Fracture behavior of pontics of fiber-reinforced composite fixed dental prostheses

Leila PEREA¹, Jukka P MATINLINNA², Mimmi TOLVANEN³ and Pekka K VALLITTU⁴

¹ Department of Biomaterials Science and Turku Clinical Biomaterials Centre-TCBC, Institute of Dentistry, University of Turku, Itäinen Pitkäkatu 4 B (2nd floor) FI-20520 Turku, Finland
² Dental Materials Science, Faculty of Dentistry, The University of Hong Kong, The Prince Philip Dental Hospital, 34 Hospital Road, Sai Ying Pun, Hong Kong, China
³ Department of Community Dentistry, Institute of Dentistry, University of Turku, Lemminkäisenkatu 2, FI-20500 Turku, Finland
⁴ Department of Biomaterials Science and Turku Clinical Biomaterials Centre-TCBC, Institute of Dentistry, University of Turku and City of Turku Welfare Division, Oral Health Care, Lemminkäisenkatu 2, FI-20500 Turku, Finland

Corresponding author, Leila PEREA; E-mail: leila.perea@utu.fi

To evaluate the load-bearing capacities and failure mechanisms of FRC FDPs using shell-shaped acrylic denture teeth as pontics with different composite resins as filling materials. Eighty-four inlay-retained FDPs with FRC frameworks were made using shell-shaped posterior artificial teeth as pontics. Different composite resins were used as filling materials to complete the shape of the pontics. Four groups (n=21/group) were formed based on the filling material. Each group was subdivided into three subgroups and tested at 90º and 30º. Each FDP was statically loaded from the pontic until the final fracture. ANOVA revealed statistically significant differences in the load-bearing capacities according to filling material, angle and storage (p<0.01). The fracture propagated from the fiber-rich part of the pontic towards the occlusal surface of the FDP. The filling material influenced the load-bearing capacities of FRC FDPs with shell-shaped denture teeth used as pontics.

Keywords: Acrylic resin denture teeth, Composite resins, Fiber-reinforced composite, Inlay-retained bridges

INTRODUCTION

The introduction of new non-metallic dental materials offers nowadays a variety of alternatives that are in line with the minimal invasive approach that has increased in dentistry. Some of the options that have been considered as conservative in prosthetic dentistry are resin bonded fixed dental prostheses (FDPs), either with metallic or ceramic frameworks⁵. However, adhesive failures have been reported as one of the main clinical problems of these kinds of prostheses⁶–¹². Fiber-reinforced composite (FRC) FDPs on the other hand offer an alternative to the conventional metal and ceramic equivalents⁵. Despite some clinical limitations reported for FRC FDPs³–⁵ their flexural strength, good esthetic values and physical stiffness of the framework are some of the advantages that they provide⁶–¹¹. FRC FDPs are also less invasive, less time-consuming and less expensive than some traditional prosthetic alternatives such as conventional full-coverage FDPs.

Clinical reports identified debonding of the veneering composite, fiber exposure and fracture at the pontic or at the connector area as the primary failure types found in FRC FDPs¹¹–¹³. To overcome these complications some alternatives have been suggested. Between them, different pontic designs¹⁰, enhanced FRC-adhesive resin interfaces¹⁵–¹⁸, improved inlay preparations for even distribution forces at the connector region⁵,¹⁹, and the treatment surface of denture teeth used as pontics in FRC FDPs to increase their adhesive properties²⁰ are recommended. The provision of an adequate adhesion between acrylic resin denture teeth and the FRC prostheses may simplify the process of making an inlay-retained FRC restoration. Wear resistance is also an important requisite in these teeth due to its contribution to the longevity of the restoration²¹. Thus, acrylic denture teeth that exhibit high wear resistance and pleasant esthetic, in addition to a composition that allows an effective bond with FRC FDPs and denture base materials would be highly valued.

