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SYSTEMATIC REVIEW
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Influence of testing parameters on the load-bearing capacity of prosthetic materials used for fixed dental prosthesis: A systematic review

Influência de parâmetros de testes na capacidade de suporte de carga de materiais protéticos utilizados para prótese dentária fixa: uma revisão sistemática

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ABSTRACT

Objective: The aim of this study was to systematically review the literature to assess static fracture strength tests applied for fixed dental prostheses (FDPs) and analyze the impact of periodontal ligament (PDL) simulation on the fracture strength. **Material and Methods:** Original scientific papers published in MEDLINE (PubMed) database between 01/01/1981 and 10/06/2018 were included in this systematic review. The following MeSH terms, search terms, and their combinations were used:"Dentistry", "Fracture Strength", "Fracture Resistance", "Fixed Dental Prosthesis", "Fixed Partial Denture", "Mechanical Loading". Two reviewers performed screening and analyzed the data. Only the in vitro studies that reported on load-bearing capacity of only FDP materials where mean or median values reported in Newnton (N) were included. **Results:** The selection process resulted in the 57 studies. In total, 36 articles were identified related to all-ceramics, 10 were fiber reinforced composite resin (FRC), 8 of composite resin (C) and 5 of metal-ceramic. As for clinical indications, 3 and 4-unit FDPs were more commonly studied (n=32; with PDL=21, without PDL=11), followed by single crowns (n=13; with PDL=3, without PDL=10), and inlay-retained and cantilever FDPs (n=12; with PDL=8, without PDL=4). **Conclusion:** An inclination for decreased static fracture strength could be observed with the simulation of PDL but due to insufficient data this could not be generalized for all materials used for FDPs.

KEYWORDS

Ceramics, Dental prosthesis, Periodontal ligament.

RESUMO

Objetivo: O objetivo deste estudo foi revisar sistematicamente a literatura para avaliar os testes de força de fratura estática aplicados para próteses dentárias fixas (FDPs) e analisar o impacto da simulação do ligamento periodontal (PDL) na resistência à fratura. **Material e Métodos:** Artigos científicos originais publicados na base de dados MEDLINE (PubMed) entre 01/01/1981 e 10/06/2018 foram incluídos nesta revisão sistemática. Foram utilizados os seguintes termos MeSH, termos de pesquisa e suas combinações: "Dentistry", "Fracture Strength", "Fracture Resistance", "Fixed Dental Prosthesis", "Fixed Partial Denture", "Mechanical Loading". Dois revisores realizaram a triagem e analisaram os dados. Apenas os estudos in vitro que reportaram a capacidade de suporte de carga de FDP, com os valores das médias ou medianas relatados em Newton (N) foram incluídos. **Resultados:** O processo de seleção resultou em 57 estudos. No total, 36 artigos foram identificados relacionados à restaurações totalmente cerâmicas, 10 em resina composta reforçada com fibra (FRC), 8 em resina composta (C) e 5 em metalocerâmica. Quanto às indicações clínicas, os PDF de 3 e 4 unidades foram mais comumente estudados (n = 32; com PDL = 21, sem PDL = 11), seguidos de coroas isoladas (n = 13; com PDL = 3, sem PDL = 10) e FDPs retidas por inlays e com cantilever (n = 12; com PDL = 8, sem PDL = 4). **Conclusão:** Uma inclinação para a diminuição da resistência à fratura estática pôde ser observada com a simulação do PDL, mas devido a dados insuficientes, isso não pôde ser generalizado para todos os materiais utilizados para as FDPs.

PALAVRAS-CHAVE

Cerâmica, Prótese dentária, Ligamento periodontal.

1 INTRODUCTION

Durability of restorations is crucial for clinical dentistry since mechanical failures in the form of fractures have financial consequences both for the patient and the dentist. Removal and repair of restorations may be arduous and have also biological costs. Thus, decision for choosing the best performing material in terms of mechanical durability is often made based on the results of in vitro studies.

Load to fracture test is a common way of testing dental materials used for fixed dental prosthesis (FDP) to assess their mechanical strength for different indications. Today, an increased plethora of metal, all-ceramic or polymeric materials are being offered for clinical use. Neither ethically, nor technically it is possible to test their performance in randomized controlled clinical trials. Therefore, preclinical evaluations help to rank physical and mechanical properties of materials. Ranking prosthetic materials after such tests are generally taken into consideration for clinical indications especially for posterior segments of the mouth where increased chewing forces are experienced. Static load-bearing tests require a controlled environment where the specimen dimensions and the loading conditions are standardized. Besides recording fracture strength values, failure type and fractography analysis after such tests provide additional information on the origins and onset of the failure.

Although there are norms for testing FDP materials (DIN EN ISO 22674) [1], among in vitro tests, a great heterogeneity is being noticed in the dental literature related to load to fracture tests. While some studies were performed on metal abutments [2-9] others used polymers [10-16], or natural tooth [4,9,16] as abutment material. An important other factor is involvement of the periodontal ligament simulation (PDL) for tooth-borne FDPs. In an attempt to simulate the biological conditions and physiologic mobility of the teeth, different types of PDL materials are being used. The lack of PDL simulation could still contain useful information for the durability of implant-borne FDPs. Yet, the consequence of using PDL in static loading tests is not known.

Since the test parameters vary considerably among the available published studies, there is apparent need to develop some guidelines in testing and interpreting the data on load-bearing capacity of different FDP materials in order to estimate their lifespan more realistically and not to deliver misleading information in terms of ranking materials for durability.

The objective of this systematic review was in particular to analyze the effect of PDL simulation on the load-bearing capacity of different FDP materials for different prosthetic indications.

2 MATERIAL AND METHODS

2.1 Search strategy

Before the initiation of the literature search, a protocol to be followed was agreed upon by the authors. An electronic search at MEDLINE (PubMed) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi) from 01/01/1981 and 10/06/2018 was conducted for English-language articles published in the dental literature, using the following MeSH terms, search terms and their combinations: ""Dentistry", "Fracture Strength", "Fracture Resistance", "Fixed Dental Prosthesis", "Fixed Partial Denture", "Mechanical Loading". The MEDLINE search are presented in Table I. In addition, hand searches were performed on bibliographies of the selected articles as well as identified narrative reviews to find out whether the search process has missed any relevant article. This did add the new four additional articles to be involved in the review process.

Table I - Search strategy in MEDLINE applied for this review. Ä: search, MeSH: Medical subjects heading, a thesaurus word.

Search	Literature search strategy
1	"Fracture Resistance and Fixed Partial Denture AND Dentistry"
2	"Fracture Resistance and Fixed Dental Prosthesis AND Dentistry"
3	"Fracture Strength AND Fixed Dental Prosthesis AND Dentistry"
4	Fracture Strength AND Fixed Partial Denture AND Dentistry"
5	"Mechanical Loading AND Fixed Dental Prosthesis AND Den-tistry"
6	Mechanical Loading AND Fixed Partial Denture and Dentistrty"
7	"Mechanical Loading AND Fracture Resistance and Fixed Dental Prosthesis"
8	"Mechanical Loading AND Fracture Resistance AND Fixed Partial Denture"
9	Mechanical Loading AND Fracture Strength AND Fixed Dental Prosthesis
10	Mechanical Loading AND Fracture Strength AND Fixed Partial Denture
11	Mechanical Loading AND Fracture Strength AND Fracture Resistance AND Dentistry

2.2 PICOs

The population, intervention, comparison and outcomes, i.e. the "PICOs" for this systematic review were defined as follows:

Population: Type of material (metal-ceramic - MC, all ceramic - AC, fibre-reinforced composite - FRC, composite resin – C. Type of restoration (FDPs of 3 units, 4 units, retained by inlay and cantilever);

Intervention: test method (static loading);

Comparison: with periodontal ligament and without periodontal ligament;

Outcomes: static fracture strength;

Study design: in vitro studies.

2.3 Inclusion/Exclusion criteria

In vitro studies reporting on load-bearing capacity of only FDP materials where mean or median values reported were included. Publications were excluded if fatigue loading was performed or data were not presented in Newton (N). Also, studies performed with finite element analysis were excluded.

