Reinforcing Endodontically Treated Posterior Teeth with Short Fiber-Reinforced Composites in Direct Restorative Techniques

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:

I. **Molnár J**, Fráter M, Sáry T, Braunitzer G, Vallittu PK, Lassila L, Garoushi S. Fatigue performance of endodontically treated molars restored with different dentin replacement materials. Dent Mater. 2022 Apr;38(4):e83-e93. doi: 10.1016/j.dental.2022.02.007.

II. Fráter M, Sáry T, **Molnár J**, Braunitzer G, Lassila L, Vallittu PK, Garoushi S. Fatigue performance of endodontically treated premolars restored with direct and indirect cuspal coverage restorations utilizing fiber-reinforced cores. Clin Oral Investig. 2022 Apr;26(4):3501-3513. doi: 10.1007/s00784-021-04319-3.

Related publications:

Battancs E, Sáry T, Molnár J, Braunitzer G, Skolnikovics M, Schindler Á, Szabó P B, Garoushi S, Fráter M. Fracture Resistance and Microleakage around Direct Restorations in High C-Factor Cavities. Polymers (Basel). 2022 Aug 25;14(17):3463. doi: 10.3390/polym14173463.

List of Abbreviations

- CEJ: cemento-enamel junction
- ET: endodontically treated
- FRC: fiber-reinforced composite
- GIC: glass ionomer cement
- MOD: mesio-occluso-distal
- NaOCl: sodium hypochlorite
- PFC: particulate filled composite
- RMGIC: resin modified glass ionomer cement
- semi-IPN: semi-interpenetrating polymer network
- SFRC: short fiber-reinforced composite

Introduction

Practitioners specializing in restorative dentistry strive to achieve the dual goals of enhancing both the aesthetics and functionality of a tooth, all while reinforcing the integrity of the remaining dental structures. To realize these objectives, the selection of the most suitable materials for restoration has long stood as a central concern within the biomimetic approach, characterized by its meticulous material selection and the creation of adhesive restorations. When determining the appropriate technique for restoring a posterior tooth, it becomes imperative to meticulously assess potential risk factors and the typical failure patterns specific to this particular region. This consideration becomes particularly crucial when addressing endodontically treated (ET) teeth. Given their compromised structural integrity, it becomes essential that ET teeth receive specialized restorative care. This becomes particularly significant because during endodontic procedures, many times an already compromised tooth is further weakened by the preparation of the access cavity. Restorative approaches for ET teeth are significantly influenced by the dimensions of the cavity, specifically the cavity's depth, the number of remaining cavity walls, and their thickness. Class I cavities are generally more favorable in terms of preserving tooth structure when compared to Class II MOD cavities. Consequently, it has been suggested that Class I occlusal cavities in ET teeth can be safely and effectively restored directly with fillings, while MOD cavities in ET teeth would mostly require cuspal coverage restorations.

The position of teeth within the dental arch plays a crucial role in dictating the direction and magnitude of these forces, making it a vital consideration when making decisions about the most appropriate approach for restoring affected teeth. In general, anterior teeth primarily bear flexural and shear stresses, while premolar teeth endure a combination of flexural and compressive loads, resulting in mixed stress loads. Molar teeth, on the other hand, predominantly resist compressive loads that run parallel to the long axis of the tooth. It is worth noting that parafunctional forces, such as those experienced during bruxism, can be up to six times greater than the forces exerted during normal chewing.

