PhD thesis

Evaluation of the retention of fiber-reinforced posts

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1. Introduction

Endodontic treatment of teeth plays a crucial role in restorative and conservative dentistry. Its goal is to treat and prevent apical periodontitis and its complications in teeth where extensive caries, infection, or trauma has affected the pulp tissue. This therapy involves the removal of the pulp tissue (whether healthy or infected), the disinfection of the root canal system, and the sealing of the canal to prevent possible reinfection.

Survival studies of restored, root-treated teeth show that, in the long term, the quantity and quality of intact tooth tissue, as well as the correct choice of restoration, play a significant role. In cases of significant tooth substance loss, there is insufficient healthy tooth material to provide the necessary retention and resistance form for a definitive restoration. Such teeth cannot be restored long-term with restorative filling material alone, making the use of an intraradicular post necessary to ensure the retention of the planned restoration.

Intraradicular posts can be classified based on various aspects: manufacturing technology (prefabricated or custom-made), material (metal alloys, ceramics, and fiber-reinforced composite), shape (parallel, tapered, or cylindroconical), and surface characteristics (smooth (passive), threaded, grooved, knurled (active), or hollow). These factors influence the properties of the posts and their application in various clinical situations.

In modern dental care, fiber-reinforced posts play a significant role, having been introduced to the dental market in the early 1990s. Among these, glass fiber-reinforced posts are the most widely used. Glass fibers offer excellent aesthetics, elasticity like natural dentin, high tensile and compressive strength, and outstanding biocompatibility. An additional advantage is that the post can be adhesively bonded, and the core is built up in the same session following root canal preparation. After bonding, the composite post-adhesive resin cement-root dentin system behaves as a monoblock, as their physical properties, particularly their modulus of elasticity, are similar.

The most common failure in fiber-reinforced post-restored, root-treated teeth is post debonding at the interface between the root canal dentin and the post after some time of bonding. This is influenced by several factors: the type of post (material, diameter, shape), bonding protocol, procedures used (intraradicular preparation, isolation, etc.), and the configuration of the root canal.

In our research, we investigated two factors that are less discussed and documented in the literature.

In our first study, we aimed to determine whether intraradicular preparation causes harmful temperature increases in the root canal. According to most post system manufacturers' instructions, water cooling is not necessary during intraradicular preparation. Our goal was to examine and compare temperature changes during preparation with and without water cooling at different temperatures.

Although many factors influencing retention have been studied in the literature, few studies have addressed the role of post diameter and the differences between root regions in this context. Our second study focused on these parameters. We examined the push-out values per unit bonding surface of posts with different diameters from one post system, while keeping other factors (root canal preparation, bonding protocol) constant. Beyond comparing the diameters, we also investigated possible differences between the various root regions.

2. Objectives

2.1. Effect of different parameters utilized for image guided endodontic root canal preparation on temperature changes - in vitro study

Despite being a new and advanced technology, guided endodontic preparation has limited representation in the scientific literature regarding studies on temperature changes during guided endodontic drilling. Additionally, few studies examined the effects of various drilling parameters influencing temperature changes during preparation. In our research, we investigated four parameters that influence temperature changes: the presence or absence of an access cavity prior to endodontic drilling, drilling speed (RPM), cooling, and the temperature of the coolant.

The aim of our study was to determine temperature changes on root surfaces during guided root canal preparation, based on the drilling parameters.

2.2. Push-out bond strength of glass fiber endodontic posts with different diameters

Numerous studies can be read that examined the bond strength of intraradicular posts. Bond strength is influenced by many factors. The post itself (material, characteristics, etc.), the adhesive material (type, thickness, etc.), the interface between the adhesive and the post (which is affected by the surface treatment and surface texture of the post), and the interface between the adhesive and the root canal wall (which is influenced by the success of bonding, residual gutta-percha, etc.) each plays important role. Most studies focus on altering bonding parameters (surface treatment, adhesive material, etc.) or comparing post systems from different manufacturers. There are, however, limited number of studies that compare posts of different diameters of the same system without changing bonding parameters.

