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ORIGINAL ARTICLE

Influence of type of luting cement used with all-ceramic crowns on load capability of post-restored endodontically treated maxillary central incisors

Anja Preuss · Martin Rosentritt · Roland Frankenberger · Florian Beuer · Michael Naumann

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Abstract Adhesive luting of the final restorations is supposed to support the overall strength of post-endodontically restored teeth. For evaluating adhesive vs conventional cementation, the load capability of adhesively restored endodontically treated teeth (ETT) with glass fibre-reinforced composite posts (GFRCP), resin composite cores and all-ceramic crowns was determined. Thirty-two caries-free human upper, central incisors were randomly assigned to four groups, endodontically treated and cut 2 mm above the cemento-enamel junction. All teeth were restored with GFRCP, composite core build-ups and all-ceramic crowns. All-ceramic crowns were cemented with zinc phosphate cement (I), glass ionomer cement (II), and a self-adhesive resin cement (III and IV). After thermo-mechanical loading, the specimens were loaded to fracture. Maximum load capability F_{max} and fracture patterns were compared using non-parametric statistics. Median values for the maximum load capability F_{max} (minimum/maximum) in [N] were: I=503 (416/1,038), II=442 (369/711), III=502 (326/561) and IV=518 (416/652). No statistically significant differences were found for F_{max} (p=0.761) and fracture patterns (p=0.094) between the experimental groups. The type of cementation of all-ceramic crowns, whether self-adhesive or conventional, appears to have no impact on the load capability of ETT restored with GFRCP and composite core build-ups.

Keywords Luting material · Fibre-reinforced posts · Chewing simulation

A. Preuss · M. Naumann
Department of Prosthodontics and Geriatric Dentistry,
Charité-Universitätsmedizin Berlin,
Berlin, Germany

M. Rosentritt
Department of Prosthetic Dentistry,
Regensburg University Medical Center,
Regensburg, Germany

R. Frankenberger
Dental Clinic 1, Operative Dentistry and Periodontology,
University of Erlangen-Nuremberg,
Erlangen, Germany

F. Beuer
Department of Prosthetic Dentistry, University clinic Munich,
Munich, Germany

M. Naumann (✉)
Department of Prosthodontics and Geriatric Dentistry,
Charité, Humboldt-University of Berlin,
Föhrerstr. 15,
13353 Berlin, Germany
e-mail: michael.naumann@charite.de

Introduction

Resin cements have gained popularity over the recent years for several restorative procedures such as endodontic post or crown cementation. As discussed [34], for post-endodontic restorations, a crown distributes the applied loads evenly over the core and concentrates forces in outer regions of the coronal third of the root, especially at the interfaces of materials with a different modulus of elasticity [4, 33, 36]. It has been reported that cemented crowns alter the force distribution markedly making the post and core design irrelevant [3]. This aspect is mainly due to the well-known ferrule effect, underlining the advantage of a minimum 1.5–2.0-mm ferrule preparation [45]. Besides an increased load capability of restored endodontically treated teeth (ETT) [38], an improved fatigue resistance of the cement seal was reported when a sufficient ferrule was provided [32]. The loss of the cement seal of the final restoration may be clinically undetectable and causes leakage, which may extend into the post space and lead to dental caries and potentially to tooth loss [22, 37]. The prognosis of ETT was found to be directly correlated with the quality of the final restoration [36] and thus dental luting cements providing an important link between the crown and supporting prepared tooth structure [17, 42].

Besides clinically relevant aspects as radiodensity [20], studies in this field mainly evaluate the retentive strength of various cements on tooth hard tissue. It was reported that resin cements, glass ionomers and resin-modified glass ionomer cements are superior regarding retentive strength to zinc phosphate cements [6, 7, 13, 23, 27, 52]. Browning et al. [12] found that a composite resin was significantly more retentive than glass ionomer cement, which was again more retentive than zinc phosphate cement. This result was supported by other investigators [50, 51]. The use of composite resin allows one to reduce the core height from 5 to 3 mm [16]. However, a correlation of retentive strength and load capability was not shown so far. More precisely, the influence of the type of cementation on the load capability of ETT was not yet investigated. Differences in retentive strength between various cements affect the retention between restoration and tooth. Thus, a loss of retention would reduce the stabilizing effect of the dentin ferrule and may noticeably reduce the load capability of ETT.

