling and 3D printing	0.7-micron sized particles of inorganic fillers **(Envision TEC's E-Dent 100)**				
Gopichander et al. (2015)	Evaluation the effectiveness of polyester fiber reinforcement on different interim FPD materials	• *In vitro* • A wax pattern of a definite size, shape, and lesser anatomic details of a three-unit resin bonded FPD consisting of the second premolar, first molar and second molar was made on the aluminum die. Were made with polyester fiber reinforcement (particle size of 100 lm, Indian Institute of Technology, Chennai)	A. **P:** PMMA **L**: Methyl methacrylate monomer, Hydroquinone (**DPI heat cure, India)** B. **P:** PMMA **L**: Methyl methacrylate monomer, Hydroquinone **(DPI-RR cold cure, India)** C. **L**: MMA, accelerant, UV-light absorber, dimethacrylate **P**: dibenzoyl peroxide, iron (III) oxide **(Unifast Trad – GC Corporation, Tokyo, Japan)**	CAD-CAM (MTAB XL MILL, MTAB Engineers Private Limited, Chennai, India) A/B/C: Self-mixing	A. 5/60 B. 5/65 C. 2.5/ 77	Compressive load test (LR 100 K, Lloyd; U.K., CIPET, Guindy, India)	Mean modulus of elasticity values (Un/ Reinforcement): A. 624/ 700.2 GPa B. 218.02/ 594.03 C. 680/ 707.99 Mean modulus of elasticity values (Un/ Reinforcement): A. 981.01/2493.01MPa B. 592/979.86 C. 1800.06/2807

Reeponmahaet al. (2020)	Evaluation the fracture strength and fracture patterns of provisional crowns fabricated from different materials and techniques after receiving stress from a simulated oral condition	• *In vitro* • A maxillary right first molar dentoform tooth (Nissin Dental Product Inc., Tokyo, Japan) • Temp-bond NE (Kerr Dental, Brea, CA, USA) • Thermocycled (5,000 cycles, 5 to 55°C) • Cyclic occlusal load (100 N at 4 Hz for 100,000 cycles)	A. PMMA **(Brylic Solid, Sagemax bioceramics, WA, USA)** B. Isopropylidenediphenol peg-2 dimethacrylate, 1,6-hexanediol dimethacrylate, 2-hydroxyethyl methacrylate, diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide, Hydroxy propyl methacrylate, (2,4,6-trimethylbenzoyl)-phosphine oxide **(Freeprint Temp, Detax GmbH, Ettlingen, Germany)** C. **L**: MMA, accelerant, UV-light absorber, dimethacrylate **P**: dibenzoyl peroxide, iron(III) oxide **(Unifast Trad, GC chemicals, Tokyo, Japan)** D. Base paste: Dimethacrylate (BisEMA6), Silane treated amorphous silica, Reaction production	A/B: CAD-CAM (3Shape TRIOS, Copenhagen, Denmark) C/D: Self-mixing	A. 2/120 B. 2.3/100 C. 2.5/ 77 D. 2.5/ 91-116	Compressive load test (Lloyd LR10K, Ametek, FL, USA)	Maximum compressive load (N): A. 953.60 B. 1004.19 C. 657.87 D. 1125.94

			products of 1,6-diisocyanatohexane with 2-(2-methacryloyl)ethyl], 6- hydroxyhexanoate and 2-hydroxyethylmethacrylate (DESMA), Silane treated silica. Catalyst paste: Ethanol, 2,2'- [(1-methylethylidene) bis (4,1-phenyleneoxy)] bis-, diacetate, Benzyl-phenyl-barbituric acide, silane treated silica, Tertbutyl peroxy-3,5,5-trimethylhexanoate **(Protemp 4, 3M ESPE, Seefeld, Germany)**				
Dureja et al. (2018)	Evaluation and compare the vertical marginal fit and flexural strength of provisional crowns prepared using CAD-CAD temporary material versus those fabricated using bis-acrylic	• *In vitro* • A mandibular left first molar (36 typodont tooth; Nissin, Germany) was prepared for a full ceramic crown: A: 20 blocks made from CAD-CAM-Temp blocks; three-	**A.** PMMA within 14% (wt) inorganic filler **(Vita CAD-temp blocks)** B. Bis-GMA, dimethacrylate polymer, zirconium particles, silica and silane, pigments **(Protemp 4, 3M ESPE, Seefeld, Germany)**	A: Exocad (GmbH, Darmstadt, Germany); 3D software (3D biocad, Renton, WA) B: Self-mixing	A. 2.8/ 80 B. 2.5/ 91-116	Compressive load test (Asian UTM, LRX 2K5, Hants, UK)	Mean flexural strength value: A. 94.06MPa B. 101.41

