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Effects of luting agent and thermocycling on bond strengths to root canal dentine

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Abstract

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Aim To investigate the effects of luting agent and thermocycling on bond strengths to root canal dentine.

Methodology Extracted maxillary canines ($n = 144$) were root filled and divided into six groups of 24 teeth each. Fibre posts (FRC Postec) were inserted using six luting agents: Panavia F, Multilink, Variolink II, PermaFlo DC, RelyX Unicem and Clearfil Core. Each root was sliced into six discs (thickness 1 mm) representing the coronal, middle and apical part of the root canal. Push-out tests were performed 24 h after post insertion ($n = 12$) as well as after thermocycling (5000×; 5–55 °C, 30 s) ($n = 12$). Statistical analysis was conducted using analysis of variance (ANOVA) followed by *post-hoc* comparisons (Tukey-B). The influence of thermocycling on bond strengths was investigated for each material and region separately using *t*-tests.

Results The bond strengths were significantly affected by the luting agent ($P < 0.001$), the root position ($P = 0.003$) and thermocycling ($P < 0.001$; three-way ANOVA). RelyX had significantly higher bond strengths compared with all other materials ($P < 0.05$; Tukey-B). The apical region of the root canal had significantly higher bond strengths compared with the middle and coronal region ($P < 0.05$; Tukey-B). After thermocycling for RelyX a significant increase in bond strengths was detected for the middle and apical region ($P < 0.01$; *t*-test, Bonferroni factor 18).

Conclusions Bond strengths were affected significantly by luting agent and root position. RelyX had higher bond strengths compared with other materials. The apical region of the canals was characterized by significantly higher bond strengths.

Keywords: fibre posts, luting agents, push-out bond strengths, root canal dentine, thermocycling.

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Introduction

Root filled teeth with excessive loss of coronal tooth structure are frequently reconstructed with posts and cores. Posts have been shown to provide retention of the core but obviously do not strengthen the root (Sorensen & Martinoff 1984). Various studies have demonstrated the favourable physical properties of fibre-reinforced composite (FRC) posts (Asmussen *et al.* 1999, Cormier *et al.* 2001, Mannocci *et al.* 2001), which are luted into the root canal. Various luting agents and corresponding adhesive systems have been proposed for bonding FRC posts to root canal dentine. These materials can be divided into self-etching adhesives and etch-and-rinse systems. Bonding to root canal dentine can be influenced by the lack of direct viewing and the difficulties of moisture control. It has been

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demonstrated that the control of moisture after the application and removal of phosphoric acid as well as incomplete infiltration of the resin into the dentine significantly affect bond strengths (Tay *et al.* 1996). Self-etching systems are generally applied on dry dentine and do not require rinsing of the acid. It can be speculated that the thickness of the smear layer inside the root canal may affect the bond strengths. Qualitative analysis of the resin–dentine inter-diffusion zone showed a smaller hybrid layer and fewer resin tags for self-etching adhesive systems compared with etch-and-rinse systems (Bitter *et al.* 2004).

Variations in the structure of the root canal dentine such as accessory root canals, areas of resorption, embedded and free pulp stones, and varying amounts of irregular secondary dentine may affect bonding to root canal dentine (Mjör *et al.* 2001). The evaluation of dentine morphology in root canals in terms of tubule orientation and density revealed a higher tubule density in the cervical compared with the central and apical parts of the root canal (Ferrari *et al.* 2000). Two recent studies did not report any influence of the region in the root canal on bond strengths (Goracci *et al.* 2004, Foxton *et al.* 2005), whereas a previous study revealed higher bond strengths in the apical third than in the other parts of the root canal (Gaston *et al.* 2001). In contrast, further studies observed decreased bond strengths in the apical region of the root canal (Bouillaguet *et al.* 2003, Mallmann *et al.* 2005).

Little is known about the long-term clinical bonding behaviour of adhesively luted FRC posts. The clinical conditions can be simulated *in vitro* by thermal or mechanical loading. Therefore, the aim of this investigation was to evaluate the bond strengths of various agents recommended for luting FRC posts to root canal dentine before and after thermocycling. The null hypothesis to be tested was that bond strengths to root canal dentine do not vary with thermocycling, type of luting agent, and region inside the root canal.

