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Impact of adhesive surface and volume of luting resin on fracture resistance of root filled teeth

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Abstract

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Aim To investigate the correlation between geometric parameters of severely compromised root filled (RCT) pre-molar teeth with irregular root canals and their fracture resistance. The null hypothesis tested was that the fracture resistance of root filled teeth is not influenced by: (i) the adhesive surface of the post-space preparation (A_{PS}), (ii) the coronal tooth surface (A_A), (iii) the amount of resin cement (V_C) and (iv) the Young's modulus of the specimens.

Methodology A total of 48 noncarious human pre-molar teeth with irregular root canals were decoronated, root filled and adhesively restored with post-retained direct composite crowns. After thermo-mechanical loading (1 200 000×, 5–50° C), static load was applied until failure. The geometric parameters of the tooth were evaluated by microcomputed tomography (μCT) using impressions taken after post-space preparation. Linear regression analyses were performed to correlate the geometric parameters of the specimens with their fracture resistance.

Results The amount of resin cement (V_C) comprised up to 88% of the entire post-space (mean 67%) and had no impact on the maximal load ($P = 0.88$). The latter was significantly influenced by post-space preparation ($P = 0.003$).

Conclusions Amongst the geometric parameters tested, the surface area in the root canal had the greatest impact on fracture resistance of root filled pre-molars restored with posts and composite crowns, whilst the fit of the post was less important.

Keywords: bonding surface, endodontic post, form congruence, fracture resistance.

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Introduction

There is general agreement that the high susceptibility to fracture of root filled teeth is associated less with changes in the dentine structure and rather more with the extent of coronal tooth tissue loss. (Schwartz & Robbins 2004, Dietschi *et al.* 2007). When posts are required for intraradicular anchorage of the coronal build-up, several parameters, such as post-type, post-fit, luting material, core material and type of coronal restoration, have been found to influence the stability of the residual tooth surface (Schwartz & Robbins 2004). In addition, the surface available for adhesion of the composite material is believed to be an important factor for tooth stabilization (Eakle 1986). Thus, in root filled teeth, the bonding area within the root canal and in the coronal part of the tooth may play a decisive role.

To assess the impact of the remaining bonding area of decayed teeth on fracture resistance, standardized measures are mandatory to accurately evaluate the decisive geometric parameters. Recently, a method has been described to define the dimensions of defects in

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root filled teeth *in vivo* and *ex vivo* (Naumann *et al.* 2006). For this evaluation, several measurements were performed in different tooth regions with a periodontal probe. Teeth were classified according to the remaining vertical tooth structure, the thickness of the cavity walls and the dimensions of the canal orifice. Although this method has been proved to be reproducible in terms of intra- and interexaminer reliability, it is more suitable for classifying defects than for accurately determining the residual tooth substance.

Laser profilometry has been used to measure the surface area of occlusal rest seats prepared for removable partial dentures (Culwick *et al.* 2000). In a different approach, the computer-aided design-unit (CAD) of the Cerec System (Sirona Dental Systems, Bensheim, Germany) was applied to measure the remaining tooth substance of decayed teeth (Naumann & Reich 2005) and the bonding area of intra- and extracoronal tooth preparations (Mörmann & Bindl 2006). This method is, however, restricted to the coronal part of the tooth and does not include the area of the root canal. The application of microcomputed tomography (μCT) facilitated the visualisation of the root canal anatomy in human maxillary molar teeth and allowed the surface area and volume of each root canal to be determined accurately (Peters *et al.* 2000).

The cement thickness is another factor associated with fracture resistance in root filled teeth with radicular posts. The thickness of the luting medium depends mainly on whether form congruence can be achieved between the post and root canal. An analysis of cross sections of human teeth demonstrated a high prevalence of teeth with long oval root canals with the long canal diameter more than two times greater than the short one (Wu *et al.* 2000). Recent μCT analyses of teeth with long oval root canals have shown that the thickness of buccal and lingual dentine walls was greater than that of mesial and distal walls at all levels of the entire root length (Grande *et al.* 2008). Thus, applying a form congruent post-space preparation results in the removal of large amounts of sound dentine and increases the risk of perforation, particularly on the mesial and distal walls. On the other hand, post-cementation without form congruent preparation may be associated with an increased volume of luting material in root canals with irregular or oval cross sections.