	composite-based autopolymerizing resin material	dimensional digital model B: Blocks was prepared using modeling wax					
Mehrpour et al. (2016)	Comparison the flexural strength of five interim restorative materials	• *In vitro* • A Plexiglas split model was used to make specimens • Thermocycled (2500 cycles, 5 to 55˚C) • Stored in artificial saliva at 37ºC for 2 weeks	A. Glass, oxide, chemicals, 1,6-Hexanediol dimethacrylate, dibenzoyl peroxide, benzoyl peroxide **(TempSpan, Pentron Clinical, orange CA, USA)** B. Bis-GMA, dimethacrylate polymer, zirconium particles, silica and silane, pigments **(Protemp 4, 3M ESPE. AG, Seefeld, Germany)** C. L: Methyl methacrylate, N, N-dimethyl-p-toluidine, Ethyleneglycol dimethacrylate, Propylidynetrimethyl trimethacrylate, 2-(2H-benzotriazol-2-yl)-p-cresol, Butylated hydroxytoluene, 6-tert-	A: Dual-cured B/C/D: Self-cured E: Light-cured	A. 1.8/250 B. 2.5/ 91-116 C. 2/ 70 D. N/A E. 1.41/59.3	3-point bending test	Flexural strength: A. 120 MPa B. 113 C. 64,2 D. 63,73 E. 40,7

			butyl-2,4-xylenol; P: ethyl-methyl metacrilate polymer, PMMA, barbituric acid derivative, organic copper compound, pigments **(Unifast III, GC corporation, Tokyo, Japan)** D. **P**: ethyl methacrylate prepolymers, benzoyl peroxide, pigments, titanium dioxide; **L**: isobutyl methacrylate, di-butyl phthalate, dimethyl-p-toluidine **(Trim, Bosworth company, Skokie, USA)** E. UDMA, trimethacrylate **(Revotek LC, GC corporation, Tokyo, Japan)**				
Lee et al. (2020)	Compare the material stiffness, material strength, and structural strength of interim 3-unit	• *In vitro* • 3-unit fixed dental prostheses with a modified-ridge lap pontic were fabricated	A. L: isobutyl methacrylate, dibutyl phthlate, dimethyl-p-toluidine; P: dibenzoyl peroxide 5%, cadmium <2%, titanium dioxide 1% **(Trim, Harry J Bosworth Co)**	A/C: Auto polymerizing B: Dual polymerizing	A. N/A B. 2.3/101.4 C. 3.2/80	4-point bend test (Instron 5567; Instron Corp)	**Gpa** (0,5/5/10mm) A. 0,95/1,37/1,43 B. 3,52/3,92/4,31 C. 2,58/3,19/3,38 **Mpa** (0,5/5/10mm) A. No failure/ No failure/70 B. 131/133/127 C. 113/111/97

	fixed dental prostheses fabricated from 3 interim materials when stressed at different loading rates.	• 3 loading rates of 0.5, 5, or 10 mm/min • Stored 24 hours in 100% humidity at 37ºC	B. PASTE A: UEDMA 25-50%, DMA 20-25%, DMA component 10%, photoinitiator <0.5%, mequinol<0.5%, activator <0.5%, amorphous silicon dioxide, butylated hydroxytoluene, titanium dioxide, iron (III) oxide; PASTE B: UEDMA 50-70%, component DMA 10-20%, butylated hydroxytoluene <0.5%, amorphous silicon dioxide **(TempSmart, GC America)** C. Barium boron alumino sillicate glass, Hydrophobic amorphous fumed silica, methacrylate monomers, Polymerizable dimethacrylate resin, Catalyst, Stabilizers **(Integrity, Dentsply Sirona)**				
Singh et al. (2016)	To evaluation and compare the flexural strength of provisional crown and bridge materials	• *In vitro* • Six temporary crown and bridge materials available commercially at	A. PMMA **(DPI** self-cure tooth molding powder, **The Bombay Burmah Trading Corp. Ltd., Batch 3152, Mumbai, India)**	A/B/C/D/E/F: Self-mixing	A. N/A B. N/A C. N/A D. 2.5/ 91-116 E. 1.8/70	3-point bending test (Instron)	Maximum compressive load, 8 days (N): PPMA group: • DPI 35,56 • SC10 25,41

