

ORIGINAL ARTICLE

Load-bearing capacity of handmade and computer-aided design–computer-aided manufacturing–fabricated three-unit fixed dental prostheses of particulate filler composite

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Abstract

Objective. To compare handmade and computer-aided design–computer-aided manufacturing (CAD–CAM)-fabricated fixed dental prostheses (FDPs) composed of a particulate filler composite. **Material and methods.** Handmade FDPs were made of restorative composite (Z 100) and CAD–CAM-fabricated FDPs were made of commercial CAD–CAM blocks (VITA Temp) and two experimental CAD–CAM blocks of particulate filler composite. Experimental CAD composite A was prepared by mixing 31.2 wt.% of dimethacrylate resin with 68.7 wt.% of filler particles of barium oxide silicate (BaSiO₂). Experimental CAD composite B was prepared by mixing 25.6 wt.% of dimethacrylate resin with 74.3 wt.% of filler particles of BaSiO₂. Six groups were fabricated ($n = 6$ in each); FDPs were statically loaded until final fracture. **Results.** Experimental CAD composites A and B revealed the highest load-bearing capacity of the FDPs, while Z 100 showed the lowest. **Conclusion.** FDPs made of experimental CAD composite blocks showed higher load-bearing capacities than handmade commercial composites and commercial blocks.

Key Words: *Experimental composite, fixed dental prostheses, load-bearing capacity*

Introduction

Since the introduction of composite resins, many attempts to increase the longevity of resin restorations have been made. Although some advances have been made, mechanical properties have yet to be improved [1].

Over the past 20 years, the use of composite resin has increased [2,3] although large restorations under high occlusal stress have been considered a contraindication. Some studies have shown a long-term withstand rate of composite resin in the posterior region [4,5], while other studies have reported acceptable results after long-term clinical use [6–8].

Particulate filler composite (PFC) resin is a group of materials comprising three major components: filler particle; resin matrix; and their interface, which is obtained using a silane-coupling agent [6]. The relatively high brittleness and low fracture toughness of current PFCs hinder their use in large stress-bearing restorations [7]. Many studies have been

performed to improve restorative PFCs by the use of specific fillers, resin compositions, and curing conditions, as well as fabrication processes [8,9]. Fiber reinforcement has also been successfully used in dentistry [10,11]. Many studies have focused on the improvement of fiber-reinforced composite crowns and the strength of fixed dental prostheses (FDPs) [12,13].

Composite resins have been classified according to several properties, such as type, size, volume of filler particles, and physical and mechanical characteristics of the materials. Currently, three categories have been proposed for composite resins: microfilled; microhybrid; and nanocomposite (nanofill or nanohybrid composite resin) [14].

The mechanical properties of a composite depend on its major components: fillers and polymer matrix [15]. The filler type, size, and content, and the union of the filler/matrix interface determine clinically relevant properties such as fracture resistance and wear resistance [16].

Recently, direct and indirect methods have been used for preparing composite FDPs. In addition to these methods, prefabricated composite blocks, such as Vita CAD-Temp blocks, are available commercially. Vita CAD-Temp is a particulate composite block that enables temporary restoration fabrication using a Sirona computer-aided design-computer-aided manufacturing (CAD-CAM) milling unit. The Vita CAD-Temp blocks consist of a high-molecular-weight acrylate polymer network with microfiller particle fillers [17].

Composite resins have not generally been used for FDPs. They are usually reinforced with fibers. There is no reported study comparing composites with FDPs. Our study focused on this subject. The aim of the study was to evaluate the load-bearing capacity of three-unit FDPs made of commercial paste-form particulate filler composite resins, one commercial prefabricated composite block, and two experimental prefabricated composite blocks using a CAD-CAM milling system. The hypothesis was that the experimental composites would demonstrate higher load-bearing capacities than the commercial composites.

Material and methods

Thirty-six laboratory-made three-unit composite FDPs replacing a lower second premolar were fabricated. Specimens were divided into six groups (*n* = 6 per group; codes 1–6). Three commercial paste-form PFC resins, one commercial prefabricated composite block, and two experimental prefabricated composite blocks were used. The materials used in this study are presented in Table I.