The aim of this study was to investigate a possible correlation between geometric parameters of root filled premolar teeth with severely compromised coronal structure and their fracture resistance. The null hypothesis tested was that the fracture resistance of root filled teeth is not influenced by: (i) the adhesive surface of the post-space preparation, (ii) the coronal tooth surface, (iii) the amount of luting resin or (iv) the Young's modulus of the specimens.

Materials and methods

Tooth preparation

A total of 48 noncarious human mandibular premolar teeth with similar dimensions at the cemento-enamel junction (CEJ) obtained directly after extraction in a population of Swiss adults were selected. All teeth were cleaned and stored in 0.1% thymol solution until further processing. The clinical crowns of all teeth were removed 1 mm apically to the CEJ using a diamond bur under water cooling to simulate severely decayed teeth. Root canals were prepared using NiTi rotary instruments (Race; FKG, La Chaux-de-Fonds, Switzerland) under intermittent rinsing with 1% sodium hypochlorite to an apical size 45. The root canals were filled with warm injected gutta-percha (Obtura II; Obtura Corp., Fenton, MO, USA) using an epoxy sealer (AH plus; De Trey, Konstanz, Germany) as described recently (Buttel *et al.* 2009). For intra-radicular anchorage of the core, pre-fabricated fibre-reinforced composite (FRC) posts were used. The root filling material was removed up to 6 mm below the amputation plane with a round bur. The FRC post (FRC Postec, size 2; Ivoclar Vivadent, Schaan, Liechtenstein) was tried in and the selected post-length of 6 mm within the post-space was verified.

When the FRC post could not be inserted up to the prepared depth of 6 mm, the diameter of the post-space was adjusted using the appropriate drills of the same size and taper. Excess gutta-percha or sealer was removed from the post-space and from the lateral canal irregularities under an operating microscope. Following this process, the root filled specimens represented tooth situations prepared for subsequent post-cementation. In this phase of the restorative procedure, an impression was made of the entire surface available for luting the post and core. This surface area comprised the cervical tooth plateau [amputation surface (A_A)] and the prepared post-space (A_{PS}) (Fig. 1). For this procedure, silicon impression material (President regular body; Coltene-Whaledent AG, Altstätten, Switzerland) was injected into the post-space and stabilized with sections of wooden toothpicks.

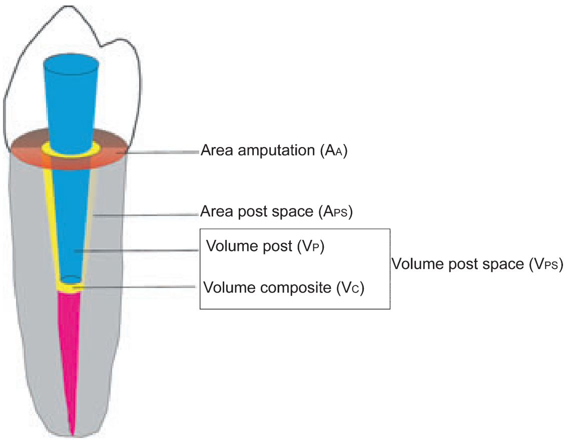

Figure 1 Schematic diagram of post-and-core specimens, illustrating the geometric parameters analysed.

Restorative procedures

After taking impressions and cleaning the dentine surface, a dual curing build-up composite material (Multicore Flow; Ivoclar Vivadent) was used to both cement the post and restore the clinical crowns. To promote adhesion to the tooth surface, a dual curing adhesive (Excite DSC; Ivoclar Vivadent) was used according to the manufacturers' instructions. Transparent moulds (Pella crowns; Odus, Dietikon, Switzerland) with anatomically formed occlusal surfaces were used to make standardized direct composite crowns (4 mm high). The roots of all teeth were coated with an air-thinned layer of polyvinylsiloxane (President light body; Coltene-Whaledent AG) to simulate a periodontal ligament. The specimens were then fixed with a light-curing composite on custom-made metallic holders (Provac, Balzers, Liechtenstein), and the roots were further embedded in self-curing acrylic resin (Demotec 20; Demotec Siegfried Demel, Nidderau, Germany). After embedding, the restoration margin was situated approximately 1.5 mm above the acrylic level. The samples were stored in water until further processing.