2.4 Study selection

The search process led to titles of 1559 journal articles reviewed by two independent reviewers for possible inclusion in this systematic review. After title screening, 125 abstracts were considered relevant, and full-text articles were downloaded. Thereafter, from 125 journal articles, 57 were included in this review. The process of identifying the studies included in the review is presented in Figure 1.

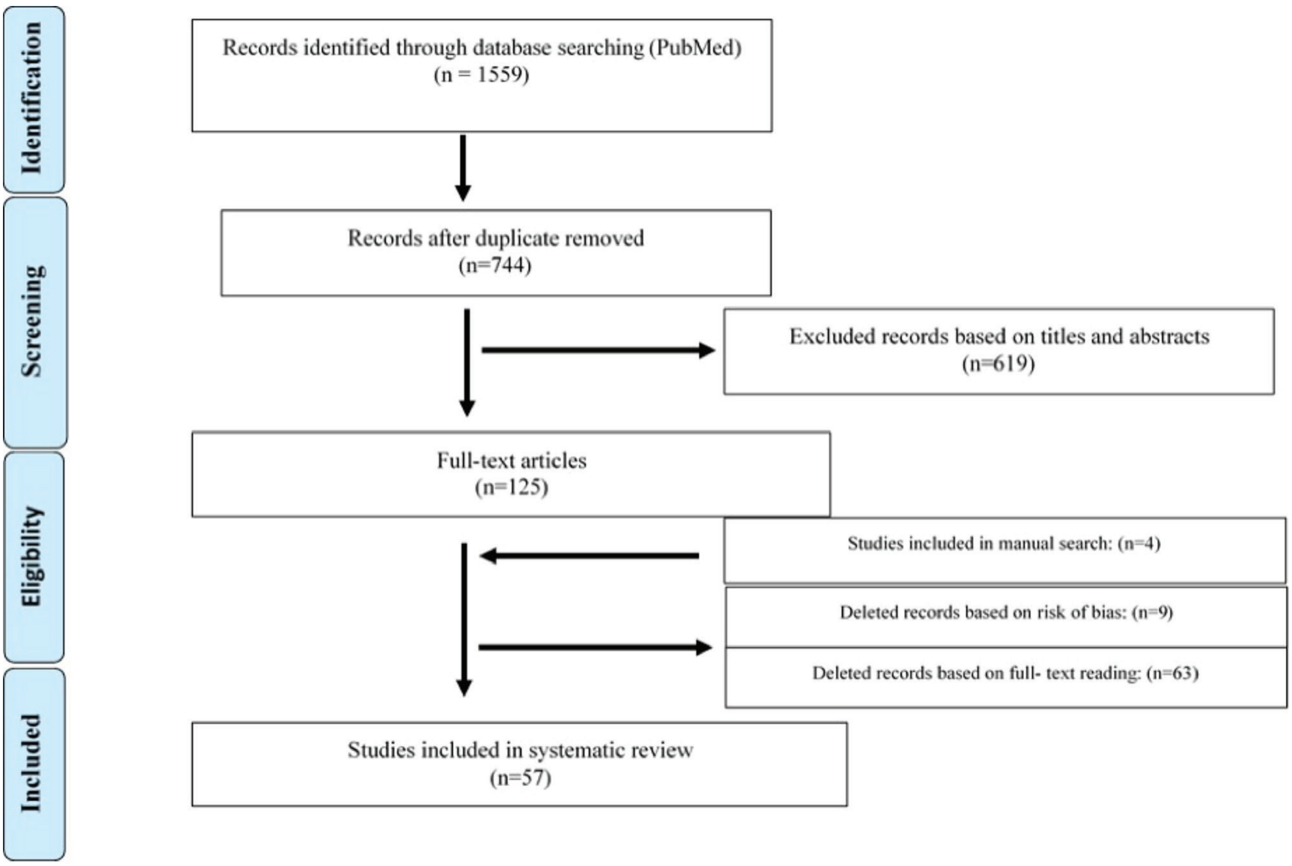

Figure 1 - The PRISMA flowchart showing the study selection process.

2.5 Data extraction

The two reviewer's extracted data independently using a data extraction form previously agreed upon. Process of identifying the studies included in the review from is presented in Fig. 1. Data on the following parameters were extracted: author(s), year of publication, type of material tested, type of restoration, number of samples per group, periodontal ligament simulation material, substrate, fatigue conditions and fracture resistance in Newton. The data were presented according to the type of restoration: single crowns, 3-unit FDP, 4-unit FDP, inlay-retained and cantilever FDPs (tables II, III and IV). Disagreement regarding data extraction was resolved by discussion and a consensus was reached.

2.6 Risk of bias assessment

The risk-of-bias was assessed based on previous studies [17]. The risk of bias was calculated from 6 criteria: sample size calculation, sample randomization, sample preparation, specified aging, standardization of procedures by ISO and operator. For each parameter values from 0 to 2 were attributed: 0 – if the authors clearly reported the parameter; 1 – if the author reported the execution/respect of the parameter but accuracy of the execution is unclear; 2 – if the author did not specify the parameter or the information is not present. If the total sum of the attributed values ranged between 0 up to 4 it was considered alow risk, between 5up to 9 a medium risk and 10 up to14 a high risk of bias.

3. RESULTS

3.1 Characteristics of the included/ excluded studies

Two independent reviewers screened the 1559 titles retrieved from the electronic search for possible inclusion in the review. After initial elimination, based on the titles and the abstracts, 744 abstracts were accepted for inclusion by both reviewers. The two reviewers independently assessed the 125 full-text articles to determine whether they fulfilled the defined criteria for final inclusion. 72 articles had to be excluded after full text reading and risk of bias. Any disagreement was resolved by discussion. Finally, 57 [2,3,5,7,9,11-15,17-62] studies were found to qualify for inclusion in the review. Among all the studies included, all-ceramics (n=36) were more commonly tested followed by FRC (n=10), composite (n=8) and metal-ceramic (n=5). As for clinical indications, 3 and 4-unit FDPs were more commonly studied (n=32; with PDL=21, without PDL=11), followed by single crowns (n=13; with PDL=3, without PDL=10), and inlay-retained and cantilever FDPs (n=12; with PDL=8, without PDL=4). Table II [2,3,5,7,13, 15,17-41] III [14,42-53] and IV [9,11,16,54-62]. According to the results, from 57 studies included, 32 involved PDL. In all selected subgroups, the search identified the use of wax, silicon, gummy resin, latex, vinyl silicone impression, acrylic resin base and silicone rubber to simulate PDL. The studied also used some kind of substrate, among them vital teeth such as third molars (n=21), pre-molars (n=18) and central incisors (n=4); artificial teeth (n=8) or implants/metal (n=7) to simulate clinical conditions.

3.2. Risk of bias

According to the bias risk assessment, 57 studies included in this systematic review presented a risk of bias medium (between 5 and 9). The rest of the articles presented a low risk of bias (between 0 and 4). The data were described in table V. Most of the studies did not describe the calculation of the sample size, the laboratory procedures by a single operator and standardization of procedures (ISO).

Table II - Characteristics from the studies included in the systematic review of Fixed Dental Prothesis 3-unit and 4-unit.