Aim of the present in vitro investigation was to evaluate the effect of the type of cement used for all-ceramic crown cementation on load capability of post-endodontically restored human maxillary central incisors, when glass fibre-reinforced composite posts (GFRCP) and composite core build-ups were provided. The null hypothesis tested was that there is no difference in load capability of the restored ETT between the cements used.

Materials and methods

The method of specimen preparation and loading was adopted from Butz et al. [14]. Caries-free, undamaged human maxillary central incisors were selected. To ensure an even distribution of the size of teeth within the specimen groups, mesio-distal (MD) and facial–lingual (FL) dimensions were measured at the level of the cemento-enamel junction (CEJ). A size assessment value was calculated from the product of MD×FL. Teeth of extreme small or large sizes were excluded. Twenty-four specimens were randomly distributed into four test groups (group size of $n=8$) by means of a ten-digit random table. All teeth were stored at room temperature in a 0.1% thymol solution. Root canals were enlarged to size 60 (Antaeos, VDW, Munich, Germany) and rinsed with 2.5% sodium hypochlorite. Root canal filling was done by lateral condensation using gutta-percha (Roeko, Langenau, Germany) and a sealer (AH 26, De Trey, Konstanz, Germany). The clinical crowns were cut 2 mm coronal to the most incisal point of the proximal CEJ.

Gutta-percha was removed (Gates-Glidden-burs) leaving at least 4 mm of the root filling in the apical portion. The root canal was prepared with a tapered drill of 1.4 mm maximum diameter (Fiberpoints Root Pins post kit, Schuetz-Dental, Rosbach, Germany) to achieve an intra-radicular post length of 8 mm [17]. The root canals and the tooth surfaces were cleaned with an air-particle abrasion system (DentoPrep™, Aluminium Oxide Microblaster, Rønvig, Danmark and Cojet™, 3M ESPE, Seefeld, Germany). Glass fibre posts (Fiberpoints Root Pins Glass, diameter 1.4 mm, total length 15 mm, Schütz-Dental) in groups I to III and titanium posts in group IV (Fiberpoints Root Pins Titanium, diameter 1.4 mm, total length 15 mm, Schütz-Dental) were luted with a self-adhesive resin cement (RelyX Unicem, 3M ESPE) and light cured for 2 s (Optilux light curing unit, Demetron Research, Danbury, USA). Excess luting material was removed. Final light curing was performed for 1 min. The composite cores (NewBond, Clearfil Core, Kuraray Europe, Duesseldorf, Germany) were built up. All teeth were prepared with a circumferential 1.2-mm shoulder to meet all-ceramic crown requirements. The preparation margin was located 2 mm below the core build-up material in dentin to ensure proper ferrule design. With the help of a silicone mould, 24 similar crowns were fabricated from an all-ceramic material (Empress II, Ivoclar-Vivadent, Schaan, Liechtenstein). The crowns were cemented with zinc phosphate (group I; Harvard slow setting, Richter & Hoffmann, Harvard Dental GmbH, Berlin, Germany), glass ionomer cement (group II; Ketac Cem, 3M ESPE) and adhesively luted with a composite resin cement (groups III and IV; RelyX Unicem, 3M ESPE) according to the manufacturer's instructions.

The roots of specimens were blocked out with wax 2 mm below the finish line. To imitate a human periodontium, the roots of the teeth were covered with a 0.1-mm-thick layer of auto-polymerizing silicone (Anti-Rutsch-Lack; Wenko, Wensselaer, Germany) [14, 25]. The teeth were embedded in auto-polymerizing acrylic resin (Technovit 4000, Kulzer, Wehrheim, Germany) directing their long axes facially 135° from the horizontal (Fig. 1). To prevent overheating, the teeth were submerged in water for 5 min during resin polymerization.

Thermo-mechanical loading (TML) was performed with 6,000 thermal cycles (5/55°C, 2 min each cycle, H_2O distilled) and 1.2×10^6 mastication cycles at an angle of 135° as described previously [43]. A force of 50 N was

