ARTICLE IN PRESS

JPD THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Comparison of CAD-CAM and traditional chairside processing of 4-unit interim prostheses with and without cantilevers: Mechanics, fracture behavior, and finite element analysis

Carolina Coelho, DDS, MSc,[a] Catarina Calamote, DDS, MSc,[b] António Correia Pinto, DDS, MSc, PhD,[c] José L. Esteves, Eng, MSc, PhD,[d] António Ramos, Eng, MSc, PhD,[e] Tomás Escuin, DDS, MSc, PhD,[f] and Júlio C. M. Souza, DDS, MSc, PhD[g,h]

ABSTRACT

Statement of problem. How processing by computer-aided design and computer-aided manufacturing (CAD-CAM) or traditional chairside fabrication techniques affects the presence of defects and the mechanical properties of interim dental prostheses is unclear.

Purpose. The purpose of this in vitro study was to compare the effects of CAD-CAM versus traditional chairside material processing on the fracture and biomechanical behavior of 4-unit interim prostheses with and without a cantilever.

Material and methods. Two types of 4-unit interim prostheses were fabricated with abutments on the first premolar and first mandibular molar, one from a prefabricated CAD-CAM block and one with a traditional chairside polymer-monomer autopolymerizing acrylic resin (n=10). Both groups were assessed by compressive strength testing and additionally with or without a cantilevered second molar by using a universal testing machine with a 5-kN load cell. A finite element model (FEM) was built by scanning both prosthesis designs. Finite element analysis (FEA) replicated the experimental conditions to evaluate the stress distribution through the prostheses.

Results. Interim fixed prostheses manufactured by CAD-CAM showed significantly higher mean fracture loading values (3126 N to 3136 N) than for conventionally made interim fixed prostheses (1287 N to 1390 N) (P=.001). The presence of a cantilever decreased the fracture loading mean values for CAD-CAM (1954 N to 2649 N), although the cantilever did not influence the traditional prostheses (1268 N to 1634 N). The highest von Mises stresses were recorded by FEA on the occlusal surface, with the cantilever design, and at the transition region (connector) between the prosthetic teeth.

Conclusions. Interim partial prostheses produced by CAD-CAM had a higher strength than those manufactured traditionally. The presence of a cantilever negatively affected the strength of the prostheses, although the structures manufactured by CAD-CAM still revealed high strength and homogenous stress distribution on occlusal loading. (J Prosthet Dent 2020;■:■-■)

The traditional chairside fabrication of interim fixed prostheses (IFPs) involves the autopolymerization of a polymer powder and liquid monomer or of 2-part composite resin pastes that lead to defects in the material's microstructure.[1-8] Such defects provide stress concentrations that can lead to mechanical failure. Computer-aided design and computer-aided manufacturing (CAD-CAM) is widely available, and industrial polymerization under controlled conditions has been reported to improve the microstructure and performance of the prosthesis.[1,4-12] The fracture strength of polymethyl methacrylate (PMMA) prosthetic structures prepared by CAD-

This work was financed by FCT (Fundação para Ciência e Tecnologia) in the subject of projects: POCI-01-0145-FEDER-031035_LaserMULTICER.
[a]PhD student, Department of Oral Rehabilitation and Maxillofacial Prosthesis, School of Medicine and Health Sciences, Universitat de Barcelona (UB), L'Hospitalet de Llobregat, Barcelona, Spain.
[b]PhD student, Department of Oral Rehabilitation and Maxillofacial Prosthesis, School of Medicine and Health Sciences, Universitat de Barcelona (UB), L'Hospitalet de Llobregat, Barcelona, Spain.
[c]Assistant Professor, Department of Dental Sciences, University Institute of Health Sciences (IUCS), CESPU, Gandra PRD, Portugal.
[d]Assistant Professor, Department of Mechanical Engineering, Faculty of Engineering, Associate Laboratory for Energy, Transports and Aeronautics (INEGI/LAETA), University of Porto, Porto, Portugal.
[e]Assistant Professor, TEMA, Department of Mechanical Engineering, University of Aveiro, Aveiro, Portugal.
[f]Full Professor, Department of Oral Rehabilitation and Maxillofacial Prosthesis, School of Medicine and Health Sciences, Universitat de Barcelona (UB), L'Hospitalet de Llobregat, Barcelona, Spain.
[g]Investigator, Center for MicroElectroMechanical Systems (CMEMS-UMinho), University of Minho, Guimarães, Braga, Portugal; and Assistant Professor, Department of Dental Sciences, University Institute of Health Sciences (IUCS), CESPU, Gandra PRD, Portugal.
[h]Assistant Professor, Department of Dental Sciences, University Institute of Health Sciences (IUCS), CESPU, Gandra PRD, Portugal.

Clinical Implications

CAD-CAM processing produces high-strength interim dental prostheses with favorable occlusal stress distribution that should provide suitable clinical performance.

CAM has been reported to be higher than that of those prepared with the traditional chairside polymerization technique.[3,6-8] High strength minimizes the risk of early fractures during normal mastication,[12-19] especially with extensive multiunit prostheses.[13,16,17,19-22]

Among several methods of mechanical assessment,[12-25] finite element model (FEM) and finite element analysis (FEA) have been applied to predict the stress distribution through different prosthetic design and materials.[26-31] Thus, factors related to loading, design, and materials can be evaluated before experimental mechanical assessment.[26-30] However, previous studies on IFPs have been separately focused on only mechanical testing or on biomechanical analysis.

The purpose of this in vitro study was to compare CAD-CAM and traditional chairside material processing on the fracture and biomechanical behavior of 4-unit interim prostheses with and without cantilevers. The research hypothesis was that the use of CAD-CAM processing can improve the mechanical performance of interim prostheses.

MATERIAL AND METHODS

A nickel-chromium model simulating a 2-tooth edentulous space (second premolar and first mandibular molar) with abutments on the first premolar and second mandibular molar was used to fabricate 4-unit interim prostheses (N=40) (Fig. 1). A second similar nickel-chromium mandibular model with missing second premolar and second molar with abutments on the first premolar and first molar was used to fabricate 4-unit cantilever prostheses (N=40) with a cantilevered second mandibular molar pontic. The abutment tooth preparations were 5-mm high with a 6-degree convergence and a 1-mm-wide chamfer finish line. The models were representative of common clinical situations and similar to those used in previous studies.[13,17]

For the CAD-CAM interim prostheses, high-density polymer blocks (inLab MC XL; Dentsply Sirona) were used, while chemically polymerized resin-based

