# Restoration of deep vital and root-canal treated MOD cavities using fiber-reinforced direct restorations

Phd Thesis

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# List of the publications providing the basis of, and related to the topic of the thesis

## Publications providing the basis of the thesis:

Fráter M, Sáry T, Vincze-Bandi E, **Volom A**, Braunitzer G, Szabó P B, Garoushi S, Forster A. Fracture Behavior of Short fibre-Reinforced Direct Restorations in Large MOD Cavities. Polymers (Basel). 2021 Jun 23;13(13):2040. doi:10.3390/polym13132040. (Q1)

**Dr. Volom András**, Dr. Fráter Márk. Transzmurális szálerősítéses merevítés a nagyméretű MOD kavitások mechanikai ellenállóképességének növelésére – technikai leírás. FOGORVOSI SZEMLE 112. évf. 3. sz. 2019. 82-86.

Jakab A, **Volom A**, Sáry T, Vincze-Bandi E, Braunitzer G, Alleman D, Garoushi S, Fráter M. Mechanical Performance of Direct Restorative Techniques Utilizing Long fibres for "Horizontal Splinting" to Reinforce Deep MOD Cavities-An Updated Literature Review. Polymers

(Basel). 2022 Apr 1;14(7):1438. doi:10.3390/polym14071438. (Q1)

**Volom A**, Vincze-Bandi E, Sáry T, Alleman D, Forster A, Jakab A, Braunitzer G, Garoushi S, Fráter M. Fatigue performance of endodontically treated molars reinforced with different fibre systems. Clin Oral Investig. 2023 Jun;27(6):3211-3220. doi: 10.1007/s00784-023-04934-2. (Q1, D1)

**Related publications:**

Sáry T, Garoushi S, Braunitzer G, Alleman D, **Volom A**, Fráter M. Fracture behaviour of MOD restorations reinforced by various fibre-reinforced techniques - An in vitro study. J Mech Behav Biomed Mater. 2019 Oct;98:348-356. doi:10.1016/j.jmbbm.2019.07.006. Epub 2019 Jul 9. Erratum in: J Mech Behav Biomed Mater. 2020 Feb;102:103505. (Q1)

# List of Abbreviations

- CEJ: cemento-enamel junction
- FRC: fiber-reinforced composite
- MOD: mesio-occluso-distal
- RCT: root-canal treated
- SFC: short fiber-reinforced composite
- UHMWPF: ultra-high molecular weight polyethylene fiber

# 1. Introduction

The early restorative materials were only able to cover the missing tooth substance. In contrast, modern restorative materials are also expected to be able to provide a functional restoration. When considering direct restorative materials for the posterior region, most posterior teeth with large cavities were restored with amalgam fillings for a long time. However, both studies and everyday clinical practice have shown that the number of cracks and fractures is significantly higher next to amalgam fillings compared to other direct restorations [1,2]. Currently, with the worldwide phasedown of amalgam, restoring large cavities (e.g., mesio-occluso-distal (MOD) cavities) is an everyday problem for practitioners from a mechanical point of view [3–5]. MOD cavities present a unique, yet frequent challenge for dental practitioners. The presence or absence of the marginal ridges have been shown to be one of the most critical factors for generating stress in the cavity walls [6]. According to studies by Reeh et al., the decrease in cuspal stiffness in case of MOD cavities, where both marginal ridges are sacrificed, is 63% [7].

Compared to MOD cavities, Plotino et al. showed that with the loss of one marginal ridge, the structural weakening is 46% [8]. According to several authors, not only the shape of the cavity but also its depth has a major influence on the mechanical resistance of the tooth [6,9,10]. In their article, Forster et al. analyzed in detail the influence of cavity extension, depth, and wall thickness on fracture resistance [11]. They found that wall thickness is a secondary factor to cavity depth in terms of fracture resistance of the cusps [11]. This is in accordance with other studies showing that the larger and deeper the cavity, the greater the cuspal deflection [12,13]. Hood stated that any restoration method that inhibits deflection of the cusps during loading will improve tooth survival [14]. His study managed to show that as the depth of the cavity increases, the force exerted by the tooth wall and the cusps also increases [14]. It can be concluded that any force that causes the cavity walls and consequently the opposing buccal and lingual cusps to move away from each other compromises the structural stability of the tooth, especially in deep cavities. Thus, stabilisation of the opposing cavity walls is of high importance in case of deep

