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Fracture resistance of short, randomly oriented, glass fiber-reinforced composite premolar crowns

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Abstract

The aim of this work was to determine the static load-bearing capacity of posterior composite crowns made of experimental composite resin (FC) with short fiber fillers and a semi-interpenetrating polymer network (IPN) matrix. In addition, we wanted to investigate how load-bearing capacity of surface composite resins was affected by substructures of fiber-reinforced composite (FRC) and FC, and by different curing systems. Five groups of crowns were fabricated ($n = 6$). The crowns were either polymerized with a hand-light curing unit (LCU) or cured in a vacuum curing device (VLC) before they were statically loaded at a speed of 1 mm min^{-1} until fracture. Failure modes were visually examined. Data were analyzed using ANOVA. ANOVA revealed that crowns made from the FC had a statistically significant higher load-bearing capacity than the control PFC composite. Crowns with FRC substructure and PFC covering gave force values of 348 N (LCU) and 1199 N (VLC), respectively, which were lower than the values of FC composite. No statistically significant difference was found between crowns made from plain FC composite and those made from FC composite with a surface layer of PFC ($P = 0.892$ and 1.00). Restorations made from short glass fiber-containing composite resin with IPN–polymer matrix showed better load bearing capacity than those made with either plain PFC or PFC reinforced with FRC substructure.

Keywords: Fiber-reinforced composite; FRC; Load-bearing capacity; Fiber composite; Crown restorations

1. Introduction

The development of fiber-reinforced composite (FRC) technology has opened the way for the fabrication of metal-free restorations of crowns and fixed partial dentures with both durability and good aesthetics, especially in the anterior region [1,2]. However, fracture or delamination of veneering composite and wear when an FRC prosthesis is used in high-stress posterior applications have all been reported [3,4]. The glass FRC substructure is typically veneered with particulate filler composite (PFC) resin. The composition of the PFC veneer resembles that of the hybrid and microfilled composites currently for direct restorations. PFCs are composed of a resin matrix, and the fillers are coated with a coupling agent [5]. The relatively high brittleness and low fracture toughness of current PFC veneers still hinder their use in large stress-bearing restorations [6]. Many studies have been undertaken to improve restorative PFCs by an appropriate choice of filler, resin composition and curing conditions [7–10]. Reinforcing the resin with micro-scale glass fibers [11–13], fiber-reinforced composite (FRC) substructure [14], whiskers [15], particulate ceramic fillers (dense and porous) [16] and by optimizing filler content are among the methods that have been studied [7]. Some other aspects relating to indirect laboratory-made composites have been investigated by using post-curing to enhance composite strength and toughness [17,18].

FRCs have been tested as dental materials and their use is growing in many dental applications. Studies have shown FRCs to have superior physical properties over PFCs. Many parameters – including fiber volume fraction, fiber adhesion to the resin matrix, water sorption of the resin

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matrix and fiber orientation – are known to influence the properties of FRCs [19–23]. Although much is known about the properties of FRC itself, less information is available on the properties of combinations of FRC and PFC.

Polymethyl methacrylate (PMMA)-based semi-interpenetrating polymer network (semi-IPN) matrix has been used in denture base materials and some dental FRCs [24]. The semi-IPN–polymer matrix in FRCs improves handling characteristics and interfacial adhesion to the veneering composite and luting cements [25]. However, to the authors' knowledge, dental composites with semi-IPN–polymer matrix in combination with glass fibers have not yet been evaluated.

It can be hypothesized that by using short electrical (E)-glass fiber fillers the composite restoration can sustain loads required for posterior crowns.

Short, random fibers provide an isotropic reinforcing effect, in other words, the strength of the material is not related to the direction of the fracture forces as described by Krenchel [26].

The aim of this study was to investigate the load-bearing capacity of crowns made either of experimental short fiber-reinforced composite (FC) with semi-IPN matrix or of PFCs. We also investigated the effect of using FC with FRC as a substructure to two different surface composites on the load-bearing capacity of a combined material. Further, we studied the effect of different light curing devices on the load-bearing capacity of crowns made of FC and FC with FRC substructure.