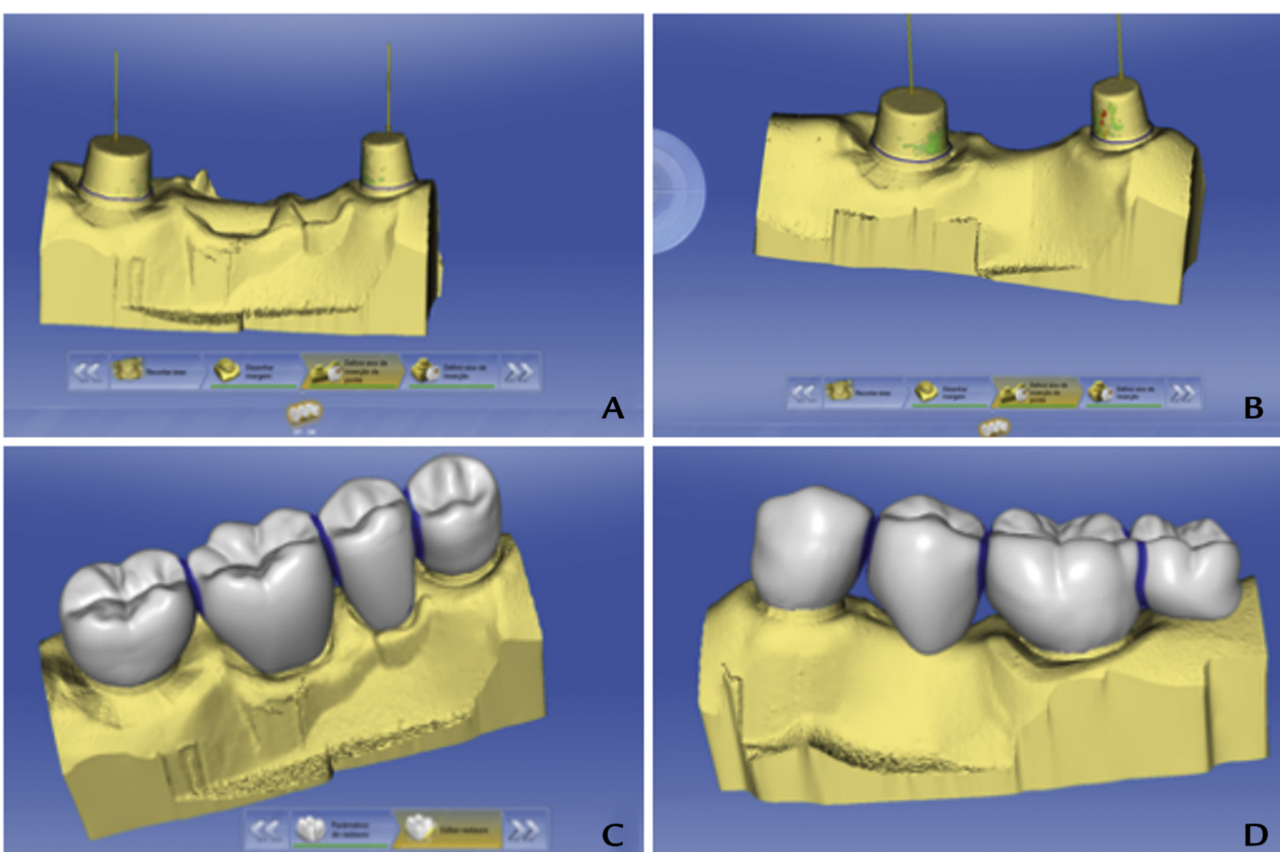

Figure 1. Virtual models of test groups recorded by using Cerec 3D (Dentsply Sirona) database. A, Nickel chromium model for prostheses without cantilever. B, Nickel chromium model for prostheses with cantilever. C, Conventional prosthesis (without cantilever). D, Prosthesis with cantilever.

Table 1. Technical specifications for test materials

Preparation	Materials	Chemical Composition	Commercial Presentation	Manufacturer	Batch Number
CAD-CAM method	Vita CAD-Temp	PMMA within 14% (wt) microfiller	High-density polymerized blocks	Vita Zahnfabrik	38810
	Telio CAD	99.5% PMMA		Ivoclar Vivadent AG	S30125
Automixture dispensing	Protemp 4	Bis-acrylic	Autopolymerizing	3M ESPE	530950
Powder/liquid mixture	Dentalon Plus	PMMA		Kulzer GmbH	Powder (10501) Liquid (10214)

Chemical composition provided by manufacturers.

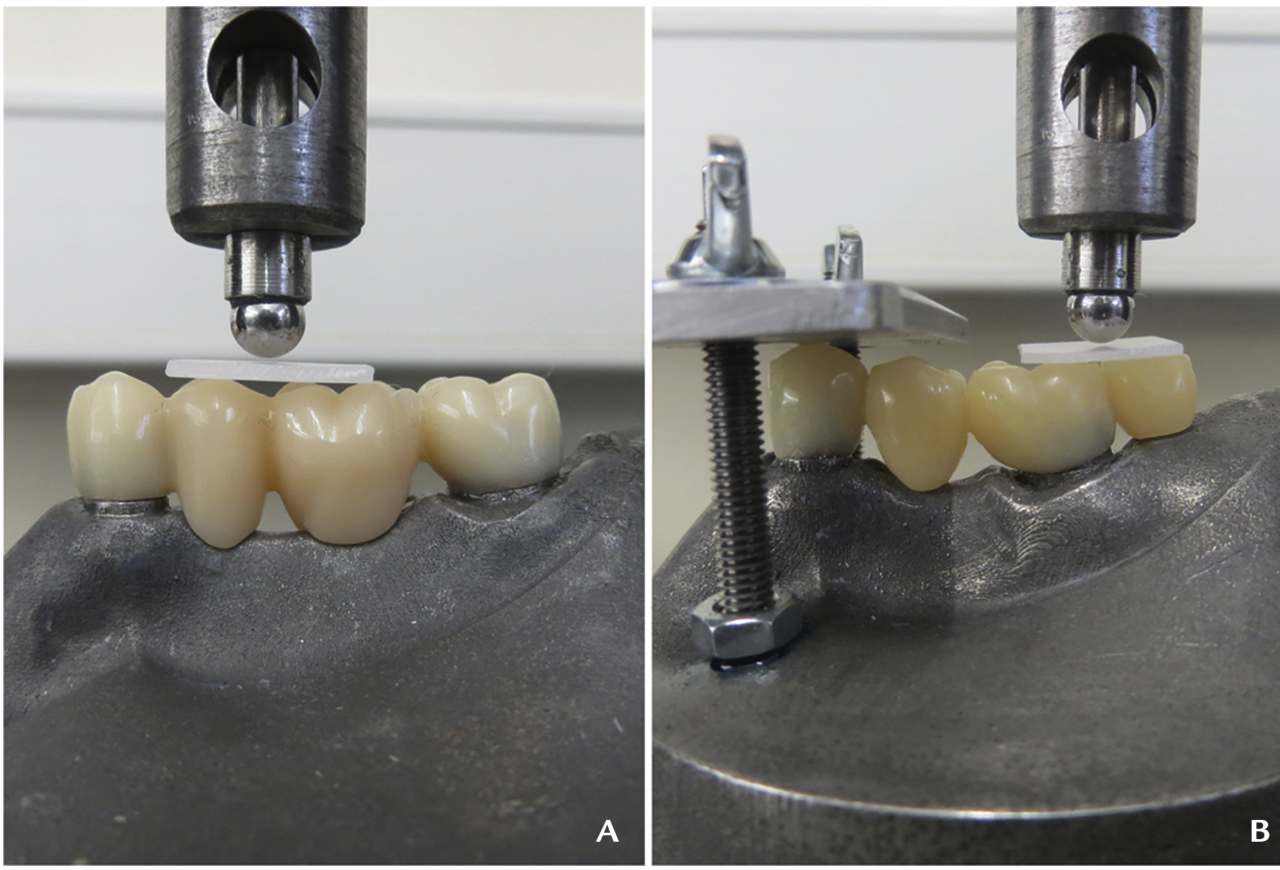

Figure 2. Four-unit prosthesis attached to fixed nickel-chromium simulation models. Load applied with 6-mm-diameter stainless-steel ball on occlusal surfaces. A, Conventional. B, Cantilever.