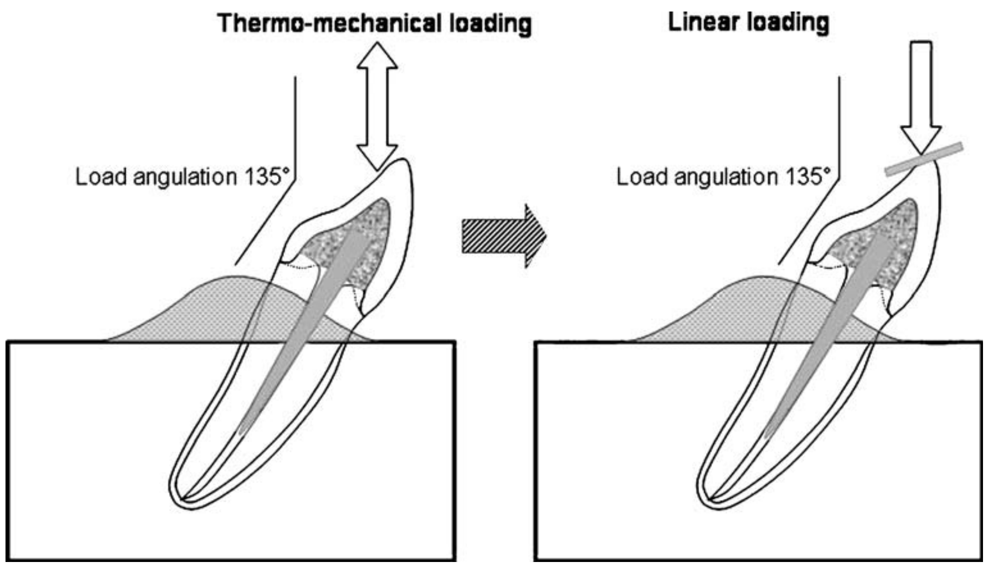


Fig. 1 Experimental setup for thermal–mechanical challenge (6,000 thermal cycles between 5 and 55°C and 1.2 million 50-N load cycles and load to failure testing (cross-head speed 1 mm/min)

applied 3 mm below the incisal edge on the palatal surface of the crown (Fig. 1). After TML, the specimens were loaded in a universal testing machine (Zwick, Germany; crosshead speed of 1 mm/min) until fracture occurred. Failure detection was set at a 10% loss of the maximum applied force. To reduce excessive stress concentrations, a 0.3-mm-thick tin foil was positioned between the steel piston and the lingual surface of the crown. The maximum fracture load at which failure occurred and the fracture patterns were recorded for all teeth. Fracture modes were categorised into three patterns: (a) oblique fracture from the CEJ palatally to a level close to the embedding material facially, (b) oblique fracture from the palatal, coronal to the CEJ to the facial at a level close to the embedding material and (c) horizontal fracture along or close to the CEJ. Fractures at the level of the embedding material were judged as non-restorable.

Because of the relatively small sample size per group, non-parametric tests were applied: Statistics were calculated for each group with the Kruskal–Wallis test to show differences between group medians of the maximum load capability $F_{\max}$. To evaluate differences in the frequency of failure modes between groups, the Fisher exact test was used. All statistics were two sided at α=0.05.

Results

The comparisons of tooth dimensions between experimental groups indicated sufficient randomisation (see Table 1). One specimen of group I, which lost crown retention during TML, was excluded from further analysis.

All-ceramic crowns placed with zinc phosphate cement (group I) revealed median fracture loads (minimum/maximum) of 503 N (416/1,038). Crowns cemented with glass ionomer (group II) and resin cement (group III) showed median load capabilities of 442 (369/711) and 502 N (326/561), respectively. Specimens in group IV that were supported by a titanium post instead of fibre posts had a load capability of 518 N (416/653; Fig. 2). No statistically significant difference in fracture load between the experimental groups (Kruskal–Wallis test, p=0.761) was found.

Fracture modes and distributions are displayed in Fig. 3. All specimens of group III failed because of an oblique fracture from the CEJ palatally to the level above or close to the embedding material. The fracture line in group IV ended facially, noticeable below the simulated bone level (type a). Six specimens of groups I and II fractured from the coronal direction to the CEJ and palatally to the level close to the embedding material (type b). For one specimen of groups I

Table 1 Tooth/specimens characteristics

	Group I (zinc phosphate)	Group II (glass ionomer)	Group III (resin)	Group IV (resin/control)
Palatal residual wall thickness[a] (mm)	2.4 (2.2; 3.1)	2.9 (2.2; 3.2)	1.9 (1.3; 2.6)	2.4 (2.2; 3.2)
Facial residual wall thickness[a] (mm)	2.9 (2.2; 3.8)	2.9 (2.0; 3.8)	3.8 (3.1; 4.5)	2.8 (2.0; 3.5)
Crown length (mm)	6.9 (5.2; 8.1)	6.9 (5.5; 8.4)	7.3 (5.8; 8.5)	7.3 (5.7; 8.3)
Root length (mm)	15.2 (13.5; 18.5)	14.5 (13.4; 17.5)	19.0 (11.3; 22.6)	16.0 (14.6; 17.8)
Surface[a] (mm^2)	51.4 (44.1; 56.2)	51.1 (46.8; 57.8)	52.3 (44.2; 58.5)	50.0 (46.9; 56.9)