Materials and methods

A total of 144 maxillary canines, predominantly extracted for periodontal reasons, were selected. Teeth with roots showing resorption, cracks or caries were excluded. External debris was removed with an ultrasonic scaler and the teeth were stored in 0.1% thymol prior to the study.

The crowns of the teeth were removed at the cemento-enamel junction (CEJ) with a diamond blade under water cooling. All roots had a length between 17 and 21 mm. The middle and coronal thirds of the root canal were enlarged using sizes 1–4 Gates Glidden burs (VDW, Munich, Germany) in descending order. Subsequently, the instrumentation phase of root canal preparation was performed at a working length of 1 mm from the apical foramen using FlexMaster rotary instruments (VDW) in a crowndown technique. Apical enlargement was performed to size .02/50. Irrigation (Endoneedle; Vedefar, Dilbeek, Belgium) was performed using 1 mL of 1% NaOCl solution after every change of file size throughout the cleaning and shaping of the root canal. After drying with paper points the teeth were filled by means of cold lateral condensation. Size 50 gutta-percha points (VDW) served as master cones and size 20 and 25 gutta-percha points were used as accessory points. AH plus (DeTrey Dentsply, Konstanz, Germany) was used as a sealer in all cases. Coronal surplus of the root filling was removed with a heated excavator and the pulp chambers were temporarily filled with Cavit (3M ESPE, Seefeld, Germany) and stored for 24 h at 37 °C in 100% humidity.

The samples were randomly divided into six groups of 24 teeth each. The root canals of each sample were enlarged with a low-speed drill provided by the manufacturer of the post system (FRC Postec Reamer Size 3, #572800AN; Ivoclar Vivadent, Schaan, Liechtenstein). All specimens were prepared by one practitioner in a standardized procedure. The depth of the post space preparation was 12 mm with the diameter of the post space preparation being constant for all teeth. Irrigation after preparation was performed with 0.9% NaCl solution. Because of the length of the roots ranging from 17 to 21 mm, at least 4 mm of the root canal filling remained inside the canal. 'FRC Postec' posts Size 3 (Ivoclar Vivadent) were tried-in and inserted with one or other of the following six different luting agents according to the manufacturers' instructions: Panavia F (PAN), Multilink (MUL), Variolink II (VAR), PermaFlo DC (PER), RelyX Unicem (REX), and Clearfil Core (CLC) (Table 1). The posts were cleaned with alcohol and the respective bonding of the luting agent used was applied prior to insertion.

For the investigated materials that required the use of phosphoric acid, the etching gel (35%) (Total Etch; Ivoclar Vivadent) was applied using an endodontic syringe (Endoneedle) to guarantee a uniform layer of acid inside the canal; after 15 s the gel was washed out with water using again an endodontic syringe. Excess water was removed using paper points and the adhesive systems were applied using a microbrush tip

Table 1 Investigated materials

Group	Luting agent	Bonding agent	Manufacturer	Composition of composite resins	Composition of primers	Polymerization mode	Conditioning method	Material for core build-up
PAN	Panavia F	Ed Primer	Kuraray, Osaka, Japan	Barium glass powder, sodium fluoride, dimethacrylate, MDP, silica, benzoyl peroxide, amine, sodium aromatic sulfinate	10-MDP, HEMA, *N*-methacryl 5-aminosalcylic, sodium benzene sulfinate, *N*,*N*′-diethanol *p*-toluidine, water	Dual	Self-etching primer	Clearfil Core (Kuraray)
MUL	Multilink	Multilink Primer A&B	Ivoclar Vivadent, Schaan, Liechtenstein	Dimethacrylate, HEMA, barium glass, ytterbium trifluoride, silica	Water, phosphoric acid acrylate, HEMA, polyacrylic acid modified methacrylate resin	Chemical with light curing option	Self-etching primer	Multicore HB (Vivadent)
VAR	Variolink II	Excite DSC		Bis-GMA, urethane dimethacrylate, triethylene glycol dimethacylate, ytterbium trifluoride, barium glass, silica	HEMA, Bis-GMA, glycerine dimethacrylate, phosphoric acid acrylate, highly dispersed silica, ethanol	Dual	H_3PO_4 (35%) 15 s	Multicore HB (Vivadent)
PER	PermaFlo DC	PermaFlo DC Primers A&B	Ultradent, Salt Lake City, UT, USA	Bis-GMA, benzoyl peroxide, tertiary amine	–[a]	Dual	H_3PO_4 (35%) 15 s	Perma Flo DC
REX	RelyX Unicem		3M ESPE, Seefeld, Germany	Silica, glass, calcium hydroxide, methacrylated phosphoric ester, dimethacrylate, acetate	No primer available	Dual	Self-adhesive resin cement	RelyX Unicem
CLC	Clearfil Core	New Bond	Kuraray, Osaka Japan	Bis-GMA, TEGDMA, silica, silanated glass powder, benzoyl peroxide, amine	10-MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, benzoyl peroxide, *N*,*N*′-diethanol *p*-toluidine, sodium benzene sulfinate, ethylalcohol	Chemical	H_3PO_4 (35%) 15 s	Clearfil Core