materials were used for the traditional chairside processing method (Table 1). The models were scanned by using an intraoral scanner (Bluecam; Dentsply Sirona), and the data set was transferred to a CAD-CAM unit (Cerec 3D, Serial nº 2866, Ref. 63748559 D 3534; Dentsply Sirona). The anatomy of the interim prostheses was designed by using information from a dental design software program (Cerec 3D; Dentsply Sirona) (Fig. 1).[6,9] The interim premolar had a height and width of 8 mm, and the width of the molar was 10 mm. The cross-sectional area of the connectors was 14 mm^2. In the 4-unit cantilever prostheses, the pontic was approximately 0.5 mm from the model. For the autopolymerized interim prostheses, a silicone (Zetalabor; Zhermack) mold was used to ensure that all the prostheses had the same design as the CAD-CAM prostheses. The material (Protemp 4 or Dentalon Plus) was injected into the silicone mold, which was then seated in the model and allowed to polymerize. As in previous studies,[3,9] the prostheses were not cemented to avoid an additional variable. The prostheses were stored in a distilled water bath at 37 °C for 30 days to simulate contact with the oral fluids.

After storage, the resin-based prosthetic structures were immediately placed without adhesive luting on the Ni-Cr abutments and then submitted to compressive loading tests at 1 mm/min until fracture by using a universal testing machine with a 5-kN load cell (TIRAtest 2705; TIRA GmbH). The universal testing machine had previously been calibrated with a digital caster and camber gauge device (AccuLevel v5; Longacre Racing Products), and the mechanical tests followed DIN EN

Figure 3. A, B, Digital models of test prostheses reconstructed by using computer-aided design software program. A, Conventional. B, Cantilever. C, Finite element model developed by using nonlinear software package.

Table 2. Mechanical properties of 4 test materials according to previous studies

Material	Young Modulus (GPa)	Poisson Ratio	3-Point Bend Strength (MPa)	Author, Year
Protemp 4	2.5	0.21	91-116	Twal and Chadwick, 2012; Yao et al, 2014; manufacturer
Telio CAD	2.9	0.24	115-130	Niem et al, 2019; Yao et al, 2014; manufacturer
Dentalon Plus	2.4	0.34	58-75	Valittu, 1999; Akova et al, 2006; manufacturer
Vita CAD Temp	2.8	0.29	80-97	Yao et al, 2014; manufacturer

Table 3. Mean maximum load force (N) for test groups according to material type

	Conventional		Cantilever			
Material	Mean	SD	Mean	SD	Difference*	*P*
Dentalon Plus	1390	82.	1268	151	122	.38
Vita CAD-Temp	3136	7	1634	152	1501	<.001
Telio CAD	3126	165	2649	686	476	.47
Protemp 4	1287	214	1954	144	667	<.001

*Difference between mean values: conventional–cantilever.

ISO/IEC 17025:2005 for calibration of material testing machines (DKD-K-16401; TIRA GmbH). A 1.5-mm-thick polytetrafluoroethylene plate was placed between the occlusal surface and stainless-steel ball to provide a homogeneous loading distribution, as seen in Figure 2. The load was applied with a Ø6-mm stainless-steel ball on the occlusal surface of the conventional prostheses between the second premolar and first molar. On the prostheses with a cantilever, the loading occurred in the region between the first molar and second molar. The data were analyzed by Student *t* test and 2-way analysis of variance (ANOVA), followed by the Tukey post hoc test by using a statistical software package (IBM SPSS Statistics, v22; IBM Corp) (α=.05).

After the compressive tests, the fracture surfaces (n=10) were photographed at ×40 magnification by using magnifying lenses (Leica Wild; Leica) coupled to a camera (Leica DFC295; Leica). The fracture surfaces of specimens (n=3) were sputter-coated with a 20-nm Au-Pd film and inspected by field emission gun electron scanning microscopy (FEGSEM) (FEI Nova 200; FEI) coupled to energy dispersive spectroscopy (EDS). FEGSEM was used to inspect the fracture surfaces and correlation with the loading spot, failure pathways, design features, and defects such as cracks and pores. FEGSEM images were gathered by secondary electron (SE) or backscattered electron (BSE) mode at 10 or 15 kV.

Finite element analysis (FEA) was performed considering the mechanical properties of materials and design of each model built from the geometric model after CAM. The anatomy of the 3D models was reconstructed from STL files by using the CAD software program (Cerec 3D; Dentsply Sirona), and then a 3D FEM was developed by using a nonlinear software package (Marc; MSC Software Corp) (Fig. 3) replicating the experimental apparatus. The mesh was performed to achieve convergence, and the 3D models had 138 000 tetrahedral quadratic elements for the nickel-chromium model and 207 600 elements for the prostheses. The contact interaction between 2 components was considered as a touching contact with a coefficient of friction at 0.3 and nonsliding between plate and the occlusal surface. The boundary conditions assumed in the FEM were equivalent to the experimental ones. The teeth and abutments were considered rigid (without periodontal ligament) in the model. The properties of the materials were assigned from similar previous studies on mechanical testing (Table 2), and the linear and isotropic model behavior was assumed until a 1-kN load was applied. Vertical asymmetric loading was applied on the polymeric prosthetic crowns perpendicularly to the occlusal plane as mentioned in the experimental testing, and the load displacement was assessed. A numerical analysis was carried out to evaluate geometric influences on the von Mises stress distribution at the joint and cantilever regions.

RESULTS

The mean values of maximum force required to fracture the conventional and cantilever interim prostheses are

Table 4. Mean values of maximum displacement (mm) for test groups according to material type

	Cantilever		Conventional			
Material	Mean	SD	Mean	SD	Difference*	P
Dentalon Plus	3.5	0.1	2.8	0.98	0.73	.31
Vita CAD-Temp	3.7	0.2	2.2	1.1	1.47	<.01
Telio CAD	4	0.2	2.9	0.9	1.04	.003
Protemp 4	3.2	0.4	2.5	1	0.73	.061

*Difference between mean values: conventional–cantilever.

Table 5. Comparison of mean maximum force values between 4 different types of materials in each type of interim prosthetic design (2-way ANOVA, post hoc tests)

	Conventional				Cantilever			
Material	P[a]	Vita[b]	Telio[b]	Protemp[b]	P[a]	Vita[b]	Telio[b]	Protemp[b]
Dentalon	<.001	<.001	<.001	<.001	.010	.164	.202	.021
Vita		—	1.000	<.001		—	.340	.220
Telio		—	—	<.001		—	—	.567

[a]Two-way ANOVA. [b]Post hoc tests.

