International Endodontic Journal

doi:10.1111/j.1365-2591.2010.01797.x

Self-adhesive cements as core build-ups for one-stage post-endodontic restorations?

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Abstract

Naumann M, Sterzenbach G, Rosentritt M, Beuer F, Meyer-Lückel H, Frankenberger R. Self-adhesive cements as core build-ups for one-stage post-endodontic restorations? *International Endodontic Journal*.

Aim To investigate the load capability of root filled teeth restored with glass fibre posts when the same self-adhesive composite resin cement was used as post cement and core build-up material.

Methodology Human maxillary central incisors were divided into four groups ($n = 10$). Teeth were root filled, decoronated and restored using glass fibre posts luted with different cements and composite resins for core build-up (i) RelyX Unicem/Clearfil Core (RXU/CC), (ii) RelyX Unicem/ RelyX Unicem (RXU/RXU), (iii) RelyX Unicem/LuxaCore-Dual (RXU/LCD) and (iv) LuxaCore-Dual/Clearfil (LCD/CC). A 2- mm ferrule crown preparation was always performed. All specimens were restored with adhesively luted all-ceramic crowns and were exposed to thermal cycling and mechanical loading (TCML) and subsequently statically loaded. For analysis of cycles-to-failure during TCML, log-rank statistics were calculated. The non-parametric Kruskal–Wallis test was applied to study group mean differences. Differences in the frequency of the failure modes between the groups were evaluated by Fisher's exact test. All tests were two-sided ($\alpha = 0.05$).

Results Three specimens of RXU/LCD and two of RXU/RXU and LCD/CC, respectively, failed during TCML ($P = 0.379$). For these specimens, the load capability value was set at 0 N. The median fracture load values (min/max) in (N) were RXU/CC = 294 (209/445), RXU/RXU = 166 (0/726), RXU/LCD = 241 (0/289) and LCD/CC = 200 (0/371) ($P = 0.091$). The RXU/CC had the highest (80%) and RXU/LCD the lowest (20%) percentage of restorable failures ($P = 0.028$).

Conclusions These results imply that self-adhesive composite achieved similar load capabilities when used as core build-up materials in root filled teeth restored with glass fibre posts and all-ceramic crowns.

Keywords: adhesion, chewing simulation, crown, dowel, post-and-core technique.

Received 13 January 2010; accepted 24 August 2010

Introduction

The fundamental prerequisites for a monoblock system in root canals (Tay & Pashley 2007) are that all materials involved in the post-and-core restoration bond to one another and to the tooth and achieve ultimately a modulus of elasticity similar to dentine.

A beneficial effect of adhesive systems for post cementation has been shown (Goldman *et al.* 1984), and the formation of a hybrid layer is possible (Bitter *et al.* 2004). However, polymerization shrinkage stresses within the root canal are high owing to the large configuration factor (Feilzer *et al.* 1987). Shrinkage stresses cannot be controlled (Bouillaguet *et al.* 2003, Lertchirakarn *et al.* 2003), and application conditions

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within the root dentine are unfavourable. Previously reported voids and gaps within the cement interface (Goracci *et al.* 2005b, Grandini *et al.* 2005) are avoidable with specific syringes (Watzke *et al.* 2008).

However, some reports (Goracci *et al.* 2005a, Pirani *et al.* 2005, Sadek *et al.* 2006, Wrbas *et al.* 2006) challenged the efficacy of adhesive posts in general. In contrast, other laboratory and *in vivo* studies have demonstrated promising results for self-adhesive resin composites as cements for glass fibre posts (Naumann *et al.* 2007b, 2008). Composite resins are appropriate (Kovarik *et al.* 1992, Ziebert & Dhuru 1995, Sirimai *et al.* 1999, Nagasiri & Chitmongkolsuk 2005) and commonly used as core materials in combination with pre-fabricated posts (Naumann *et al.* 2006a). An advantage for the clinical application would be to combine luting and core build-up in a one-stage procedure.

Thus, the following null hypotheses were tested in this study:

- Self-adhesive cements, to date only indicated for post cementation, are as load capable as a well-suited adhesive combined with a typical core build-up resin composite material.
- There is no difference between the load capability of self-adhesive and conventional resin composite core build-ups after TCML.