Materials used in the present investigation including compositions of primer and composite resin, polymerization mode, conditioning method and the used material for the core build up.
[a]Data not given by the manufacturer.

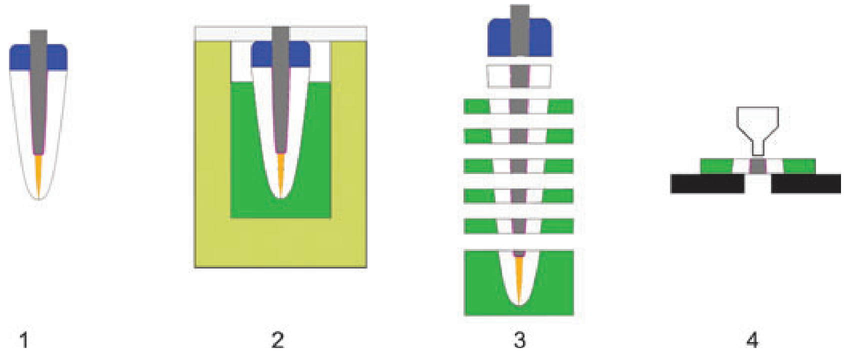

Figure 1 Sample preparation: after insertion of the post the roots received a resin core build-up (1) and were embedded in methacrylate resin (Technovit) perpendicular to the long axis of the post 2 mm below the CEJ (2). Subsequently, the roots were sectioned into six slices (1 mm thick) starting 2 mm below CEJ (3) and push-out tests were performed using a universal testing machine (4).

(Microbrush International, Grafton, WI, USA). Subsequently, the cement was applied onto the surface of the posts as well as into the orifice of the root canals using a small spatula. The posts were inserted into the canal and surplus was removed. In cases of dual curing systems air block gel was applied and light curing was performed for 30 s using a halogen lamp (1200 mV cm^{-2}; Astralis 10, Ivoclar Vivadent). A crown build-up (height 4 mm) was performed freehand using the materials represented in Table 1 (Fig. 1(1)).

All samples were stored in saline solution for 24 h at 37 °C. The roots were then embedded in methacrylate resin (Technovit 4071; Heraeus Kulzer, Wehrheim, Germany) 2 mm below the CEJ perpendicular to the long axis of the post. For this purpose plastic moulds with a central cylindrical hole (25 mm deep) and acrylic glass plates with a central cut-out in the size of the top of the post (diameter 2 mm) fitting exactly onto the plane surface of the plastic moulds were fabricated (Technical Department, Charité – Universitätsmedizin Berlin, Berlin, Germany). For the embedding process the top of the post was fixed into the cut-out of the acrylic glass and the methacrylate resin was placed into the hole of the plastic mould. Subsequently, the acrylic glass was placed onto the plastic mould and, consequently, the specimens were embedded perpendicular to the long axis of the post (Fig. 1(2)).

The push-out bond strengths were determined in all groups after 24 h water storage ($n = 12$) as well as after thermocycling ($n = 12$). Thermocycling was performed for 5000 cycles in deionized water from 5 to 55 °C with a dwelling time of 30 s in each bath and a transfer time of 2 s. Because of the surrounding methacrylate resin the crown build-up was predominantly loaded by the thermal stresses.