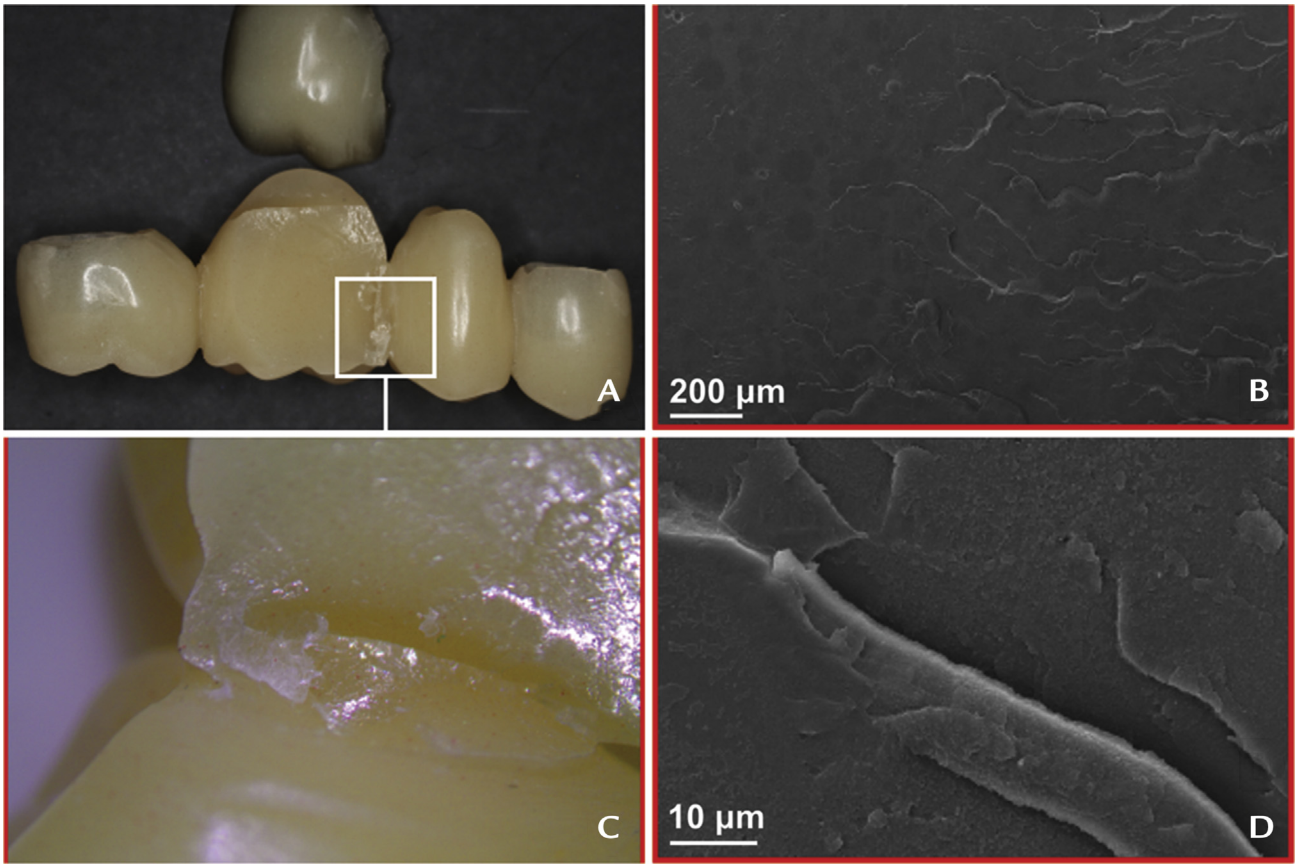

Figure 4. Fracture regions recorded for prostheses produced by traditional powder-liquid mixture of Dentalon Plus. A, Photograph for visual inspection. B, Scanning electron microscope image of fracture region (original magnification ×200). C, Photograph of fracture region (original magnification ×10). D, Scanning electron microscope image of the fracture region (original magnification ×5000).

shown in Table 3. The interim prostheses processed by CAD-CAM showed the highest maximum force values: VITA CAD-Temp (3136 ±7.4 N) and Telio CAD (3126 ±165 N) (P=1.0). Dentalon Plus had a mean maximum force value approximately 60% lower (1390 ±82 N) than the highest maximum force values. The bis-acrylic showed the lowest mean of maximum load (1287 ±214 N), which was approximately 29% less than the materials processed by CAD-CAM. No significant statistical differences were found between the conventional and cantilever prostheses when using an autopolymerized PMMA (Dentalon Plus), although statistical differences were recorded for the bis-acrylic group (Protemp 4), as seen in Table 3. Regarding loading displacement for each type of material and prosthetic design, the Dentalon Plus and ProTemp4 groups showed similar mean values of maximum displacement, as seen in Table 4. VITA-CAD Temp and Telio CAD showed similar maximum displacement regarding the design free of cantilever. Results for the cantilever interim prosthesis group were less variable among the different test materials. The highest mean values of maximum load (2649 ±686 N) were recorded for the Telio CAD group, followed by the ProTemp4 group (1954 ±144 N) and VITA-CAD group (1634 ±152 N). The lowest values were recorded for the Dentalon Plus group (1268 ±151 N). Within the