Material and methods

Specimen pre-treatment

Human maxillary incisors were stored at room temperature in a 0.5% chloramine solution. To ensure the use of teeth of comparable dimension, mesio-distal (MD) and facial–lingual (FL) dimensions were measured at the cemento-enamel junction (CEJ). Table 1 gives detailed information on tooth geometry. Specimens were randomly assigned to four groups ($n = 10$) by means of a ten-digit random table. Root canals were enlarged to size 60 (Antaeos, VDW, Munich, Germany) and rinsed with 2.5% sodium hypochlorite. Root canal filling was achieved using lateral compaction technique using Gutta-percha (Roeko, Langenau, Germany) and sealer (AH 26; Dentsply DeTrey, Konstanz, Germany). The crowns were removed 2 mm coronal to the most incisal point of the proximal CEJ.

Roots were covered with wax 2 mm below the CEJ. To imitate the human periodontium, roots were covered with a 0.1 -mm-thick layer of silicone (Anti-Rutsch-Lack; Wenko, Wensselaer, Germany). The teeth were than embedded in acrylic resin (Technovit 4000; Kulzer, Wehrheim, Germany) up to the level of the wax ensuring a distance between the acrylic resin and the CEJ of 2 mm imitating the biological width to a crestal bone level. The tooth axis was directed 45° to the horizontal.

Gutta-percha was removed leaving at least 4 mm of the apical root filling. The root canal was prepared with a tapered drill (∅ 1.4 mm, Fiberpoints Root Pins post kit; Schuetz-Dental, Rosbach, Germany) to achieve a post length of 8 mm. Fiberpoints Root Pins Glass (GFP, diameter 1.4 mm, total length 13 mm; Schuetz-Dental) were placed, and core build-up was performed as described below.

Experimental group preparation

Group I: RelyX Unicem (RXU) – Clearfil Core (CC)

GFP were luted with self-adhesive cement (RelyX Unicem, capsule; 3M ESPE, Seefeld, Germany) and light-cured (2 s, Optilux light-curing unit, 850 W cm^{-2}; Demetron Research Corp., Danbury, CT, USA). Excess luting material was removed. Final light curing was performed for 1 min. The composite cores were built up with an etch-and-rinse bonding system (NewBond; Kuraray Europe, Duesseldorf, Germany) and a composite resin material (Clearfil Core; Kuraray Europe). Transparent, light-transmissive celluloid crowns (Frasaco strip crowns; Frasaco GmbH, Tettnang, Germany) were used as moulds to form the core build-up.

Group II: RelyX Unicem (RXU) – RelyX Unicem (RXU)

GFP were placed as described in group I. The cores were built up using the same self-adhesive cement (RXU) as

Table 1 Tooth characteristics to describe the geometry and dimension of the specimens

Group (cement/core build-up)	Total tooth length (mm)	Root length (mm)	Crown length (mm)	Mesial–distal extension (mm)	Facial–palatal extension (mm)
RelyX Unicem/Clearfil	22.0 (1.0)	15.0 (1.2)	7.0 (0.8)	6.4 (0.5)	6.8 (0.4)
RelyX Unicem/RelyX Unicem	21.9 (1.5)	15.0 (1.5)	6.9 (0.6)	6.3 (0.5)	6.8 (0.4)
RelyX Unicem /LuxaCore-Dual	22.9 (1.9)	15.9 (1.5)	7.0 (1.1)	6.4 (0.4)	6.8 (0.4)
LuxaCore-Dual/Clearfil	22.9 (1.9)	15.8 (1.5)	7.1 (1.1)	6.4 (0.4)	6.8 (0.4)

for post cementation. The use of strip crowns as described for group I was mandatory because the manufacturer instructions highlight the need for pressure when applying the self-adhesive material.

Group III: RelyX Unicem – LuxaCore-Dual (LCD)
GFP were placed as described in group I. The core build-up procedure was performed using an etch-and-rinse system (LuxaBond-Total Etch; DMG, Hamburg, Germany) and the corresponding composite resin material (LuxaCore-Dual; DMG) according to manufacturers' instructions. Coronal tooth surface were etched with 37% phosphoric acid (15 s, Etching Gel Medium Viscosity; DMG), pre-treated (Pre-Bond, DMG) and bonded (Bond A and Bond B, DMG, 1 : 1 ratio). Transparent, light-transmissive celluloid crowns (Frasaco strip crowns; Frasaco GmbH) were used as moulds to form the core build-up.