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Partiyan et al., 2017 [17]	Zirconia: manually aided design–manually aided milling (MAD/MAM) and Computer assisted design–computer assisted milling (CAD/CAM)	Three-unit zirconia fixed partial denture	n=20 Group I (MAD/MAM) conventional. Group II: (MAD/MAM) Innovative. Group III (CAD/CAM). Conventional Group IV (CAD/CAM). Innovative.	Yes/acrylic resin base	second premolar and second molar	Stored in distilled water/ thermocycling	72hrs / 1000 cycles	37°C / 5°/ 55°C, 30s.	G2>G4>G3>G1 (P<0.0001).
Murase et al., 2014 [18]	5% Y-TZP (Aadva Zirconia, GC)	All-ceramic fixed partial dentures (FPDs)	n=15 cross-sectional áreas: 1: 9.0mm^2 2: 7.0 mm^2 3: 5.0 mm^2	Yes/vinyl silicone impression	Central and lateral incisors	stored in distilled water	24hrs	37°C	1> 2 > 3. (p<0,001)
Chaar, et al., 2013 [19]	LV (layering technique/Vintage ZR); LZ (layering technique/ ZIROX); PP (CAD/CAM and press-over techniques/PressXZr	3-unit posterior fixed dental prostheses (FDPs)	n=16 G1: LV G2: LZ G3: PP	Yes/gum resin	Human premolars	thermo-mechanica	1 200 000 cycles	-	G2> G1>G3. (NON-AGED) G3>G2>G1 (AGED) (P<0,05)
Eroglu and Gurbulak 2013 [20]	zirconia-ceramic (ZC), galvano-ceramic (GC), and porcelain-fused-to-metal (PFM)	Fixed partial denture 3- unit	n = 10 ZC, GC and PFM with or without thermocycling and mechanical loading (TCM)	No	Metal (maxillary canine and second premolar)	Thermocycling and mechanical loading	- Thermocycling: 10,000 cycles - Mechanical loading: 100,000 cicles.	Thermocycling: 5º - 55º; Mechanical loading: 50 N;	GC (1678.1 ± 211.6) > GC/TCM (1475.8 ± 227.9) - p < 0.05 PFM (1878.5 ± 176.5) > PFM/ TCM (1687.8 ± 162.2) - p < 0.05
Takuma, Y. et al., 2013 [21]	3% Y-TZP (Everest® Zirconium Soft)	4-unit all-ceramic FPDs	Framework connectors cross-sectional áreas: A:9.0 or B: 7.0mm^2). Cross-sectional forms: a circular form (1:1 (Type A); an oval form, (3:4 (type B); and another oval (2:3 (type C). Connector types: mesial/distal connectors (A-A, B-B, C-C) and central connector (-A-,-B-, -C-).	-	-	stored in distilled water	24hrs	37°C	Cross-sectional área: A>B. (p<0,01) Mesial and distal connector's type: A-A> C-C. (p<0,01) Central connector's type: A>C (p<0,05); A>B (p<0,01)
Preis et al., 2012. [22]	Yttria-stabilized zirconia (Cercon ht, Degudent)	Three-unit zirconia-based FPDs	n=8 G1: AD – sintered; G2: AD – sintered – glazed; G3: AD – sintered – sandblasted – glazed; G4: AD – sintered – polished – grinded (contact points adjusted); G5: AD – sintered – polished – grinded – repolished; G6: ARD – sintered – veneered; G7: control: analogous to #3 but without thermal cycling (TC) and mechanical loading (ML).	Yes/wax	Artificial identical polymethylmethacrylat (PMMA) molars	thermal cycling and mechanical loading	TC: 6000	5°/55° × 2 min each cycle 1.2 × 106 × 50 N; 1.6 Hz)	No statistically significant differences were found between the groups (p = 0.910)

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Salimi, H. et al., 2012 [23]	Cercon Base ceramic, Degudent, Germany	Zirconium oxide posterior fixed partial dentures (FPD)	Group I: copings with 3 × 3 connector dimension and standard design Group II: copings with 3 × 3 connector dimension and modified design Group III: copings with 4 × 4 connector dimension and standard design Group IV: copings with 4 × 4 connector dimension and modified design.	-	Maxillary typodont model	artificial saliva at 37°C/ thermocycling	2000 cycles	5 and 55°C for 30 s each, with an intermediate pause of 15 s.	Group IV was significantly higher than group I ($P < 0.001$) and group II ($P < 0.001$), but there was not any significant difference between group IV and group III ($P = 0.156$)
Nothdurft et. al 2011 [24]	Zirconia	Fixed partial denture 3- unit	n = 8 Implant - tooth supported restorations (IT) or implant -implant (II) with: - individualised abutments (i) or no individualised (ni) - with (TC) or without thermocycling (N)	Yes/ Gum resin	Zirconia abutments and cast metal teeth (First molar and pre-molar)	Thermocycling	- Thermocycling: 10,000 cycles	Thermocycling: 5° - 55°;	IT < II- $p < 0.05$ iTC < nTC- $p < 0.05$
Onodera et al., 2011 [25]	3 vol% (YTZP: Kavo Everest ® Zirconium Soft, Biberach, Germany)	all-ceramic FPDs molar region	n=15. Cross-sectional area: A: 9.0, B: 7.0; C:5.0mm. Conector shape: A: 1:1, B: 3:4, C: 2:3	Yes/Silicone material	Second premolar and second molar	stored in distilled water	24hrs	37°C	Cross-sectional area (mm2): A>B>C. $P<0.05$). Conector shape: A=B=C. ($p<0,05$)
Rosentritt, M. et al., 2011 [26]	Glass-infiltrated, alumina based, all-ceramic material (Inceram Alumina, Vita Zahnfabrik)	All-ceramic three-unit fixed partial dentures (FPDs)	n=8 Group A (control): in polymethyl methacrylate (PMMA). Group B: polyether layer (Impregum, 3M ESPE). Group C: polyether layer during aged.	Yes/ wax bath	human molars	Thermal cycling and mechanical loading	TC: 6000 cycles.	5°/55° × 2 min each cycle; $1.2 \times 10^6 \times 50$ N; 1.6 Hz)	Group A> Group C ($P = .047$)Ö B ($P = .364$). Goup C=B. ($P = .961$)
Eisenburger et. al. 2008 [27]	Composite resin. (Protemp, Luxatemp, Cron-Mix).	Fixed partial denture 4- unit	30	Yes/ Latex varnish	Artificial resin teeth (24 and 27)	Thermocycling	10.000	5 – 55 °C	Luxatemp » CronMix ($p=0.014$) Luxatemp - Without fibre Stick » EverStick ($p= 0.004$) CronMix: Without fibre » EverStick ($p = 0.015$)

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Att et al. 2007 [28]	Zirconia (DCS, Procera and Vita CerecInlab)	Fixed partial denture 3- unit	n= 8 G1: DCS with artificial aging; G2: DCS without artificial aging; G3: Procera with artificial aging; G4: Procera without artificial aging; G5: Vita with artificial aging; G6: Vita without artificial aging.	Yes/ Gum resin	Human mandibular premolars and molars	Termomechanical fatigue	- 1,200,000 cycles	- Mechanical loading: 49 N; - Thermo-cycling: 5º - 55º.	G3 (1297) < G5 (1593) – p= 0.015 G3 < G1 (1618) – p= 0.038
Att et al. 2007* Zr [29]	Zirconia (DCS, Procera and Vita CerecInlab) veneered using Vita VM9.	Fixed partial denture 3- unit	n= 8 G1: DCS with artificial aging; G2: DCS without artificial aging; G3: Procera with artificial aging; G4: Procera without artificial aging; G5: Vita with artificial aging; G6: Vita without artificial aging.	Yes/ Gum resin	Human mandibular premolars and molars	Termomechanical fatigue	- 1,200,000 cycles	- Mechanical loading: 49 N; - Thermo-cycling: 5º - 55º.	G3 (1094) < G1 (1481) – p= 0.042
Larsson et al. 2007 [30]	Zirconia (Procera)	Fixed partial denture 4- unit	8 G1: 2.0 mm connector;/ G2: 2.5 mm conector;/ G3: 3.0 mm conector;/ G4: 3.5 mm conector;/ G5: 4.0 mm conector.	No	Artificial acrylic resin teeth (34 and 37)	Thermocycling, and mechanical loading.	- Mechanical loading: 10 000; - Thermocycling: 5000.	- Mechanical loading: 30 -300 N; - Thermo-cycling: 5º - 55º.	G1 and G2 fractured during preload (30–300 N, 10 000 cycles); G5 (897) > G4 (602) > G3 (428).
Kohorst et al. 2007 [31]	Zirconia – Partially sintered (Cercon); Fully sintered zirconia (Digizon)	Fixed partial denture 4- unit	10 G1: Cercon without preliminar echanical damage; G2: Cercon with preliminar mechanical damage; G3: Digizon without preliminar mechanical damage; G4: Digizon with preliminar mechanical damage.	Yes/ Latex	Artificial polyurethane resin teeth (24 and 27)	Storage, thermocycling and mechanical loading	- Storage: distilled water at 36 °C for 200 days; - Thermo-cycling: 104 cycles - Mechanical loading: 106 cucles.	- Thermo-cycling: 5º - 55º; -Mechanical loading: 100 N;	G1 (903.7) < G3 (1262.6); G2 (921.1) < G4 (1132.4).
Pfeiffer et al. 2006 [32]	Thermoplastic polymer (Promysan Star), veneering composite (Vita Zeta or Sinfony), non-impregnated (Ribbond) and impregnated polyethylene fiber reinforced resin (Targis/Vectris);- Conventional poly methyl methacrylate (Biodent K+B).	Fixed partial denture 4- unit	n= 3 G1: Biodent – 4.3 pontic height; G2: Biodent – 5.8 pontic height; G3: Promysan - 4.3 pontic height; G4: Promysan - 5.8 pontic height; G5: Promysan/Vita Zeta - 4.3 pontic height; G6: Promysan/Vita Zeta - 5.8 pontic height; G7: Ribbond/Sinfony - 4.3 pontic height; G8: Ribbond/Sinfony - 5.8 pontic height; G9: Vectris/Targis - 4.3 pontic height G10: Vectris/Targis - 5.8 pontic height	No	CoCr-alloy (premolar maxillary and molar)	Thermocycling	5.000	5 – 55 °C	- G9 and G10 (197.4 – 377.0) > others groups (p < 0.05); - G6 (97.2) < G1, G2,G3, G4, G7, G8 (p « 0.05); - G1 (197.4) < G2 (377.0) - p < 0.05).