In order to obtain the sections for the push-out testing the methacrylate barrels were placed on a slide perpendicular to the long axis of the tooth. Six slices of the roots (thickness: 1 mm) were obtained using a microtome saw (Exakt Apparatebau, Norderstedt, Germany) starting 2 mm below the CEJ (Fig. 1(3)). The thickness of the saw blade was 0.1 mm and the inter-slice thickness was 0.3 mm which was included into the calculation of the bonding surface of the post.

The first two sections represented the coronal, the following two the middle and the last two the apical region of the post space preparation. Subsequently, all specimens were observed with a stereomicroscope (DV 4; Zeiss, Jena, Germany) to detect any artefacts caused by the slicing process; no artefacts were observed.

After the slicing process the push-out tests were performed at a cross-head speed of 0.5 mm min^{-1} using a universal testing machine (Zwick; Roell, Ulm, Germany) (Fig. 1.4). With regard to the tapered design of the post, three different sizes of punch pins as well as three different openings were used for the push-out testing. The diameter of the punch pin was 1.2 mm and the diameter of the opening 2.5 mm for the coronal two slices, 1.0 and 2.0 mm for the two middle slices and 0.8 and 1.5 mm for the two apical slices. This way, it was guaranteed that the overlaying root dentine was sufficiently supported during the loading process.

The maximum failure load was recorded in N and converted into MPa. The maximum stress was calculated from the recorded peak load divided by the computed surface. In order to calculate the exact

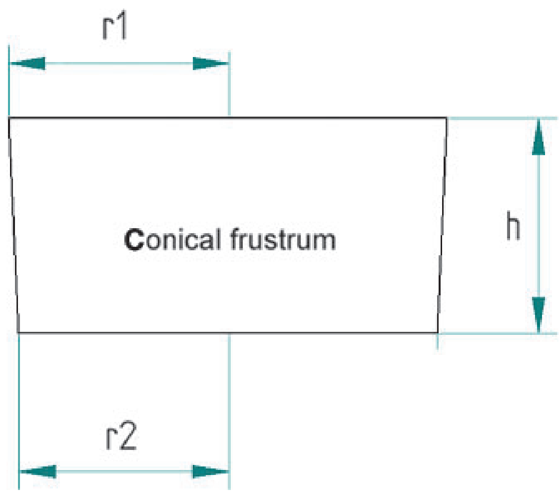

Figure 2 Illustration of a conical frustrum to demonstrate the calculation of the bonded post surface according to the formula: $\pi\ (R_1 + R_2)\surd(R_1{-}R_2)^2 + h^2$.

bonding surface, the tapered design of the posts with regard to the respective part of the post was considered. Therefore, each specimen was measured with a micrometer screw (Mitutoyo Messgeräte GmbH, Neuss, Germany) and the bonding surface was calculated using the formula of a conical frustrum: $\pi\ (R_1 + R_2)\surd(R_1{-}R_2)^2 + h^2$ (Fig. 2).

After the push-out tests each specimen was observed using a stereomicroscope (DV 4; Zeiss) at 40× magnification from the cervical as well as from the apical direction to determine the failure mode. The observation was performed by two independent operators and the specimens were divided into four groups according to the failure mode: group 1: adhesive failures between dentine and cement; group 2: adhesive failures between post and cement; group 3: cohesive failures inside the cement; group 4: cohesive failures inside the dentine. Furthermore, representative samples of the fracture modes of each group were studied using scanning electron microscopy (SEM) (Cam Scan Maxim 2040; Cam Scan Maxim Electron Optics Ltd, Cambridge, UK). The evaluation was conducted using the low vacuum-mode at 50× and 300× magnification.

For each tooth six measurements were entered into the statistical analysis and were aggregated into three measurements for each tooth representing the respective three regions of the root canal.

All statistical analyses were performed using commercially available software (SPSS for Windows 12.0; SPSS GmbH, Munich, Germany). The effect of luting agent, thermocycling and region inside the root canal on bond strengths was analysed using analysis of variance (ANOVA) and *post hoc* comparisons were performed using Tukey-B. In order to determine the bond strengths of the region for each material separately one-way ANOVA with *post hoc* Tukey-B were performed. Furthermore, the influence of thermocycling on bond strengths was investigated regarding each luting agent and region separately using *t*-test with an adjusted *P*-level (factor 18). In a secondary analysis the luting agents were divided according to their mode of polymerization and conditioning method. The influence of these factors on bond strengths was analysed using a two-way ANOVA. The level of significance was 0.05.