MOD cavities. This will be in the focus of this thesis. Currently, direct resin composite restorations are the primary choice for the rehabilitation of caries-related cavities in the posterior dentition, characterized by high clinical performance and durability [15–17]. However, polymerization shrinkage and related stress are still relevant issues with direct composite restorations. Polymerization shrinkage generates stress within resin composites at the interface between the composite restoration and the tooth substance, as well as within the tooth structure [18]. This can lead to various problems including marginal gap formation [19], micro-cracking (of the restorative material and/or the tooth itself), marginal staining, and cuspal movement [20]. These, in turn, may lead to postoperative sensitivity, pulpal complications, and restoration loss [21,22]. If strong and stable adhesion is reached, polymerization shrinkage is expected to cause cuspal deformation and enamel cracking on the external surface [23–25]. The other main inherent problem of direct composite filling materials, besides polymerization shrinkage and related stress, is inadequate fracture toughness as compared to the dentin [26]. Modern composite resin materials are rigid; they do not lack strength, but they do lack fracture toughness [26]. Fracture toughness is a mechanical property that describes the resistance of brittle materials to the catastrophic propagation of flaws under an applied load [27]. This way, it describes damage tolerance and can be considered as a measure of fatigue resistance which predicts structural performance of the examined material [27,28]. It should be emphasized that the lack of toughness is a factor of major importance in extensive direct restorations (e.g., deep vital and root-canal treated (RCT) MOD cavities), as the volume of the restorative material increases in these cases [10]. So far a few studies have shown that conventional direct composite restorations are not able to reinforce deep MOD cavities [11,28].

In recent years, many different innovative restoration techniques and new materials have appeared, utilizing fiber reinforcement. The use of fibers in dentistry has expanded the possible applications of direct restorations, as they are capable of reinforcing the restoration [29]. Short fiber-reinforced composite (SFC) materials are a good option for dentine replacement in extensive preparations, as they can act as a stress-absorbing layer in the restoration [30]. In SFC materials, the fibers are randomly oriented, and reinforcement occurs in three directions. In contrast, bidirectional and woven continuous fibers provide reinforcement in only two directions; however, this reinforcement is stronger than it is in SFC materials. Bidirectional FRC (e.g., EverStick Net; GC Europe, Leuven, Belgium) and ultra-high molecular weight polyethylene fiber (UHMWPF) ribbon (Ribbond THM; Ribbond Inc., Seattle,WA, USA) have been used in various direct restorative techniques. Apart from the capability of acting as a stress-absorbing layer in the restoration, these fibers are suggested to act as an internal splint to increase the fracture resistance [31,32]. Fibers are also available as long unidirectional fibers, capable of reinforcing in only one direction, however, to a greater extent, compared to the bidirectional or random oriented fibers. Unidirectional long fibers in the form of fiber-reinforced composite (FRC) posts have been used to restore RCT teeth in the past decades to increase the retention of the core build-up material [33]. The question arises whether the usage of fiber-reinforced materials could reinforce the above mentioned, demanding clinical situations.

**The null hypotheses were the following:**

(1) The deep non-RCT MOD cavities restored with the flowable SFC would show similar mechanical resistance to teeth restored with conventional composite filling.
(2) The fracture patterns in deep non-RCT MOD cavities would not depend on the applied restorative technique.
(3) The tested direct restorative options utilizing continuous fibers, with or without cuspal coverage would not differ from the control group in fatigue survival in RCT molar MOD cavities.
(4) The tested direct restorative options utilizing continuous fibers, with or without cuspal coverage would not differ from the control group in fracture pattern in RCT molar MOD cavities.

## 2. Materials and Methods

A total of two hundred and sixty mandibular 3rd molars extracted for periodontal or orthodontic reasons were selected for the investigations. The inclusion criteria were a visual absence of caries or root cracks and an absence of previous endodontic treatment, posts, crowns, or resorptions.

