The influence of pressure changes on the retentive force and coronal microleakage of different types of posts in endodontically treated teeth during simulated dives

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Abstract

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Objectives: We assessed the influence of a simulated diving environment on the interfacial microleakage and retentive forces of different post types in root-canal-filled teeth.

Materials and methods: One-hundred-and-twenty extracted, single-rooted teeth were endodontically treated and were randomly divided into three groups according to the post and cement used: ER Post/Harvard cement (Titanium), CeraPost/DentinBuild Evo (Zirconia), DT Light Post/Calibra (FRC). Each group was randomly divided into two equal subgroups, a control group, and an experimental group, subjected to simulated dives to 456 kPa in a diving chamber. For 10 specimens of each subgroup the pull-out strength and the coronal microleakage were measured.

Results: Significant differences in the linear coronal penetration were observed between the Titanium and FRC groups (experimental group $P \leq 0.001$; control group $P = 0.02$). Diving simulation had no significant impact on the microleakage for the three post types. The FRC groups showed significantly higher retentive strength values compared to the Titanium and Zirconia groups before and after simulated diving. The pull-out strength of the titanium experimental group was significantly less than the control group ($P = 0.008$).

Conclusions: Following root canal treatment the combination of fibre-reinforced posts and resin cement should be preferred for patients requiring retention for tooth restorations using posts that are likely to be exposed to hyperbaric conditions.

Key words

Dental; pressure; barotrauma; barodontalgia

Introduction

Changes in external pressure, for example, during flying, diving or hyperbaric oxygen treatment, can cause dental pain. Clinical signs and symptoms are observed in aircrew[1] and divers[2] and the term "*barodontalgia*" is used to describe the pain experienced in teeth and initiated by changes in barometric pressure. The incidence of this type of tooth pain is 0.26–2.8% in aircraft personnel, air passengers and divers.[3,4] Barodontalgia appears to occur irrespective of the type of pressure change or, in other words, regardless of whether pressure increases or decreases and can even persist after pressure equalization.[5] Apart from the subjective experience of pain, pressure changes are also reported to cause fractures in dental restorations and a reduction in prosthetic device retention.[6,7]

The effect of barotrauma is directly related to Boyle's Law. The pressure-related changes in volume were found to reduce the retentive strength in materials used for the cementation of full cast crowns,[7,8] orthodontic appliance or glass fiber posts.[9] Loosening or loss of fillings can lead to serious complications, especially in divers.[10] Problems arise when the enclosed spaces containing gases cannot expand or contract to adjust the internal pressure to correspond to the outer pressure.[11] It is known that trapped air can develop even after the completion of an endodontic treatment causing microleakage to occur between the restoration and the walls of the pulp chamber.[12] This could explain the findings of a previous in-vitro study that focused on the pressure changes in root canal-treated teeth during simulated dives and showed that significant differences exist between the pressure inside the pulp chamber and the pressure in the diving chamber after root canal filling.[13]

Depending on the degree of coronal destruction, restorations for root canal-treated teeth sometimes need retention from within the root canal and this is provided by a cemented post and core. It is still unclear however, whether these pressure differences can influence the coronal microleakage and the retention of the different post systems used in post-endodontic restorations. Therefore, the objective of this study was to assess the influence of a simulated diving environment on the interfacial microleakage and retention forces of different post types in root-canal-treated teeth. The tested null hypothesis was that, regardless of the post type used, the initially measured coronal microleakage of the tested posts and the retentive strengths would not decrease after the simulated dives.

Materials and methods

The Ethics committee of the University of Hanover Medical School approved the use of teeth extracted in the Department for Oral and Maxillofacial Surgery. The committee decided that no written or verbal approval was required. The study was performed on 120 recently extracted human single-rooted teeth. The included teeth were with complete root formation and were free of caries, fractures and endodontic treatment prior to extraction. Only teeth with an angulation of the root lower than 45° were included in the study. Selected teeth were stored in isotonic saline solution containing 0.2% sodium azide. The coronal portions of the teeth were removed with carborundum disks at the level of the cement-enamel junction on the buccal surfaces.