The goal of our research was to examine the bond strength (PBS - Push-out Bond Strength) of glass fiber-reinforced posts of different diameters in various regions of the root canal using push-out tests. Our first null hypothesis stated that the push-out bond strength (PBS) would be the same for posts of different diameters. Our second null hypothesis asserted that the PBS would be uniformly distributed along the length of the root canal, with no differences observed between the regions tested.

3. Materials and methods

3.1. Effect of different parameters utilized for image guided endodontic root canal preparation on temperature changes - in vitro study

In this study, seventy-two human teeth with straight root and narrow root canal were used. The teeth were embedded in custom-made holders made from class IV super-hard gypsum and acrylic, which provided stable fixation during the tests. A total of six holders were created, with each holder containing twelve teeth, summing up to 72 teeth. On the outer side of each holder, channels were formed up to the middle third of the roots' surface to accommodate the conductive electrodes of the digital thermometer.

CBCT scans were taken of each holder using the Planmeca ProMax 3D imaging system at a resolution of 200 microns and a field of view (FOV) of 8 × 8 mm. The CBCT images were uploaded into a software designed for guided surgical planning, which was used to plan the endodontic drill guides. These drill guides were then 3D printed using transparent resin material.

The channels in the holders were filled with thermal compound material, and the conductive electrode was placed in the channel up to the middle third of the roots' surface. The other end of the conductive electrode was connected to a digital thermometer. The tooth surface was marked through the sleeve, and enamel was removed from each tooth using a diamond bur with water cooling, following the guide. For some randomly selected holders, the dentin was also removed (using the guide and water cooling) to create an access cavity. After creating the access cavities, a guided endodontic preparation was performed using an Ø 1.0 mm spiral drill, during which the temperature increase was recorded.

In this study, we examined four parameters affecting temperature change: (1) the presence or absence of an access cavity before endodontic drilling, (2) drilling speed (RPM), (3) cooling, and (4) the temperature of the cooling liquid. Twelve teeth were assigned to each of the following test groups:

Group 1: Guided drilling without access cavity preparation (only enamel removal) at 800 RPM, without cooling.

Group 2: Guided drilling without access cavity preparation (only enamel removal) at 1000 RPM, without cooling.

Group 3: Guided drilling after access cavity preparation (enamel and dentin removal) at 1000 RPM, without cooling.

Group 4: Guided drilling after access cavity preparation (enamel and dentin removal) at 800 RPM, without cooling.

Group 5: Guided drilling after access cavity preparation (enamel and dentin removal) at 1000 RPM, with cooling using a 21°C cooling liquid.

Group 6: Guided drilling after access cavity preparation (enamel and dentin removal) at 1000 RPM, with cooling using a 4-6°C cooling liquid.

Statistical analyses were performed using SPSS analytical software. The Kolmogorov-Smirnov test was used to assess the normality of data distribution. Temperature changes between the groups were compared using one-way ANOVA, followed by Tukey's HSD post hoc test. P-values below 0.05 were considered significant.

3.2. Push-out bond strength of glass fiber endodontic posts with different diameters

In this study, forty single-rooted, intact mandibular premolars were used. The crowns of the teeth were separated from the roots at the cementoenamel junction using a diamond-coated circular saw with ample water cooling. To standardize root canal length, all roots were trimmed to a length of 14 mm. Endodontic treatment was then performed on the roots using the following parameters: #40 apical stop, #60 step-back, and final root canal filling with lateral condensation technique. The access cavities were sealed with light-curing temporary filling material.

The roots were randomly divided into four test groups according to the post diameters: Ø 1.0 mm (Group 1), Ø 1.2 mm (Group 2), Ø 1.5 mm (Group 3), and Ø 2.0 mm (Group 4). Each group contained ten roots.

Root canal fillings were removed using a #3 Gates-Glidden drill, leaving the last 4 mm in the apical third intact. Each root canal was prepared to a working length of 10 mm from the occlusal surface of the specimens. Post cementation was performed according to the manufacturer’s instructions (Futurabond DC SingleDose bond, QuickMix Rebilda DC luting and core build-up cement).