Results

The bond strengths were significantly affected by the luting agent ($P < 0.001$), the region inside the root canal ($P = 0.003$) and thermocycling ($P < 0.001$; three-way ANOVA).

The *post hoc* analysis revealed REX had a significantly higher bond strength compared with all other materials ($P < 0.05$; Tukey-B). For VAR significantly lower bond strengths compared with all other materials except MUL were observed ($P < 0.05$; Tukey-B) (Fig. 3).

The apical region revealed significantly higher bond strengths [11.4 (5.5) MPa] compared with the middle [10.0 (4.6)] and the coronal [10.0 (3.8) MPa] region ($P < 0.05$; Tukey-B).

For PAN a significant influence of the region on bond strengths could be detected ($P = 0.006$; one-way ANOVA, Bonferroni factor 6). Significantly higher bond strength values were measured in the apical [12.7 (4.8) MPa] compared with the middle [9.6 (4.0) MPa] and coronal [8.4 (2.6) MPa] part ($P < 0.05$; Tukey-B). The region of the root canal did not affect the bond strengths to root canal dentine of all other materials ($P > 0.05$; one-way ANOVA, Bonferroni factor 6).

Thermocycling significantly affected the bond strengths of REX to root canal dentine ($P < 0.01$; *t*-test, Bonferroni factor 18). After thermocycling significantly higher bond strength values for the middle [17.4 (5.1) MPa] and the apical [18.3 (4.1) MPa] regions of the root canals compared with the initial bond strengths in the middle [9.8 (4.1) MPa] and the apical [11.3 (3.1) MPa] parts of the root canals were observed. For all other materials no significant influ-

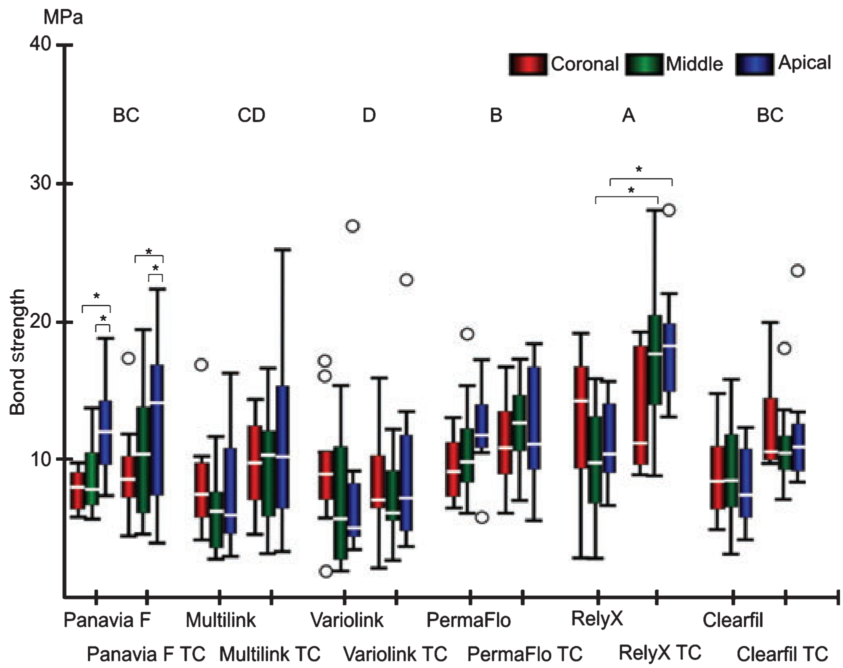

Figure 3 Box-and-whiskers-plot representing the bond strengths of the investigated materials before and after TC. Different superscript letters indicate significant differences between the groups. For each material the bond strengths of the three regions inside the root canal (red = coronal, green = middle, blue = apical) are demonstrated. *Significant differences between regions. For Panavia F significantly higher bond strength values were detected for the apical region ($P = 0.006$; one-way ANOVA, Bonferroni factor 1). RelyX revealed higher bond strengths after TC in the middle and apical region of the root canals ($P < 0.01$; *t*-test, Bonferroni factor 18). The upper and lower limitations of the boxes indicate the first (25%) and third (75%) quartile of the observations ($q_{0.25}$ and $q_{0.75}$). The box length thus is defined as $d = q_{0.75} - q_{0.25}$. The upper antennae terminate at the maximum of observations within the range $q_{0.75} + 1.5d$. The lower antennae are defined analogously. All observations smaller than $q_{0.25} - 1.5d$ or larger than $q_{0.75} + 1.5d$ are indicated as circles.

ence of thermocycling on bond strengths could be detected ($P > 0.05$; *t*-test, Bonferroni factor 18).