SPECIMEN PREPARATION

The root canal of each tooth was instrumented with endodontic files (Mtwo; VDW GmbH, Munich, Germany) operated at 300 rpm resulting in a preparation with 6-degree taper and a 0.25 mm diameter at the apex. Prior to file usage, files were coated with the chelating agent File Care (VDW, Munich, Germany). After each instrument, the canals were irrigated alternately with sodium hypochlorite, sodium chloride and chlorhexidine solutions. The final irrigation (3% NaOCl) was activated ultrasonically for 30 seconds using the VDW.ULTRA™ System (VDW, Munich, Germany), and the root canals were dried with paper points (Roeko paper points, Roeko, Langenau, Germany). Each canal was then obturated using warm vertical compaction of gutta-percha with the BeeFill™ 2in1 system (VDW, Munich, Germany) in combination with a resin-based endodontic sealer (AH Plus, Dentsply De Trey, Konstanz, Germany). The length of the root fillings and the quality of the seal were assessed using radiographs, which were taken in two planes.

After endodontic treatment the teeth were stored for 72 hours in isotonic saline solution. Then 10 mm of gutta percha was removed from the coronal region and the root canals were enlarged with a slow-speed tapered drill (ISO 90) from the Komet ER post kit (Komet, Lemgo, Germany) compatible with the three different post types used in the study. A new drill was used for every 10 specimens. The preparations were acid-etched with 37% phosphoric acid (Total Etch, Ivoclar, Schaan, Liechtenstein) for 20 seconds and thoroughly rinsed and dried with paper points immediately prior to the restoration with the respective post.

The 120 prepared roots were randomly divided into three experimental groups (Table 1). The placement of the posts, the preparation of the cement and the cementation technique were all performed with strict adherence to the manufacturers' instructions. The posts were positioned, and the excess of cement was removed using a microbrush.

In Group 1, titanium posts (ER 61L16, Komet, Lemgo, Germany) were used. The posts were tried in, cleaned with alcohol and dried. A zinc-phosphate cement (Harvard cement, Richter und Hoffmann, Berlin, Germany) was mixed on a glass plate, the posts were coated with cement and then inserted in the prepared spaces using finger pressure and a rotation of 180 degrees. The posts were then manually fixated in this position for two minutes.

Table 1
The three post systems and cementation methods studied; FRC – fiber-reinforced composite

Material	Post	Cement	Adhesive
Titanium	ER 61L16	Harvard Cement	
Zirconia	CeraPost	DentinBuild Evo	DentinBuild Evo
FRC	DT Light SL	Calibra	Prime&Bond NT

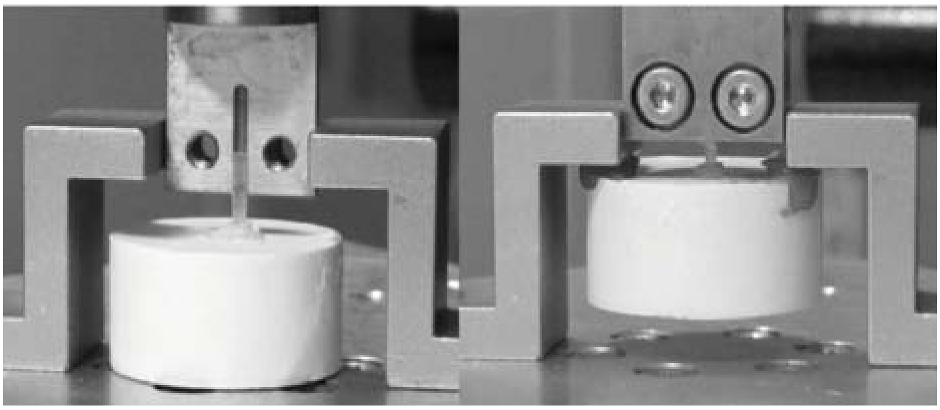
In Group 2, zirconia posts (CeraPost, Komet, Lemgo, Germany) were placed using a dual curing resin (DentinBuild Evo, Komet, Lemgo, Germany), recommended by the manufacturer, after the canals were conditioned with the corresponding DentinBuild Evo self-etching dual-curing adhesive for 30 seconds and the post surface was treated with a silane coupling agent (Monobond S, Ivoclar Vivadent, Schaan, Liechtenstein) for 20 seconds. The resin cement was mixed using a Minimix syringe and was applied to the posts directly from the mixing cartridge. The posts were then seated in the root canal; the excess resin was subsequently removed. Finally light activation was performed for 20 seconds.

For Group 3, fiber-reinforced composite (FRC) posts (DT Light SL Post, VDW, Munich, Germany) were luted with a dual-curing resin cement (Calibra, Dentsply, De Trey, Konstanz, Germany). A self-priming dental adhesive (Prime&Bond® NT, Dentply DeTrey, Konstanz, Germany) was applied with a disposable brush to the canal surfaces for 20 seconds. After removing excess solvent by gently drying, the adhesive was cured for 10 seconds using a curing light. Mixed resin cement was spread on the post surface and posts were seated and stabilized with moderate and consistent pressure, excess was cleaned up and the posts were light-cured for 20 seconds.