Mechanical loading

All specimens were mechanically loaded at the centre of the occlusal surface in a computer-controlled masticator (CoCoM 2; PPK, Zurich, Switzerland). Stressing comprised 1.2 million occlusal loads of 49 N at a frequency of 1.7 Hz using human cusps and simultaneous thermal stress with 3000 temperature cycles of 5-50-5 °C. These conditions were intended to simulate approximately 5 years of clinical service (Krejci *et al.* 1994). The fatigued samples were further tested for fracture resistance in a universal testing machine (Zwick, Ulm, Germany). Specimens were fixed in a metal holder with the long axis of the roots at an angle of 45° to the direction of the load. A linear load (crosshead speed of 0.5 mm min^{-1}) was applied on the central fissure of the occlusal surface in the direction of the buccal cusp until fracture. The maximal loads (N) yielded the fracture resistance. The effective Young's modulus of the entire experimental set-up was determined for each specimen using the data obtained from the static loading procedure (Fig. 2).

Surface analysis

All impressions were exposed to an interface analysis with microcomputed tomography (μCT). Using the conventional μCT-system SkyScan 1174™ (Kottich, Belgium), each individual specimen was scanned with an accelerating voltage of 50 kVp, a beam current of 0.8 mA and an isotropic pixel size of 14.34 μm. The 1800 projections equidistantly taken over 360° with 1.5 s exposure time per projection were used for the reconstruction with the Necron software package (SkyScan), based on a modified Feldkamp algorithm. The resulting three-dimensional data were qualitatively evaluated using VG Studio Max 2.1 (Volume Graphics, Heidelberg, Germany). Subsequently, the data sets were analysed with the dedicated software code (Image Lab GmbH, Winterthur, Switzerland). The reconstructed

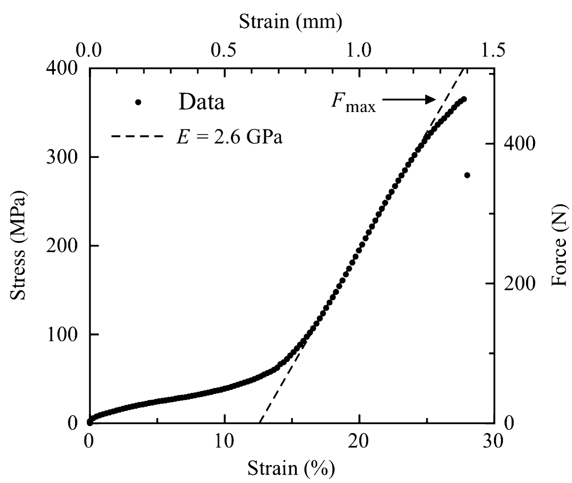

Figure 2 Typical stress–strain curve of one specimen from the load-to-fracture analysis. The Young's modulus is calculated as the slope of the straight line portion of the curve.

axial data sets were converted into transversal radial profiles across the post-centre and used for semi-automatic segmentation. Each impression specimen was characterized by nearly one hundred profile charts. The border of the preparation margin, i.e. the outermost points of the horizontal amputation surface (A_A), was set manually in each cross section. The demarcation line along the post and the amputation face was drawn automatically by distinguishing the different local X-ray absorption (grey scale) values basically between the impression paste and the ambient air. Discriminating between the surface of the post-space (A_{PS}) and the surface of the amputation plane (A_A) occurred automatically in the zone of their angular point. During this procedure, misplaced demarcation points, which had potentially occurred because of open air bubbles in the impression, were identified and adjusted manually.