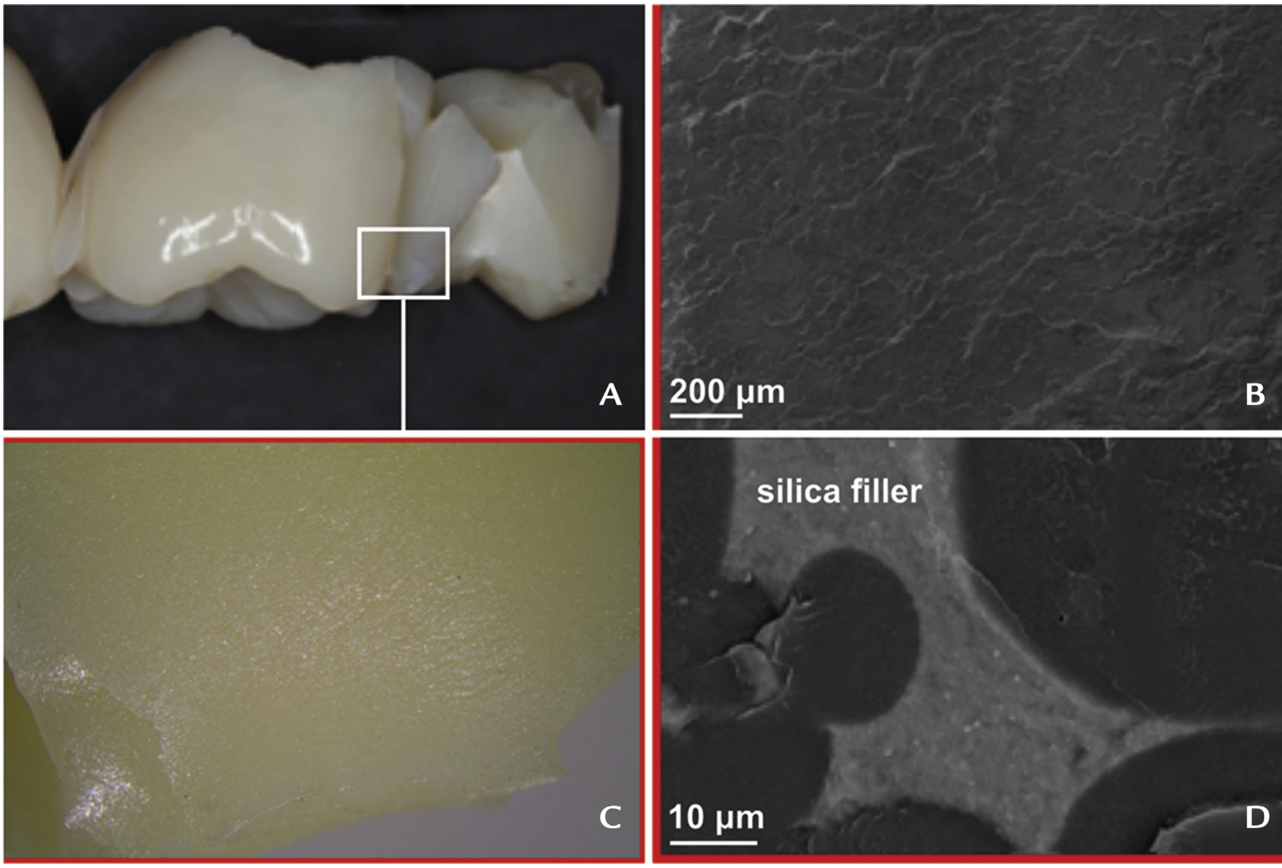

Figure 5. Fracture regions recorded for prostheses manufactured from Vita CAD material. A, Photograph for visual inspection. B, Scanning electron microscope image of fracture region (original magnification ×200). C, Photograph of fracture region (original magnification ×10). D, Scanning electron microscope image of the fracture region (original magnification ×5000).

cantilever interim prosthetic group, statistically significant differences were detected between the Dentalon Plus and Protemp 4 materials (P=.021), while no significant differences were found between the remaining materials (P>.05), as shown in Table 5.

The macroscale view of the fracture zone by photographic images at ×40 revealed catastrophic and bending failures along the vertical axis of the prosthetic structure (Figs. 4-7). Fractures occurred on the prosthetic teeth out of the abutment region and at the connection regions in the cantilever (Figs. 4-6). A variation of fracture regions was noted for the PMMA-based materials composed of acrylic resin powder and liquid. Results of the von Mises stresses recorded by FEM (equivalent stress) on the interim prostheses are seen in Figure 8. On both prostheses, the highest values of the von Mises stress of around 6 MPa to 7 MPa were detected on the occlusal contacting regions, at the connectors, and within the transition region between the teeth. The decrease in prosthetic thickness promoted stress concentrations for crack propagation on loading. No significant differences in von Mises stresses were found regarding the materials on the 4-unit prostheses manufactured by CAD-CAM or traditional chairside processing method. Regarding the influence of design, the cantilever model revealed the highest von Mises stresses in the nickel-chromium framework and pontics. Also, the loading displacement was higher in the prostheses with the cantilever (ranging from 3.2 to 4 mm) than that recorded for the groups without cantilever (ranging from 2.2 to 2.9 mm), as seen in Table 4.

DISCUSSION

The present study combines the experimental mechanical testing, microscopic inspection, and biomechanical assessment of 4-unit interim prostheses with and without cantilevers. The results of this study revealed significant differences in maximum fracture force for the processing type or cantilever design; and therefore, the null hypothesis was rejected. Within the CAD-CAM processed materials, the VITA CAD Temp 4-unit prostheses withstood the highest maximum force values of about 3136 N followed by Telio CAD. For the cantilever

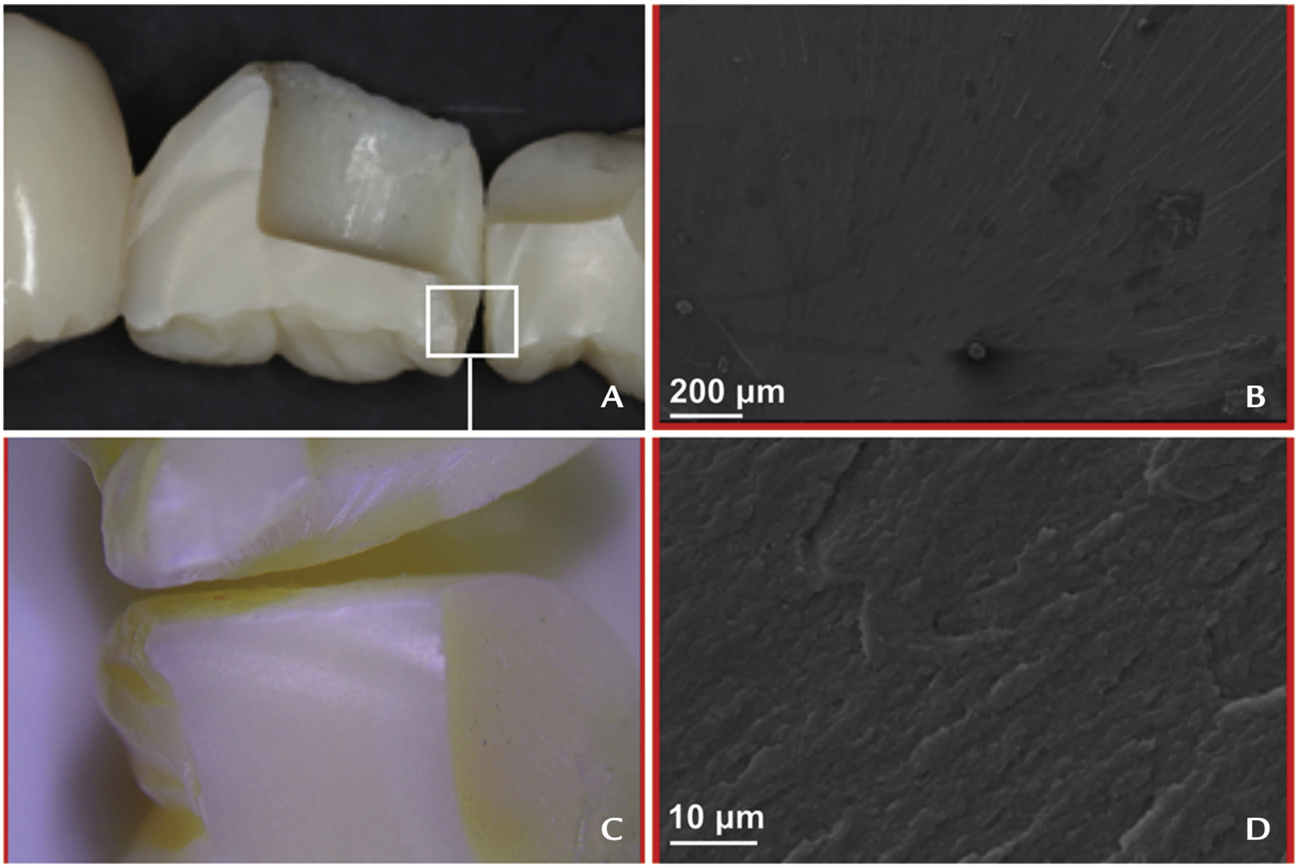

Figure 6. Fracture regions recorded for prostheses produced by automixed Protemp 4. A, Photograph for visual inspection. B, Scanning electron microscope image of fracture region (original magnification ×200). C, Photograph of fracture region (original magnification ×10). D, Scanning electron microscope image of the fracture region (original magnification ×5000).

design, the fracture resistance statistically decreased ($P<.001$). The lowest mean fracture force value at 1287 N was recorded for the cantilever design with autopolymerized resin ($P<.001$). Dentalon Plus and Telio CAD revealed similar results for designs with or without a cantilever.