A broad variety of artificial teeth are currently available. Some of them are developed with modifications of their components as an approach to improve their mechanical properties, color stability and wear resistance²²,²³. Artificial teeth made from a matrix of urethane dimethacrylate (UDMA) with inorganic filler particles are also available²⁴. Double cross-linking (DCL), interpenetrating polymer networks (IPN) and blend polymers are some of the technologies used to enhance the mechanical properties of artificial teeth²²,²⁴. The manufacturing process of the new artificial denture teeth not only includes a variety of compositions, but also layer designs. Two different layers, enamel and dentin layer, as well as several layers are found in some artificial denture teeth that provide some properties, such as hardness and monomer diffusion²⁵. It is expected that the enamel layer of artificial teeth have good wear-

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resistance properties, while the ridge-lap portion should be the least possible cross-linked to provide good bonding with the denture base material.26

The ridge-lap surface of acrylic resin denture teeth that are used as pontics in the fabrication of FRFDPs are commonly modified. Such a modification has the intention of creating the space needed to place the FRC framework. The modification of the gingival side of the acrylic teeth may remove the least cross-linked side needed for the promotion of the adhesive properties. Hence, pre-shaped acrylic denture teeth that allow the incorporation of an FRC framework without the modification of the ridge-lap surface might represent a desirable alternative that could be time-saving, cost-effective, esthetically pleasing and foremost long-lasting. However, to the author’s knowledge, no published reports exist on the capacity of these kinds of denture teeth to withstand masticatory forces when used as pontics in FRFDPs. Thus, the aims of this study were: a) to evaluate the load-bearing capacities of FRFDPs using shell-shaped acrylic resin denture teeth as pontics and b) to determine the influence of the composite resin filling material needed to complete the shape of the pontics on the behavior of these type of prostheses. The tested hypotheses were that shell-shaped acrylic denture teeth would positively affect the fracture resistance of FRFDPs and that between the filling materials used, the short fiber-reinforced composite resin would stand higher loads than the other composite resins tested, due to the addition of fibers in its composition.

### MATERIALS AND METHODS

#### Specimen preparation

Table 1 illustrates the materials used in this study. Inlay-retained FRFDPs were made using a modified polymer phantom model (Frasaco, Tettnang, Germany). The modifications in the phantom model were made to replicate a situation as if a first molar was missing. Standard Class II box preparations for retaining the FRFDPs were made on the mesial side of the second molar, and distal side of the second premolar. The dimensions for the box preparation in the molar were: buccolingual (BL) 3.5 mm, mesiodistal (MD) 6 mm, and cervico-occlusal (CO) 3.5 mm. The preparations for the premolar were BL 3.5 mm, MD 4 mm and CO 3.5 mm. The distance between the abutment teeth was 11 mm. Following the inlay preparations, impressions of the polymer phantom model were taken using a vinyl polysiloxane impression material (Affinis Precious, Coltene Whaledent, Langenau, Germany) and silicone putty (Affinis Puty, Coltene Whaledent). Impressions were poured in Type IV dental stone (Fujirock EP, GC, Leuven, Belgium) to fabricate the working cast for the FRFDPs.

Eighty four inlay-retained FRFDPs with FRC frameworks were made using continuous unidirectional E-glass fibers (everStick C&B, Stick Tech-GC, Turku, Finland) as the framework. The FRC frameworks were made in the conventional way using a universal flowable composite (G-ænial Universal Flo, GC, Tokyo, Japan) to attach two bundles of continuous unidirectional FRC between the inlays of the abutments, with one additional