In the secondary analysis the mode of polymerization revealed a significant influence on bond strengths ($P = 0.006$), whereas no significant influence could be detected for the conditioning method ($P = 0.553$; two-way ANOVA). Dual cured resin cements revealed significantly higher mean (SD) bond strengths [10.9 (5) MPa] compared with chemical cured resin cements [9.6 (4.2) MPa].

Analysis of failure modes is presented in Table 2. PER had significantly more adhesive failures between composite and post (91.7%) compared with the other materials; after thermocycling a significant increase in adhesive failures between composite and dentine (59.7%) was detected ($P < 0.001$; chi-square test).

Representative SEM observations of the different failure modes in overview pictures (50×) and detailed images (300×) are presented in Fig. 4a–c.

Discussion

The present study investigated the bond strengths of various resin cements to root canal dentine using a push-out model. Push-out tests result in a shear stress at the interface between dentine and cement as well as between post and cement (Van Meerbeek *et al.* 2003); this is comparable with the stresses under clinical conditions. The push-out design is characterized by polymerization stresses that would happen in the clinical situation (Frankenberger *et al.* 1999a). Reproducible bond strength measurements using a conical version of the push-out design with slices of 1 mm in thickness compared with microtensile techniques has been reported (Frankenberger *et al.* 1999b). Recently the effect of friction that contributes to the bond strengths of fibre posts using a push-out model was emphasized; it was demonstrated that the friction stresses occurring seemed to exceed the bond strengths

Table 2 Failure mode

		Failure mode (%)			
Material	Loading	Adhesive composite/ dentine	Adhesive composite/ post	Cohesive composite	Cohesive dentine
Panavia	Initial	52 (72.5)	12 (16.7)	7 (9.7)	1 (1.4)
	TC	61 (84.4)	1 (1.4)	9 (12.5)	1 (1.4)
Multilink	Initial	69 (98.6)	1 (1.4)	0	0
	TC	70 (97.2)	0	2 (2.8)	0
Variolink	Initial	69 (95.8)	1 (1.4)	0	0
	TC	64 (88.9)	3 (4.2)	5 (6.9)	0
PermaFlo	Initial	5 (6.9)	66 (91.7)*	0	1 (1.4)
	TC	43 (59.7)*	23 (31.9)	6 (8.4)	0
RelyX	Initial	42 (58.3)	13 (18.1)	17 (23.6)	0
	TC	40 (55.6)	19 (26.4)	13 (18)	0
Clearfil	Initial	64 (88.9)	2 (2.8)	14 (8.3)	0
	TC	55 (76.4)	3 (4.2)	14 (19.4)	0

Analysis of failure mode observed for the different investigated materials before and after TC. For PermaFlo significantly more adhesive failures between composite and post compared with all other investigated materials could be observed. After TC a significant increase of adhesive failure between composite and dentine could be detected (*$P < 0.001$; chi-square test).

of the adhesive systems (Goracci *et al.* 2005). Resin cements without using adhesives did not reveal any significantly reduced bond strengths compared with the application of adhesive systems. Nevertheless, previous studies demonstrated substantial premature failures, if using the microtensile technique to evaluate the bond strengths to root canal dentine because of the lower bond strength values with this substrate (Bouillaguet *et al.* 2003, Goracci *et al.* 2004, Mallmann *et al.* 2005). Therefore, the push-out design was used in the present investigation.

The materials were selected because of the different conditioning methods and modes of polymerization. In the present investigation, the measurements of bond strengths were performed before and after thermocycling with the aim of imitating clinically occurring thermal stresses. The samples were embedded into methacrylate resin 2 mm below the CEJ; thus, the thermal stresses predominantly reached the core build-up, the top of the fibre post and the cervical region of the teeth, which is comparable with the clinical situation. Nevertheless, no evidence exists that failures in clinical practice occur because of thermal stresses, notwithstanding their theoretical expectation (Gale & Darvell 1999). Therefore, the results of the present investigation have to be interpreted carefully with regard to predicting the clinical performance of post and core restorations.