N=8; median (minimum; maximum)

[a] On the level of the CEJ

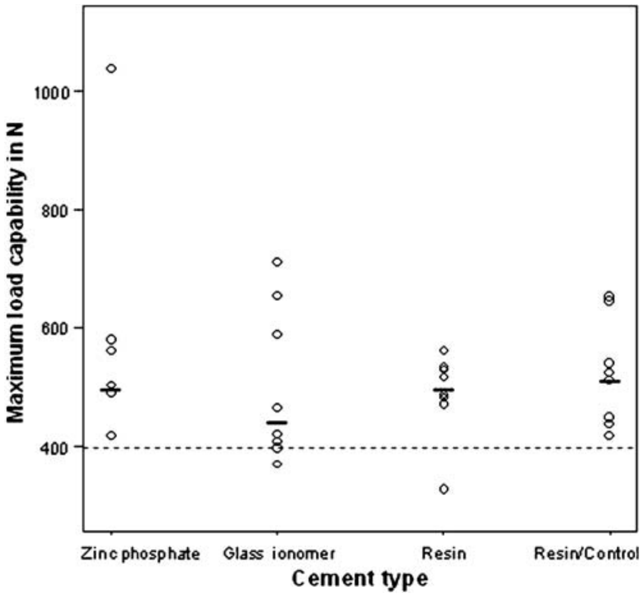


Fig. 2 Individual specimen data for fracture load testing (median values as *bold line*; in group I, two values=503 N)

and II, a horizontal fracture on the level of the CEJ (type c) was found. One crown of group II lost retention during linear loading without affecting the core build-up. The comparison of the frequency of restorable and non-restorable fracture modes between the groups with the Fisher exact test revealed no significant differences (p=0.094).

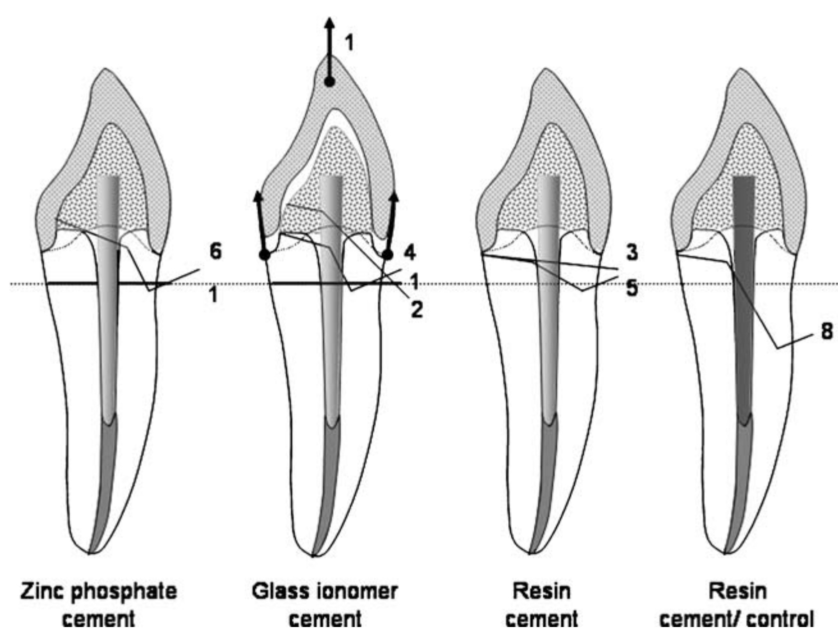
Discussion

This in vitro investigation aimed to assess the impact of the luting material on the maximum load capability of teeth, which were post-endodontically restored with GFRCP, composite core build-ups and all-ceramic crowns. A group in which a titanium post was placed instead of GFRCP served as a control for the post effect. As a model of post-endodontic-restored teeth, all-ceramic crown-restored upper central incisors were chosen. No significant influence of the type of cement, neither for the conventional non-bonding nor for the adhesive bonding cements, on the load to failure of the specimens could be determined.