	available commercially	24 hours, 8 days and after repair • A custom-made metal mold was used for making specimens • Artificial saliva for 24 hours	B. PMMA **(SC10 tooth colored cold cure, Jagdish Lal Sethi Company, Batch SC411, Wazirpur, Delhi, India)** C. PMMA **(Trulon, Jayna Industries, Ghaziabad, UP, India)** D. Dimethacrylate (BIS-MEPP), modified Silica, Methacrylated polyurethane, Silane treated silica (**Protemp 4, 3M ESPE, Lot 559121, Germany)** E. Methacrylates, Bariumglass silanized, Amorphous silica hydrophobed (**Cooltemp, Coltene Whaledent, Lot F27307, Article no- 5805, Switzerland)** F. Base paste: Acrylic resin glass power silica; Catalyst paste: Urethane dimethacrylate, Aromatic dimethacrylate, Glycol methacrylate (**Luxatemp fluorescence, DMG, Lot**		F. 2/250		• Trulon 35,42 Bis acrylic group: • Protemp 35,83 • Cooltemp 37,77 • Luxatemp 36,28

			705679, Hamburg, Germany)				
Kadiyala et al. (2016)	To evaluation the flexural strength of different provisional restorative resins used for prosthetic rehabilitation	• *In vitro* • A customized 3-piece brass flask was machined, compromising four equal sized mold spaces • Thermocycling for 2500 cycles (5°C to 55°C) • Stored in artificial saliva for 14 days	A. PMMA **(Dental Products of India Ltd., Mumbai, India)** B. PMMA **(Dental Products of India Ltd., Mumbai, India)** C. Barium boron alumino sillicate glass, Hydrophobic amorphous fumed silica, methacrylate monomers, Polymerizable dimethacrylate resin, Catalyst, Stabilizers **(Integrity, Dentsply Caulk, USA)** D. UDMA, trimethacrylate **(Revotek, GC Corporation, Japan)**	A/C: Auto polymerizing B: Heat cure D: Light cure	A. N/A B. N/A C. 3.2/80 D. 1.41/59.3	3-point bending test	Mean flexural strength values: A. 79,13MPa B. 91,86 C. 102,98 D. 60,01
Schwantz et al. (2017)	Characterization and compare four commercial bis-acryl composite resins using optical, surface, physical-chemical and mechanical analyses	• *In vitro* • Paste and catalyst pastes of each bis-acryl composite resin were mixed with dispensing guns and automix syringes and placed into	A. Polyfunctional methacrylates (48 wt.%), inorganic fillers (47 wt.%), plasticizers, initiators, stabilizers and pigments (5 wt.%) **(Systemp C&B II, Ivoclar Vivadent, Schaan, Liechtenstein)** B. Dimethacrylate (BIS-MEPP), modified Silica,	A/B/C/D: Self mixing	A. 1.7/90 B. 2.5/ 91-116 C. 1.8/90 D. 2.6/90	Compressive load test (DL500; EMIC, São José dos Pinhais, PR, Brazil)	Average of 3 days: A. 8,6GPa/ 42,3MPa B. 9,6/ 53,4 C. 4,7/ 34,2 D. 4,7/ 30,2