The adhesive bonding properties of such materials and restorations often permit more conservative cavity preparations compared to indirect restorative treatments. Within the spectrum of well-established restorative materials, amalgam, glass ionomer cements, and composite resin are considered suitable for restoring both Class I and Class II cavities in premolar and molar teeth. However, in contemporary practice, composite resins have largely supplanted and, in fact, almost entirely replaced amalgam as the preferred restorative material. An unbonded amalgam filling exerts comparable stresses on the tooth as if the cavity were left empty. Glass ionomer cements (GICs) find extensive use in various dental applications among restorative materials, primarily owing to several unique advantages. When preparing direct restorations in deep cavities, clinicians have a range of options at their disposal to replace the missing dentin. These options encompass materials such as GICs, resin-modified GICs (RMGICs), conventional packable particulate filled composite (PFC), short fiber-reinforced composite (SFRC), dual-cure core build-up composites, and more. In the super-closed sandwich technique, as elucidated by Magne, the dentin is initially hybridized using an adhesive system, and the proximal walls are established with PFC. GIC is then injected as a dentin substitute. The occlusal surface is subsequently sealed with PFC, resulting in a closed and encapsulated unit. In this model, it is important to note that the GIC is not bonded to the PFC; instead, it functions as a 'mega-filler' particle, effectively reducing polymerization stresses. In the modern biomimetic approach, it is imperative for the restoration and the tooth to establish a structurally adhesive and mechanically unified system. The term frequently employed in the realm of restorative dentistry, "biomimetic", pertains to the investigation of the tooth's structure, function, and biology, serving as a model for the development and engineering of materials, techniques, and equipment used for tooth restoration or replacement. Permanent restorative materials, such as microhybrid and nanohybrid PFCs, exhibit notably lower fracture toughness compared to dentin. The fracture toughness values are determined by the physical properties and chemical composition of the individual components of the restorative material. A material with high fracture toughness is better equipped to resist the initiation and propagation of cracks. As it stands, fracture toughness and flexural strength have emerged as significant criteria in evaluating the longevity of dental materials. Dentin comprises collagen fibers embedded within a hydroxyapatite matrix. Consequently, fiber-reinforced composites (FRCs) present an ideal choice for emulating the composition of healthy dentin. Ideally, by replacing missing dentin tissue, the appropriate restorative material would internally fortify the tooth and serve as a preventive measure against fractures. EverX Posterior (GC Europe, Leuven, Belgium), is designed for use in high-stress bearing areas, particularly in molars, to withstand a range of random forces. The reinforcing effect of fibers depends on the transfer of stress from the polymer matrix to the fibers. The flowable variant of SFRC (everX Flow, GC Europe) was introduced in 2019, boasting ease of handling and adaptability. Thus far, flowable SFRC has exhibited promising outcomes when employed in direct restorations across various clinical scenarios.

Research has demonstrated that incorporating fiber reinforcements offers a potential avenue for enhancing the strength and fracture resistance of glass ionomer cements as well. Effective adhesion between the fiber and matrix plays a pivotal role in facilitating robust load transfer between these two components, ensuring that the load is effectively transferred to the stronger fiber, thereby serving as reinforcement. Conversely, weak adhesion or the presence of voids between the fiber and matrix can create potential initial fracture sites within the matrix, facilitating material breakdown. Consequently, the adhesion between the fiber and matrix holds significance for both the mechanical performance and the durability of restorations.

The question arises as to which material would be most suitable for replacing missing dentin and simultaneously reinforcing the remaining cavity in ET posterior teeth. It is evident that the solution cannot be uniform for ET premolar and molar teeth, given the previously mentioned differences in loading forces between these regions. Therefore, in our effort to address this question, we designed two distinct setups to analyze the fatigue performance and failure modes of ET posterior cavities. Specifically, we devised a Class I cavity design for ET molar teeth and a Class II MOD cavity design for ET premolar teeth. These two unique scenarios were restored using varying direct and indirect restorative techniques and dentin-replacing materials.

The null hypotheses were the following:

1. No significant difference in fatigue resistance would be observed among ET molar teeth with Class I cavities restored using various restorative techniques when compared to the control group (composite filling).
2. The failure mode of ET molar teeth with Class I cavities restored through different techniques would exhibit no significant differences among them.
3. ET premolar teeth with Class II MOD cavities restored using different restorative techniques would not exhibit any significant variance in fatigue resistance when compared to the control group (composite filling).
4. Among ET premolar teeth with Class II MOD cavities restored using various techniques, no significant differences in their failure modes would be evident.

Materials and Methods

For the purpose of our **molar** study, a total of two hundred fifty mandibular third molars, that were extracted due to orthodontic reasons, we gathered. Inclusion criteria were strictly adhered to, encompassing the absence of caries or root cracks, no prior history of endodontic procedures, the absence of posts or other coronal restorations, and the absence of resorptions. Additionally, the coronal dimensions of the selected teeth were standardized as follows: only specimens falling within the size range of 10.0 to 10.9 millimeters, measured at the widest bucco-lingual dimension, were considered eligible for inclusion in this research. Furthermore, the mesio-distal dimension of each specimen was measured, and this parameter allowed for a maximum deviation of 10% from the calculated mean. These teeth were randomly allocated to ten study groups denoted as G1-10, with each group comprising 25 teeth. In all cases, a Class I occlusal cavity preparation was initially conducted, which was subsequently extended into a conventional endodontic access. Following cavity preparation, endodontic treatment was administered to each specimen. Root canal filling was executed utilizing a matched-single-cone obturation technique, employing a master cone tailored to match the final instrument used for preparation, along with an AH plus sealer. Afterward, the temporary filling material was removed, and the access cavity was refreshed using a diamond bur. The gutta-percha was cut back by 4 mm below the orifice using a No. 3 Gates Glidden bur. Following the gutta-percha adjustment, the root canal was rinsed with chlorhexidine and dried using paper points. Among the study groups, Group 1, 2, 3, 5, 7, 9, and 10 received identical adhesive treatment, while the remaining groups did not undergo adhesive treatment at this stage. Various materials and material configurations were employed to replace the missing dentin and restore the specimens within Groups 1-10. Two-group were restored with either packable or flowable SFRC. Two-group were restored by experimental fiber-reinforced GIC with and without adhesive treatment. Four-group were restored by conventional and resin-modified GICs with or without adhesive treatment. One-group was restored with a dual-cure composite resin and last group was restored with only conventional composite resin (control).