The maximum force values are suggestive of the mechanical behavior of the prostheses in the oral cavity that can be compared with a maximum mean posterior masticatory force of around 400 N.[6,18] The CAD-CAM test materials had significantly higher fracture force values than 400 N, consistent with previous studies.[1,3,6] Compressive fracture load values of the CAD-CAM groups suggested that the polymerization of the CAD-CAM resin-matrix blocks was well controlled by the manufacturers.[1,3,9,12,19] The industrial CAD-CAM prefabrication polymerization techniques lead to a high degree of conversion of the organic matrix and maintenance of the materials' properties. Different chemical compositions of the test materials may be partly responsible for the differences found in strength.[3]

A previous study[1] reported a higher strength of 3-unit interim prostheses manufactured by CAD-CAM over prostheses produced by a traditional chairside polymerization method. Also, the resin-matrix composites yielded higher strength than that recorded for PMMA-based materials.[1] The results of the present study were consistent with the findings of another study[3] evaluating the strength of materials manufactured by CAD-CAM. The use of traditional polymeric structures (free of fillers or infrastructure reinforcement) for a cantilever is not recommended. Thus, the strength of acrylic resin interim dentures increased with the decrease of cantilever length.[20,21] An in vivo study reported the fracture strength of 3- and 4-unit prostheses with cross-sectional surfaces of 12 mm^2 and 16 mm^2 and with the presence or absence of a cantilever.[5] VITA CAD-Temp was one of the materials tested. At the end of 11 months, fracture occurred on 4 of the 9 cantilevers attached with resin-matrix cements. It should be emphasized that all the fractures occurred in the connector regions without exposing the tooth surface. Concerning those results, the study did not recommend the interim material for

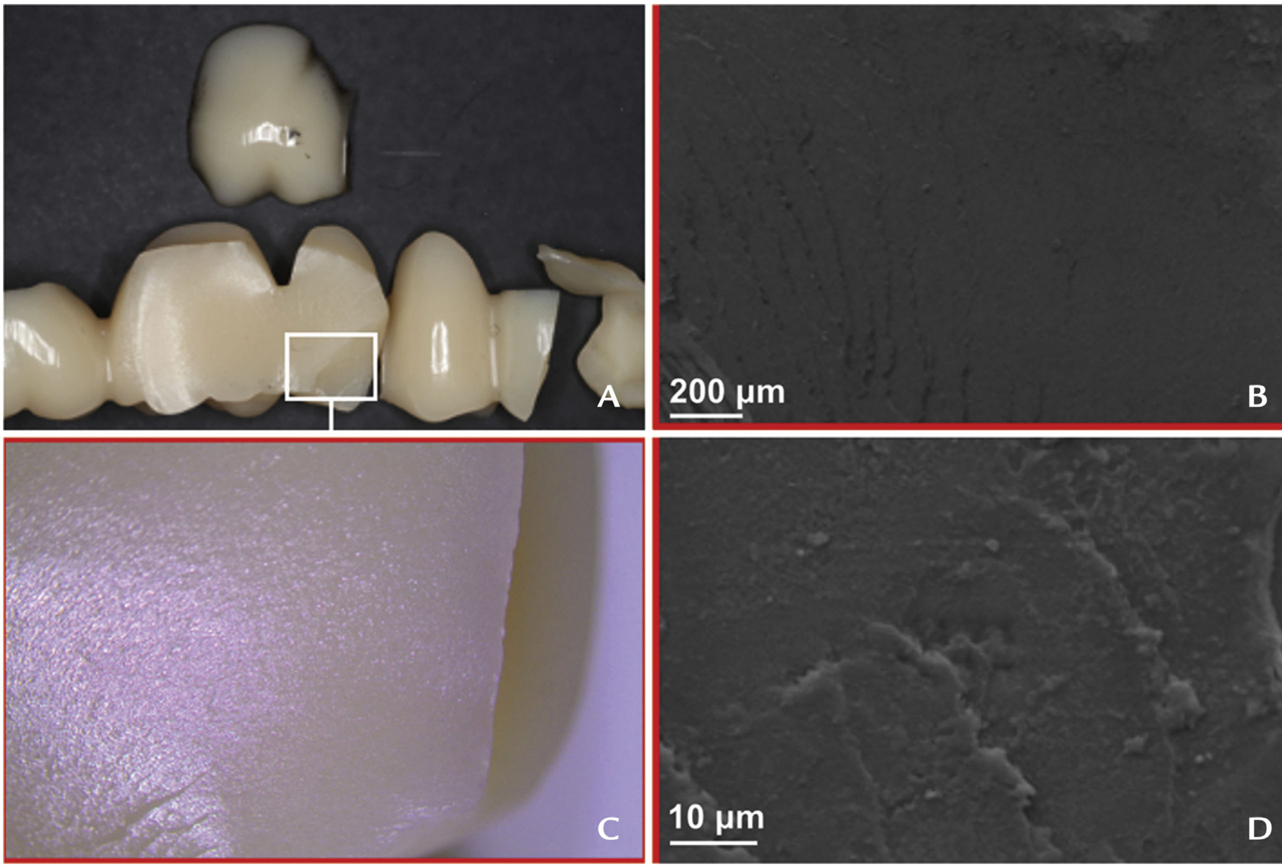

Figure 7. Fracture regions recorded for prostheses manufactured from Telio computer-aided design materials. A, Photograph for visual inspection. B, Scanning electron microscope image of fracture region (original magnification ×200). C, Photograph of fracture region (original magnification ×10). D, Scanning electron microscope image of the fracture region (original magnification ×5000).

prostheses with cantilever prostheses.[5] Considering the material properties, acrylic resin-based materials may not be the most suitable for multiple units when the width of the pontic exceeds 1 unit.[2] Unfilled polymeric prostheses depend only on the properties of polymers such as PMMA, which has a low molecular weight and poor mechanical properties.[3] Previous studies have suggested the incorporation of fibers or particles to reinforce bis-acrylic material for multiunit prostheses.[16,20,22] Thus, the fracture strength of resin-matrix composites is related to the inherent properties of the polymeric matrix and fillers. The content, size, and shape of the fillers play a significant role in the stress distribution and strength of the resulting composite resin recorded by FEA. The presence of the silica particle fillers in PMMA-based materials promotes crack deviation beginning from the nanoparticle pole and surrounding the filler.[23,24] Crack deviations are represented by multiple radial cracks around the area of fracture and seem to protect the polymeric matrix by increasing the fracture toughness of the composite resin material.[23,24]