		molds of polyvinyl siloxane impression material (Scan Denso; Yller, Pelotas, RS, Brazil) • Stored in water at 37 °C for 1, 15 and 30 days	Methacrylated polyurethane, Silane treated silica **(Protemp 4, 3M ESPE, St.Paul, MN, USA)** C. Bis-GMA, BHT, amines, benzoyl peroxide, dimethacrylates, glass particles **(Structur 2, Voco, Cuxhaven, Germany)** D. Catalysts: DMA groups, inorganic filler, catalyst, stabilizer and preservative; Base: DMA groups, ionorganic filler; catalyst; stabilizer, preservative and pigments **(Proviplast, Biodinamica, Ibiporã, PR, Brazil)**				
Psarri et al. (2020)	Evaluation the effect of three different methods of fiber reinforcement (glass fibers preimpregnated, glass fibers non-preimpregnated,	• *In vitro* • Control groups (A, B, C) reinforced with fiber: STICK **(Stick Tech Ltd),** POLYDENTIA **(Polydentia SA, CH-6805 Mezzovico,**	A. PMMA, 2-Hydroxyethyl Methacrylate, N, N-Dimethyl-p-Toluidine **(JET, Lang Dental Manufacturing Co., Chicago, Illinois)** B. **P**: ethyl methacrylate prepolymers, benzoyl peroxide, pigments, titanium dioxide; **L**:	A/B/C: Self-mixing	A. N/A B. N/A C. 2.5/ 91-116	3-point bending test (Instron 4467; Instron Co, Buckinghamshire, England)	Control/Polydentia/ IBBOND/Stick: A. 71.4/97/100.5/174.1MPa B. 34.9/44.8/58.1/75 C. 62.2/77.1/73.8/151.1 A. 1.64/1.85/2.05/3.17GPa B. 0.78/1.06/1.16/1.55 C. 1.66/2.21/1.93/3.01

	and polyethylene fibers)	**Switzerland)** and RIBBOND **(Inc., Seattle, Washington)** • Stored in distilled water at 37ºC for 24 hours	isobutyl methacrylate, di-butyl phthalate, dimethyl-p-toluidine **(TRIM, H.J. Bosworth Co., Skokie, Illinois)** C. Bis-GMA, dimethacrylate polymer, zirconium particles, silica and silane, pigments **(Protemp, Espe-Premier, Norristown, Pennsylvania)**				

4. DISCUSSION

The present integrative review reported the major results of relevant previous studies considering the strength of different resin-based materials manufactured by traditional chairside and CAD-CAM for interim prostheses. The degree of conversion, porosity and thickness affect the strength of resin-based materials. Also, the type of resin-matrix materials and manufactured method are determinant. Thus, the findings validate the hypothesis of this study.

4.1. Materials for interim prostheses

Two major groups of materials for interim dental prostheses are commercially to fabricate temporary restorations, namely: methyl methacrylate (MMA) and bis-acryl materials, as seen in **Table 1**. Traditional MMA-based molecules have a low molecular weight, and linear organic chain which in turn exhibit low strength. (1,3,5,22) Methyl methacrylate polymerizes by an addition pathway through the carbon-carbon double bonds to form polymethyl methacrylate (PMMA). Regardless of the intended application, PMMA is often commercially available in powder/liquid system. The powder component contains PMMA, benzoyl peroxide initiator, a plasticizer (dibutyl phthalate), opacifiers (titanium and zinc oxides), fibers, and pigments or dyes. (14,17,29,30) The liquid component often contains MMA monomer, ethylene glycol dimethacrylate as a cross-linking agent, and hydroquinone as an inhibitor. (17) However, bis-acrylic matrix has multifunctional monomers such as Bis-GMA or TEGDMA, resulting in a cross-linked polymer having a enhanced strength (14–16,29,30) Bis-acryl composite materials reveal advantages when compared to PMMA considering a low polymerization shrinkage, low exothermic reaction, higher wear resistance, and proper overall mechanical properties. Nonetheless, the costs can be the main disadvantage. (13) On the traditional chairside technique, the elastic modulus of PMMA has been recorded at around 0.78 to 8 GPa while the bis-acryl materials reveal an elastic modulus at around 1.66 to 9 GPa. (4,6,27)

The 3-point bending strength of PMMA is recorded at around 40 to 102 MPa that is lower than the strength recorded for the bis-acryl materials at 62 to 126 MPa. (1,6,7,10,13,22–24,28)