A GFRCP in combination with a composite build-up was adhesively placed representing a situation consistent with esthetic demands and claim to clinical relevance [18]. GFRCP were used, as they are regarded as particularly advantageous and their Young's modulus is regarded as similar to dentin [2, 30], enabling a tooth to flex under load with a more even stress distribution between the post and dentin [8]. Therefore, the risk of root fracture should be reduced [26]. Zinc phosphate, glass ionomer and resin cements were chosen because they are the most popular materials for crown cementation [42]. Fatigue testing in an aqueous environment as performed by TML in the present investigation is claimed to be sufficient for demonstrating modulus-related properties of dental materials [44]. A fatigue failure is caused by cyclic or repeated sub-critical loads, usually resulting in minute cracks, followed by tearing and rupture termed brittle failure or fracture [10, 41]. Fatigue fractures in the anterior maxillary dentition are caused by tension. Because the amount of shear forces is lower in the posterior region, anterior restorations are more susceptible to failures being caused by fatigue [47, 51]. Hence, fatigue fractures emerge where maximum cyclic stress occurs [48].

It is generally accepted that the materials used for the post-endodontic restoration with post, post-luting cement,

Fig. 3 Fracture patterns and distributions observed for all groups tested, one specimen of group I is not included because of early failure during TML (loss of crown retention); *thin lines* mark simulated bone level; fractures close to bone level were judged as not restorable



core build-up and crown should ideally have a similar modulus of elasticity [40]. The application of adhesive procedures should result in a restorative unit termed as 'mono-block' [21, 40]. According to this approach, the use of composite resin cements seem to be beneficial [40]. Studies have reported a significant increased post retention using bonding resins compared to conventional cements [36]. In vitro studies suggest that there is a strengthening effect of the application of bonding techniques within a flared root canal [28, 29, 31, 35].

The null hypothesis of this investigation was supported by the results, as no significant differences could be determined between the experimental groups neither for median load capability nor in the fracture patterns. However, the cements show significantly different values of bond strength to dentin and the modulus of elasticity [11, 31, 39, 48]. Under linear loading, all-ceramic crowns luted with resin cement showed improved load capacities compared to glass ionomer cementation [1, 15]. When specimens without endodontic treatment are cyclically loaded, zinc phosphate cement was more susceptible to crack propagation in comparison to resin cement [49] and after TML adhesively luted all-ceramic crowns achieved higher load capabilities than crowns cemented with resin-modified glass ionomer cement [9] or zinc phosphate cement [5].

The high standard deviations of the load values observed were probably caused by a number of factors. The variability of mechanical properties of the human dentin is probably the main factor, as dentin is weak in which strength and toughness are varying [24]. The dentinal changes can affect the tooth elasticity and hence the fracture patterns during loading [18]. Furthermore, some impacts are factors such as patient's age, variations in tooth tissue or the position of the root canal, the distance between the coronal surface and dentino-enamel junction and damage introduced during extraction or storage [18, 34]. To minimize these influences, we randomly assigned the teeth to the experimental groups. A control for the residual wall thickness (Table 1) was performed, as it was shown to have some impact on the fracture patterns observed [46].

The predominant fracture type was oblique from or above the level of the palatal CEJ to the facial site close to the level of the embedding material. As a result of the different bending ability/modulus and in accordance with a recently published review [19], the teeth restored with titanium posts fracture more apically to the facial bone level than all other groups. Crowns luted with zinc phosphate and glass ionomer cement revealed a fracture above the level of the CEJ palatally, whereas crowns luted with resin cement showed fractures at the level of the CEJ palatally. However, the fracture pattern does not allow for drawing any conclusions on the quality of the restoration. One specimen of the zinc phosphate group lost retention during chewing simulation, and one specimen of the glass ionomer lost retention under linear loading. The loss of retention may be caused by de-bonding.

The results of the present investigation are difficult to generalize in part because the interaction of the type of post-endodontic restoration with the cementation of the final restoration on the abutment was not investigated. Despite the existing evidence for the retentive strength, we could not show that the bonding cements were superior to zinc phosphate cement with regards to load capability. Our results suggest that high retentive values for a certain luting material may not necessarily correlate with an improved load capability of a post-endodontic restoration. An advantage with regards to load capability of a complete adhesive restorative approach, i.e. the 'mono-block' concept, when restoring ETT could not be shown.

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