Group IV: LuxaCore-Dual (LCD) – Clearfil Core (CC)
Prior to post placement, root canal surfaces were etched with 37% phosphoric acid (15 s, Etching Gel Medium Viscosity; DMG), pre-treated (Pre-Bond, DMG) and bonded (Bond A and Bond B, DMG, 1 : 1 ratio). Posts were cemented with dual-curing composite cement and light-cured (40 s, LCD). Coronal tooth surfaces were etched with 37% phosphoric acid (15 s, Etching Gel Medium Viscosity; DMG). Clearfil New Bond was applied (universal liquid and catalyst liquid in the proportion of 1 : 1). Universal paste and catalyst paste were mixed in an equal quantity. The core build-up procedure was performed using transparent, light-transmissive celluloid crowns (Frasaco strip crowns, Frasaco GmbH) as moulds to form the core build-up.

Crown restoration

All teeth were prepared with a circumferential 1.2 -mm shoulder to meet all-ceramic crown requirements. The margin was located 2 mm below the core build-up in dentine to ensure proper ferrule design. With the help of a silicone mould, 40 similar crowns were fabricated from an all-ceramic (Empress II; Ivoclar-Vivadent, Schaan, Liechtenstein). The crowns were adhesively luted with composite resin cement (RXU) according to the manufacturers' instructions.

Loading protocol

Thermal cycling and mechanical loading (TCML) were performed (6000 thermal cycles, 5/55 °C, 2 min each cycle; dist. water; 1.2×10^6 mastication cycles with 50 N; 135°; 3 mm below the incisal edge on the palatal surface of the crown). After TCML, specimens were loaded in a universal testing machine (Zwick 1446; Zwick, Ulm, Germany; $v = 1$ mm min^{-1}) until failure. Failure detection was set at 10% loss of the maximum force ($F_{\max}$). To reduce excessive stress concentrations, a 0.3- mm-thick tin foil was positioned between the steel piston and the palatal crown surface.

Evaluation of fracture modes

The failure modes were distinguished between restorable or not restorable. Fractures or failures above or at the crestal bone level were assumed to be restored clinically (restorable failure), whilst those below the crestal bone level were judged as nonrestorable, i.e. it is likely that teeth would be extracted clinically.

Statistical analysis

The number of cycles until failure was analysed with log-rank statistics. Kaplan–Meier survival plots were constructed (Fig. 1). Nonparametric Kruskal–Wallis tests were applied to determine differences between group mean values of the maximum load capability $F_{\max}$.

Differences in the frequency of the failure modes between the groups were evaluated by Fisher's exact test. All statistics were two-sided at $\alpha = 0.05$.

Results

The results of chewing simulation and linear load tests are displayed in Table 2. In groups RXU – RXU and LCD – CC 20% and in group RXU – LCD, 30% of all specimens failed early during TCML. These specimens were assigned a load capability value of 0 N (Roulet & Van Meerbeek 2007). The log-rank analysis of the Kaplan–Meier survival plots (Fig. 1) revealed no statistically significant difference amongst all groups ($P = 0.379$).

In group RXU – CC, three crowns fractured and three fractures above the crestal bone level were observed. In the latter, the post remained intact and the fragments were not dislocated. These failures were judged as restorable. Twice a fracture through the core build-up occurred whilst the posts maintained intact. In group RXU – RXU, five crown fractures were observed. Two fractures during thermomechanical loading occurred early as nonrestorable failures at 21 843 and 318 050 cycles. This equals year one and two of simulated