The resulting data were further converted with the MeshLab software (Visual Computing Lab at the ISTI – CNR, http://meshlab.sourceforge.net) and a three-dimensional mesh was reconstructed (Fig. 3). Different types of smoothing filters accessible for MeshLab were used to remove noise. All specimens were segmented and processed by the same investigator (J.G.) in an analogous manner. The Green's theorem gives the relationship between a closed mesh and the volume inside. Thus, the volume of the post-space could be quantified (V_{PS}). Using the information from the manufacturer regarding the geometric morphology of the fibre posts, the volume of the post-segment inserted into the root canal (V_P) was calculated. Further, the volume of the composite luting material (V_C) was determined by subtracting V_P from V_{PS}. The proportion of the post-space filled with composite after post-cementation was calculated (V_C/V_{PS}) and given in per cent.

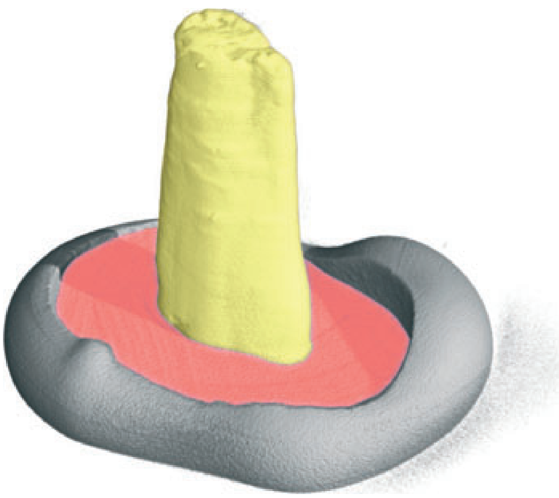

Figure 3 Three-dimensional reconstruction of a typical impression specimen, showing a non-circular root canal.

Statistical analysis

The entire statistical analysis was performed using the R software package (R Development Core Team 2009, Version 2.9.2). The means and standard deviations of the geometric parameters V_{PS}, A_A, V_C, and V_{PS} and of the mechanical parameters (maximal load and Young's modulus) were calculated. The percentage of the post-space filled with composite after post-cementation was determined.

To analyse the effect of area amputation (A_A), area post-space (A_{PS}), volume composite (V_C) and Young's modulus on maximal load, linear regression models were applied and resulted in the effect of the given predictor with confidence intervals (CI). The effect is the difference in the maximal load measured when the predictor increases from the first to the third quartile. Prior to this, a possible nonlinear influence of the predictors was tested using restricted cubic splines (rcs) (Harrell 2001).

Results

All the tooth specimens prepared with their restorations survived thermomechanical loading without loss of retention or visible fractures. They were then tested for fracture resistance in the universal testing machine. The mean values of the mechanical and geometric evaluation are presented in Table 1. The average surface of the amputation area (A_A) was 35 mm^2 (CI: 31–38) and was significantly larger than the surface area of the post-space (A_{PS} with 25 mm^2, CI: 23–27, $P < 0.0001$). The proportion of the post-space filled with composite after post-cementation varied between 29% and 88% (mean value 67%, CI: 65–73%). Because none of the parameters showed a nonlinear influence ($P > 0.2$), only linear models were applied. In the first step of the regression analysis, A_{PS} had the greatest

Table 1 Mean values (±standard deviation) of mechanical and geometric evaluations ($n = 48$)

Maximal load (N)	A_A (mm^2)	A_{PS} (mm^2)	V_{PS} (mm^3)	V_C (mm^3)	Young's modulus (GPa)
401 ± 115	35 ± 12	25 ± 7	129 ± 71	97 ± 71	2.8 ± 1.7

A_A, amputation area; A_{PS}, post-space area; V_{PS}, volume post-space; V_C, volume composite.

effect on maximal load. From the first to the third quartile, maximal load increased by 88.6 units (N) and the adjusted R^2 value reached 0.28 (the highest value of the four parameters). Beside A_{PS}, A_A and V_C also had significant effects on maximal load, whereas the Young's modulus had no significant effect (Table 2).