FDP preparation

A zirconia model (IceZirconia; Zirconc Zahn, Bruneck, Italy) of a mandibular first premolar, a missing second premolar, and a first molar was prepared as a three-unit FDP (total length 24 mm, 20 mm from abutment to abutment). The zirconia model was made with a manual milling machine (Zirconc Zahn; Figure 1). Crown preparations of the abutments were made with 2-mm occlusal and axial reduction.

The FDPs were fabricated according to the group to which they belonged:

- A ‘nanofilled’ resin composite restorative [Filtek Supreme (FS); 3M ESPE, St. Paul, MN; Group 1] containing silica particles (5–20 nm diameter) and agglomerations of zirconia and silica particles forming ‘nanoclusters’ (0.6–1.4 μm diameter) with a fraction of 59.5 vol. %.
- A ‘nanohybrid’ resin composite [Grandio (GR); VOCO GmbH, Cuxhaven, Germany; Group 2] containing silica particles (20–60 nm diameter)

Table I. Materials used.

Brand	Manufacturer	Lot No.	Resin	Filler	Total filler content (wt.%)
Grandio	VOCO, Cuxhaven, Germany	321467	Bis-GMA, UDMA, TEGDMA	Silica: 20–60 nm; barium-alumina borosilicate: 0.1–2.5 μm (87 wt.%)	87.0
Filtek Z 100	3M ESPE, St Paul, MN	20040420	BisGMA, TEGDMA	Zirconia/silica: 0.01–3.5 μm (84.5 wt.%)	84.5
Filtek Supreme	3M ESPE, St Paul, MN	20050722	Bis-GMA, UDMA; Bis-EMA, TEGDMA	Silica: 5–20 nm nanoparticle (8 wt. %); zirconia/silica: 0.6–1.4 μm	79.0
Vita CAD-temp block	Vita Zahnfabrik, Sackingen, Germany	0124	Acrylate polymer	Microfiller	
Experimental CAD composite A blocks	Esstech, Essington, PA		BisGMA-TEGDMA	BaSiO ₂ : 5% silane, 0.7-μm glass	68.75
Experimental CAD composite B blocks	Esstech, Essington, PA		BisGMA-TEGDMA	BaSiO ₂ : 1% silane, 0.7-μm glass	74.36
RelyX Unicem	3M ESPE, Seefeld, Germany	3415	Methacrylated phosphoric ester, dimethacrylate, acetate, stabilizer, and initiator	Glass powder, silica, calcium hydroxide, pigment, substituted pyrimidine, peroxy compound, and initiator	

Bis-GMA = Bisphenol-A-glycidyl dimethacrylate; UDMA = Urethane dimethacrylate; TEGDMA = Triethyleneglycol dimethacrylate.



Figure 1. Photograph of a zirconium model.

- and irregular barium–alumina borosilicate glass fillers (0.1–2.5 μm diameter) loaded to 71.4 vol.%.
 • A ‘microfilled’ resin composite [Z 100 (Z1); 3M ESPE AG, Seefeld, Germany; Group 3] reported by the manufacturer to contain fused spheroidal zirconia/silica fillers (0.01–3.5 μm diameter) loaded to 66.0 vol.%.
 • Commercial prefabricated composite block [Vita CAD-Temp (VC); Vita Zahnfabric, Sackingen, Germany; Group 4].
 • Experimental composite A (Group 5) was prepared by mixing 31.2 wt.% of dimethacrylate resin with 68.7 wt.% of fillers of particles of barium oxide silicate (BaSiO_2) (5% silane, 0.7- μm particle size glass; Esstech, Essington, UK). Fillers were added gradually to the final weight fraction.
 • Experimental composite B (Group 6) was prepared by mixing 25.6 wt.% of dimethacrylate resin matrix with 74.3 wt.% of fillers of particles of BaSiO_2 (1% silane, 0.7- μm particle size glass). The mixing was carried out by using a high-speed centrifugal mixing device for 5 min (SpeedMixer; DAC, Hamm, Germany; 3500 rev/min). The particulate fillers were silanated by the manufacturer (Esstech, Essington, PA).

A silicon mold was used to fabricate blocks from experimental composites with the same dimensions as the Vita CAD-Temp blocks. The resin composite was applied to the mold, vacuumed for 1 h, and then heat-cured under elevated pressure using an Ivomat (Ivoclar AC, Schaan, Liechtenstein) polymerization device.