The fracture patterns of acrylic resin FPDs with or without fiber reinforcement have been classified into 3 types based on clinical observation. Catastrophic failure by fracture occurs when the pontics are sheared off by the compressive load, when a bending failure occurs with an observable gap between the pontics, and when a partial fracture occurs where the specimens remain intact and only fracture lines can be detected.[20,22] In the present study, catastrophic and bending failures were detected after the mechanical testing as seen in Figures 4-7. The connector and thin region of the prostheses were the sites of stress concentration, as seen in Figure 8, and therefore the starting point for crack propagation.[20,22] The finite element analysis in the present study was consistent with the findings reported in the literature once the stress concentration took place over the occlusal contacting surface and at the connector regions.[25,26] Additionally, previous studies reported that the presence of filler-reinforcement improved the stress distribution through the prostheses.[25] In the present study, the FEA results were consistent with the fracture analyses by FEGSEM. Regions of fractures were detected mainly in the transition region between pontics, at thin regions, and at the cantilever. The cantilever negatively affected the stress distribution through the prosthetic material

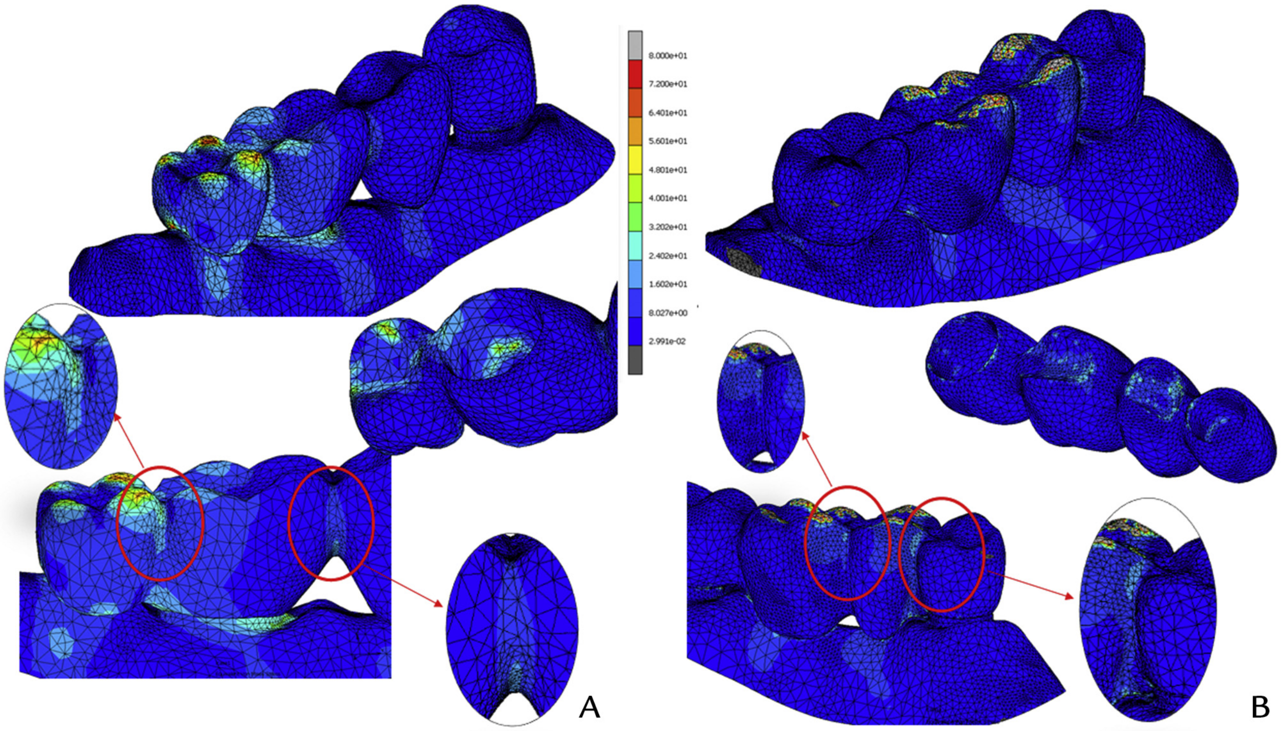

Figure 8. von Mises equivalent stress on prostheses. A, Cantilever. B, Conventional (without cantilever). Images obtained by using a nonlinear finite element analysis solution (MSC Marc). Models with 207 600 tetrahedral quadratic elements for prostheses.

that was concentrated at the pontics. Such distribution of stresses depends also on the properties and microstructure of the materials.[28,29]

FEA has been used in association with findings from in vitro and in vivo studies and therefore is an important tool in predicting the mechanical behavior of implant and prosthetic materials regarding different clinical situations, design, materials, and loading.[27-31] Nevertheless, the success of FEA depends on the accurate modeling of the prosthetic design and surrounding structures (teeth and periodontal tissues) and data on the materials and loading.[27-30]

Limitations of the present in vitro study included the lack of assessment of the percentage of defects and polymerization rate. Also, the prostheses were not cemented to avoid bias concerning factors related to the thickness, defects, microstructure, and properties of the resin-matrix cement layer. Another limitation is inherent in the computational modeling and analyses when the teeth and surrounding tissues (such as the periodontal ligament) were not considered in the stress distribution analyses. Factors related to the materials, the resin-matrix cement layer, and testing should be correlated with the fracture behavior of the prostheses in future studies. Additionally, the combination of experimental and theoretical methods should be followed to properly assess the mechanical behavior of the prostheses.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Interim fixed partial prostheses produced by CAD-CAM had higher strength than those fabricated by traditional chairside polymerization.
2. The traditional polymerization technique is susceptible to a low degree of polymerization and the occurrence of pore-like defects that could affect the strength of the prostheses.
3. The presence of a cantilever negatively affected the strength of the test materials, although the prostheses manufactured by CAD-CAM still revealed the highest compressive force values.
4. The highest von Mises stress values were recorded on the occlusal surface and at the transition region (connector) between the prosthetic teeth. Also, increased stress was noted with the cantilever design.

REFERENCES

1. Alt V, Hannig M, Wöstmann B, Balkenhol M. Fracture strength of temporary fixed partial dentures: CAD/CAM versus directly fabricated restorations. Dent Mater 2011;27:339-47.
2. Yao J, Li J, Wang Y, Huang H. Comparison of the flexural strength and marginal accuracy of traditional and CAD/CAM interim materials before and after thermal cycling. J Prosthet Dent 2014;112:649-57.