However, an overall model including all predictors tended to strengthen the most potent effect and simultaneously attenuated the weaker effects. In this model, only A_{PS} remained as a significant effect ($P = 0.003$). No statistically significant relationship was detected for A_A ($P = 0.89$) and V_C ($P = 0.88$).

Discussion

In the current laboratory model, the adhesive tooth surface available for luting the post with build-up was determined by µCT of surface impressions and three-dimensional data analysis of these specimens. The results demonstrated that the fracture resistance of restored root filled premolars was mainly influenced by the area of the post-space, whilst the larger amputation surface and the amount of luting resin had less impact.

The use of µCT has become increasingly popular in different areas of endodontic research. Previous µCT analyses of teeth have yielded data on parameters, such as root canal anatomy and morphology (Bjorndal *et al.* 1999, Peters *et al.* 2000, Guillaume *et al.* 2006), canal alterations after root canal preparation (Moore *et al.* 2009, Paque *et al.* 2009) or ultrasonic removal of fractured instruments (Madarati *et al.* 2009), volume changes in the hard tissue following endodontic procedures and post-space preparations (Ikram *et al.* 2009). Furthermore, the homogeneity and sealing ability of different root filling techniques has been analysed (Hammad *et al.* 2009), and the effectiveness of different instrumentation techniques for removing the root filling material in retreatment cases studied (Hammad *et al.* 2008). The µCT has been shown to provide reproducible data on surface determinations.

Table 2 Effects of various predictors on maximal load determined using linear regression models (shown separately for each predictor)

Predictor	Effect (95% CI)	Adjusted R^2	P-value
A_A	54.2 (16.7, 91.6)	0.13	0.007
A_{PS}	88.6 (49.5, 127.8)	0.28	<0.001
V_C	58.3 (19.1, 97.4)	0.14	0.005
Young's modulus	−14 (−57.6, 29.7)	−0.013	0.53

A_A, amputation area; A_{PS}, post-space area; V_{PS}, volume post-space; V_C, volume composite.

Moreover, µCT data has revealed a high correlation with video-digitized area measurements, which suggests that µCT is an accurate tool for this purpose (Rhodes *et al.* 1999). Although geometric parameters have already been evaluated in several studies after µCT image acquisition, this investigation is, to our knowledge, the first to address the effect of the bonding surface measured or the volume of luting material on the fracture resistance of RCT teeth. By processing µCT data with the customized software described here, it was possible to analyse and calculate separately the bonding surfaces in different regions of the tooth.

In contrast to surface data from optical Cerec camera recordings after coronal tooth preparation (Mörmann & Bindl 2006), the present approach can be applied to evaluate the bonding area in the root canal and is not impaired by pre-existing or preparatory dentine undercuts. Furthermore, the degree of mismatch between the post and root canal was quantified as the volume of the luting material. This approach describes the situation in irregular root canals more precisely than measuring the cement gaps in a few selected regions, as performed after histological sectioning in another study (Schmage *et al.* 2005).

When restoring root filled teeth, the remaining tooth structure, the surface available for adhesion of the build-up and the presence of a ferrule effect are key factors relating to fracture resistance (Dietschi *et al.* 2007, 2008). In the present material, the clinical crowns of pre-molar teeth were removed completely to simulate a severely damaged tooth as the 'worst case' scenario. Further, no ferrule effect was established to reduce the number of variables and to focus primarily on the impact of the bonding surface. Although the measured surface of the resulting flat amputation area was significantly larger than the bonding area inside the post-space preparation, the latter had the most impact on fracture resistance. These results suggest that it is not possible to predict the fracture resistance of restored root filled teeth just from the amount of the bonding area. The greater effect of A_{PS} is not necessarily the result of composite adhesion to root canal walls. Other factors, such as the remaining macroretention and the different dentine structure, may also play a role. Pirani *et al.* (2005) evaluated the drawbacks associated with bonding procedures in root canals with a high c-factor. They found interfacial gaps after the FRC posts had been cemented adhesively and suggested that the clinical success associated with bonded posts might be predominantly because of frictional retention (Pirani *et al.* 2005).

