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ORIGINAL ARTICLE

Influence of fatigue testing and cementation mode on the load-bearing capability of bovine incisors restored with crowns and zirconium dioxide posts

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Abstract The aim of the study was to evaluate the influence of fatigue and cementation mode on the fracture behavior of endodontically treated bovine incisors restored with zirconium dioxide posts and crowns. Forty-eight endodontically treated bovine primary incisors were restored with zirconium dioxide posts (Cerapost, Brasseler), composite build-ups, and crowns cast from a chromium cobalt alloy. In 16 teeth, each of the posts was cemented conventionally with KetacCem (3M ESPE) or adhesively with Panavia F (Kuraray) or RelyX UniCem (3M ESPE). One-half of the specimens in each group were subjected to thermocycling with 10,000 cycles at 5–55°C and mechanical aging, loading the specimens at an angle of 45° in 1,200,000 cycles with 50 N. Fracture resistance was determined by loading the specimens until fracture at an angle of 45° to the long axis of the teeth. The loading test showed that neither cementation mode nor fatigue testing had an influence on the load bearing capability. Most specimens fractured in a favorable way, independent from the type of cementation.

Keywords Post and core · Fracture mode · Zirconium dioxide · Fracture resistance · Load bearing capability

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Introduction

Metal post-and-core foundations may negatively affect the esthetic outcome of all-ceramic restorations of endodontically treated teeth, e.g., by altering light transmission [11, 47].

In addition to post systems based on the classical materials (e.g., precious gold alloys or titanium), tooth-like colored materials (e.g., ceramics and composites) have been introduced [10, 24]. Zirconium dioxide and glass (or quartz) fiber-reinforced composites (FRC), in particular, are the foundation of many modern post-and-core concepts [27].

Zirconium dioxide posts can be fixed conventionally, as well as adhesively [33, 36]; the dentin-like Young's modulus of FRC posts and its postulated protective effect on root fractures due to force peaks, as transmitted by rigid materials, makes an adhesive cementation necessary [14, 25].

It has been reported that the formation of resin tags, adhesive lateral branches, and a resin dentin interdiffusion zone is possible to achieve with available adhesive systems applied on root dentin [2]; some studies have demonstrated improved retention of posts [31] and decreased microleakage [1] and higher fracture resistance [28] of teeth when posts are cemented with a resin cement than with other cements.

However, the bond strength to root dentin may be influenced by a variety of factors [14], e.g., sclerotic processes and the deposition of secondary and tertiary dentin [37], structural differences between radicular dentin and coronal dentin [12, 46] or the presence of provisional cements, endodontic sealers, and rinsing solutions [40, 41].

In general, conventional cements offer some advantages over resin cements, including lower costs and less complicated procedures with less opportunities for procedural errors [7, 29, 37].

This in vitro study investigated the influence of thermomechanical fatigue testing and cementation mode on the fracture behavior of severely damaged bovine incisors restored with zirconia posts covered by a full metal crown.

The hypotheses were as follows: (1) Irrespective of fatigue testing, severely damaged bovine incisors restored with crowns and conventionally cemented zirconium oxide posts do not show a lower fracture resistance than do incisors with crowns and adhesively luted posts, and (2) no difference exists between the use of conventional cementation compared to adhesive luting of zirconia posts concerning the failure mode.

Materials and methods

Forty-eight bovine primary incisors with mature root development, a straight root with a minimum length of 16 mm and a similar diameter, were decapitated at a distance of 16 mm from the apex and randomly divided into six groups (n=8); the specimens were stored in a solution of water and 0.1% thymol at room temperature. Teeth were removed from the thymol solution only for the purpose of processing them as specimens in the study.

The root canals were instrumented in a crown-down technique to an apical size of ISO 40 and obturated with gutta-percha (Coltene/Whaledent, Langenau, Germany) and sealer (AH plus, Dentsply DeTrey, Konstanz, Germany) using cold lateral condensation.

All teeth were embedded in an acrylic resin (Palapress Vario; Heraeus Kulzer GmbH, Hanau, Germany) cube. The acrylic level was adjusted 3 mm below the coronal plateau.

Table 1 shows the materials used for the restorative procedures in the test groups. The cylindro-conically shaped zirconium dioxide post Cerapost (Brasseler, Lemgo, Germany) with 1.75 mm in diameter was inserted in all specimens.