For the investigation involving **premolars**, a total of one hundred and eight maxillary premolar teeth were selected, all of which had been extracted either for periodontal or orthodontic reasons. These freshly extracted premolars were immediately immersed in a solution of sodium hypochlorite (5.25%) for a duration of 5 minutes and were subsequently stored in a saline solution (0.9%) at room temperature for a maximum period of 12 weeks before being employed in this study. Post-extraction, meticulous removal of soft tissue covering the root surface was carried out using hand scalers. Regarding the inclusion criteria, in terms of coronal dimensions, approximately 90% of the teeth fell within the range of 9 to 10 millimeters bucco-palatally, as measured at the widest bucco-palatal dimension. Similarly, around 90% of the samples exhibited an average mesio-distal dimension between 7 and 7.5 millimeters. All teeth underwent MOD cavity preparation with the following dimensions: the bucco-palatal width of the occlusal isthmus accounted for one-third of the intercuspal width, and the width of the proximal box was half that of the bucco-palatal width of the crown. The gingival floor of the cavity was positioned 1 mm above the CEJ. All internal angles were rounded, and the margins of the cavosurface were set at a 90° angle. After cavity preparation teeth were root canal treated. During the endodontic treatment, all teeth were instrumented with rotary files (ProTaper Universal) to the same apical enlargement (F2) and were obturated with a matched single cone obturation. Afterward, the temporary filling material was removed, and the access cavity was refreshed using a diamond bur. The gutta-percha was cut back by 6 mm below the orifice using a No. 3 Gates Glidden bur. Following the gutta-percha adjustment, the root canal was rinsed with chlorhexidine and dried using paper points. The teeth were assigned randomly to 9 study groups, each containing 12 specimens (A1 = control, A2–3, B1–3, C1–3) and were restored according to different restorative approaches. Three groups (A1–A3) were restored with either conventional composite core (PFC; control) or flowable SFRC core with/without elastic fiber posts and without overlays. Six groups had similar post-core foundations as described above but with either direct PFC (B1–B3) or indirect CAD/CAM (C1–C3) overlays.

Both **molar and premolar** specimens were then embedded in methacrylate resin approximately 2 mm from the cementoenamel junction (CEJ) to mimic the bone level. To conduct mechanical testing, the restored specimens underwent an accelerated fatigue-testing procedure. 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.

Results and Discussion

In the **molar** study Group 2 (flowable SFRC) demonstrated significantly higher survival rates ($p < 0.05$) compared to all other groups, with the exception of Group 1 (packable SFRC) ($p = 0.189$). Comparatively, the control group (Group 10; PFC) exhibited a notably higher survival rate ($p = 0.005$) when contrasted with Group 6 (RMGIC without adhesive), while simultaneously displaying a significantly lower survival rate ($p = 0.008$) in comparison to Group 2 (flowable SFRC). The remaining groups did not exhibit statistically significant differences from the control group. In terms of individual group comparisons, the restored Group 4 (fiber-reinforced RMGIC without adhesive) displayed significantly higher survival rates ($p = 0.025$) when compared to Group 3 (fiber-reinforced RMGIC with adhesive), Group 5 (RMGIC with adhesive) ($p = 0.013$), Group 6 (RMGIC without adhesive) ($p = 0.000$), and Group 9 (dual-cure composite resin) ($p = 0.003$). Notably, adhesive treatment was found to have no significant influence on the fatigue performance of the tested commercial glass ionomer materials (Groups 5–8). Regarding fracture mode of molar samples, all restored groups showed dominantly catastrophic non-restorable fractures. However, in Groups 1 and 2 more than 60% of restored teeth did not fail after completion of 40.000 cycles. Optical microscope and SEM images of the examined restorations revealed that the fatigue crack path extended from the loading surface (occlusally) towards the interior of the dentin-replacing materials. Although everX Flow exhibits a slightly higher fracture toughness value than everX Posterior when tested independently, there was no significant difference in the survival of teeth restored with everX Posterior (Group 1) compared to those restored with everX Flow (Group 2) when applied within an actual cavity. With ongoing improvements in GIC materials, a pertinent question arises regarding their potential utilization as dentin-replacing materials for the restoration and reinforcement of root canal-treated molars. Another intriguing query is whether a GIC core could derive benefits from adhesive pre-treatment, akin to the "super-closed sandwich technique." This research marks the first instance we are aware of that compares various GIC materials, both with and without adhesive treatment, as direct restorative materials for the rehabilitation of ET molar teeth. In this investigation, adhesive treatment before the application of any of the examined GIC materials did not yield an increase in survival. GIC materials establish a tangible chemical bond with dentin, albeit a relatively weak one, and do not appear to significantly enhance their performance when subjected to prior adhesive treatment as dentin-replacing materials. direct restorations using GIC materials could serve as a viable alternative to direct composite fillings for deep Class I cavities in endodontically treated molar teeth. fiber-reinforced RMGIC without prior adhesive treatment (Group 4) did not display significant differences in survival rates when compared to either the control group (Group 10) or teeth restored with packable SFRC (Group 1). According to the findings of this optical stereomicroscopy and a scanning electron microscopy analysis, the primary crack originated on the occlusal surface of the restoration, propagated downward, and extended through the various layers of both the restoration and the tooth structure. A majority of the failed specimens, regardless of the presence or absence of incorporated fibers, predominantly exhibited catastrophic non-restorable fractures. Therefore, the second null hypothesis was confirmed. Consequently, the thickness of the conventional composite resin on the restoration's surface can influence crack propagation and the overall survival of the restoration. When dealing with premolar teeth, both the direction and nature of forces differ in comparison to molar teeth. Therefore, it stands to reason that distinct reinforcement techniques may be necessary.