The zirconia model was transferred to the Cerec 3 Sirona milling unit (Sirona Cerec MC L; Sirona Dental Systems, Bensheim, Germany) using a CAD-CAM technique by the optical impression method. An intraoral camera was used for transferred photographs. A three-unit FDP (span length 20 mm) was created in the computer and saved in a file. Vita CAD-Temp blocks and experimental composite blocks were milled by the Cerec 3 Sirona milling

unit (Figure 2). The same CAD file was used for all FDPs.

A transparent polyvinylsiloxane template matrix (Memosil 2; Heraeus Kulzer GmbH, Herau, Germany) of a finely contoured and milled Vita CAD-Temp FDP was used to standardize the dimensions and occlusal morphology of handmade composite resin FDP fabrications. The FDPs, handmade with paste-from composite resin, were veneered (four layers) and polymerized with a handheld light-curing unit (Optilux 501; Kerr, Danbury, CT) in 40-s increments (wavelength 380 and 520 nm with maximal intensity at 470 nm, light irradiance 800 mW/cm^2).

Load-bearing capacity

The FDPs were cemented to the zirconia model with a dual curing–luting agent (Rely X Unicem App.; 3M ESPE AG) according to the manufacturer’s protocol. After cementation, the model with the FDP was fixed to the metal base of the testing device. The load-bearing capacity of the FDPs was determined using a universal testing machine (Model LRX; Lloyd Instruments Ltd., Fareham, UK) at a cross-head speed of 1.0 mm/min, and data were recorded using PC software (Nexygen Lloyd Instruments Ltd.). The load was applied in the central fossa of the pontic using a steel ball (diameter 3 mm; Figure 3). The specimens were loaded until final fracture occurred. Dyer et al. [18] described the identification of initial failure (IF) and final failure (FF). IF was identified if at least two of the following conditions were present: (1) a sharp decline in the load/displacement curve; (2) visible signs of fracture; or (3) audible emissions. FF was characterized as one of the following: (1) attainment of an ‘instability condition’, defined as a zero (or negative) slope of applied stress versus strain; or (2) the maximal load or displacement before the load decreased by 50% or an apparent catastrophic rupture. Fracture patterns of FDPs were analyzed visually

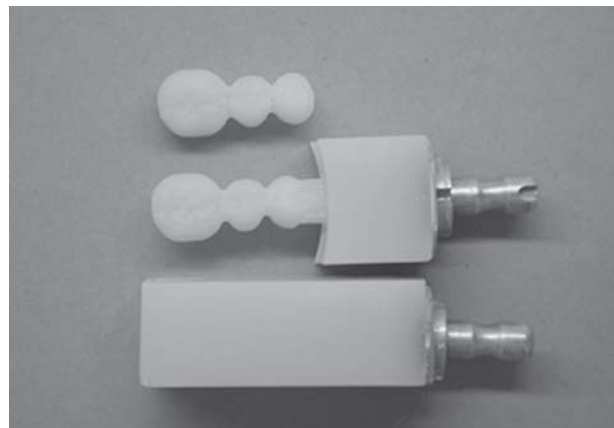


Figure 2. Milled experimental composite resin block.

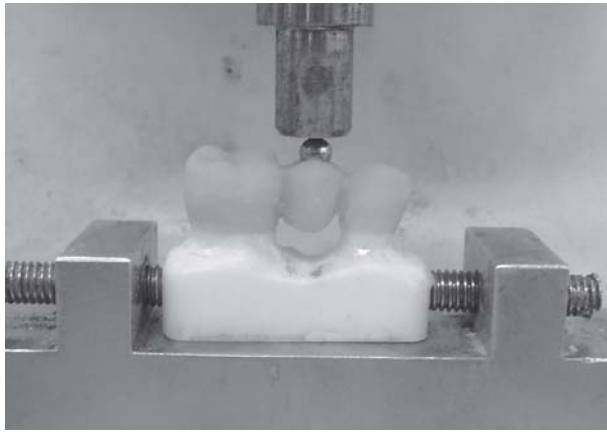


Figure 3. Test set-up and position of loading tip.

and determined to be either total, partial, or hairline fractures.

Statistical analysis

Means and standard deviations (SDs) were calculated and reported. The Kruskal–Wallis test and the Mann–Whitney U-test were used to determine statistically significant differences between groups.