Thirteen-millimeter deep post spaces were prepared as measured from the coronal plateau using the system-specific preparation instruments, according to the manufacturer's recommendations.

The posts in groups 1 and 2 were cemented in a conventional way using automatically mixed (Cap-Mix; 3M ESPE, Seefeld, Germany) glass ionomer cement (KetacCem, 3M ESPE, Seefeld, Germany).

In groups 3 and 4, the dentinal and post surfaces were conditioned by applying a self-etching primer (ED primer, Kuraray, Osaka, Japan). Panavia F 2.0 (Kuraray) was mixed for 30 s and applied to the total post surface. Following seating, excess cement was removed and light curing took place for 40 s.

In groups 5 and 6, RelyX UniCem (3M ESPE) was mixed automatically (Cap-Mix; 3M ESPE). The post was seated without further conditioning of the dentinal surfaces. Light curing took place after removing excess cement for 40 s.

The cores were built up in increments using a microhybrid composite (Herculite XRV, Kerr Hawe, Bioggio, Switzerland) after etching the dentin (15 s) with 37.5%

Table 1 Restoration in groups 1–6

	Groups					
	1	2	3	4	5	6
Brand name	Cerapost					
Material	Zirconium dioxide					
Manufacturer	Brasseler, Lemgo, Germany					
Diameter apical	0.9 mm					
Diameter coronal	1.75 mm					
Color Code	Red					
Post shape	Cylindro-conical					
Conus angle	4.2°					
Post cementation	KetacCem; 3M ESPE, Seefeld, G	KetacCem; 3M ESPE, Seefeld, G	Panavia F; Kuraray, Osaka, J	Panavia F; Kuraray, Osaka, J	RelyX UniCem; Osaka, J	RelyX UniCem; 3M ESPE, Seefeld, G
Fatigue testing	No	Yes	No	Yes	No	Yes
Preparation design	Crown preparation					
Core material	Herculite XRV; KerrHawe, Bioggio, CH					
Adhesive system (group 1–4)	Optibond FL; KerrHawe, Bioggio, CH					
Crown material	NEM Remanium GM 800+; Dentaurum, Pforzheim, G					
Crown cementation	KetacCem; 3M ESPE, Seefeld, G					

Table 2 Mean force (N) at fracture with standard deviations

Groups	*n*	Mean	SD
1. KetacCem, no FT	8	576	108
2. KetacCem, FT	8	480	34
3. Panavia F, no FT	8	580	73
4. Panavia F, FT	8	557	84
5. RelyX UniCem, no FT	8	521	118
6. RelyX UniCem, FT	8	494	85

FT Fatigue testing

phosphoric acid (Kerr Etchant, KerrHawe) and application of an adhesive system (Optibond FL, Kerr Hawe).

A 0.6-mm chamfer preparation for a crown was prepared with a tapered diamond bur (8878KP 018, Brasseler) with the finishing line ending 1.5 mm apical to the composite build-up. The palatal surface was prepared with an oval-shaped diamond bur (8899.314 031, Brasseler). The resulting total height of the prepared abutments was 6 mm on the vestibular face and 3 mm on the oral face. Crowns were cast from a chromium cobalt alloy (Remanium GM 800+, Dentaurum, Pforzheim, Germany) and cemented with glass ionomer cement (KetacCem).

The samples in groups 2, 4, and 6 were subjected to thermocycling (Willytec, Gräfelfing, Germany) with 10,000 cycles at 5–55°C, and mechanical aging was performed in a chewing simulator (Willytec), loading the specimens at an angle of 45° in 1,200,000 cycles with 50 N.

All samples were loaded until failure in a universal testing device (Zwick/Roell, Ulm, Germany) at an angle of 45° to the long axis of the roots using a stainless steel spherical antagonist (diameter: 4 mm) at a crosshead speed of 0.5 mm min^{-1}, with the force transferred to the palatal surface 2 mm below the incisal edge. A sudden decrease in force of more than 30 N was regarded as an indication of failure, and the maximum force up to this point was recorded as the force at fracture.

Due to the chosen sample size (n=8), the mean fracture loads were analyzed applying the non-parametric Kruskal–Wallis test. The level of significance was set at $p<0.05$.