In the **premolar** study Group C3 exhibited the highest survival rate, while the control group displayed the lowest survival rate in this study. Group C3 demonstrated significantly higher survival values compared to all other tested groups ($p < 0.05$). The control group did not exhibit statistical differences from Groups B1 and A2 ($p = 0.076$ and $p = 0.135$, respectively). Notably, the remaining tested groups demonstrated statistically significantly higher survival rates compared to the control group ($p < 0.05$). Group B3 exhibited higher survival rates than the control group, as well as Groups A2, B1, and B2 ($p < 0.05$), although it did not significantly differ from Groups A3, C1, and C2 in terms of survival. In terms of fracture types, it is important to note that all restored groups predominantly exhibited non-restorable fractures. These non-restorable fractures either terminated below or at the bone level, emerging from the buccal or palatal wall, or extended into the root, causing the tooth to split. The highest frequency of non-restorable fractures was observed in Group C3. Assessing the impact of personalized fiber-reinforced designs, both with and without cuspal coverage, on fatigue survival. Additionally, the study aimed to explore whether direct cuspal coverage could be as effective as its indirect counterpart. Unlike static load-to-fracture testing, cyclic loading was employed in both of our studies. This approach, which generates repetitive forces akin to those experienced during normal chewing, better simulates the actual clinical scenario when testing tooth-restoration units. Maxillary premolars with MOD cavities were selected, as they exhibit unfavorable anatomical characteristics in terms of crown volume and crown-to-root proportion. These factors render them more susceptible to cusp fractures when subjected to occlusal loads than other posterior teeth. premolars are subjected to a more adverse combination of lateral forces, specifically a mix of shear and compressive forces during mastication. This heightened combination elevates the risk of potential cusp fracture in the future. Fiber-reinforced composites consistently outperformed their non-fiber-reinforced counterparts in various cavity formations and clinical scenarios. Furthermore, given that flowable SFRC has demonstrated superior mechanical properties when compared to packable SFRC, it is a logical choice for core build-up either independently or in conjunction with an FRC post. When focusing on direct restorations without cuspal coverage within this study, Group A3 (flowable SFRC with an elastic FRC post) exhibited superior survival rates compared to the control group (p=0.006). Consequently, the third null hypothesis was refuted. Interestingly, when direct cuspal coverage was combined with the Bioblock technique (Group B2), survival rates significantly improved compared to the control group (p=0.043). This improvement can be attributed to the reinforcing effect of incorporating flowable SFRC into the restoration while simultaneously providing cuspal coverage. It is noteworthy that not only did the Bioblock technique with direct cuspal coverage (Group B2) not exhibit a significant difference in terms of survival compared to the elastic FRC post with flowable SFRC (Group A3), but it also did not significantly differ from the outcomes observed with indirect cuspal coverage restorations on either composite (Group C1) or Bioblock core build-up (Group C2).

Conclusions

1. The use of SFRC as a dentin-replacement material in Class I molar ET teeth restoration demonstrates its potential to reinforce dental structures and enhance load-bearing capacity when compared to composite fillings.
2. Prior adhesive treatment of different GIC materials, when used as dentin-replacement materials, does not significantly improve survival compared to non-adhesively treated GICs.

3. Elastic fiber posts, combined with flowable SFRC as the post luting material, either with or without cuspal coverage, exhibit favorable performance in terms of fatigue resistance and survival when employed in the restoration of ET premolars with MOD situations.
4. Among the various tested restorative methods for ET premolar MOD situations, the highest survival rate is achieved when indirect cuspal coverage is provided using an elastic FRC post and flowable SFRC core build-up.