For the push-out tests, each root was sliced into three sections using a 0.5 mm thick diamond-coated circular saw. The slicing began 1 mm below the CEJ. One slice was selected from each region at 1-, 4-, and 7-mm depths, creating a coronal ("C" region), a middle ("B" region), and an apical ("A" region) slice, each 2 mm thick, with their apical surfaces marked. Following the slicing, 116 slices were obtained. Each slice was placed in a separate, labeled, sterile saline-filled Eppendorf tube and transported to the Department of Materials Science and Technology at the Faculty of Mechanical Engineering, Budapest University of Technology and Economics, where the push-out tests were conducted.

Each slice was secured in a specially designed and manufactured holder specifically made for this test. Due to the geometry and functionality of the holder, the slices were optimally positioned throughout the entire push-out test. Steel (X210Cr12) rod tips with different diameters matching the post diameters were used to push out the glass fiber-reinforced posts. The load was applied in an apico-coronal direction due to the taper of the root canal.

The push-out tests were conducted using a commercially available Instron® 5965 testing machine. Forces were recorded in real-time as a function of displacement by the testing machine software, which also determined the peak forces. To calculate the push-out bond strength (expressed in MPa), the recorded peak forces (N) were divided by the bonding surface area, which allows for a more accurate comparison as the force is calculated per unit bonding surface.

Statistical evaluations were performed using SPSS analytical software. The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to check data distribution. Tukey post-hoc test and factorial ANOVA were used to compare independent groups between the three root canal regions and the four different post sizes.

4. Results

4.1. Effect of different parameters utilized for image guided endodontic root canal preparation on temperature changes - in vitro study

The highest average temperature was observed during the preparation without prior access cavity preparation. In this experimental setup, drilling at 800 RPM (Group 1) resulted in a higher average temperature increase (14.62°C ± 0.63) compared to drilling at 1000 RPM (Group 2) (13.76 °C ± 1.24). The difference between the two groups was not statistically significant ($p = 0.243$), but both groups showed significantly higher ($p < 0.01$) temperatures compared to any of the groups with access cavity preparation (Groups 3, 4, 5, and 6).

In the groups where an access cavity was prepared (Groups 3 and 4), significantly lower ($p < 0.01$) average temperatures (10.09 °C ± 1.32 and 8.90 °C ± 0.50, respectively) were measured compared to the groups without an access cavity (Groups 1 and 2). However, Groups 3 and 4 showed significantly higher average temperatures compared to the groups where cooling was applied (Groups 5 and 6; $p < 0.01$). In this experimental setup (access cavity preparation, drilling without cooling), the drill speed had a significant effect: 1000 RPM resulted in a significantly higher average temperature than 800 RPM ($p < 0.05$).

Cooling significantly reduced ($p < 0.01$) the average temperature increases in both Groups 5 (4.01 °C ± 0.22) and 6 (1.60 °C ± 1.17) compared to the non-cooled groups (Groups 1, 2, 3, and 4). The temperature of the cooling fluid was a significant influencing factor ($p < 0.01$): cooler fluid (4-6°C, Group 6) was more effective than room-temperature fluid (21°C, Group 5) in reducing temperature during drilling at the same speed (1000 RPM).

4.2. Push-out bond strength of glass fiber endodontic posts with different diameters

The lowest peak force values (N) were recorded in the apical ("A" region) post slices, while the highest values were observed in the middle ("B" region) slices (except for the 1.0 mm post). On average, the highest peak force was recorded for the 2.0 mm diameter posts, with a value of 111.99 ± 10.40 N, while the lowest value was recorded for the 1.0 mm diameter posts, with a value of 99.98 ± 8.05 N.

The results varied when the peak forces were divided by the calculated bonding surface area of each post region. The highest average MPa value was recorded for the 1.0 mm posts (18.20 ± 1.67 MPa), while the lowest was recorded for the 2.0 mm posts (12.08 ± 1.05 MPa).

Both the Kolmogorov-Smirnov and Shapiro-Wilk tests indicated a normal distribution of the data ($p < 0.200$ and $p < 0.140$, respectively).