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Rosentritt et al. 2006 [7]	Lithium disilicate (Empress 2)	Fixed partial denture 3- unit	n= 8	Yes/ Polyether	Human molar or CoCr-alloy or Liquid Crystal Polymer	Termomechanical fatigue	- 1,200,000 cycles	- Mechanical loading: 50 or 150 or 50-100-150 N; - Thermocycling: 25° or 5° - 55°.	Human abutments and artificial periodontium (410) < human abutments and no artificial periodontium (783)
Stiesch -Scholz et al. 2006 [33]	Fiber-reinforced (EverStick or Vectris), composite resin (Sinfony or Vita Zeta or Targis)	Fixed partial denture 4- unit	n= 10 G1: Sinfony; G2: Sinfony/ EverStick; G3: Vita Zeta. G4: Vita Zeta/ EverStick ; G5: Targis; G6: Targis/ EverStick G7: Targis/ Vectris.	Yes/ Latex	Polyurethane-based resin (24 and 27 teeth)	Thermocycling	10.000	5 – 55 °C	G2, G4, G6, G7 (615 – 1191) > G1, G3, G5 (178 – 307) – p< 0.05; G2 (1137) > G4 (878), G6 (615) - p< 0.05; G1 (307), G5 (276) > G3 (178) – p< 0.05; G6 (615) < G7 (1191) – p< 0.05.
Rosentritt et al. 2005 [34]	metal-based FPDs (gold) with composite resin veneering metal-based FPDs with different composite veneering	Fixed partial denture 3- unit	n= 4 G1: Adoro LC. G2: Adoro HP. G3: Adoro Thermo Graud. G4: Belleglass. G5: Sinfony	Yes/ polyether	Human molars	Thermocycling and mechanical loading	- Thermocycling: 6000 cycles - Mechanical loading: 106 cucles.	- Thermocycling: 5° - 55°; -Mechanical loading: 100 N;	G1 (1555) > G5 (909) - p = 0.005 G4 (1051) > G5 (909) – p = 0.0029 G3 (1700) > G5 (909) – p = 0.007
Sundh et al 2005 [5]	Yttria-stabilized zirconia	Fixed partial denture 3- Fixed partial denture 3- unit	n= 5 G1: delivered after machining, G2: delivered after machining, no dynamic loading in water. G3: heat-treatment similar to veneering (HT) with a glass–ceramic (Eris) G4: HT with feldspar-based ceramic (Vita D) G5; veneered (V) with ERis. G5: V with Vita D	No	Stainless steel (second lower molar - second lower premolar)	Storage and mechanical loading	- Storage: distilled water at 37 °C for 24 h; - Mechanical loading: 105 cicles.	-Mechanical loading: 50 N;	G2 (2251 ± 120) > G3 (1611 ± 463) – p < 0.05 G1 (3291 ± 444) and G2 (3480 ± 139) > the others groups – p< 0.05
Pfeiffer, et al., 2003. [35]	Prosthodontic resin materials	Fixed partial dentures (FPDs)	n=3 G1: PMMA material. G2: Promysan Star G3: Promysan Star/Vita Zeta G4: Ribbond/Sinfony G5: Vectris/Targis	Yes/Wax	-	Storagem and thermocycling	24 hours/5000 cycles	at room temperature (21°C)/ 5°/55°C, 30s.	G1=G2(p<0,05). G3<G4 and G5 (p<0,05)
Chitmongkolsuk et al., 2002. [36]	All Ceramic(AL) and Porcelain-fused to metal (PMF)	FDP 3 - unit	N=48/n=16 G1: AL Normal Preparation. G2: AL Modified preparation. G3: PMF - Control	Yes/gum resin	Human mandibular premolars and molars	-	-	-	PMF>G1>G2. (p<0,05)
Kolbeck et al., 2002* FDP [37]	Polyethylene-Fibre-reinforced-composite system (PFRC) glass-Fibre-reinforced-composite system (GFRC).	FDP 3- unit	N=64	Yes/impregum	Human third molars	-	-	-	PFRC-FPDs (830 N) = GFRC-FPDs (884 N) (p =0,60)

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Nakamura et al., 2002 [15]	Glass–ceramic	FPD- 3 unit	N=5 G1: Lithium disilicate (Empress2* Core), G2: layering dentin porcelain (Empress2 Porcelain), G3:leucite-based glass-ceramics(Empress*), G4: castable glass-ceramics (Dicor†)	No	-	Storage	24hours	At romm	G1>G3>G4. (p<0,01)
Ellakwa et al. 2001 [13]	Fibre-reinforced composite (Connect and Herculite XRV(-Dentine).	FDP 3-unit	n=10 G1: Connect/Wet. G2: Connect/Dry. G3: Herculite/Wet. G4: Herculite/Dry G5: Control/Wet. G6: Control/Dry.	No	No	distilled water or dry in air at 37 °C for 2 weeks Wet: distilled water 37 °C. Dry: air at 37 °C for 2 weeks.	-	-	The Connect fibre and Herculite XRV improved the fexural properties (p<0,05). Wet =Dry. (P>0,05)
Kheradmandan et al., 2001 [38]	GC: AGC galvano-ceramic. CA:Celay In-Ceram Alumin. (E2): IPS Empress 2. CM) ceramo-metal (control).	FDP 3-unit GC: AGC galvano-ceramic. CA:Celay In-Ceram Alumin. (E2): IPS Empress 2 CM) ceramo-metal (control).	N=64/n=8	Gum resin	Human maxillary incisors	-	-	-	CM (681N) > GC (397N)>-CA(239N); (p=0,085). E2 (292N) = CA (p=0,17) and GC. (p=0,14)
El-Mowafy et al. 2000 [39]	Nonprecious metal alloy (Litecast B, Ivoclar/ Williams)	Modified resin-bonded fixed partial denture (RBFPD) - Cement-It. - Panavia 21	N=70/n=7 G1: conventional RBFPDs- Cement it. G2 and G3: modified RBFPDs with retentive-slot Cement-It G4: RBFPDs with retentive-slot- Panavia 21. G5: similarly to the groups 2 and 3 but with inlay preparations instead of the retentive slots-Cement-It.	No	Premolar and Molar	Load cycling	230,000 cycles	4 Hz under water.	G2 (525 N) and G3(562 N)> G5(417 N> G1(361 N). (P = 0.0022)
Koutayas, et al., 2000 [40]	Aluminum-oxide ceramic (In-Ceram, Vita, Bad Sackingen, Germany	All-ceramic, resin-bonded fixed partial dentures (RBFPDs) – 3 unit. W1- cantilevered single -retainer Design. W2: conventional 2-retainer Design.	N=48/n=8 G1: W1/45 degree long axis angle. G2: W1/0 degree. G3: W2/45 degree G4: W2/0 degree	Yes/ gum resin	Maxillary central incisor	Dynamic load/ Thermocycling	n.a	50 or 25 N at 1.3 Hz/5'-55' °C.	45-degree loading, were between 134 and 174 N and under 0-degree loading about 233 N. (p>0,05)