### Table 1  Materials used in the fabrication of the specimens

| Name          | Manufacturer  | Lot No.          | Composition                                                                 |
|---------------|---------------|------------------|-----------------------------------------------------------------------------|
| Creopal       | KLEMA         | Experimental teeth | Enamel layer: UDMA with fillers, Dentin layer: PMMA                         |
| everStick C&B | Sticktech-GC  | 240020121120     | PMMA, Bis-GMA, E-glass fibers                                               |
| Stick Resin   | Sticktech-GC  | 121219I          | Bis-GMA, TEGDMA                                                             |
| G-ænial Universal Flo | GC | 1109211 | UDMA, Bis-MEPP, TEGDMA, Silicon dioxide, Strontium glass                   |
| G-ænial Posterior | GC       | 1109161         | Methacrylate monomers, pre-polymerized fillers (silica, strontium), inorganic fillers (silica, fumed silica) |
| EverX Posterior | GC         | 1306041         | Bis-GMA, PMMA, TEGDMA, Short E-glass fiber filler                          |
| Scotchbond Universal | 3M ESPE | 471010        | Bis-GMA, HEMA                                                               |
| RelyX Ultimate | 3M ESPE      | 491284           | Base paste: methacrylate monomers, silanated fillers, initiator components |
| Tetrahydrofuran | Sigma-Aldrich | 40750           | Catalyst paste: methacrylate monomers, alkaline fillers, initiator components |

UDMA: Urethane dimethacrylate; PMMA: polymethylmethacrylate; Bis-GMA: bisphenol A-glycidyl dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; Bis-MEPP: 2,2-Bis (4-methacryloxypolyethoxyphenyl) propane; HEMA: hydroxyethylmethacrylate.
FRC bundle placed transversally in the pontic area (Fig. 1). A variation of the conventional FRC framework was made without the addition of the transversal fiber to be used in one of the experimental groups (Fig. 2).

Shell-shaped acrylic resin denture teeth (Creopal, KLEMA, Meiningen, Austria) were used as pontics (Fig. 3). The dimensions of each pre-fabricated denture tooth were: 11 mm at the buccolingual direction, 10.5 mm from mesial to distal, 10 mm in the gingival-occlusal direction in buccal, 4 mm in the gingival-occlusal direction in the lingual side and 3 mm in the gingival-occlusal direction in mesial and distal sides. Its thickness was 1.5 mm in all surfaces with the exception of the occlusal surface where the thickness was 2 mm. Three composite resins were used as filling materials to complete the shape of the pontics: a universal flowable composite (G-ænial Universal Flo, GC), a hybrid composite (G-ænial Posterior, GC), and a discontinuous short fiber-reinforced composite resin (everX Posterior, GC). Three experimental groups were formed according to the filling material using the conventional FRC framework, which was conformed by two bundles of continuous unidirectional FRC with one additional FRC bundle placed transversally in the pontic area as previously described. A fourth experimental group that had everX Posterior as a filling material was made using a variation of the framework without the transversal bundle of fiber in the pontic area.

Each FRC framework was cut at the appropriate length, placed in position between the inlay preparations, curved cervically towards the gingival side in the middle of the pontic area, and light polymerized using a handheld light curing unit (3M ESPE Elipar S10, Seefeld, Germany) with a light intensity of 680 mW/cm² for 40 s. A 2 mm of space was left between the framework and the gingival reference to be covered by the veneering composite material. A photopolymerizable dimethacrylate resin (Stick Resin, StickTech-GC) was applied to the FRC surfaces using a microbrush and stored under a light-protection shield (Viva Pad, Ivoclar Vivadent AG, Schaan, Liechtenstein) for 5 min to allow monomers to dissolve into the FRC. Next, the FRC was light-polymerized for 40 s and removed from the working model using a pair of tweezers. In the four experimental groups, a flowable composite was applied to the walls of the inlay preparations covering the cervical one third of the box. Then, the pretreated and light-polymerized FRC framework was placed in position followed by a light-polymerization of the flowable composite for 40 s. The remaining two thirds of the inlay restorations were incrementally built up using a hybrid composite (G-ænial Posterior, GC).