Results

The load-bearing capacities of the tested FDPs are given in Figure 4. Kruskal–Wallis analysis was used to evaluate differences between all the groups (Table II) and revealed that all groups had significantly different load-bearing capacities ($P < 0.001$). The Mann–Whitney U-test was used to evaluate the differences between the groups.

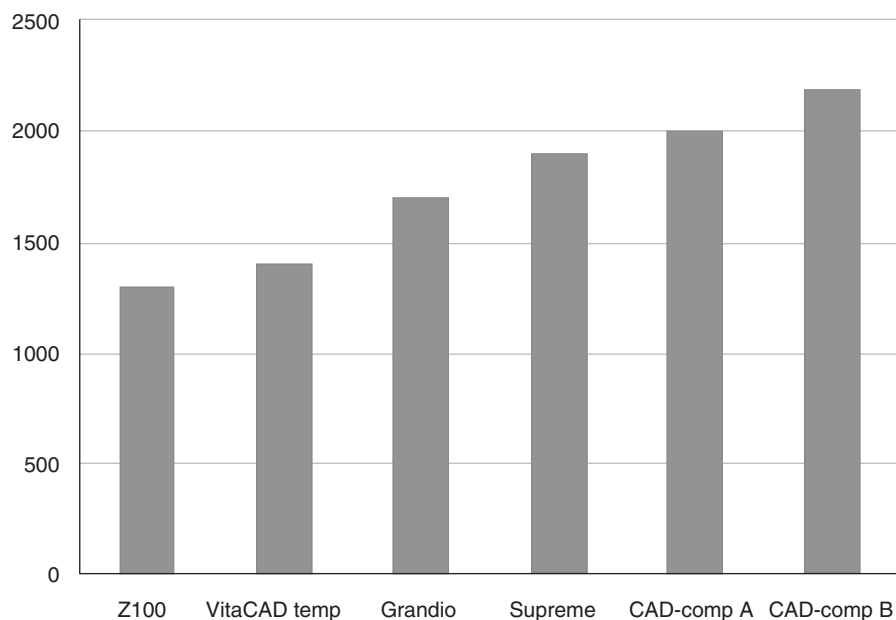


Figure 4. Load-bearing capacity (N) of tested FDPs with standard deviations.

Experimental CAD composite B revealed the highest mean value for load-bearing capacity (Figure 4). However, there was no significant difference between experimental CAD composites B and A, or between experimental composite B and FS composite ($P > 0.05$). Although the Z1 composite resin showed the lowest load-bearing capacity, there was no significant difference between the Z1 and VC groups ($P > 0.05$).

Fracture pattern analysis showed three types of fracture. Total and partial fractures were present in Groups 1–4. Partial and hairline fractures were seen in Groups 5 and 6. All the fracture patterns are shown in Figure 5.

Discussion

Many studies have been performed to improve restorative composite resins by improving filler composition and coupling to the polymer matrix, resin composition, and curing conditions [8,9]. Mitra et al. [19] suggested that a nanofilled composite had similar or slightly better mechanical properties than a conventional hybrid composite resin. Additionally, the nanocomposite showed high translucency as well as good ability to be polished and polish retention. On the other hand, in an attempt to overcome the clinical problems related to the polymerization shrinkage of composite resins, laboratory-processed indirect composite resin systems have been introduced [20,21]. Fabrication processes for indirect restorations include hand fabrication by dental laboratory technicians and, recently, CAD-CAM-based design and milling systems. The present study used a CAD-CAM milling system because of its accuracy [22,23].

Table II. Differences in load-bearing capacity between groups ($n = 6$ in each) according to Kruskal–Wallis analysis.

Group	Mean rank	Chi-square	SD	P
1	24.50	23.385	5	<0.001
2	19.83			
3	6.00			
4	8.33			
5	23.25			
6	29.08			

Of the composite resins used in this study, FS contained silica and zirconia nanoparticles, which are partially calcined to produce micron-sized porous clusters that are infiltrated with silane prior to incorporation into a resin matrix [24]. The manufacturer claims that the system matches hybrid resin-bonded composites for strength and microfills for surface finish [25]. The authors demonstrated that the ‘nanoclusters’ of FS exhibited multiple fractures and a higher force at fracture compared with the spheroidal and irregular filler technologies. It was hypothesized that incorporation of the ‘nanocluster’ particles into the polymer matrix would have produced better mechanical properties for the composite because the particle clusters may resist crack propagation [24]. The high load-bearing capacity values of the FS composite FDPs may support this, especially because materials reinforced with nanosized filler particles and agglomerations exhibit distinct properties compared with conventional filler types, where filler size and morphology influence water uptake and the resulting mechanical properties [26].