All samples were assessed for failure modes by visual inspection in combination with ink staining (Parker, Baden-Baden, Germany). "Favorable failures" were defined as repairable failures as fractures of the root on or above the level of bone simulation. "Unfavorable failures" were defined as unrepairable failures as root fractures below the level of bone simulation [15]. The results were reported using descriptive statistics.

Results

Table 2 and Fig. 1 show the results of load-bearing capacity testing. Specimens fractured at failure loads of 480 N (RelyX UniCem, fatigue testing) to 580 N (KetacCem, no fatigue testing). Comparing the different modes of cementation similar values for fracture load could be found, before fatigue testing as well as afterwards. The roots restored with conventionally cemented posts revealed the highest decrease in fracture resistance after fatigue loading. Nevertheless, the difference between fracture loads before and after artificial aging was not statistically significant.

Most specimens fractured in a favorable way, independent from the cementation variant (Table 3). Predominantly, post fractures together with root fractures on or above the simulated root level were observed.

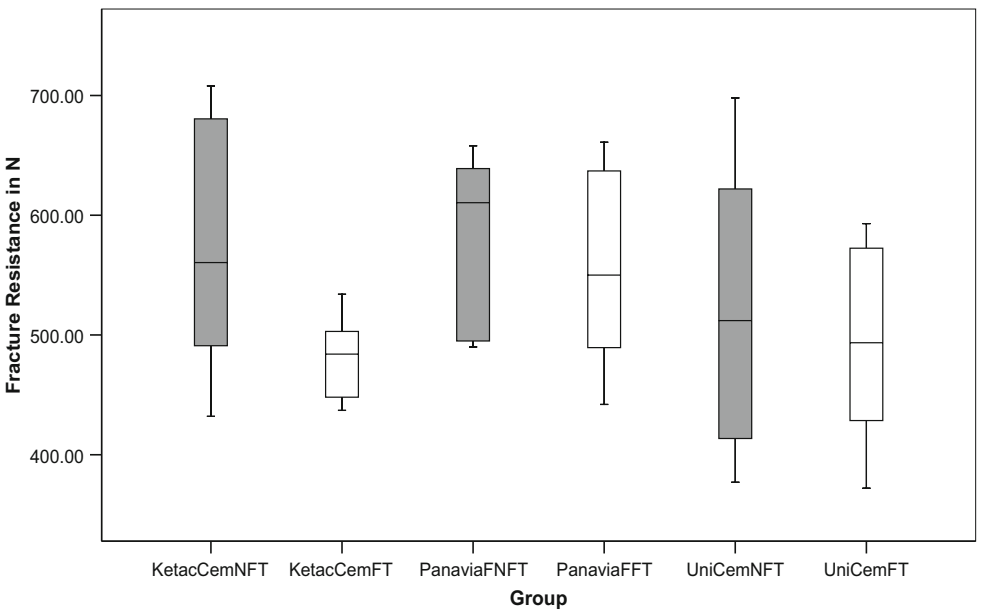

Fig. 1 Box-plot diagram of load-bearing capacity. p values indicate no significant differences in the fracture resistance before and after thermomechanical aging (Kruskal–Wallis test; level of significance, $p<0.05$)

Table 3 Frequencies of failure modes in the six tested groups

Root fracture	No root fracture		On/above bone level		Below bone level	
Post fracture	Bone level	Above bone level	Bone level	Above bone level	Bone level	Below bone level
KetacCem NFT	1		6	1		
KetacCem FT			6			2
Panavia F NFT			6	1		1
Panavia F FT		1	4	1	1	1
UniCem NFT	1	1	3			3
UniCem FT			6	1	1	

Discussion

Bovine teeth were used in this study to provide a more uniform root anatomy and standardized sample length. Studies have reported little difference between human and bovine dentin as a bonding substrate [30, 39].

The specimens were stored in 0.1% thymol solution at room temperature. Thymol has an anti-fungal action, less influence on the adhesive mechanisms in comparison to alternative storage media (e.g., saline or formalin), and has been repeatedly described in other studies [17, 19].

In this study, the crowns were cast from a cobalt chrome alloy. This is not reflective of clinical practice, but is a technically and financially less expensive method to simulate a full coverage restoration in an in vitro setting.