A dimethacrylate resin (Stick Resin, StickTech-GC) was used as surface conditioner to dissolve and soften the internal surface of the shell-shaped acrylic resin denture teeth. This resin was left unpolymerized in contact with the acrylic surface during 15 min protected from the light to allow the monomers to penetrate into the acrylic surface. After that, 5 min were used for light-polymerization. The shell-shaped pontics were attached to the FRC frameworks and completed their shape by using the filling composites as follows: in group 1 flowable composite, group 2 hybrid composite, groups 3 and 4 a short fiber-reinforced composite resin. An index made of 1 mm of wax was placed between the abutment teeth to create the identical form of the cervical side of the pontic area. A silicone mold was used to build-up the pontic to achieve standard dimensions. Excess resin composite was removed using coarse, medium, fine, and ultrafine finishing disks (Sof-Lex, 3M Dental Products, St Paul, MN, USA). The thickness of the filled pontic was 11 mm at the buccolingual direction, 10 mm in the gingival-occlusal direction in buccal, and 6 mm in the
gingival-occlusal direction in the lingual side. In the mesial and distal areas the pontic width was 5 mm at the buccolingual and cervico-occlusal direction.

The FDPs were divided into the four groups (n=21/group) mentioned previously. Each group was subdivided into three subgroups: a) dry specimens to be tested at 90°, b) dry specimens to be tested at 30° and c) specimens stored in water for one month to be tested at 90° to the plane of the occlusal surface. The dry specimens were stored in dry conditions for 24 h at room temperature (23°C±1°C). The specimens stored in water were placed in deionized water for one month at 37°C until the load test was performed.

Cementation
A zirconia model was used to cement the inlay-retained FRC FDPs. A bonding agent (Scotchbond, 3M ESPE, St Paul, MN, USA) was applied to the restorations and subsequently light-polymerized for 10 s. Then, a universal luting cement (Relyx Ultimate, 3M ESPE) was used following the manufacturer’s instructions. A spatula was used to remove any excess of luting cement. The light-polymerization of the luting cement was made from occlusal, buccal and lingual. After cementation, the zirconia model with the FDP was placed in the testing device.

Testing and failure analysis
A universal testing machine (Model LR 30K plus, Lloyd Instruments, Fareham, UK) was used for the static compressive fracture test at a crosshead speed of 0.5 mm/min. Two different angulations, 90° and 30° to the direction of the occlusal surface, were used to apply the load. In the specimens tested at 90° the load was applied from the occlusal direction to the central fossa. In the specimens tested at 30° the model was angulated to the applied load from the occlusal direction to the buccal cusps. A steel contact ball of 6 mm diameter was used, as well as a sheet of tin foil (0.4 mm) between the steel ball and the pontic to avoid local peaks. The load was applied until the fracture load decreased by 10% of the maximum load. The initial fracture was read from the load-deflection graph and visual analysis was made to determine the fracture types of the FDPs. The software package Nexxygen 4.0 (Lloys Instruments) was used to record data.

Microscopic analysis
The specimens were evaluated using SEM (JSM 5500, Jeol, Tokyo, Japan) to demonstrate the polymer structure features of the denture teeth used. In addition, SEM examination was made to show the fracture path of the tested FRC FDPs. For that, cross-sectioned parts of the FDP were analyzed after the loading test was performed. These parts were polished and examined visually for determination of the fracture path.

Statistical analysis
Means and standard deviations (SD) were calculated for the initial and final fracture loads for each filling material, angle and storage. The statistically significant differences between them were evaluated with a 2-way ANOVA. Due to the fact that the specimens stored in water were tested at only one angulation, and the dry specimens were evaluated using two different angles, a 3-class variable describing both, angle and storage (1= in water and tested at 90°, 2=dry and tested at 90°, 3= dry and tested at 30°) was created. The independent factors were filling material, angle-and-storage variable, and their interactions. The dependent factors were initial and final fracture load, a separate model for both. All analyses were conducted using IBM® SPSS® 19.0 for Windows (Microsoft).

RESULTS
The differences observed in the load-bearing capacities of the tested FRC FDPs according to filling material, angle and storage are represented in Figs. 4, 5 and 6. ANOVA showed statistically significant differences in the load-bearing capacities of the tested inlay-retained FRC FDPs according to filling material, angle and storage (p<0.01). FDPs with everX Posterior showed the highest load-bearing capacity when tested at 90°, and G-ænial Universal Flo provided the most durable FDP when tested at 30°. Table 2 shows the p values for the initial and final fracture from a 2-way ANOVA with Tukey HSD post hoc test for effects of filling material, storage and angle, and their interactions.