A comparison of the post slices by region showed no significant differences in the average push-out bond strength values between the three regions ($p = 0.219$, based on factorial ANOVA analysis). However, when comparing the sizes of the posts, factorial ANOVA showed a significant difference in the average push-out bond strength values among the four groups ($p < 0.002$). The Tukey post-hoc test, using a 5% significance level, showed a significant difference between the 1.0 mm and 1.5 mm posts ($p < 0.023$) and between the 1.0 mm and 2.0 mm posts ($p < 0.003$).

5. Discussion

5.1. Effect of different parameters utilized for image guided endodontic root canal preparation on temperature changes – in vitro study

Various anatomical variables, including the length and diameter of the root canal and the calcified tissue within the root canal, may contribute to heat generation, but these are immutable factors and cannot be generalized. Procedural factors that can be modified, such as the type and novelty (degree of wear) of the drill used, the presence of a properly prepared access cavity, drilling speed, cooling, and the temperature of the cooling fluid, can also contribute to heat generation. However, the importance and impact of these procedural factors have not been comprehensively studied in scientific research.

Our results showed that in this in vitro study, all four examined drilling parameters influenced heat generation. In our experiment, the absence of access cavity preparation before guided endodontic preparation had a detrimental effect, as it increased the root surface temperature by more than 10 °C, regardless of the drilling speed applied.

Our data indicate that drilling speed also has a significant impact on heat generation, even when an access cavity was prepared before preparation. It appears that lower speeds (800 RPM) cause less heat generation than higher-speed drilling (1000 RPM). In our measurements, we recorded near-average temperature values for lower-speed preparation. This may also suggest that lower-speed preparation is less sensitive to varying root canal anatomy.

The cooling of the drill and the temperature of the cooling fluid also had a significant impact on heat generation, even when using higher drilling speeds. The highest temperature increase measured with cooling was still lower than the lowest temperature increases without cooling. In two cases, no temperature increase was observed at all throughout the entire drilling process when using cool cooling fluid. Therefore, it can be assumed that drill cooling is the most controllable method to reduce collateral thermal damage. The average temperature data of our study's 5th group (4.01 °C ± 0.22) (preparation at 1000 RPM with access cavity preparation and cooling with room temperature cooling fluid) were consistent with the published average temperature data of the group that examined guided endodontic preparation (5.07 °C).

It should be noted that these data only apply to the specific type of drill used in this study. The material, diameter, shape, and cutting-edge configuration of the drill may also contribute to heat generation, but studying these parameters is beyond the scope of our research.

5.2. Push-out bond strength of glass fiber endodontic posts with different diameters

In our study, several factors influencing the retention of the posts remained unchanged (steps of endodontic treatment, root canal preparation, post shape, bonding and cementing protocol, procedural methods), while the diameter of the posts was varied. In total, four different diameters of fiber-reinforced posts (ø 1.0 mm, ø 1.2 mm, ø 1.5 mm, and ø 2.0 mm) were used and examined in this experiment.

Our study supports the findings of other authors: the push-out bond strength of the individual posts varies depending on the diameters, with the posts that better fit the prepared root canal and adapt better to its shape achieving the highest results. The greater bond strength can be explained by the fact that a smaller amount and thinner layer of bonding cement is required to fill the space between the post surface and the dentin wall. By using less bonding cement, polymerization shrinkage of the material is minimized, and less stress is generated at the bonding interface. Bonding cements have various physicochemical properties (e.g., viscosity and flow), which also affect bond strength: materials with higher flow and lower viscosity can fill spaces more perfectly, resulting in better bonding. Other factors, such as root canal preparation, surface treatment of the posts, and different post systems, also contribute to bond strength. From practical view, the most accurately fitting post should be bonded into the prepared root canal without over-preparing and weakening the remaining tooth and root structure, thereby optimizing the thickness of the bonding cement.

Comparing the regions of the root canals showed no significant difference in the average values among the three groups ($p < 0.219$). Our results are similar to previous research, as we did not find statistical differences between the root canal regions, while few studies achieved the lowest bond strength in the apical third and the highest in the middle third. The lower recorded bond strength in the apical segments can be explained by the practical implementation of bonding (application and drying of the appropriate amount of bonding material) and the increased space between the dentin wall and the post due to the drill oscillation, leading to a thicker cement layer and increased polymerization shrinkage.