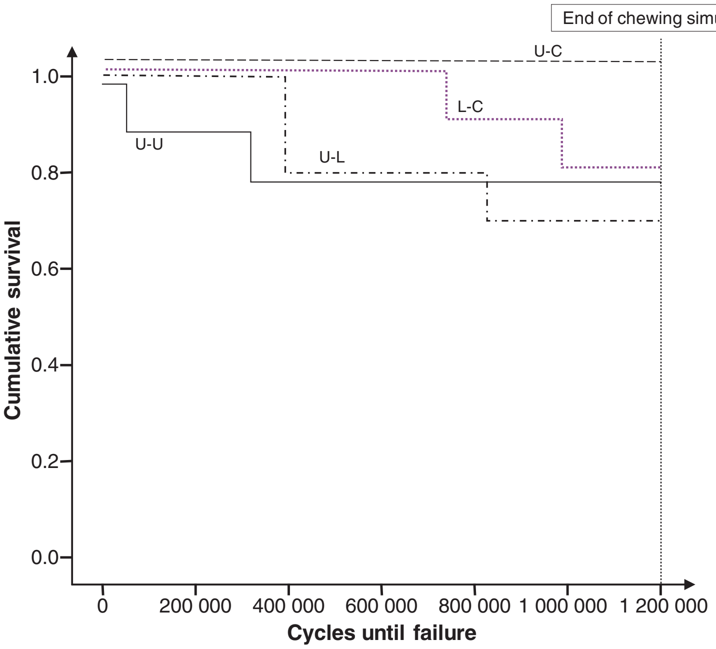

Figure 1 Kaplan–Meier curves of experimental groups during 5-year simulation of clinical functional forces (thermal cycling and mechanical loading: 1.2×10^6 cycles between 1 and 49 N; thermocycles 5/55 °C in distilled water).

clinical service, respectively, given that 1 year is represented by 240 000 cycles (1.2 million cycles = 5 years). After linear loading, one specimen failed and was nonrestorable as a horizontal root fracture in an area close to the post tip occurred. When the combination RXU – LCD was tested, one specimen failed during chewing simulation at 825 847 cycles and two more at 391 799 cycles. The failure mode resembled an oblique fracture below the simulated crestal bone level with dislocation of the post and the fragment (not restorable). Five more specimens had an oblique fracture below the crestal bone level without dislocation of the post or the fragment. Two crowns fractured. Besides three crown fractures in group LCD – CC, two early oblique fractures were observed: one at 987 245 cycles below (not re-restorable) and one at 739 196 cycles above (restorable) the crestal bone level. After linear loading, five more specimens fractured in an oblique manner below the crestal bone level.

The highest median $F_{\max}$ (294 N) was observed for the group RXU – CC for post cementation and core build-up. The combination of RXU with RXU resulted in the lowest values (166 N) (Fig. 2).

The statistical analysis revealed no significant differences between the experimental groups regarding survival during TCML (log rank: $P = 0.379$) or load capability (Kruskal–Wallis test: $P = 0.091$). Most restorable failures were found in group RXU – CC followed by the combination RXU – RXU. Most specimens that were restored with RXU as cement and LCD as core material showed catastrophic, i.e. nonrestorable, failures. The comparison of the frequency of the fracture patterns between the experimental groups with means of the Fisher's exact test showed significant differences ($P = 0.028$) (see Fig. 3).

Discussion

Both null hypotheses of this laboratory investigation regarding the impact of the type of core build-up material were confirmed. All specimens survived TCML only when a self-adhesive resin was used for post cementation and an etch-and-rinse system was used for bonding conventional resin composite core build-ups, all other combinations showed early failures. When these failed specimens were set at a load capability value of 0 N, the load capability values of the static load test were lowest for the combination of an etch-and-rinse core-build-up resin acting as cement and core build-up resin. The moderate failure rate and acceptable load capability suggest that the use of self-adhesive composite resins might be an alternative approach for a one-stage post-and-core build-up in smaller defect extensions. When a significant amount of hard tissue is missing, an early failure becomes more likely compared to cases when a conventional core build-up material is used.