Resin-matrix composites reveal proper mechanical properties when compared to PMMA. The chemical composition of resin-matrix composites varies according to the manufacturers, as described in **Table 1**. The organic matrix often involves different monomers such as bisfenol A-glycidyl methacrilato (Bis-GMA), trietileno glicol dimethactilato (TEGDMA), Urethane Dimethacrylate (UDMA), bisphenol A diglycidyl methacrylate ethoxylated (Bis-EMA), and photo initiators (i.e., canforquinone). The inorganic content can reach up to 90wt% fillers in the chemical composition of resin-matrix composites. Inorganic fillers can include one or two types of silanized ceramic or glass–ceramic particles such as colloidal silica, zirconia, zirconium silicate, barium silicate, or ytterbium fluoride. (15,16,29) Those fillers increase the strength and elastic modulus and reduce polymerization shrinkage, the coefficient of thermal expansion, and water absorption of the composite material. (16,31) Composite materials can be also reinforced with fibers such as carbon, polyethylene, glass-ceramics, or ceramics. The balance in the percentage of the organic matrix and inorganic fillers determine the physicochemical properties of the resin-matrix composites.(15,16) The mean values of elastic modulus, hardness, flexural strength, and wear resistance recoded for resin-matrix composites are quite higher when compared to the mechanical properties of PPMA or bis-acryl materials.

The manufacturing of prosthetic using by the CAD-CAM process guarantee the physicochemical properties of the materials taking into consideration the high clinical success rate. The major benefits of the CAD-CAM technique include the decrease in the defect incorporation (i.e., pores and cracks) in the material bulk in comparison with the chairside powder/liquid technique. (2,7,10–12,18,22,24) Nowadays, several based materials are commercially available in CAD-CAM blocks. CAD-CAM blocks composed of

PMMA reveals a 3-point bending flexural strength at 90 MPa, Vickery's hardness at 20 HV, and fracture toughness at 2.53 MPa m^{-1}. The CAD-CAM blocks composed of resin-matrix composite, with 61 to 70wt% filler content, have elastic modulus at around 9 to 15 GPa, Vickers hardness between 65 and 97 HV and 3-point bending strength at around 150 to 220 MPa and flexural strength between. (18) The interim PMMA prostheses manufactured by CAD-CAM is a highly polymerized polymer within a well-controlled environment regarding pressure and atmosphere. Highly crosslinked polymer promotes prostheses with enhanced mechanical properties that can minimize mechanical failures and release of monomers, as illustrated in **Figure 2**. (1,2,7,9,10,12,18) Therefore, the water absorption of the polymers manufactured by CAD-CAM is significantly decreased when compared to the chairside powder/liquid mixture technique. PMMA manufactured by CAD-CAM showed the highest values of fracture maximum loading in the selected studies (**Table 1**). (1,2,5,7,9–11,18,19,22–24,26,32) In this way, CAD-CAM becomes the first-choice technique for maintenance of the long-term clinical success of interim restorations.

4.2. Strength of the interim dental prostheses

The mechanical properties of interim dental prostheses play a key role on the provisional oral rehabilitation considering the chewing forces and related fatigue process. Experimental testing are recommended for novel materials and different design mimicking clinical conditions, as illustrated in **Figure 3**. (14,17) Results from different type of strength testing were discussed in this review since several factors could be assessed on design, materials and testing set up. The typical flexural testing are performed on specimens of materials by 3- or 4-point bending set up. However, some studies also performed an evaluation of the flexural behavior of prostheses by compressive loading on multi-unit prostheses supported by tooth or implants.

The force produced by human occlusal loading has the following values: 40N on swallowing; 170 to 881N on chewing nuts; 39 to 788N for corresponding chewing loads; 200 to 500N for the posterior regions; and 200-300 N for anterior regions. (3,19)

Materials for interim prostheses must be able to withstand that loading magnitude. (1,2,5,7,19,23,24)

A previous study evaluated the flexural strength of different methacrylate-based polymers materials manufactured by CAD-CAM. The findings validate the hypothesis that the methacrylate-based materials produced by CAD-CAM (31-34 MPa) revealed the highest strength values when compared to the materials (˜16 MPa) manufactured by chairside powder/liquid technique. (1) The analysis of the results was associated to the lack of polymerization, water absorption, residual stresses, and presence of defects such as pores and cracks. Thus, the efficiency of the polymerization and compaction of the material previously to the CAD-CAM procedure is responsible for the decrease in defects and the enhanced polymerization. Another study corroborated such findings on the enhanced properties of materials manufactured by CAD-CAM. The flexural strength of PMMA manufactured by CAD-CAM revealed the highest mean values (106-131 MPa) when compared to a bis-acryl composite (85 MPa) and PMMA manufactured by chairside powder/liquid mixture (66 MPa). (23) Regarding those strength values, interim prostheses must be manufactured by CAD-CAM method on clinical situations over long periods up to the final prosthetic placement. (10)