Other factors contributing to the retention of posts have been extensively studied, but there is a limited number of scientific publications focusing on different diameters of the same post system and root regions. The correlations between posts with different diameters and root regions require further research to draw reliable conclusions.

6. Conclusion and summary of results

Based on our first study, it can be concluded that the preparation of an initial cavity, the selection of an appropriate drilling speed, and cooling and its temperature all significantly impacted our preparation. Guided endodontic preparation performed at speeds not exceeding 1000 RPM, after the preparation of an initial cavity, with constant cooling using a coolant colder than room temperature, provided the best result in preventing additional thermal damage. The necessity of cooling contradicts the recommendations of several system manufacturers, thus further research on this topic is needed, and its results may necessitate a review of professional protocols and instructions.

The results of our second study are supported by the literature: increasing the diameter of the posts does not increase the push-out bond strength and may even have a negative effect. The differences between root canal regions have been debated in the literature, with some studies finding no significant difference and others reporting significant differences between regions. Our research did not find significant differences between the three groups. From a practical standpoint, the post that fits most precisely should always be bonded to the prepared root canal without over-preparing and thereby weakening the remaining tooth and root structure, while also optimizing the thickness of the adhesive cement.

A limitation of our studies is that they were both conducted in vitro, not in vivo. Due to these limitations and the lack of related studies, further research and data are needed on these topics.

7. Publications

7.1. Publications related to the PhD thesis

Rajnics Z, Mandel I, Nagy Á, Turzó K, Mühl A, Marada G. Effect of different parameters utilized for image guided endodontic root canal preparation on temperature changes: an in vitro study. *BMC Oral Health*. **2024**;24(1):76. Published 2024 Jan 13. doi:10.1186/s12903-023-03799-x

Q1; IF$_{2023}$ 2.6

Rajnics Z, Pammer D, Kőnig-Péter A, Turzó K, Marada G, Radnai M. Push-Out Bond Strength of Glass Fiber Endodontic Posts with Different Diameters. *Materials (Basel)*. **2024**;17(7):1492. Published 2024 Mar 25. doi:10.3390/ma17071492

Q2; IF$_{2023}$ 3.1

7.2. Publications not related to the PhD thesis

Markovics D, Szendi R, Vicko K, Rajnics Z, Marada G, Radnai M. A kombinációs szindróma gyakorisága a Pécsi Tudományegyetem Klinikai Központ Fogpótlástani Tanszékén a 2009 és 2014 között készült orthopantomogramok alapján [Incidence of combination syndrome based on the orthopantomograms made between 2009 és 2014 at the Department of Prosthodontics, University of Pécs, Hungary]. *Fogorv Sz*. **2016**;109(1):23-27. doi:10.33891/FSZ.109.1.23-27

Rajnics Zs, Marada G, Moetaz E, Radnai M. Effects of Silane on the Push-out Bond Strength of Fiber-reinforced Resin Posts luted with different Self-adhesive Resin Cements. *Int J Experiment Dent Sci.* **2017**;6(1)22-25. doi:10.5005/jp-journals-10029-1148

Rajnics Z, Radnai M. The effect of Periogen solution on dental calculus in vitro: A pilot study. *Int J Experiment Dent Sci.* **2017**;6(1):33-34. doi:10.5005/jp-journals-10029-1150

7.3. Conference presentations and poster presentations related to the PhD thesis

Rajnics Zs, Pammer D, Marada Gy, Radnai M. Rebilda üvegrost megerősített csapok retenciójának push-out vizsgálata. Fogpótlástani Napok: Magyar Fogorvosok Egyesülete Fogpótlástani Társaságának XXI. kongresszusa és továbbképző tanfolyamai, Pécs, Magyarország 2015.09.24. - 2015.09.26. – **Presentation (own) - Hungarian**

Zsolt Rajnics, Dávid Pammer, Anikó Péter, Gyula Marada, Márta Radnai. Push-out study of the retention of Rebilda glass fiber-reinforced posts (PP 105). 40th European Prosthodontic Association (EPA) 65th German