Table 2 Number of preliminary failures and cycles until failure, mean values and standard deviation for load capability in (N) of load testing after thermal cycling and mechanical loading (TCML), fracture patterns pooled in two main categories according to clinical consequences for statistical analysis

Group (cement/core build-up)	Adhesive system (post cementation/core build-up)	Curing mode core build-up	*n*	Preliminary TCML failure (*n*)	Cycles until failure	Median (min/max) $F_{\max}$ (N)	Restorable failure (*n*)	Catastrophic failure (*n*)
RelyX Unicem/Clearfil	Self-adhesive/etch-and-rinse	Chemical	10	0	–	294 (209/445)	8	2
RelyX Unicem/RelyX Unicem	Self-adhesive/self-adhesive	Dual	10	2	1 × 21 843; 1 × 318 050	166 (0/726)	6	4
RelyX Unicem /LuxaCore-Dual	Nonadhesive/etch-and-rinse	Dual	10	3	1 × 391 799;1 × 391 902 1 × 825 847	241 (0/289)	2	8
LuxaCore-Dual/Clearfil	Etch-and-rinse/etch-and-rinse	Chemical	10	2	1 × 739 196; 1 × 987 245	200 (0/371)	3	7

The test arrangement used is well documented (DeLong & Douglas 1983) and has been successfully applied to post-and-core restorations (Naumann *et al.* 2006b, 2007a). Whilst microtensile or push-out tests provide valuable basic results for the evaluation of retentive properties of a luting material (Goracci *et al.* 2005a, Pirani *et al.* 2005, Wrbas *et al.* 2006, Faria e Silva *et al.* 2007), it is important to test the whole restorative complex – including the final restoration – in a simulation of clinical functional forces (Naumann *et al.* 2008). The approach to use core build-up resins for cementation was investigated with regard to the bond strength achievable (Aksornmuang *et al.* 2007, Ohlmann *et al.* 2008). Fibre posts were chosen because they improve the fracture resistance beneath lithium-disilicate ceramic crowns (Naumann *et al.* 2007a, Salameh *et al.* 2007). The defect extension with decoronation and ferrule preparation was chosen, because it is most challenging for the materials used (Feilzer *et al.* 1987). The importance of the ferrule effect is well documented (Stankiewicz & Wilson 2002). Post silanization was avoided as it appears to be without clinical impact (Wrbas *et al.* 2007). A Kaplan–Meier analysis was performed because it provides information about the failure development. Thus, it adds valuable data to the evaluation of maximum load capability values (Naumann *et al.* 2008).

Self-adhesive resin cement was used, and an etch-and-rinse system with dual-curing cement (LCD) served as a control. CC as chemically curing build-up composite resin in combination with RXU served as the positive control owing to its shown value during the 5-year simulated clinical function with both glass fibre and titanium posts (Naumann *et al.* 2007a), which was also confirmed clinically (Naumann *et al.* 2007b).

To date, research has focussed on the properties of the endodontic post and the luting abilities of the cements, although both are needed only to retain the core (Morgano & Brackett 1999), with the core retaining the final restoration. In a nondynamic load test, it was found that core stiffness did not affect failure resistance of post-and-core restored teeth. Hence, it was suggested that composites might work for both as core and cement (Boschian Pest *et al.* 2002). The elastic modulus for the materials used is ∼8 GPa (Sakalauskaite *et al.* 2006) for RXU and ∼9 GPa for LCD (manufacturers' information). In general, a range of 7–13 GPa is reported for composite resins for core build-up (Ausiello *et al.* 2002, Pegoretti *et al.* 2002, Li *et al.* 2006), whilst that of dentine is ∼19 GPa (Ausiello *et al.* 2002, Pegoretti *et al.* 2002, Lanza *et al.*

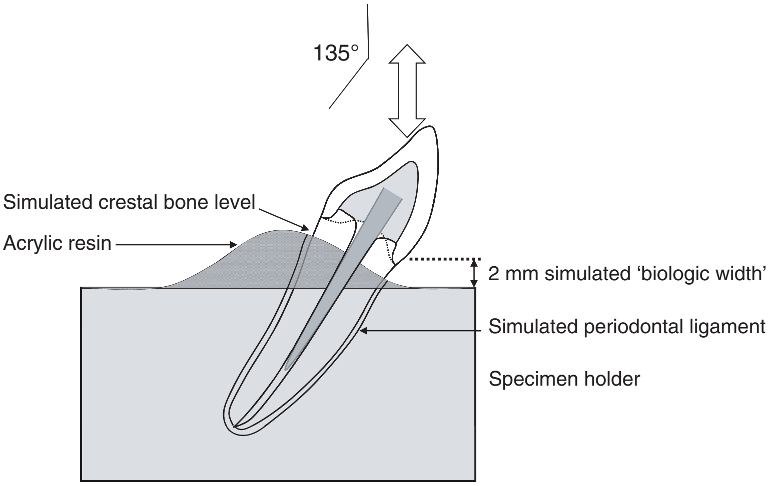

Figure 2 Experimental set-up for the dynamic load test.