In the experimental set-up used here, the size of the amputation surface (A_A) is rather underestimated compared to clinical situations, in which parts of the coronal dentine structure are most likely preserved, thereby providing retentive structures and increasing the coronal bonding surface. Amongst the geometric data evaluated in this study, the highest variability was associated with the volume of the luting material (V_C). Because the selected teeth had similar dimensions in the cervical area and the same post-size was used in every specimen, these findings are presumably related to the high variability of the root canal morphology. Whilst root canals with a circular cross-sectional shape are rare (Kerekes & Tronstad 1977a–c, Wu *et al.* 2000), most teeth have oval, long oval, flattened or irregular canals (Jou *et al.* 2004). Thus, a considerable mismatch between circular post and the irregular post-space is frequently encountered. The amount of resin cement in the present material was rather high and comprised up to 88% of the entire post-space (mean 67%). Grandini *et al.* (2003) and co-workers have described an approach to reduce resin cement thickness and to improve post-adaptation in wide irregular root canals. Without adhesive pre-treatment of the dentine surface, an FRC post was covered with composite resin, inserted into the root canal and polymerized. After this individualisation step, the so-called anatomical post was conventionally luted. Investigating this technique *in vitro* revealed that the layer of resin cement was significantly less thick than when standardized posts were used (Grandini *et al.* 2005), whilst the fracture resistance was improved (Bonfante *et al.* 2007, Clavijo *et al.* 2009).

In the current study, however, the volume of luting resin seemed to be less important, which indicates that a post that fits perfectly is not necessarily required. During the era of traditional cementation of posts and dowels with zinc phosphate, there was no doubt that retention relied on the close adaptation to the root canal walls and therefore on a form congruent post-preparation (Hanson & Caputo 1974, Trabert *et al.* 1975, Standlee *et al.* 1978). However, circular post-space preparation in oval, flattened or irregular canals to obtain an optimized post-fit requires larger drills and leads to more dentine removal and subsequently to a higher risk of perforation and/or weakening of the root. If posts are not made form congruent, as in the current study, more luting material has to be used. There is increasing evidence that a lack of form congruence can be successfully compensated for by post-luting with resin cements. In laboratory studies, the increased thickness of composite material around the post did not impair retention (Assif & Bleicher 1986, Hagge *et al.* 2002, Perdigao *et al.* 2007) or the fracture resistance of the restored teeth (Buttel *et al.* 2009). Moreover, if the cement layer is thin, the curing contraction stress will increase significantly as a result of an unfavourable bonded/unbonded surface area ratio (high C-factor) (Alster *et al.* 1997).

Fracture resistance was not found to be influenced by the Young's modulus of the experimental set-up. Because the elastic modulus of dentine (~19 GPa) (Naumann *et al.* *2008*) and the applied FRC post (~45 GPa, manufacturers information) are higher than the average value of 2.8 GPa, the values resulting from the area of elastic deformation in the stress/strain plots may be attributed to the adhesive system or to the composite material used for both build-up and post-cementation. Most of the conventional dentine adhesives exhibit an elastic modulus lower than 5 Gpa (Magni *et al.* 2010). For composite materials, a reduced filler volume fraction in flowable composites correlates much more with a reduced Young's modulus than do highly filled materials (Masouras *et al.* 2008) and results in typical values between 2 and 7 GPa. According to the information provided by the manufacturer, the modulus of Multicore flow (7 GPa) lies in the range of the values measured in the current study (1–8 GPa, mean 2.8 GPa).

However, the standard deviation in the present study was much higher than in other experimental designs, in which standardized material samples were tested (Ilie & Hickel 2009). This discrepancy might be associated with differences in the homogeneity and conversion rate of the dual-cured materials used in the specimens tested.

Conclusion

Amongst the geometric parameters investigated in the present study, the area in the root canal had the greatest impact on fracture resistance of RCT premolars restored with FRC posts and composite crowns, whilst the volume of luting resin was less important. Within the limitations of this laboratory study, it can be suggested that a perfectly fitting post is not necessarily required and, therefore, invasive post-preparation aimed to obtain form congruence should be avoided.

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