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Nohrström et al. 2000 [3]	Resin reinforced fiber	Fixed partial dentures (FPD) 3 and 4 – unit	N=5 FPD unreinforced FPD reinforced	n.a	No	Storage	30 days.	Water at 37 for ± 1°C	The load fracture the unreinforced FPDs (372 to 1061 N) < that mean fracture load of reinforced FPDs (508 to 1297 N). (P < 0.001.
Rosentritt et al. 2000 [12]	All ceramic (classical IPS Empress, layering technique, Ivoclar).	Fixed partial dentures (FPD)	N=8 3- unit 4 -unit	Yes/ Impregum,	Human third molars	Thermal cycling and mechanical loading (TCML)	-6000 thermal cycles). -1.2 × 106 mastication cycles	5°C/55° C/ 50 N, 8,3d	After TCML, the 4- unit FPDs > 3- unit FPDs. (p=0.455)
Vallittu et al. 1998 [2]	Resin	Fixed partial dentures (FPD)	n=5 G1: No reinforcements (Control) G2:FPD 1R/ G3:FPD:2R/ G4:FPD:3R/ (unidirectional glass fiber reinforcements (R) G5: FDP3R+1W (glass fiber weave reinforcement)	No	-	Storage in distilled water	10 days	37° ± 1°C	Control< 2R (p = 0.002) < 3R (p = 0.003)< 3R+1W (p < 0.001); 1R< 2R (p = 0.010); 1R< 3R (p = 0.013); 1R< 3R+1W (p = 0.001); 2R<3RU1W (p = 0.025); and 3R< 3R+1W (p = 0.044).
Kern et al. 1994 [41]	Oxide all-ceramic	Fixed partial dentures 3-unit.	n=10 Design A: In-Ceram pontic was veneered on the labial aspect only. Design B: In-Ceram pontic framework was shifted to the labial aspect and veneered circumferentially	Yes/ gum resin	-	Storage and thermocycling	Storage 7 days: in 0.1 thymol solution at 37' C. Storage: 150 days in av tificial saliva at 37' C and 18,750 thermal cycles.	5'-55' °C.	Design A 7 days: 214.5N > design A 150days:171.6N < design B 7 days: 388.9N < design B: 150days: 296.0N. (p < 0.01).

Table III - Characteristics from the studies included in the systematic review of single crowns.

Author/ Year	Type of material	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
					Aging	Number of cycles	Force / temperature	
Dogan, et al., 2017 [42]	lithium disilicate glass (LD) IPS e.max CAD, feldspathic glass ceramic (FEL) Vita Mark II, and resin nano-ceramic (RNC) Lava Ultimate. Lithium disilicate glass (LD) IPS e.max CAD, feldspathic glass ceramic(FEL) Vita Mark II, and resin nano-ceramic (RNC) Lava Ultimate.	n=12	Titanium abutments	Titanium abutments	Thermocycling/	6,000 thermocycles	5°C/55°C	lithium disilicate glass (LD) IPS e.max CAD, feldspathic glass ceramic (FEL) Vita Mark II, and resin nano-ceramic (RNC) Lava Ultimate. LD >FEL> RNC for F-initial load value and (LD > RNC) > FEL for F-max load value.
Hussien et al., 2016 [43]	Implant-supported crowns : monolithic zircônia (MZ), veneered zircônia(VZ), and lithium disilicate(LD)	n=10	-	-	-	-	-	MZ>LD>VZ. (p<0,05)
Weyhrauch, et al., 2016 [44]	(Vita Mark II, [FSC]; Empress CAD, [LrGC]; Ivoclar e.max CAD, [LiDS]; Vita Suprinity, [PSZirLS]; Vita Enamic, [PolyFSP]; Lava Ultimate; [ResNC]; Celtra Duo, [FcZirLS	N=525		implant abutments	37°C for 30 minutes/	5,000 cycles of thermocycling	5°C/55°C	LiDS, PSZirLS, PolyFSP, and ResNC > that FSP, FcZirLS, and LrGC. The PSZirLS ceramic especially showed significantly better results. (p<0,05)
Altamimi et. al 2014 [45]	Bilayered zirconia/fluorapatite and monolithic lithium disilicate	n = 10 G1: bilayered zirconia/ standard design crown copings . G2: bilayered zirconia/ anatomical design crown copings.G3: lithium disilicate monolithic crowns	-	Metal	100,000 masticatory cycles	250 N		G1 (561.87 ± 72.63) < G2 (1,014.16 ± 70.18) < G3 (1,360.63 ± 77.95)
Taguchi., et al 2014 [46]	Porcelain-fused-to-metal crowns (PFM), zirconia-based all-ceramic crowns (ZAC), zirconia--based indirect composite-layered (ZIC-E), and zirconia-based indirect composite-layered crowns (ZIC)	n=11	-	-	37°C for 24 h	-	-	ZIC< PFM, ZAC, ZIC-E. (P < 0.044)
Nie et. al 2013 [47]	Cobalt–chromium	n = 22 G1: mechanical loading G2: no pre-treatment	-	human premolars	37°C/ 3 days 1,200,000 masticatory cycles	127.4 N		G1 = G2
Abou-Madina, et al., 2012 [48]	Empress 2	n=16 G1: Unprepared molars. G2: cemented with Panavia F 2.0. G3: cemented with Rely X Unicem	Yes/ silicone rubber (Imprint II, 3M ESPE)	human maxillary first molars	Thermocycling/ stored in distilled water	5,000 thermocycles	5°C/55°C 60 seconds, transfer time: 12 seconds./ (37°C ± 1°C).	G1 (1,043)> G2 and G3. (P < .05). Cement type did not significantly affect fracture resistance (P > .05)