The mechanical properties of interim restorations can be enhanced with fibers or particle-like fillers. A high content and a submicron-scale size of the fillers improve flexural strength of the resin-matrix composites (1,2,5,6,9,10,19,28). Interim prostheses reinforced with fibers have demonstrated a higher fracture loading values than those recorded for restorations free of fibers. (6,11,26) A previous study compared the fracture loading values of interim prostheses fabricated from Telio CAD or chairside powder/liquid technique with different materials reinforced with glass fibers. Materials

reinforced with glass fiber revealed increased fracture loading values. Interim prostheses reinforced with glass fibers revealed maximum values of fracture loading of around 471 ±62.4 N while Telio CAD showed maximum values of fracture loading of around 531.1 ±150.1 N. (11) Another previous study evaluated the mechanical effects of three different fiber reinforcement methods: Ribbond polyethylene fibers, Polydentia non-impregnated glass fibers and stick pre-impregnated glass fibers). The 3-point bending of three provisional reinforced materials showed higher values (by 20 to 50%) when compared to non-reinforced ones. (6)

Regarding the oral environment, the mechanical testing can be performed after degradation (aging) or cyclic loading (fatigue) simulation assays. Thus, the flexural strength of provisional materials may be influenced by saliva, common dietary, acidic beverages, and interactions among such factors (28). The rate of mastication has been estimated at 5 to 8 mm/s (300-480 mm/min) in the posterior region of the mouth, although mandibular movements rapidly decelerate when teeth are in contact. The actual loading rate can therefore not be easily deduced from the chewing rate or muscle movements, which typically record cycle times. The optimal physiological loading rate for *in vitro* testing is therefore still unclear although that is likely higher than 0.5 mm/min. Stresses from mechanical and thermal oscillations as well corrosive substances can negatively affect the mechanical properties of prostheses. (2,28) On the retrieved studies, it has been well reported that thermocycling affects the mechanical properties of interim materials. (2,7) A previous study performed thermal cycling (5000 cycles) on stored specimens in water bath at 37ºC. They showed that PMMA-based provisional CAD-CAM prostheses (Telio CAD) had higher flexural strength before (124 MPa) and after thermal cycling (95.35MPa) when compared to the prostheses manufactured by chairside techniques. However, the strength decreased significantly after thermal cycling for all materials. Prostheses manufactured from bis-acryl composites were recommended for long-term provisional treatments. (7) Another study assessed the synergistic effects of both thermocycling process (5,000 cycles at 5-55ºC) and occlusal fatigue loading (100,000 cycles of 100N at 4Hz). PMMA-based materials

manufactured by chairside powder/liquid showed lower strength values when compared to bis-acrylic and materials manufactured by CAD-CAM.(2)

Regarding the stress distribution, a previous study reported the region of prosthetic connectors concentrated higher stress magnitude regardless the restorative material. (18) However, the elastic modulus magnitude determines the stress

distribution since materials with a high stiffness are recommended for the prosthetic frameworks. A previous study identified fracture regions at the connector or abutment, whereas lower strength materials tended toward connector or mixed fractures. (19) *Coelho et al.* reported that the highest von Mises stress values were recorded on the occlusal surface and at the connector, between the prosthetic teeth. (12) Also, the presence of a cantilever negatively affected the strength of the test materials, although the prostheses manufactured by CAD-CAM still revealed the highest fracture loading values (1634-2649 N). (12)

5. CONCLUSION

The present integrative review reported findings on the strength of different resin-matrix prostheses and materials manufactured by CAD-CAM or traditional chair-side methods. Within the limitations of the selected studies, the following conclusions can be drawn:

- Different resin-matrix prostheses and materials manufactured by CAD-CAM showed the highest strength values when compared to the materials manufactured by traditional chairside powder/liquid mixture methods;
- The highest strength values revealed by resin-matrix materials manufactured by CAD-CAM occurred due the low porosity rate and high degree of polymerization of the materials. The polymerization method used for materials manufactured by traditional chairside powder/liquid mixture provides a low degree of polymerization, that leads to the release of monomers and defects. Those defects are spots for stress concentrations that can negatively affect the strength of the prostheses;
- Future mechanical testing should be performed in association with physicochemical methods to determine the degree of conversion of the resin-matrix prostheses and materials. Also, the percentage of pores and other defects should be carefully evaluated to clarify its effects on the mechanical properties of the materials. Computational simulation by using finite element method could be useful for the prediction of stress distribution and fracture regarding different design and materials.