In the **non-RCT molar study**, one hundred teeth were chosen and teeth were evenly divided into 5 groups (n = 20). All teeth received standardized MOD cavity preparation with a depth of 4.5–5 mm and a 2.5 mm wall thickness on both vestibular and oral aspects as described by Forster et al. [11]. After adhesive treatment the cavities were restored as follows:

Group 1: The cavity was restored with a bulk injection of flowable SFC (EverX Flow Bulk Shade, GC Europe), and the occlusal aspect was restored cusp by cusp in 2 mm-thick oblique increments of packable composite resin (G-aenial Posterior A2, GC Europe).

Group 2: The central part of the cavity was restored in the same way as described in Group 1. The occlusal aspect was restored cusp by cusp in 2 mm-thick oblique increments of highly filled low-viscosity flowable composite (G-aenial Universal Injectable Flow A2, GC Europe).

Group 3: The central part of the cavity was restored with oblique increments (each maximum 2 mm thick) of SFC Flowable (EverX Flow Bulk Shade), and the occlusal aspect was restored cusp by cusp in 2 mm-thick oblique increments of packable composite resin (G-aenial Posterior A2).

Group 4: The central part of the cavity was restored in the same way as described in Group 3. The occlusal aspect was restored cusp by cusp in 2 mm-thick oblique increments of highly filled low-viscosity flowable composite (G-aenial Universal Injectable Flow A2).

Control Group: The cavity was restored with consecutive 2 mm thick oblique increments of packable composite resin (G-aenial Posterior A2).

In the **RCT molar study** the rest of the teeth were evenly divided into 6 groups (n = 20). Standardized 5-millimeter-deep MOD cavities with a wall thickness of 3 mm were prepared according to the method of Forster et al. [11]. After cavity preparation, all specimens were root canal treated. Endodontic treatment was carried out exactly as described in the study of Szabó and colleagues [34]. After the gutta-percha was cut back 2 mm below the orifices, the following preliminary modifications were made. In groups restored with cuspal coverage (SFC+CC, PFRC + CC, GFRC + CC Group, please check table 1. for group labelling) all cusps were reduced by 2 mm. In groups restored with continuous FRC systems (PFRC, PFRC + CC, GFRC, GFRC + CC Group), on both the buccal and the lingual walls, an artificial tunnel of a diameter of approximately 3 mm was prepared in the occlusal third of each wall. After covering the orifices and the floor of the pulp chamber with glass-ionomer cement (Equia Forte, GC Europe, Leuven, Belgium), all samples were adhesively treated.

| Group | Reinforcement system | Cuspal coverage (CC) |
|---|---|---|
| SFC (control) | Discontinuous SFC | No |
| SFC+CC | Discontinuous SFC | Yes (conventional direct PFC) |
| PFRC | Continuous FRC in form of polyethylene ribbon | No |
| PFRC+CC | Continuous FRC in form of polyethylene ribbon | Yes (conventional direct PFC) |
| GFRC | Continuous FRC in form of glass FRC post | No |
| GFRC+CC | Continuous FRC in form of glass FRC post | Yes (conventional direct PFC) |

**Table 1**: *Different fiber reinforcement systems and cuspal coverage restorations (n=20/group)*

From this point on, the cavities were restored as follows:

SFC group (control group): The cavity was restored applying two 4–5-mm-thick layers of flowable SFC (EverX Flow Bulk Shade), leaving 1.5–2 mm of space for the occlusal layer of flowable SFC (EverX Flow Dentin Shade).

SFC+CC group: The cavity was restored with flowable SFC (EverX Flow Bulk Shade), to the level of the occlusal reduction. The previously reduced cusps were built back with a highly filled flowable composite material (G-aenial Universal Injectable A3) with the aid of a silicon index.

PFRC group: First, a 1-mm-wide piece of LWUHMW polyethylene ribbon fiber (Ribbond Ultra Orthodontic; Ribbond Inc., Seattle, WA, USA) was placed through the previously prepared tunnels in the buccal and lingual walls, resulting in a "transcoronal splint" inside the cavity. After light curing, the cavities were restored with packable composite material (G-aenial Posterior PA3) applied with an oblique incremental technique.