The null hypothesis of the present investigation has been rejected. The bond strengths did vary with the type of luting cement, thermocycling and region inside the root canal.

The self-adhesive resin cement RelyX Unicem revealed higher bond strength values compared with all other materials; these values even increased after thermocycling.

RelyX Unicem exhibits a moisture tolerance because of water forming during the neutralization reaction of phosphoric-acid methacrylate, basic fillers and hydroxy apatite (data provided by the manufacturer). This could be an explanation for the good performance in the present study, because moisture content after rinsing the root canal is difficult to control because of the poor visibility. Furthermore, the narrow canal holds water by surface tension, making it difficult to displace water with bonding agents (Helfer *et al.* 1972). Thus, enhanced moisture content inside the root canal might have led to reduced bond strength values of the other systems, even though the root canals were dried carefully using paper points.

The present results contradict the outcome of another study that revealed significantly higher bond strengths for the combination of Excite DSC/Variolink compared with RelyX Unicem (Goracci *et al.* 2004). In this investigation RelyX Unicem was auto-cured, whereas in the present study it was initially light cured. The increase in bond strengths with RelyX Unicem after thermocycling is difficult to explain. Complete polymerization of the chemically cured part of this composite material could have contributed to

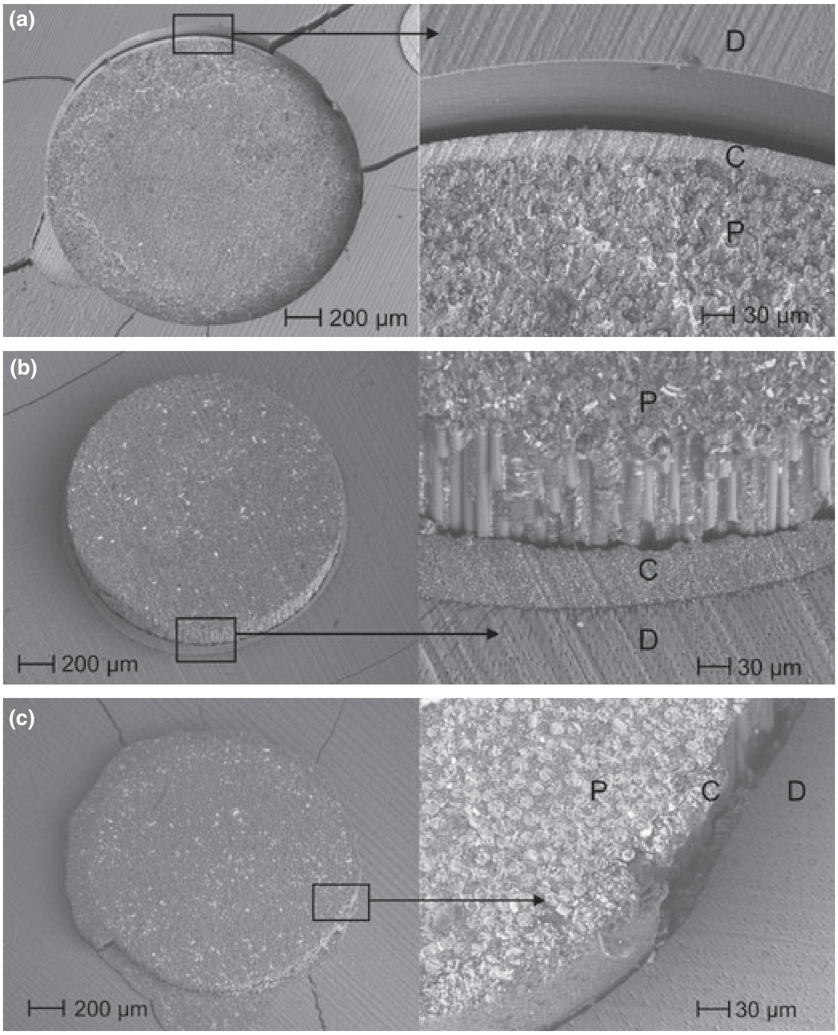

Figure 4 (a) Representative SEM observation of an adhesive failure between cement (C) and dentine (D) of the material Multilink (C) of the coronal part of the root canal in overview (50×) and detailed image (300×). Cracks that could be seen are due to drying artefacts during SEM observation. (b) Representative SEM analysis of an adhesive failure between post and cement of the material Clearfil Core of the apical part of the root canal (50× and 300×). (c) Cohesive failure inside the resin cement of the apical part of the root canal (RelyX Unicem) (50× and 300×).