For each post type, the influence of simulated dives on the coronal microleakage and the post retention were evaluated. The specimens were then randomly divided into four sub-groups of 10 teeth, in accordance with the experimental procedures outlined in the test protocol:
Group 1: Control group, pull out test;
Group 2: Control group, coronal microleakage evaluation;
The specimens in the control groups underwent no pressurisation. After post placement, the teeth of the control groups were stored in saline solution.
Group 3: Simulated dive, pull out test;
Group 4: Simulated dive, coronal microleakage evaluation.

The simulated dives were performed in a specially equipped diving chamber (Haux; Draegerwerk, Luebeck, Germany) using compressed air. During the dives, changes in pressure at a rate of 101.3 kPa·min^{-1} simulated descents and ascents. For example, a descent of 50 m equivalent sea depth was simulated by increasing pressure to a maximum of 456 kPa.

Figure 1
Pull-out test set up; left – sample embedded in a block of acrylic resin and vertically mounted in the grip assembly; Right – sample fixed with acrylic resin to the universal testing machine before pull out testing



This pressure was maintained in the diving chamber for 5 min. Then the pressure was decreased again at a rate of 101.3 kPa·min^{-1} to simulate the ascent.

CORONAL MICROLEAKAGE EVOLUTION

The samples used for evaluation of the coronal microleakage were immersed and stored for seven days in saline solution at 37^{O}C degrees before applying a homogeneous layer of nail polish on the root surface. After the barrier layer had dried, the teeth were fixed vertically using silicone (Coltoflax Putty, Coltene/Whaledent, Altstaetten, Switzerland) and immersed for 72 hours in methylene blue dye (Löfflers methylene blue solution, Merk, Darmstadt, Germany).

A clearing technique, described previously,[14] was used for direct assessment of dye penetration in which the maximum depth of dye penetration could be accurately recorded. After the barrier layer was removed, the specimens were placed in a 5% sodium hypochlorite solution for 24 hours to dissolve organic debris from the root canal system and washed in running tap water for four hours. The specimens were decalcified for three days in 5% nitric acid at room temperature. The nitric acid solution was changed daily and agitated by hand three times each day. After completion of decalcification, the teeth were rinsed in running tap water for four hours. The dehydration process consisted of a series of ethyl alcohol rinses starting with 80% solution overnight, followed by a 90% solution for an hour, and three 100% ethyl alcohol rinses for an hour each.

The teeth were stored in petri dishes with methyl silicate and the depth of the penetration was measured using an optical stereomicroscope (Carl Zeiss, Oberkochen, Germany). The linear dye penetration was measured at x 20 magnification from the resected coronal root-end, calculated using a graduated measuring scale previously mounted on the microscope lens. The maximum linear leakage was recorded for each specimen.

PULL-OUT TEST

Macro retentions of 1 mm depth were cut with diamond burs perpendicular to their long axis, promoting retention during the pullout test. Each specimen was then embedded in a cylindrical block of chemically-cured acrylic resin (height: 25 mm, diameter: 50 mm), the acrylic resin extending to a level 1 mm below the buccal aspect of the cement enamel junction. To ensure that the posts remained vertical during testing, the lower portion of the post that protruded from the root was affixed to the grip assembly of an universal testing machine (Zwick, Ulm, Germany). Following that, the acrylic block was attached to the inferior portion of the testing machine using acrylic resin (Pattern Resin LS, GC America Inc., Alsip, USA) (Figure 1). After full polymerization of the acrylic resin a pull-out test was performed at a crosshead speed of 2 mm·min^{-1}. The force to dislodge the posts in tension was measured in Newton (N) and the mean calculated for each test group.

STATISTICAL ANALYSIS

Statistical evaluation was performed with SPSS for Windows, Release 17.1 (SPSS Inc., Chicago, Ill, USA). Non-parametric tests (Mann-Whitney U test) were used to determine significant differences ($P \leq 0.05$), as data were not normally distributed (Shapiro-Wilk test, $P < 0.05$). Statistical significance was set at 0.05.