Clinical failures of dental restorations most commonly result from fatigue [42]. Therefore, all specimens were artificially aged, applying dynamic thermal and mechanical loading with similar parameters as found in the scientific literature to simulate about 5 years of clinical function [20, 23]. Dynamic and static loading were performed at an angle of 45° to the long axis of the roots to simulate a clinical situation, which represents a biomechanical "worst case scenario". This is also in accordance with published reports about post-and-core fracture and fatigue testing of endodontically treated teeth [22, 34].

Regarding the fracture behavior, the use of zirconium dioxide posts showed no differences compared with titanium or cast gold posts when restoring endodontically treated teeth with substantial horizontal loss of the clinical crown [20, 32]. Fatigue studies have shown the influence of post properties on the restoration behavior and indicated that posts, which exhibit physical properties close to the dentin, allow minimization of the incidence of adhesive failures or specimen fractures [21, 22, 26].

However, the superiority of posts with a dentin-like modulus of elasticity, which is reported in a number of publications and is attributed to more advantageous stress distribution to the residual tooth structure [13, 18], could not be confirmed in all studies on this topic. The rigidity of post-and-core systems seems to have no influence on the fracture behavior of severely damaged endodontically treated teeth with limited ferrule [16].

In current scientific literature, failures of the ceramic post-tooth complex were predominantly described as fractures of the posts, without root fractures. The fracture of the ceramic post seems to absorb most of the energy, thereby saving the remaining root from fracture [15]. In the present study, we observed predominantly post fractures together with root fractures on or above the simulated root level. A reason for this finding may be found in the chosen test set-up. A sudden decrease in force of more than 30 N was regarded as an indication of failure; it may be that the decrease in force after post fracture did not reach 30 N and load was transferred on the specimen until fracture of the dental hard tissue.

Although hydrofluoric acid etching and the application of a silane-coupling agent to silica-based ceramics increase the bond strength between all-ceramic restorations and composite resins [35], these techniques do not improve the bond strength of zirconium and alumina ceramics, as their high crystalline content renders them resistant to acid etching [8]. Studies on the shear bond strength to zirconia ceramic have shown that a composite resin cement containing an adhesive phosphate monomer provides significant bond strength values [5].

Nevertheless, in an in vitro evaluation of push-out bond strength of various luting agents to tooth-colored posts, fiber-reinforced composite posts demonstrated significantly higher bond strength values compared to the zirconium oxide posts [4].

In the present study, we compared two adhesive phosphate monomer containing resin cements, which showed a strong bond to zirconium oxide ceramic in previous in vitro investigations and one glass iomomer cement [4, 45]. In a study on the effects of luting agent and thermocycling on bond strength to root canal dentine, the self-adhesive resin cement RelyX UniCem revealed higher bond strength values compared to Panavia F used together with its corresponding bonding agent [3]. Despite this findings, varying the luting agents did not affect the failure mode of the specimens in our study.

Furthermore, applying a glass ionomer cement did not result in a lower fracture resistance nor a less advantageous fracture mode, though other authors did not recommend conventional cementation of zirconium dioxide posts, due to low bond strength values to post and root dentin [4, 9].

Despite a presumed negative effect on the bonding of zirconia posts to root dentin [6, 9], fatigue loading showed no effect on the fracture resistance of endodontically treated and severely decayed bovine incisors restored with adhesively luted zirconia posts. Furthermore, there was no significant difference in the fracture behavior of specimens with conventionally and adhesively cemented posts. Therefore, hypotheses 1 and 2 of this study are confirmed.

Due to the high rigidity of the posts, the load-bearing capability of the restored tooth may be primarily dependent on the fracture resistance of the post and not on the post/hard tissue bonding.

The less technique-sensitive conventional cementation of zirconium dioxide posts seems to be further on a reliable alternative to luting procedures. Increased microleakage may be a problem of endodontically treated teeth restored with rigid, conventionally cemented posts [38, 43]; but uncertainty remains when predicting the clinical effect of microleakage. Valderhaug et al. [44] showed that root filled teeth with a high quality endodontic treatment and an optimal morphology of the conventionally cemented cast post and core have a similar survival rate as crowned teeth with a vital pulp over an observation period of 25 years. The incidence of periapical lesions on radiographs was low for both groups.

Conclusion

With respect to fracture behavior, adhesive fixation of zirconium dioxide posts bears no advantage over conventional cementation.

Conflict of interest statement The authors declare that they have no conflict of interest.

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