When analyzing the effect of filling material, Tukey HSD post hoc test showed statistically significant differences for the initial fracture between everX Posterior and flowable composite, and between everX Posterior and hybrid composite. everX Posterior in this case was used with the three bundles of fibers in the framework. For the final fracture, when evaluating the effect of filling material, the statistically significant differences were found between everX Posterior and Hybrid composite, in both ways that everX Posterior
was examined, with two and with three bundles of fibers in the framework.

Tukey HSD post hoc test was also used to evaluate the statistically significant differences for angle-and-storage. For initial fracture the differences were found in all groups (Table 2). For the final fracture the differences were found between the dry specimens tested at 90° and 30°, and between the specimens stored in water tested at 90° and the ones dry tested at 30°.

Analyses of the failure types revealed no debonding of any of the FDPs from the inlay preparations. No catastrophic pontic fractures were observed. The failure types per experimental group are demonstrated in Table 3. SEM examination showed the structural composition of the shell-shaped acrylic resin denture teeth (Fig. 7). Two layers can be identified, the one that correspond to the enamel layer clearly shows fillers, in contrast to the layer below, that is conventional PMMA. SEM images were also taken from an orthogonally sectioned pontic that was previously loaded until the final failure. These images illustrate the crack propagation through the pontic (Fig. 8). The fracture progressed from the main FRC framework towards the occlusal surface.
Table 3  Failure types per experimental group

| Filling material     | Angle used for testing | Storage | Failure types |
|---------------------|------------------------|---------|--------------|
|                     | 90°                    | Dry     | I  II  III  IV|
| Flowable composite  | 90°                    | Dry     | 7   0   0  0    |
|                     | 90°                    | Water   | 1   0   6  0    |
|                     | 30°                    | Dry     | 0   3   4  0    |
| Hybrid composite    | 90°                    | Dry     | 2   1   4  0    |
|                     | 90°                    | Water   | 2   1   4  0    |
|                     | 30°                    | Dry     | 4   3   0  0    |
| everX Posterior1    | 90°                    | Dry     | 2   2   3  0    |
|                     | 90°                    | Water   | 0   2   5  0    |
|                     | 30°                    | Dry     | 1   6   0  0    |
| everX Posterior2    | 90°                    | Dry     | 3   2   2  0    |
|                     | 90°                    | Water   | 0   3   4  0    |
|                     | 30°                    | Dry     | 0   3   4  0    |

1FRC framework with a transversal reinforcement in the pontic area. 2FRC framework without the transversal reinforcement.

I: Cohesive fracture in the shell-shaped acrylic resin denture tooth. II: Cohesive-adhesive fracture in the shell-shaped acrylic resin denture tooth. III: Cohesive fracture that includes the filling composite without fiber exposure. IV: Cohesive fracture that includes the filling composite with fiber exposure

DISCUSSION

This experimental study was designed to investigate the load-bearing capacities of fiber-reinforced composite fixed dental prostheses using prefabricated shell-shaped acrylic resin denture teeth as pontics. The influence of the composite resin filling material on the behavior of these types of prostheses was evaluated. Two different angulations were used to perform the static fracture resistance test, in addition to the inclusion of storage as another variable. The results showed statistically significant differences between the filling materials used, finding the highest values for both initial and final fracture in the group made of a short fiber-reinforced composite resin (everX Posterior, GC) when tested dry at 90°.

Dental reconstructions are subjected to biting and chewing forces during clinical function. Forces in the range of 500–900 N have been reported by some authors as the stress that a restoration should be able to withstand in the molar region. The results of this study exhibited a mean fracture strength higher than 1,700 N. Results that could position these types of prostheses as suitable and strong enough to be used in clinical applications. That suitability has been previously noted, where successful applications of FRC restorations in clinical dentistry was reported. In addition, various studies have shown improved aspects of FRCs such as flexural and fatigue properties, framework design, and load-bearing capacities.