Author/ Year	Type of material	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
					Aging	Number of cycles	Force / temperature	
Attia et al 2006 [49]	Composite resin (CR) or lithium dissilicate (LD) Thermal cycling and mecânica lloading (TCM)	n = 8 G1: CR, RelyX ARC, TCM G2: CR, RelyX ARC, no TCM. / G3: CR, GC Fuji CEM, with TCM. /G4: CR, GC Fuji CEM, no TCM./ G5: CR, zinc phosphate, with TCM./ G6: CR, zinc phosphate, no TCM./ G7:LD, RelyX ARC, TCM. G8: LD, RelyX ARC, no TCM. G9: LD, GC Fuji CEM, with TCM. G10: LD, GC Fuji CEM, no TCM G11: LD, zinc phosphate, with TCM. G12: LD, zinc phosphate, no TCM	Gum resin	human premolars	Storage in distilled: 1 week / 37°C 600,000 masticatory cycles 3500 thermal cycles	58°C - 4°C (for 60 seconds) / 49 N		G4 (914.7 ± 131.7) » G6 (827.1 ± 86.3) – p = 0.12 G10 (923.6 ± 153.5)> G12 (772.3 ± 134.7) – p = 0.12 G2 (955.9 ± 130.6) > G6 (827.1 ± 86.3) – p = 0.003 G8 (929.1 ± 148.5) > G12 (772.3 ± 134.7) – p = 0.003 G3 (706.2 ± 122.8) > G5 (552.5 ± 123.6) – p = 0.002 G9 (721.1 ± 141.5) > G11 (571.5 ± 117.9) – p = 0.002 G1 (724.4 ± 117.8) > G5 (552.5 ± 123.6) – p = 0.001 G7 (752.7 ± 99.6) > G11 (571.5 ± 117.9) – p = 0.001
Mitov et. al 2005 [50]	Monolithic zirconia crowns	n = 10 Groups: shoulderless preparation (SP)/ no pre-treatment X thermal cycling and mechanical loading.	-	Acrylic maxillary right molar	3 hours of autoclave treatment/ 134°C/ 2 bar 1,200,000 masticatory cycles 5,000 thermal cycles	5°C - 55°C / 50 N		Shoulderless preparation > chamfer preparation - p < 0.001 No pre-treatment > artificial aging procedures - p < 0.001
Attia et al., 2004 [51]	All-ceramic crowns: lithium disilicate glass-ceramic (IPS-Empress 2) and a leucite-reinforced glass ceramic (ProCAD)	n=8 IPS- Panavia F IPS Superbond ProCAD –Panavia F ProCAD- Superbond	Yes/gum resin	human premolars		Under wet conditions for 600,000 masticatory cycles and 3500 thermal cycles between 4°C and 58°C (dwell time 60 seconds		Cyclic loading did not significantly influence the median fracture load of the natural teeth (control) (P=.430), Empress 2 (P=.431) and ProCAD (P=.128) crowns luted using Panavia F.
Ku et al., 2002. [14]	Metal-ceramic crowns and three ceromer crowns (Artglass, Sculpture, Targis).	N=40/n=10	No	Maxillary central incisor	No	-	-	Metal-ceramic crowns (1317) > Artglass (575),Sculpture (621) and Targis (602). (p<0,05). Artglass (575) = Sculpture (621)= Targis (602) (P>0,05)
Rosentritt et al. 2000 *single crowns [52]	All- ceramic (Empress 2, Ivoclar)	N=28	No	Artificial teeth (Vectra, Ivoclar)/ Metal Alloy Teeh (Co-Cr-Mo; Bioseal F, Kulzer)/ Human molars	Thermocycling and mechanical loading	6,000 thermocycles -1.2 Ä 106	5°C/55°C 50N	Fracture force was higher for crowns fixed on substitute materials (alloy = 1,838 N; LCP = 1,392 N) than for crowns on human teeth (888 N). (p<0,05)
Scherrer et al. 1996 [53]	Oxide all-ceramic	N=40 G1: feldspathic Porcelain; G2: castable glass-ceramic.; G3: glass-infiltrated alumina ceramic.	No		Storage in distilled water.	5 days	room temperature	G1(1.28 kN) =G2(1.56 kN)=G3(2.06kN). (p=n.a)

Table IV - Characteristics from the studies included in the systematic review of inlay-retained and cantilever FDPs.

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Özcan et al., 2012 [54]	Inlay-retained FRC FPDs	Resin composite /natural tooth/acrylic denture/ porcelain denture tooth/resin composite.	n=9 Material Type: a) resin composite; b) natural tooth, c) acrylic denture tooth, d) porcelain denture tooth and e) resin composite;Occlusal morphology: i) 'circular; ii) 'elliptic I';; iii) 'elliptic II'	Yes/Silicon	Premolar and molar	-	-	-	Group e (1,186 N) » a, b,c,d. (p<0,05). Groups a=b=c=d (p>0,05). Group iii (871 N) < ii and i. (p<0,05)
Mohsen et al., 2010 [55]	Ceramic inlay-retained fixed partial dentures	Zircon milled ceramic material.	n=10 G1: inlay-shaped (occluso-proximal inlay + proximal box), G2: tub-shaped (occluso-proximal inlay), G3: proximal box-shaped preparations.	Yes/ epoxy resin	artificial teeth	stored and thermocycling	24 hours/6000 cycles.	37 °C (5–55 °C)	G1>G2>G3 (p<0,05)
Xie et al. 2007 [56]	Fiber-reinforced composite (FRC)/ fixed partial dentures (FPDs) 3-unit	Composite resin	n = 6 G1: unidirectional glass fiber; G2: unidirectional glass fiber with multidirectional fiber in pontic portion; G3: unidirectional glass fiber with short unidirectional fiber pieces in pontic portion; G4: unidirectional glass fiber with short unidirectional fiber pieces in pontic portion in 908 angle to the main framework.	Yes/ Polyether impression material	Human mandibular premolars and first molars	Storage and thermocycling	- Storage: distilled water at 37 °C for 24 h - Thermocycling: 6000Ä cycles	5–55 °C	G4 (2353.8) > G1 (1497.8) - p = 0.000; G4 > G2 (1563.0) – p = 0.000; G4 > G3 (1711.2) – p = 0.005. - Buccal cusp: G4 (1416.3) > G1 (1205.8) - p = 0.044; G4 = G2 (1106.7) – p = 0.065; G4 > G3 (1075.2) – p = 0.010. - Occlusal Fossa> Buccal cusp – for all groups (p < 0.05).
Dyer et al. 2005 [57]	Fixed partial denture 3- unit	Reinforced composite resin with glassfibers	nŬ5 G1: Crown preparation G2: Slot preparation G3: No tooth preparation G4: Combination design with a slot preparation and the thin, broad surface	no	Maxillary human molars	Storage and thermocycling	- Storage: distilled water at 37 °C for 1 week; - Thermocycling: 5000 cycles	- Thermocycling: 5° - 55°	- Initial failures: G2 (1284) < G4, G1 p<0.5 - Final failures: G2 (1313) < G1 (1755), G3 (1758), G4 (1836) – p<0.5
Ohlmann et al. 2005 [9]	Fixed partial denture 3- unit or 4 - unit	Zircon frames veneered with the polymer glass (G) or zircon frames veneered with a press ceramic (C)	n= 8 Proximal box (P) Occlusal box (O) Proximal and occlusal box (PO)	no	Cobalt–chromium alloy (second premolar, second molar or frist premolar and second molar)	Thermocycling, and mechanical loading.	- Mechanical loading: 600 000; - Thermocycling: 104.	- Mechanical loading: 50 N; - Thermocycling: 6.5° - 60°.	Proximal box (P): - 7 mm span length < 12 mm span length – p = 0.021 - 12 mm span length < 19 mm span length – p = 0.007 C > G – p<0.5