2. Materials and methods

The materials used in the study are listed in Table 1. Experimental FC was prepared by mixing 22.5 wt.% of silanized short E-glass fibers 3 mm in length (everStick fiber, Turku, Finland; 15 μm in diameter, coated with PMMA and BisGMA matrix) first with 22.5 wt.% of photopolymerizable dimethacrylate resin matrix (Stick Resin, Turku, Finland), in order to have complete wet fiber surfaces; then 55 wt.% of filler particles of silica (SiO_2, Aldrich, Steinhein, Germany) 3 ± 2 μm in size were gradually added to create the final homogeneous structure. The mixing was performed by using a high-speed (3500 min^{-1}) mixing machine for 5 min (SpeedMixer, DAC, Hauschild, Germany). Before the silica filler particles were incorporated into the resin matrix, they were silane treated, as described previously [27]. In polymerization, the resin matrix of dimethacrylate–PMMA formed a semi-IPN polymer matrix for the composite FC. A metal die was fabricated, simulating an upper premolar tooth with 2 mm of axial and occlusal reduction. A transparent template matrix of an ideally contoured crown was used to aid standardized crown construction.

Crowns were constructed via five different approaches in order to simulate clinical and laboratory-fabricated techniques with two different composite resins.

Crowns were fabricated according to the groups they belonged to:

- Group A (control group): made from plain PFC (Z100 or Sinfony according to the curing device used) without FRC reinforcement.
- Group B: made from PFC (Z100 or Sinfony) reinforced with two layers of continuous bidirectional E-glass FRC substructure (thickness = 0.12 mm) which were placed over the axial and occlusal surfaces except the finish line. The orientation of the two fiber layers was opposite to each other in order to have fiber reinforcement in all directions. The fibers were impregnated in Stick resin for 15 min before application.
- Group C: made from plain experimental FC.
- Group D: made from FC composite with two layers of continuous bidirectional E-glass FRC substructure.
- Group E: made from FC composite as core material and veneered with a 1 mm layer of PFC (Z100 or Sinfony) extending over the whole crown surface.

The crowns of each group ($n = 6$) were polymerized once according to the type of PFC used. This was done either with a hand-light curing unit (LCU, Optilux-501, Kerr, CT) for 80 s from all directions (halogen light source, wavelength 380–520 nm with maximum intensity at 470 nm, light irradiance 800 mW cm^{-2}) (Z100 composite, $n = 6$), or in a vacuum light-curing device (VLC, Visio Beta, ESPE, Seefeld, Germany) for 15 min (program 1, wavelengths 400–500 nm) (Sinfony composite, $n = 6$). After polymerization, the metal die with the crown was tightly fixed to the inclined metal base to provide a 45° angle between the occlusal surface of the tooth and the

Table 1
Materials used in the study

Brand	Manufacturer	Lot no.	Composition
Z100	3M ESPE, St Paul, MN, USA	20040420	Bis-GMA, UDMA, BisEMA
Sinfony	3M ESPE, Seefeld, Germany	FW 0061790	Aliphatic and cycloaliphatic acrylic monomer
StickNet	StickTeck Ltd, Turku, Finland	2040315-w-0050	Porous PMMA pre-impregnated bidirectional E-glass fibers
everStick	StickTeck Ltd, Turku, Finland	2050426-ES-125	E-glass fibers, PMMA, bis-GMA
Stick resin	StickTeck Ltd, Turku, Finland	540 1042	60% Bis-GMA–40% TEGDMA, 1% CQ and DMAEMA

PMMA, polymethyl methacrylate, molecular weight 220.000 kDa; bis-GMA, bisphenol A-glycidyl dimethacrylate; TEGDMA, triethylenglycol dimethacrylate; UDMA, urethane dimethacrylate; bis-EMA, bisphenol A polyethylene glycol diether; CQ, camphorquinone; DMAEMA, dimethylaminoethyl methacrylate.