PFRC+CC group: The cavities were restored as described in group 3, to the level of the occlusal reduction. The previously reduced cusps were built back with a highly filled flowable composite material (G-aenial Universal Injectable A3) with the aid of a silicon index.

GFRC group: One piece of FRC post (FibreKleer, Petron, Orange, CA, USA) was inserted through the artificial tunnels of the remaining cavity walls. After the horizontal application of the FRC post, the cavities were restored with packable composite material (G-aenial Posterior PA3) applied in oblique increments.

GFRC+CC group: The cavities were restored as described in group 5, to the level of the occlusal reduction. The previously reduced cusps were built back with a highly filled flowable composite material (G-aenial Universal Injectable A3) with the aid of a silicon index.

Both **non-RCT and RCT molar** specimens were then embedded in methacrylate resin approximately 2 mm from the cemento-enamel junction (CEJ) to mimic the bone level. To conduct mechanical testing, the restored specimens underwent an accelerated fatigue-testing procedure. In the non-RCT molar study the survived specimen also underwent static load-to-fracture testing. The specimens that experienced failure were subjected to examination through both visual inspection and the use of a stereomicroscope at various magnifications and illumination angles. This examination aimed to identify the type and location of the failure, as well as the direction in which cracks propagated. A restorable fracture was defined as one located above the CEJ, signifying that the tooth could potentially be repaired. Conversely, a non-restorable fracture extended below the CEJ, indicating that the tooth was likely to require extraction.

## 3. Results and Discussion

In the non-RCT molar study there was no statistically significant difference in terms of survival between the tested groups. When conducting the static load-to-fracture mechanical testing all groups using flowable SFC showed statistically significantly higher fracture resistances compared to the control group ($p < 0.05$). There was no significant difference regarding fracture resistance among the fiber-reinforced study groups.

Regarding the fracture pattern in the non-RCT molar specimen, all teeth with restorations utilizing flowable SFC showed a dominantly restorable type of fracture, while the control group presented dominantly non-restorable ones.

In the RCT molar study the PFRC+CC group was characterized by significantly higher survival compared to all the groups ($p = 0.000$ for SFC+CC group, $p = 0.030$ for PFRC group, $p = 0.000$ for GFRC group, and $p = 0.014$ for GFRC+CC group), except for the control group (SFC, $p = 0.317$). In contrast, the GFRC group showed significantly lower survival compared to all the groups (p = 0.001 for SFC group, p = 0.005 for PFRC group, p = 0.000 for PFRC+CC group, and p = 0.006 for GFRC+CC group), except for the SFC+CC group (SFC with coverage, p = 0.118). The control group showed statistically higher survival than the SFC+CC group (p = 0.037) and GFRC group (p = 0.001), but it did not differ from the rest of the groups.

Regarding the fracture patterns in the RCT molar specimen, all specimens with restorations reinforced by horizontal FRC post (GFRC with and without CC) showed predominantly restorable fractures, while the rest of the groups presented either mostly non-restorable ones (control group and PFRC group) or an equal number of restorable and non-restorable ones (SFC+CC group and PFRC+CC group).

# 4. Conclusions

Within the limitations of these ex vivo studies, it can be concluded that:

- deep non-RCT MOD cavities can be restored with both fiber-reinforced and non-fiber-reinforced direct restorations as long as the biting forces are in the normal range.
- In the case of extreme forces, direct restorations utilizing flowable SFC to restore deep non-RCT MOD cavities perform better compared to conventional composite fillings. The use of flowable SFC allows a favorable fracture profile.
- When directly restoring RCT MOD molar cavities by transcoronal fixation with polyethylene fibers, direct cuspal coverage is recommended in order to increase survival of the restored tooth.
- When directly restoring RCT MOD molar cavities by horizontal splinting with an FRC post, direct cuspal coverage is recommended in order to increase survival of the restored tooth.

- When directly restoring RCT MOD molar cavities with flowable SFC, it is advised to maximize the amount of fibers without cuspal coverage.

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