Author/ Ano	Type of material	Type of restoration	Number of specimens each group	Periodontal ligament / material	Substrate	Fatigue conditions			Fracture strength (N)
						Aging	Number of cycles	Force / temperature	
Ozcan et al. 2005 [58]	Fixed partial denture 3- unit	Reinforced composite resin with glassfibers	n= 7 G1: conventional inlay burs G2: SONICSYS approx tips (small) G3: SONICSYS approx tips (large)	no	human mandibular right first premolars and first molars	Storage and thermocycling	- Storage: distilled water at 36 °C for 72 h; - Thermocycling: 6000 cycles.	- Thermocycling: 5º - 55º	Initial and final failures: G1(842 ± 267 N, 1161 ± 428 N) = G2 (1088 ± 381 N, 1320 ± 380 N) = G3 (1070 ± 280 N, 1557 ± 321 N) p = 0.3
Behr et al., 2003 [16]	Fixed glass fibre -reinforced molar crowns	Fibre-reinforced system Vectris/ Targis	n=8 G1: Inner fibre framework. G2: Control group; G3: Inner composite layer	Yes/Impregum	third human molars	Thermal and mechanical loading	-6000 thermal cycles). -1.2 × 106 mastication cycles	5°C/55° C 50 N, 1.66 Hz	G1 (1896 N)=G3 (1754 N) > G2 (1509 N). p(<0,05).
Rosentritt. et al., 2003 [59]	Three-unit FPDs and inlay FPDs.	IPS Vectris/ Empress 2, zircon ceramic (Lava) and Vectris/ targis	FDP: G1: Vectris/Empress . G2: Zircon. G3: Vectris/targis Inlay FDP: G4: Vectris/Empress .G5: Zircon. G6: Vectris/targis	Yes/Impregum	human molars	Thermociclyng	5.000 cycles	5°C/55° C	FDP: G1 (1400N) > G2(800 N) > G3(350N). Inlay FDP: G5 (1000N) and G6 (14000N) > G4(500N)
Song et al., 2003. [60]	Inlay fixed partial dentures	Targis/Vectris system	N=10 A) a 7-mm tub-shaped B) an 11-mm tub-shaped C) a 7-mm box-shaped D) an 11-mm box-shaped.	Yes/Impregum	Premolars and molars	-	-	-	C (1779N)> A (1368 N)>B (885N)> D (1336N). (P <.001)
Kolbeck et al., 2002 [61]	Inlay fixed partial dentures (IFPDs) – 3 unit	Polyethylene fiber–reinforced composite. Glass fiber–reinforced composites. All-ceramic material.	n=80 G1:Connect/BelleGlass, G2: FibreKor/Conquest Sculpture, G3: Vectris/Targis, G4: Everstick/ Sinfony, G5:Empress2	Yes/Impregum	Human molars	Thermal and mechanical loading	-6000 thermal cycles). -1.2 × 10^6 mastication cycles	5°C/55° C 50 N, 1.66 Hz	FibreKor (368N) < Connect/ BelleGlass (898 N), Vectris/Targis (723 N), Everstick/Sinfony (634 N) and Empress2 (520 N).
Behr et al. 1999 [62]	Fixed partial inlay – 3 unit	Fibre-reinforced system Vectris/ Targis	N=60 G1: box-shaped G2: tub-shaped	No.	-	Thermocycling and mechanical loading	- 6000 thermal cycles -1.2X106 mastication cycles	5°C/55° C/50 N, 1.66 Hz	No significant differences (p= 0.065).
Rosentritt et al.1998 [11]	Fiber-reinforced composite (FRC)/ fixed partial dentures (FPDs) 3-unit	Composite resin	N=73 -Original, -Repaired A (2400 × 5° C/55° C, 480.000 Ä 50 N) Repaired B 6000 × 5° C/55° C, 1.2 Ä 106 × 50 N)	Yes/ Impregum	-	Thermal and mechanical loading	-6000 thermal cycles). -1.2 × 106 mastication cycles	5°C/55° C/50N	Original FPD (1450 N) > repaired A (1000 N) and B (1190 N). (p=0,0026)

Table V - Risk of Bias of the Studies Considering for the inclusion in the systematic review.

Author / Year	Sample size calculation	Randomization	Preparation of samples	Aging	Standardization of procedures (ISO)	Operator	Total
Partiyan et al., 2017[17]	1	1	0	0	2	2	6
Murase et al., 2014[18]	2	1	0	0	2	2	7
Chaar, et al., 2013 [19]	2	1	0	0	2	2	7
Eroglu and Gurbulak 2013 [20]	2	1	0	0	2	2	7
Takuma, Y. et al., 2013[21]	2	1	0	0	2	2	7
Preis et al., 2012.[22]	2	1	0	0	0	2	5
Salimi, H. et al., 2012[23]	2	1	0	0	2	1	6
Nothdurft et. al 2011 [24]	2	2	0	0	2	2	8
Onodera et al., 2011. [25]	2	1	0	0	2	2	7
Rosentritt, M. et al., 2011 [26]	2	1	0	0	0	2	5
Eisenburger et. al. 2008 [27]	2	2	0	0	2	2	8
Att et al. 2007 [28]	2	1	0	0	2	2	7
*Att et al. 2007 [29]	2	1	0	0	2	2	7
Larsson et al. 2007 [30]	2	2	0	0	2	2	8
Kohorst et al. 2007 [31]	2	2	0	0	2	2	8
Pfeiffer et al. 2006 [32]	2	2	0	0	2	2	8
Rosentritt et al. 2006 [7]	2	2	0	0	2	2	8
Stiesch-Scholz et al. 2006 [33]	2	1	0	0	2	2	7
Rosentritt et al. 2005 [34]	2	2	0	0	2	2	8
Sundh et al 2005 [5]	2	2	0	0	2	2	8
Pfeiffer, et al., 2003 [35]	2	2	1	0	2	2	9
Chitmongkolsuk et al., 2002 [36]	2	1	0	2	2	2	9
*Kolbeck et al., 2002 [37]	1	1	0	0	0	1	3
Nakamura et al., 2002 [15]	2	1	0	0	1	2	6
Ellakwa et al. 2001 [13]	1	0	0	1	1	1	4
Kheradmandan et al., 2001 [38]	2	1	0	2	2	2	9
El-Mowafy et al. 2000 [39]	2	1	0	0	0	1	4
Koutayas, et al., 2000 [40]	1	0	0	1	0	1	3
Nohrström et al. 2000 [3]	1	0	0	0	1	1	3
Rosentritt et al. 2000[12]	1	0	0	0	0	1	2
Vallittu et al. 1998[2]	2	1	0	0	1	1	5
Kern et al. 1994[41]	2	2	0	0	1	2	7
Dogan, et al., 2017[42]	2	1	0	0	2	2	7
Hussien et al., 2016[43]	2	1	0	2	2	2	9
Weyhrauch, et al., 2016[44]	2	1	1	1	1	2	8
Altamimi et. al 2014[45]	2	2	0	0	2	2	8
Taguchi., 2014[46]	2	1	0	0	2	2	7
Nie et. al 2013[47]	2	1	0	0	2	2	7
Abou-Madina, et al., 2012[48]	2	1	0	0	2	2	7
Attia et al 2006[49]	2	2	0	0	2	2	8
Mitov et. al 2005[50]	2	1	0	0	2	2	7

Author / Year	Sample size calculation	Randomization	Preparation of samples	Aging	Standardization of procedures (ISO)	Operator	Total
Ku et al., 2002[51]	2	2	0	0	2	2	8
Rosentritt et al. 2000[52]	1	0	0	0	0	1	2
Scherrer et al. 1996[53]	2	1	1	0	1	1	6
Özcan et al., 2012 [54]	0	0	0	1	1	0	2
Mohsen et al., 2010[55]	2	1	0	0	2	2	7
Xie et al. 2007 [56]	2	1	0	0	2	2	7
Dyer et al. 2005 [57]	2	2	0	0	2	2	8
Ohlmann et al. 2005[9]	2	2	0	0	2	2	8
Ozcan et al. 2005 [58]	2	2	0	0	2	1	7
Behr et al., 2003 [16]	1	2	0	0	1	2	6
Rosentritt. et al., 2003 [59]	2	1	0	1	2	2	8
Song et al., 2003. [60]	2	1	0	2	2	2	9
Kolbeck et al., 2002 [61]	1	1	0	0	0	1	3
Behr et al. 1999 [62]	2	1	0	0	1	1	5
Rosentritt et al.1998 [11]	2	1	0	0	1	1	5

3.3 Characteristics of studies with different materials tested with and without PDL simulation

3.3.1 Metal-ceramic (MC)

With MC without PDL simulation for 3-unit, 4-unit, one study was found [39]. With PDL simulation, for 3-unit, 4-unit, two studies [34, 36] reported the use of materials such as polyether and gum resin, respectively, to simulate the PDL. With PDL simulation data were not available for single crowns and for inlay-retained FDPs. Thus, the effect of PDL could not be identified for single crowns and inlay-retained FDPs and cantilever made of MC.

3.3.2 All-ceramic (AC)

With AC material without PDL simulation, five studies were available for 4-unit FDPs. Of these, four studies have used Yttria-stabilized zirconia as a ceramic material [5, 23, 30, 20] and one study using glass-ceramic [15].

For single crowns, only three studies with AC material had PDL simulation [48, 49, 51]. The ceramic materials varied widely among the studies and ceramics such as: Lithium disilicate glass, feldspathic glass ceramic, monolithic zirconia, leucite-reinforced glass ceramic, zirconia-reinforced lithium silicate ceramic (Vita Suprinity, polymer reinforced finestructure feldspathic ceramic (Vita Enamic).

For inlay-retained FDPs and cantilever the simulation of PDL was observed in all studies with the AC material.