ATTACHMENTS

Figure 2. Schematic representation of PMMA material manufactured by CAD-CAM.

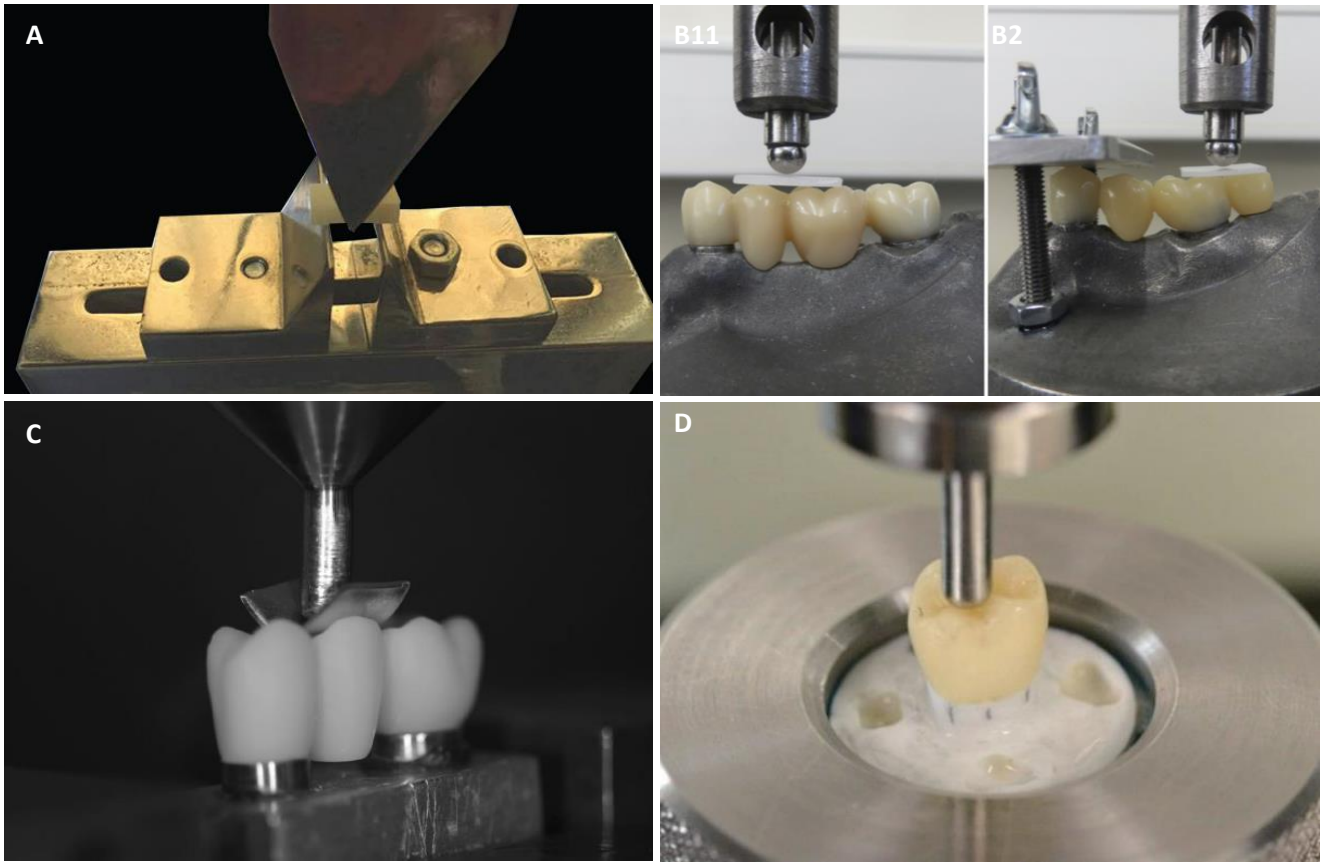
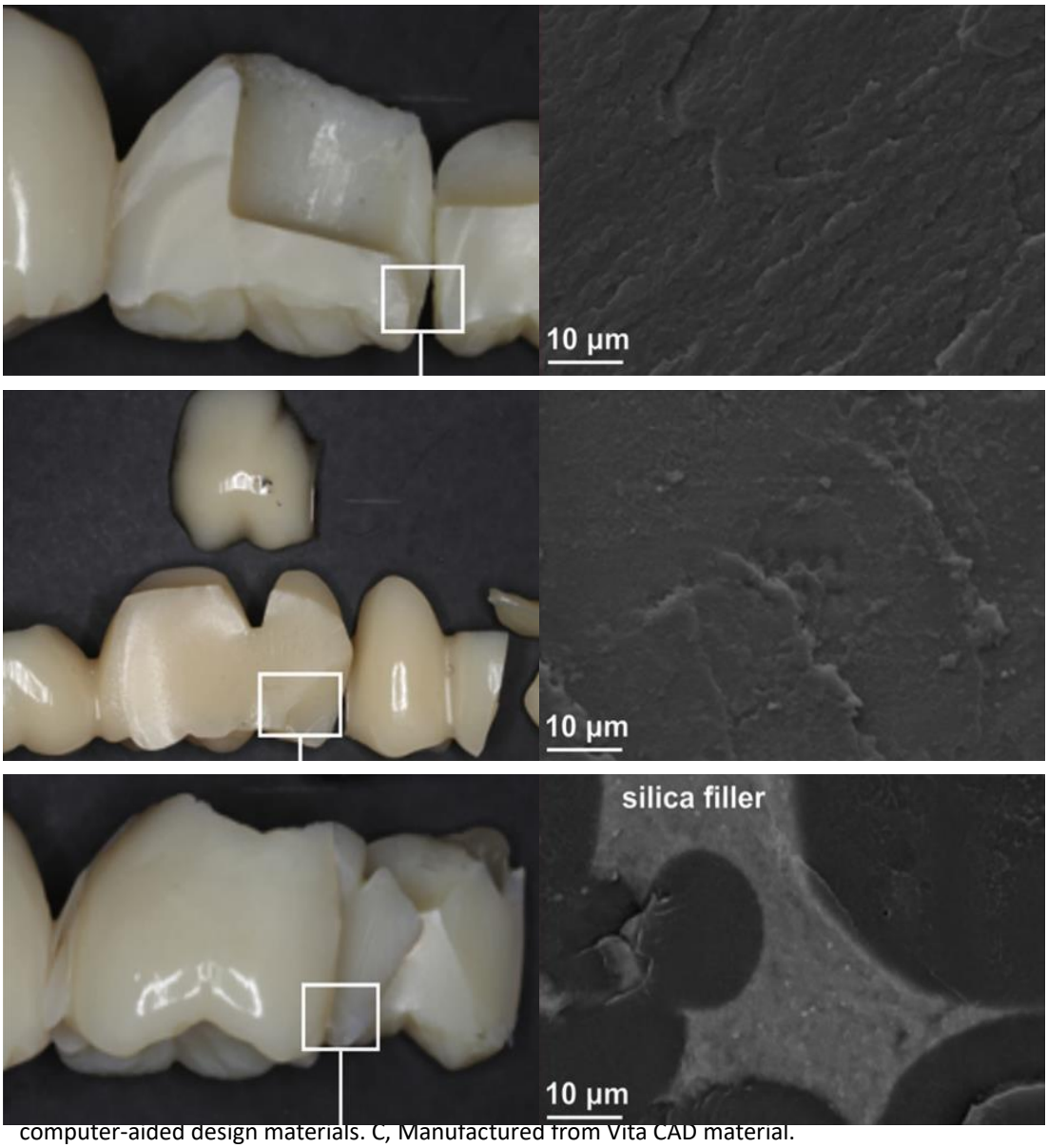


Figure 3. Images illustrating the mechanical tests used for testing flexural strength. **A-** Samples placed in universal testing machine (*Dureja et al.)*; **B-** Four-unit prosthesis attached to fixed nickel-chromium. B_1- Conventional, B_2- Cantilever (*Coelho et al.*); **C-** Test design for fracture load measurement in a universal test machine (*Reymus et al.*); **D-** Specimen mounted on universal testing assembly for the compressive load test (*Reeponmaha et al.*)



computer-aided design materials. C, Manufactured from Vita CAD material.

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