Other studies have investigated the association between mechanical properties of composite resins and differences in filler volume fractions. It has been reported that materials with higher filler volume fractions demonstrate better mechanical properties [27,28]. According to Curtis et al. [26], in GR and Z1 composite resins with relatively high filler loading (71.4 and 66.0 vol.%, respectively), GR composites failed to survive pre-loading regimes of 50 and 100 N; also, approximately half of the Z1 composite specimens survived pre-loading regimes of 100 N. The high flexural modulus combined with the low fracture strain percentage of GR and Z1 composites may induce accumulation of surface and bulk defects, resulting in premature failure [29,30]. This could be related to the lower load-bearing capacity values found in the present study.

De Moraes et al. [31] reported that the nanohybrid resins often demonstrated inferior properties compared with the nanofilled composite, and similar or better properties compared with the microhybrid material. Beun et al. [32] concluded that nanofilled composite resins showed higher elastic moduli than universal and microfilled composites, except for the Z1. The microfilled composites showed the worst mechanical properties. In all of the particulate filler composite resins, the particulate shape of the fillers with low aspect ratios did not allow the fillers to hinder crack propagation; thus, the reinforcing effect was minor. This can also be seen from the fracture pattern analysis of the present study. To improve fracture resistance and toughness, fillers with continuous fibers having high aspect ratios are in development [10–13,33].



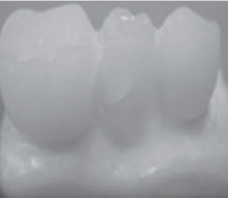
Fracture type	Total fracture	Partial fracture	Hairline fracture
Group			
Supreme	2	4	–
Grandio	3	3	–
Z100	4	2	–
VitaCAD temp	4	2	–
CAD-comp-A	–	5	1
CAD-comp-B	–	4	2

Figure 5. Fracture patterns categorized according to fracture type.

Experimental CAD composites cured in an oven demonstrated a higher degree of conversion and less porosity than hand-prepared composites because they were vacuum- and pressure-treated during polymerization. Jones et al. [34] suggested that porosity will reduce mechanical properties, such as flexural strength and fracture toughness, as a result of incomplete micro-mechanical retention of fillers and resin. Porosity develops during mixing. According to Rapp et al. [35] and Ruddell et al. [36], mixing porous fillers with the resin matrix using a vacuum can be the best way to eliminate porosity. Rapp et al. [35] investigated macroscopic blocks prepared by impregnation under vacuuming. This method leads to low porosity. Ruddell et al. [36] suggested that vacuum-impregnated blocks showed a high flexural strength that was at least as high as that of those immersed in unfilled resin. The numerical values obtained suggested that there may be some advantage to using a vacuum method.

The rigidity of the test set-up used could have negatively affected the load-bearing capacities [37]. According to Fischer et al. [38], the FDP mean fracture loads were decreased by 13% by rigidly mounted abutments compared with non-rigidly mounted abutments. The elastic modulus of the abutments had an influence on the load-bearing capacities. Scherrer and de Rijk [39] showed that increasing the elastic modulus of the supporting material results in increased fracture strength. Non-rigidly mounted abutments with an elastic modulus similar to that of natural teeth behave similarly to a natural oral situation [37].

According to Tinschert et al. [40], fractures of dental bridges typically occur between the abutment and the pontic. In the study of Fischer et al. [38], finite element analysis indicated that the connector between the bridge abutment and the pontic was the critical bridge area. The fracture patterns in this study showed some differences that may have been caused by the rigid support material.

Conclusions

CAD-CAM-manufactured composite FDP revealed a higher load-bearing capacity than hand-fabricated composites and commercial-block FDPs. This result supported the hypothesis of this study. Regarding the limitations of *in vitro* studies, this result is promising in that CAD-CAM-manufactured composites could be an alternative to FDPs; however, clinical studies are needed to support the use of CAD-CAM-manufactured composite FDPs in long-term restorations.

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