Results

CORONAL MICROLEAKAGE

The results of the dye penetration analysis are shown in Figure 2 and Table 2. Using x 20 stereoscopic magnification coronal leakage could be observed in the samples of all experimental groups. Significant differences in the linear coronal penetration could be observed between the Titanium and FRC groups (experimental group, $P \leq 0.001$;

Table 2
Results of the microleakage evaluation; the penetration depth in mm (standard deviation); FRC – fiber-reinforced composite

Penetration depth	Titanium	Zirconia	FRC
Control group	2.66 (2.29)	1.15 (1.6)	0.16 (0.26)
Simulated dive	4.29 (3.79)	1.19 (1.6)	0.27 (0.33)

Table 3
Results of the pull-out tests: mean pull-out strength (standard deviation) in Newtons (N); FRC – fiber-reinforced composite

Pull-out bond strength	Titanium	Zirconia	FRC
Control group	135 (44.2)	130 (70.2)	260 (59.1)
Simulated dive	77 (34.1)	93 (48.5)	256 (66)

Figure 2
Boxplots for the linear coronal penetration of methylene blue dye in single-rooted human teeth restored, by titanium, zirconia and FRC (fiber-reinforced composite) posts: control group without simulated dives (white); after simulated dives (gray); * $P < 0.001$; † $P = 0.02$

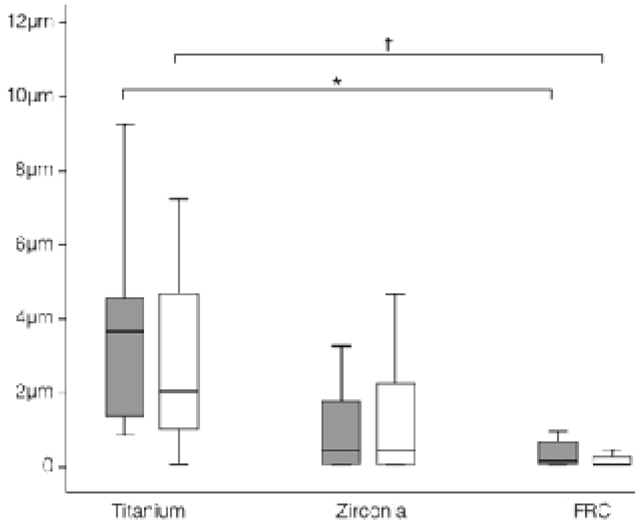
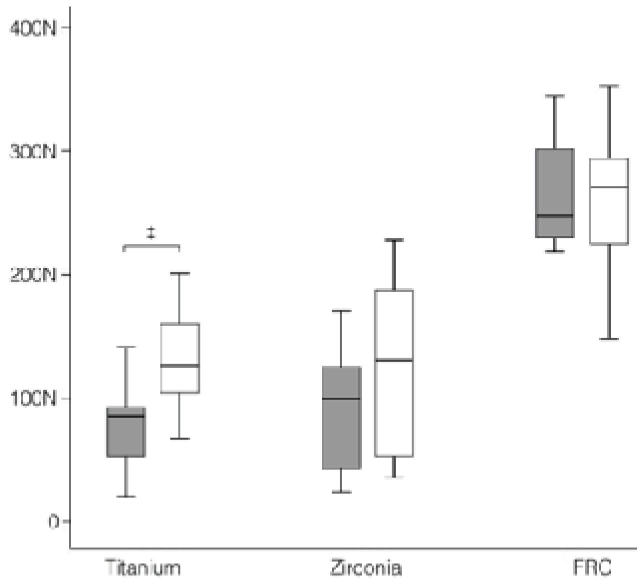


Figure 3
Boxplots for the pull-out strengths, measured on titanium, zirconia and FRC (fiber-reinforced composite) posts: control group without simulated dives (white); after simulated dives (gray); ‡ $P = 0.008$



control group, $P = 0.02$). Mann-Whitney U test showed no significant influence of the diving simulation on the microleakage for the three post types.

PULL-OUT TEST

The results of the pull out test are presented in Table 3 and as box plots in Figure 3. The highest pull-out forces were observed for the FRC post both for the control group (mean 260 N, median 270.1 N, interquartile range 80.1) and the specimens of the simulated dive group (mean 256 N, median 247.7 N, interquartile range 79.7) respectively. These values were significantly higher than the retentive strength values for the Titanium and Zirconia groups. The results of this study indicated that the pull-out strength of the titanium experimental group was significantly less than the control group ($P = 0.008$), but that the pull-out strengths of the experimental groups with Zirconia and FRC posts were not significantly different from the controls.