3.3.3 Fiber-reinforced composite (FRC)

Five studies of FDP3-unit and 4-unit using FRC were found. Of these, only one was without PDL. [32]. For single crowns no studies using FRC were found.

Two studies of the FRC material inlay-retained FDPs and cantilever observed the effect of the PDL simulation [61, 62].

3.6 Composite (C)

\No FDP3-unit and 4-unit studies were found with material C. For Single crowns, only one study used this material [49] and simulated the PDL. All five studies with FRC composite material inlay-retained FDPs and cantilever simulated PDL.

4. DISCUSSION

Teeth are surrounded by the periodontal ligament (PDL) which is a thin membrane consisting of collagen fibers. This ligament provides the attachment of the tooth to the surrounding alveolar bone, and under normal circumstances there is no direct contact between the root and the bone. Forces applied to the crown of the tooth are transmitted to the alveolar bone through this layer, stretching, and compressing the ligament [63]. Different cell types, like fibroblasts, osteocytes and osteoblast, respond to the changes in mechanical environment. This biological environment is tried to be simulated using different materials when testing load-bearing capacity of different materials used for various clinical indications. In this way, an artificial periodontal membrane can be used, as previously described in the literature, to simulate the human periodontal membrane and the physiological mobility of the teeth [41]. In addition, some studies report that the support relationship of the abutments may influence the in vitro evaluation of fracture resistance [64,38], thus when this artificial material is used, for example a polyether, represent the alveolar bone relative to a simulated biological "width" of 2 mm, conditions that approximate the clinical situation. In this sense, the objectives of this review were to identify the materials used for this purpose and to clarify whether such simulation would decrease the ultimate strength of the restorations. Unfortunately, data were missing for some materials and some clinical indications to state whether PDL simulation decreases the results or not. yet, some trend could be observed for decreased results that could not be statistically verified. As for materials interestingly, although metal ceramics are being used for decades, proper number of in vitro tests was not performed with and without PDL. It was also not considered as a control group when comparing AC, FRC or C materials with that of MC.

Some authors preferred to simulate the PDL with polyether [7,12,56,59,62,64,65], others gum resin [19,36,49,65,66] latex [27,31], wax [22,26] or silicone [12,48] presented an analytical way of predicting significant quantities (stresses, strains, strain-energy breakdown, tooth mobility and the position of the centre of resistance) relating to the horizontal translation of a single-rooted tooth [67]. Followed the work of Haack and Haft (1972) [68] in representing the root of a maxillary central incisor as a paraboloid, surrounded by the ligament. However, the shape of the root can be approximated better by using an elliptical paraboloid. In the analyzed in vitro studies, dipping the roots in these materials simulated the presence of PDL. This simplistic approach considered neither the elastic modulus nor the thickness of the used PDL materials. Certainly, simulation of biological structures in vitro is a challenge. Yet, the arbitrary choice of the PDL materials may not translate the stretching behaviour of this biological structure. Furthermore, since lateral displacement forces are dominated with the thickness of the PDL material, it can be anticipated that the forces would be unfavourable when PDL is thicker. In that respect, failure type analysis could have been an adjunct to the fracture strength values alone in understanding the effect of displacement forces in the presence of PDL. However, although initially intended, no description or the heterogeneous description of failure types and lack of fractography analysis could not allow us to focus on the PDL effect on the failure types.

Overall, regarding to materials for single crowns, fracture strength of FRC was higher than that of AC and MC. This could possibly be attributed to lack of delamination with the FRC as oppsed to AC and MC where bilayered ceramics are used in the latter two. Delamination of the veneering ceramic leads to seizing the further load application and thereby, an early failure of the whole reconstruction. In this review, similar results were observed made for 3-unit FDPs where FRC and C presented comparable results being higher than those of all-ceramic and metal ceramic. In principle, metal tends to prevent the tensile stresses for veneering ceramics but when veneering ceramic is chipped or fractured, ultimate failure of the metal is not measured since the universal testing machine stops further loading. For 4-unit FDPs, AC showed higher fracture strength values than those of FRC and C. In such long span FDPs possibly polymeric materials did not stand the bending forces. For inlay-retained FDPs, FRC and AC showed similar results yet not being identified statistically. This kind of indication is highly governed by the adhesion of the cement to the abutment and the restorative material. Better adhesion of resin-based cements to FRC might have compensated for its low flexural strength as opposed to AC.

Ultimate goal in measuring load-bearing capacity of materials is to know clinically whether they could endure chewing forces. Different testing methods and the difficulty in measuring masticatory forces result in a wide range of force values. Stress applied during mastication may range between 441 N and 981 N, 245 N and 491 N, 147 N and 368 N, and 98 N and 270 N in the molar, premolar, canine, and incisor regions, respectively [69]. A restoration should be able to withstand stress to approximately 500 N in the premolar region and 500 N to 900 N in the molar region. The results of this study indicated values lower than 500 N only in C material with PDL simulation (393 N).

Although initially intended, failure type analysis could not be classified in this review due to inconsistency of reporting. In fact, the mode of fracture is a good indicator of the path of crack propagation. In a previous study, the changes in energy levels revealed small failures occurring between 300 N to 500 N and continuing until final failure occurred [58]. Future studies should identify and report failures in a more systematic way perhaps also using acoustic emission (AE) signals from the material [58].

One of the main causes of structural failure in restorative dentistry is often as a consequence of fatigue, although static fracture tests may help to screen the durability of FDPs, cyclic loading could be considered a more clinically relevant testing approach. It has been reported that dental restorations fail more frequently under cyclic loading tests that are well below the ultimate flexural strength of these materials as opposed to the application of a single, relatively higher static load [69]. Repeated stresses can predispose restorations to fail under fatigue. By selecting materials with a lower modulus of elasticity than those of cast metal alloys, stress at the interface can be diminished. However, there is no standard method for cyclic loading tests since the chewing cycles vary in every individual.

The studies on in vitro FDP systems in the dental literature practiced cycling times ranging from 100 to $28x10^6$ [11]. It has been previously reported that $2x10^6$ cycles correspond to approximately four years of normal occlusal and masticatory activity [69]. The load applied also showed variations between 5 to 100 N. On the other hand, from the technical point of view, the magnitude of the applied load with regard to the highest-level force in a fatigue test, should not exceed 50% of the ultimate strength of the material on trial. Unfortunately, this information was not available in the references that performed static loading after fatigue. For this reason, they were excluded from the selection. Therefore, future studies should incorporate the fatigue component in the study set-up in order to deduce more clinically relevant information considering the ultimate strength of the material to be tested.

The cement plays an important role on the retention of FDPs on the abutment materials. Abutment material let alone, may further affect the ultimate strength of the FDPs. In this study, abutment materials, namely, metals, polymers, ceramics and tooth substance were all pooled in one group in order to increase the number of selected studies. Whether abutment type affects the fracture strength results needs further focus in future studies.

Clinically, sufficient fracture strength values are not known for durable FDPs. The great variation in testing parameters and testing environment would continue to create the confusion in the dental literature. Since in the future new studies are expected to appear in this field, the following items it's advised be disclosed in in vitro studies:

- The dimensions of the FDP and abutment type, abutment material, cement type and its chemical composition, loading conditions (jig dimensions, type, cross-head speed) should be defined precisely.
- A consensus needs to be made on simulating periodontal ligament material and its thickness.
- The fracture strength data should be presented with confidence intervals, mean, minimum and maximum values.
- At least 6 specimens should be tested in one experimental group.
- Failure types after fracture test should be listed in detail and preferably fractography should be performed.

- Fracture strength results before and after fatigue conditions should be reported.

5. CONCLUSION

From this study, the following could be concluded:

1. Current studies regarding the fracture strength of FDPs made of different materials should be evaluated cautiously considering testing conditions. Some more systematic approach especially regarding the simulation conditions is needed when studying fracture strength of FDPs.

2. PDL simulation seems to show some tendency for decreased fracture strength values. Yet, it could not be verified statistically because in vitro data with and without PDL in the same clinical conditions are not sufficient.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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