Clinical studies have reported veneering composite fractures as the most common mode of failure observed. This failure type is attributed to an insufficient support at the pontic area that could be solved by using a bundle of fibers oriented perpendicularly towards longitudinal fibers. Therefore, it is recommended to apply more than one fiber bundle in the framework and to use an additional reinforcement at the pontic area. In this study, the most common fracture type observed was a cohesive fracture that included the filling composite without fiber exposure, in other words delamination of the veneering composite. However, this delamination occurred when the stress applied exceeded 1,569 N, which was the lowest mean value achieved for...
the final fracture in the FDPs tested at 90°. This said, a possible explanation of the high values observed in this study could be the inclusion of two bundles of fibers in the framework, and the addition of the additional fiber at the pontic area as recommended in the clinical studies previously mentioned. Nonetheless, one of the experimental groups was made without the transversal fiber at the pontic area to evaluate its influence in the performance of the FRC FDPs tested. The results showed similar mean values with and without the transversal reinforcement in the groups where everX Posterior was used as filling material. The properties of everX Posterior, which includes short fibers in its composition, might have played a role in the similarity of mean values achieved despite the non-inclusion of the transversal bundle of fiber at the pontic area.

Cross-sectional SEM analysis demonstrated the fracture initiation at the lower surface of the main FRC framework. The fracture path proceeded to the additional fibers and minor delamination at the interface of the FRC and the filling composite resin can be seen. The propagation of the fracture continued through the composite material until it reached the denture teeth. Minor delamination demonstrated that the adhesion between the composite resin and the acrylic tooth was not good enough. Thereafter, the fracture progressed towards the occlusal surface.

The FRC-adhesive resin interface is of great importance for the survival of these kinds of restorations. Some authors have reported the dissolving capabilities of adhesive resin monomers into pre-polymerized FRC, demonstrating the possibilities to achieve an intimate bond between pre-cured FRC and freshly applied monomers\(^\text{18}\). Other reports also show the ability of monomers to dissolve and penetrate the surface of acrylic resin denture teeth. These reports suggest that option as a way of increasing the durability of the bond between pontics and FRC frameworks in FDPs [31]. In the current study, both approaches were used, the dissolution of the FRC framework and of the internal surface of the shell-shaped acrylic resin denture teeth used. Water storage was also included in this study to evaluate its influence on the mechanical properties of the FRC FDPs. No statistically significant differences were found in terms of storage in the load-bearing capacities of the tested FDPs. It might mean that the treatment surface of both, the FRC framework and the acrylic denture teeth may improve the effectiveness of these type of prostheses. Although, delamination between the composite resin and the denture teeth suggests that in stress conditions adhesive failure may occur.

One limitation of this study was not to simulate the physiological tooth movement or the mobility of periodontal ligaments. The use of a non-rigid model for testing could give a more accurate representation of the performance of these prostheses in oral conditions. With the limitations of this study, the tested shell-shaped acrylic resin denture teeth demonstrated their capacity to resist the stress applied. These kinds of denture teeth might be able to withstand the masticatory forces in clinical applications when used as pontics in FRC FDPs. The composite filling material used to complete the shape of the pontics had an influence on the load-bearing capacity of the tested FRC FDPs. The FDPs that had everX Posterior as filling material showed the highest load-bearing capacity when tested at 90°, and G-enial Universal Flo provided the most durable FDP.

Fig. 8  Cross-sectional view of crack propagation through the pontic. From the top to the bottom, the first two layers (a, b) correspond to the shell-shaped acrylic denture tooth, the third part (c) is the filling composite (a flowable composite in this case), below (d) is the transversal bundle of the FRC framework followed by (e) two bundles of the main FRC framework. At the bottom of the photo the filling composite (a flowable composite) is seen again (×30 magnification).
when tested at 30°.

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DECLARATION OF INTEREST

The author Pekka K VALLITTU consults for Stick Tech-GC in research, development and training. The authors alone are responsible for the content and writing of the paper.

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