Discussion

In the present in-vitro study, root-canal-treated teeth, restored with different types of posts were subjected to simulated dives in a diving chamber and the influence of the hyperbaric conditions on the coronal microleakage and the pull-out retentive strength of the posts was investigated. For the teeth with titanium posts cemented with zinc phosphate cement, the tested null hypothesis could be rejected. The simulated dive groups showed significantly lower pull-out strengths and higher values of microleakage then the control groups. For the zirconia and FRC posts, cemented with adhesive resin cements, neither the pull-out strength, nor the microleakage was affected by the simulated dives. Zirconia posts showed the lowest mean in the pull-out test values among the control groups, while the Titanium groups exhibited the highest coronal microleakage.

The study confirmed previous findings on the effect of pressure cycling on the retentive force of zinc phosphate cement for full cast crowns,[7,8] glass fiber posts[15] and orthodontic bands.[9] With conventional cementation, the bond of the restoration is created almost entirely by static friction between the luting material and the restoration and is highly sensitive to the mechanical integrity of the cement layer. Different approaches have been used to explain the retentive force deterioration of conventionally cemented restorations.

On the one hand, it has been shown that pressure changes can lead to volume reduction of the luting material, resulting in microcracks.[16] On the other hand, a finite element study on crowns with different preparation geometries demonstrated that external pressure might increase the internal stress in the cement that subsequently may create cement microfractures and promote microleakage.[17] The estimated stress values for the different types of cement were higher (approximately 20% to 40%) for zinc phosphate cement than other cements.

In the present study, the titanium posts were cemented with a zinc phosphate cement with an average grain size of 8–10 μm. According to the manufacturer's recommendations the zinc oxide powder and phosphoric acid liquid are hand-mixed until a fixation consistency has been reached. Compared to resin cements, zinc phosphate cements pose higher open porosity and specific pore volumes.[18] Larger pores in the set cement can be related to air entrapment in the encapsulated cement during mixing while small pores (0.1–0.5 μm diameter) are indicative of vapourisation porosity commonly seen with exothermic reactions.[19]

Each porous material might have three types of pores: blind, through (open porosity) and closed pores.[20] The closed pores are not accessible to fluids. The blind pores terminate inside the material. The through pores are those that enable the complete passageway of fluids. Porosity that includes closed pores has a great influence on mechanical properties of a material; open porosity has its direct impact in the possibility of penetration of undesired oral fluids, bacteria and bacterial toxins. The effect of barotrauma is directly related to Boyle's Law. With closed pores, the contained gases cannot expand to any extent, corresponding to the outer pressure. The gas pressure dynamics in these pores during pressure cycling might cause microstructural changes and strength reduction of the cement layer, consequently affecting the post retention in the root canal.

A recent study on the differences between the pressure inside the pulp chamber and the pressure in a diving chamber during the various stages of root canal treatment in a simulated diving environment, showed that the lack of adhesively bonded composite sealing of the pulp chamber results in an insufficient pressure-tight seal.[13] In this case, the authors considered that the reason for the differences between the pressure inside the pulp chamber and the pressure in the diving chamber is the irreversible movement of trapped air along the pressure gradient. As for the titanium group, no additional adhesive sealing was performed, a phenomenon that might serve as a further explanation of the reduction of retentive force after pressure cycling.

The most common reason for failure of root canal treatment is the presence of bacteria within the root canal, either as a result of incomplete disinfection during preparation or reinfection due to a poor coronal seal. If a post and core is necessary to provide retention for a crown, the post should provide a hermetic seal. In the present study, titanium posts, placed with zinc phosphate cement showed the highest linear coronal penetration of methylene blue dye before and after the simulated dives. In accordance with other studies,[21,22] this indicates that resin cements provide a far more efficient coronal seal, preventing dye penetration into the post-space region.

The present study demonstrated the superiority of FRC posts over zirconium and titanium posts. For the study, it was decided not to use the same posts for both types of tests in order to avoid a possible influence of the methylene blue dye and the clearing technique on the retention of the posts. Thus, no direct conclusions can be drawn regarding the relationship between coronal microleakage and retentive strength of posts. A comparison of the test results among all groups after pressure cycling revealed an inverse proportionality between the retentive force values and the microleakage. Further research is needed to evaluate a possible correlation of both factors under environmental pressure changes.

Conclusions

Simulated diving, with compression to 456 kPa, decreased significantly the pull-out strength of conventionally cemented titanium posts. Under hyperbaric conditions, the combination of fibre reinforced posts and resin cement for post-endodontic treatment showed the best pull-out strength and coronal microleakage values.

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