Society for Prosthetic Dentistry and Biomaterials (DGPro) Annual Conference. Halle, Németország 2016.09.15. - 2016.09.17. – **Poster presentation (own) - English**

Rajnics Zsolt, Pammer Dávid, Kőnig-Péter Anikó, Marada Gyula, Radnai Márta. Különböző átmérőjű Rebilda üvegrost megerősített csapok retenciójának push-out vizsgálata. MAÁSZT XXI. Kongresszusa, Magyar Fogorvosok Egyesülete Fogpótlástani Társaságának XXII. Kongresszusa Debrecen, 2017. 09. 28-30. – **Presentation (own) – Hungarian**

Rajnics Zsolt, Mühl Attila, Marada Gyula. Navigált gyökércsatorna preparálás során termelődő hőmérséklet in vitro vizsgálata. Magyar Fogorvosok Fogpótlástani Társasága XXV. és Magyar Gnathológiai Társaság I. Konferenciája. Pécs, 2023. szeptember 21-23. – **Poster presentation (own) - Hungarian**

Rajnics Zsolt, Mandel Iván, Nagy Ákos, Turzó Kinga, Mühl Attila, Marada Gyula. Navigált gyökércsatorna preparálás során termelődő hőmérséklet in vitro vizsgálata. Magyar Élettani Társaság (MÉT) 86. Vándorgyűlése és a Magyar Mikrocirkulációs és Vaszkuláris Biológiai Társaság 2024. évi Konferenciája. Debrecen, 2024. május 29-31. – **Presentation (own) - Hungarian**

7.4. Conference presentations and poster presentations not related to the PhD thesis

Rajnics Z, Marada G, El-Hag M, Radnai M. Bond strength of fibre-reinforced resin posts. 39th Annual Conference of the European Prosthodontic Association. Prága, Csehország 2015.09.03. - 2015.09.05. – **Poster presentation (own) – English**

Markovics D, Szendi R, Vicko K, Rajnics Z, Marada G, Radnai M. Incidence of combination syndrome over a five-year period at the University of Pécs, Department of Prosthodontics. 39th Annual Conference of the European Prosthodontic Association. Prága, Csehország 2015.09.03. - 2015.09.05. – **Poster presentation (other) - English**

Markovics D, Szendi R, Vicko K, Rajnics Z, Marada Gy, Radnai M. A kombinációs szindróma gyakorisága a Pécsi Tudományegyetem Fogorvostudományi Szak Fogpótlástani Tanszékén az elmúlt öt évben készült panoráma röntgenek alapján. Fogpótlástani Napok : Magyar Fogorvosok Egyesülete Fogpótlástani Társaságának XXI. kongresszusa és továbbképző tanfolyamai, Pécs, Magyarország 2015.09.24. - 2015.09.26. – **Presentation (other) – Hungarian**

Rajnics Zsolt, Horváth Olivér, Gelencsér Gábor, Olasz Lajos, Radnai Márta. Az állcsonttörések gyakoriságának és típusainak elemzése a Pécsi Tudományegyetem Szájsebészeti Klinikáján 2011 és 2015 között megjelent betegek adatai alapján. A Magyar Fogorvosok Egyesületének Árkövy Vándorgyűlésé. Perspektívák a paro-implantológiában és a komprehenzív fogászatban. Szeged, 2016. május 5 – 7. – **Presentation (own) – Hungarian**

Rajnics Z, Radnai M. The effect of periogen solution on dental calculus In-vitro – a pilot study (PP 112). 40th European Prosthodontic Association (EPA) 65th German Society for Prosthetic Dentistry and Biomaterials (DGPro) Annual Conference. Halle, Németország 2016.09.15. - 2016.09.17. – **Poster presentation (own) – English**

Rajnics Zsolt, Horváth Olivér, Gelencsér Gábor, Olasz Lajos, Radnai Márta. Etiology and incidence of maxillofacial trauma at University of Pécs between 2011 and 2015. 21st Congress of the European Association of Dental Public Health. Budapest, Magyarország 2016.09.29. - 2016.10.01. – **Presentation (own) - English**

Impact factor of the author

Impact factor of publications related to the PhD thesis: 5.7

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