enhanced bond strengths after thermocycling. However, because of the isolation of the embedding methacrylate resin thermocycling exhibited only small weakening effects to the adhesive–dentine interface inside the root canal. Although an increase in bond strengths after thermocycling for RelyX Unicem was also observed in other studies (Abo-Hamar *et al.* 2005, Piwowarczyk *et al.* 2005, Reich *et al.* 2005), further studies are clearly warranted on this topic.

The interaction between the high C-Factor of the 'post-space-preparation-cavity' and the polymerization shrinkage of the resin materials resulted in highly unfavourable conditions for the adhesive luting of endodontic posts (Tay *et al.* 2005). In contrast to theoretical expectations, dual-cured resin cements revealed significantly higher bond strengths in the present investigation compared with chemically cured cements that exhibit more flow during the slow setting polymerization process (Feilzer *et al.* 1993). Furthermore, other investigators revealed significantly higher bond strengths of chemically cured resin cements compared with dually cured luting agents (Ari *et al.*

2003, Bouillaguet *et al.* 2003). On the other hand, any significant differences in bond strengths to root canal dentine were not reported between light-cured and self-cured adhesive systems (Foxton *et al.* 2005, Mallmann *et al.* 2005). However, the differences in bond strengths for the mode of polymerization were less than 1.5 MPa in the present study. Thus, the clinical relevance of the demonstrated differences should be considered carefully.

The demineralization of root canal dentine either with phosphoric acid or self-etching systems did not reveal any significant influence on bond strengths. Accordingly, a recently published investigation did not show any significant difference in bond strengths to coronal dentine between an etch-and-rinse adhesive compared with a two-step-self-etch adhesive, even after long-term thermo-mechanical loading (Frankenberger *et al.* 2005). Furthermore, it has been reported that the thickness of the smear layer did not influence the adhesive capacity of self-etch adhesive systems (Tay *et al.* 2000).

The bond strengths in the present study were significantly affected by the region of the root canal. This overall significance can be mainly attributed to the material Panavia F that revealed significantly higher values for the apical region. A previous study also demonstrated significantly higher bond strength values for the apical region inside the root canal (Gaston *et al.* 2001). The present results contradict another study that revealed no differences in regional bond strengths for the material Panavia F (Bouillaguet *et al.* 2003). Therefore, it can be concluded that bond strengths to root canal dentine seem to be related more to the area of solid dentine than to the density of dentinal tubules (Gaston *et al.* 2001, Foxton *et al.* 2005).

As observed previously (Bouillaguet *et al.* 2003, Goracci *et al.* 2004), bond strengths to root canal dentine exhibited lower values compared with coronal dentine. Analyses of the failure modes in the present investigation also demonstrated only isolated cohesive failures inside the root canal dentine, which indicates that bond strengths to root canal dentine were weaker compared with the shear bond strength of the dentine itself. For PermaFlo, significantly more adhesive failure between post and cement compared with the other occurring failure modes could be detected. Therefore, the bond strength between post and cement should be considered as the limiting factor of the measured bond strength values.

A recently published investigation revealed degradation of collagen fibrils because of bacterial colonization, release of bacterial enzymes, and host-derived matrix metalloproteinases in root dentine after clinical function. The authors speculated that these enzymatic activities may also occur within incompletely resin-infiltrated, subsurface regions of hybrid layers that may have been created by contemporary adhesive systems (Ferrari *et al.* 2004). Therefore, hydrolytic degradation of root dentine–resin cement–post interfaces should be investigated in further studies, in addition to prospective long-term clinical studies on the clinical performance of adhesively luted fibre posts.

Conclusion

The present study revealed that bond strengths to root canal dentine did vary with type of luting agent, thermocycling and region inside the root canal. The material RelyX Unicem showed significantly higher bond strength values compared with all other investigated materials.

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