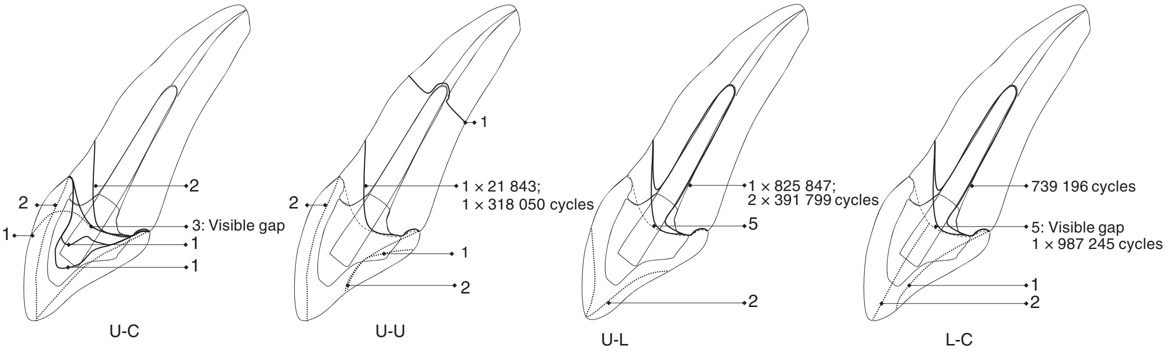

Figure 3 Fracture patterns of experimental groups, number of fractures are marked, in case of early failure during thermomechanical loading number of cycles are indicated.

2005, Li *et al.* 2006) and that of the glass fibre post used in this study is 54 GPa (manufacturers' information). Thus, the elastic modulus of the composite resins is somewhat lower than that of dentine. Owing to the threefold higher elastic modulus of the post compared to dentine, this might be an advantage. Composite resin might act as a stress dumping elastic interface, which appears to be consistent with the monoblock concept (Tay & Pashley 2007).

From the fracture patterns observed, it appears that the combination of RXU and CC is mechanically more stable than the other, because no early failure during thermomechanical loading occurred. Furthermore, it might be clinically relevant that most of the failures were restorable. Only two of 10 specimens fractured below the simulated crestal bone. However, in two cases, the core build-up itself fractured whilst the post remained intact. When the self-adhesive material is used to both cement the post and to build up the core, half of the crowns fractured during linear loading. This might be owing to a lack of support for the all-ceramic crown. It is remarkable that in that group, the only deep horizontal fracture around the post tip was observed. However, there were more restorable failures than not restorable. For RXU – LCD and LCD – CC, this was not true. For both combinations, most failures were catastrophic, i.e. not restorable. Most, i.e. seven of 10, specimens for both groups fractured below the crestal bone level.

Superficial wetting, bonding performance and contraction stresses during polymerization play an important role in the formation of the strength of the whole restorative complex (Reill *et al.* 2008). Curing mode and the viscoelastic behaviour were defined as factors contributing to contraction stress (Braga *et al.* 2003). Viscoelastic behaviour is characterized by its flow capacity at an early stage of the curing reaction, the polymerization shrinkage and the elastic modulus acquired during polymerization. Reducing polymerization stress, for example by incorporating pores during hand-mixing, has been shown to significantly reduce stress levels. However, porous materials might have impaired cohesive strength (Braga *et al.* 2003) and are not likely to be an appropriate alternative to capsule applications.

The use of a self-adhesive material for both post cementation and core build-up tends to be less reliable during simulated function and less load capable when static loaded compared to an etch-and-rinse-bonded specific core composite resin. However, the results are promising and highlight the possibilities introduced by self-adhesive materials after respective enhancement of their mechanical properties.

Conclusion

These results imply that self-adhesive composite achieve similar load capabilities when used as core build-up material in root-treated teeth restored with glass fibre posts and all-ceramic crowns.

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