3. Karaokutan I, Sayin G, Kara O. In vitro study of fracture strength of provisional crown materials. J Adv Prosthodont 2015;7:27-31.
4. Guth J-F. Potential of innovative digital technologies and CAD/CAM composites in complex cases with change in the VDO. Int J Esthet Dent 2017;12:274-85.
5. Huettig F, Prutscher A, Goldammer C, Kreutzer CA, Weber H. First clinical experiences with CAD/CAM-fabricated PMMA-based fixed dental prostheses as long-term temporaries. Clin Oral Investig 2016;20:161-8.
6. Stawarczyk B, Ender A, Trottmann A, Özcan M, Fischer J, Hämmerle CHF. Load-bearing capacity of CAD/CAM milled polymeric three-unit fixed dental prostheses: effect of aging regimens. Clin Oral Investig 2012;16:1669-77.
7. Edelhoff D, Beuer F, Schweiger J, Brix O, Stimmelmayr M, Guth JF. CAD/CAM-generated high-density polymer restorations for the pretreatment of complex cases: a case report. Quintessence Int 2012;43:457-67.
8. Rayyan MM, Aboushelib M, Sayed NM, Ibrahim A, Jimbo R. Comparison of interim restorations fabricated by CAD/CAM with those fabricated manually. J Prosthet Dent 2015;114:414-9.
9. Wimmer T, Ender A, Roos M, Stawarczyk B. Fracture load of milled polymeric fixed dental prostheses as a function of connector cross-sectional areas. J Prosthet Dent 2013;110:288-95.
10. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J 2008;204:505-11.
11. Stawarczyk B, Trottmann A, Hämmerle CHF, Özcan M. Adhesion of veneering resins to polymethylmethacrylate-based CAD/CAM polymers after various surface conditioning methods. Acta Odontol Scand 2013;71:1142-8.
12. Nguyen JF, Migonney V, Ruse ND, Sadoun M. Resin composite blocks via high-pressure high-temperature polymerization. Dent Mater 2012;28:529-34.
13. Eisenburger M, Riechers J, Borchers L, Stiesch-Scholz M. Load-bearing capacity of direct four unit provisional composite bridges with fibre reinforcement. J Oral Rehabil 2008;35:375-81.
14. Magne P, Knezevic A. Thickness of CAD-CAM composite resin overlays influences fatigue resistance of endodontically treated premolars. Dent Mater 2009;25:1264-8.
15. Niem T, Youssef N, Wöstmann B. Energy dissipation capacities of CAD-CAM restorative materials: a comparative evaluation of resilience and toughness. J Prosthet Dent 2019;121:101-9.
16. Al Twal EQH, Chadwick RG. Fibre reinforcement of two temporary composite bridge materials - effect upon flexural properties. J Dent 2012;40:1044-51.
17. Keul C, Stawarczyk B, Erdelt KJ, Beuer F, Edelhoff D, Güth JF. Fit of 4-unit FDPs made of zirconia and CoCr-alloy after chairside and labside digitalization - a laboratory study. Dent Mater 2014;30:400-7.
18. Canabarro S de A, Shinkai RSA. Medial mandibular flexure and maximum occlusal force in dentate adults. Int J Prosthodont 2006;19:177-82.
19. Alp G, Murat S, Yilmaz B. Comparison of flexural strength of different CAD/CAM PMMA-based polymers. J Prosthodont 2019;28:49195.
20. Perea L, Matinlinna JP, Tolvanen M, Lassila LV, Vallittu PK. Fiber-reinforced composite fixed dental prostheses with various pontics. J Adhes Dent 2014;16:161-8.
21. Colán Guzmán P, De Freitas FFA, Ferreira PM, De Freitas CA, Reis KR. Influence of different cantilever extensions and glass or polyaramid reinforcement fibers on fracture strength of implant-supported temporary fixed prosthesis. J Appl Oral Sci 2008;16:111-5.
22. Peñate L, Basilio J, Roig M, Mercadé M. Comparative study of interim materials for direct fixed dental prostheses and their fabrication with CAD/CAM technique. J Prosthet Dent 2015;114:248-53.
23. Topouzi M, Kontonasaki E, Bikiaris D, Papadopoulou L, Paraskevopoulos KM, Koidis P. Reinforcement of a PMMA resin for interim fixed prostheses with silica nanoparticles. J Mech Behav Biomed Mater 2017;69:213-22.
24. Schwantz JK, Oliveira-Ogliari A, Meereis CT, Leal FB, Ogliari FA, Moraes RR. Characterization of bis-acryl composite resins for provisional restorations. Braz Dent J 2017;28:354-61.
25. Paes-Junior T, Tribst J, Dal Piva A, Amaral M, Borges A, Goncalves F. Stress distribution of complete-arch implant-supported prostheses reinforced with silica-nylon mesh. J Clin Exp Dent 2019;11:1163-9.
26. Bramanti E, Cervino G, Lauritano F, Fiorillo L, D'Amico C, Sambataro S, et al. FEM and von Mises analysis on prosthetic crowns structural elements: evaluation of different applied materials. Sci World J 2017;2017:1-7.
27. Fabris D, Souza JCM, Silva FS, Fredel M, Gasik M, Henriques B. Influence of specimens' geometry and materials on the thermal stresses in dental restorative materials during thermal cycling. J Dent 2018;69:41-8.
28. Macedo JP, Pereira J, Faria J, Alves L, Henriques B, López-López J, et al. Finite element analysis of peri-implant bone volume affected by stresses around Morse taper implants: effects of implant positioning to the bone crest. Comput Methods Biomech Biomed Engin 2018;21:655-62.
29. Macedo JP, Pereira J, Faria J, Pereira CA, Alves JL, Henriques B, et al. Finite element analysis of stress extent at peri-implant bone surrounding external hexagon or Morse taper implants. J Mech Behav Biomed Mater 2017;71:441-7.
30. Rodrigues Y, Mathew M, Mercuri KG, Sandro Silva JS, Souza JCM, Henriques V. Biomechanical simulation of temporomandibular joint replacement (TMJR) devices: a scoping review on the finite element methods. Int J Oral Maxillofac Surg 2018;47:1032-42.
31. Bins-Ely L, Suzuki D, Magini R, Benfatti CAM, Teughels W, Henriques B, et al. Enhancing the bone healing on electrical stimuli through the dental implant. Comput Methods Biomech Biomed Engin 2020;27:1-11.

Corresponding author:
Dr Júlio C.M. Souza
University Institute of Health Sciences (IUCS)
CESPU, Gandra PRD 4585-115
PORTUGAL
Email: jsouza@dem.uminho.pt or julio.souza@iucs.cespu.pt

Acknowledgments
The authors thank the Dentalbasto laboratory for the support on the manufacturing of the specimens. Also, the authors acknowledge Prof Luis Moreira from the Deptartment for Quality Assurance and Office of Methodological Studies and Data Processing, Institute Jean Piaget, Portugal, for the statistical analyses.

CRediT authorship contribution statement
Carolina Coelho: Data curation, Writing - original draft. **Catarina Calamote:** Data curation, Writing - original draft. **António Correia Pinto:** Conceptualization, Supervision, Project administration. **José L. Esteves:** Software, Validation. **António Ramos:** Software, Validation. **Tomás Escuin:** Conceptualization, Supervision, Project administration. **Júlio C.M. Souza:** Conceptualization, Methodology, Supervision, Writing - review & editing.

https://doi.org/10.1016/j.prosdent.2020.11.007