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Influence of core material on fracture resistance and marginal adaptation of restored root filled teeth

M. I. Reill[1], M. Rosentritt[1], M. Naumann[2] & G. Handel[1]

[1]Department of Prosthetic Dentistry, Regensburg University Medical Centre, Regensburg, Germany; and [2]Department of Prosthodontics and Material Sciences, University of Leipzig, Leipzig

Abstract

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Aim To investigate *ex vivo* the influence of direct placement core materials on the fracture strength and marginal adaptation of root filled maxillary central incisors restored with glass fibre-reinforced posts, various core materials and all-ceramic crowns.

Methodology Forty-eight human maxillary incisors were root filled. Posts were placed and teeth restored with composite cores and crowns (n = 8). Six core materials were examined after thermal cyclic and mechanical loading (TCML). Fracture force was determined under static loading. The marginal adaptation at the interfaces between cement-tooth and cement-crown were categorized as 'intact margin' or 'marginal gap' using scanning electron microscopy. Statistical analysis was undertaken with the Mann–Whitney U-test ($\alpha = P \leq 0.05$).

Results Median fracture strength varied between 204 N (low viscous experimental core) and 1094 N (Multicore). No difference in fracture resistance was found with varying viscosity of the core material. The layering technique improved the fracture performance (P = 0.059) to a minor degree. Crowns with dedicated core materials (Rebilda 1063 N; Multicore 1094 N) had a significantly higher fracture resistance than crowns with a conventional restorative material (Tetric Ceram 509 N). Significantly poorer marginal adaptation before TCML was found for the layering technique at the tooth–cement interface and for all experimental cores after TCML. At the crown–cement interface significant differences in marginal adaptation could be determined between Multicore-layered core (P = 0.002) and Multicore-Rebilda (P = 0.001) after TCML.

Conclusions The fracture strength of post and core restorations was dependent on the core material and bonding system. Marginal adaptation was influenced by the method of application of the core material and by TCML.

Keywords: anterior ceramic crowns, core material, fibre-reinforced posts.

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Introduction

Following root canal treatment post and core restorations are commonly used to replace missing tooth structure prior to crown preparation. For restoration of maxillary anterior teeth all-ceramic crowns may be preferred because of their superior natural appearance compared to metal ceramic restorations (Bello & Jarvis 1997). A post is placed to provide a substructure that increases the retention of the core and crown (Cohen *et al.* 2000) where the degree of tooth conservation and ferrule preparation affect the resistance of the restoration (Naumann *et al.* 2006). Alternatives to simplifying chairside procedures include the use of prefabricated posts and direct placement composite resins to build up the core (Monticelli *et al.* 2004). The use of tooth-coloured fibre posts in combination with a resin-based core build-up material has been found to yield a more natural and aesthetic appearance of the final restoration compared to a cast metal post and core

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Correspondence: Margarete Ingrid Reill, Department of Prosthetic Dentistry, Regensburg University Medical Centre, Franz-Josef-Strauss-Allee 11, D-93053 Regensburg, Germany (Tel.: +49 941 944 6055; fax: +49 941 944 6171; e-mail: margarete.reill@klinik.uni-regensburg.de).

(Mentik *et al.* 1993). In contrast, fibre-reinforced materials provide even higher impact strength, good shock absorption and good fatigue performance (Boschian Pest *et al.* 2002), as well as a lower modulus of elasticity. Composite methyacrylate resins are used due to the convenience of a single visit core placement and preparation stage. In combination with the corresponding primer and bonding agent, reliable bond strength to dentine (11–28 MPa) has been reported (De Munck *et al.* 2005). For a composite which is used as a core material (E-modulus between 16 and 25 GPa, Pegoretti *et al.* 2002, Torbjörner & Fransson 2004) mechanical characteristics similar to those of dentine (E-modulus: 15–25 GPa) are desired (Sunnegardh-Grönberg *et al.* 2003). Such composite cores that are directly built-up have been reported and have a fracture resistance comparable to that of cast gold cores (Fredriksson *et al.* 1998, Reagan *et al.* 1999, Sirimai *et al.* 1999, Akkayan & Gulmez 2002). Various viscosities of core composites are available to allow the dentist to build-up the core either in one step, in layers, or with the help of a mould when using low viscosity materials. Only an optimal interaction between tooth substance and cementation, post and core, and crown can maximize an effective clinical application, while incompatible individual components may reduce the reliability of the restoration.

This investigation examined the influence of commercial and experimental core materials and the various procedures for their application on the fracture resistance and marginal adaptation of post and core-restored incisor teeth. Experimental core composites were provided by a dental manufacturer with composition and properties comparable to that of commercial products.

Materials and methods

Caries-free human maxillary central incisor teeth ($n = 48$), which were stored in 0.5% chloramine solution, were randomly divided into six groups of eight specimens each. To simulate an artificial periodontium, the roots of all teeth were covered with an approximately 1 mm thick layer of polyether (Impregum; 3M Espe, Seefeld, Germany). The teeth were embedded under a 45° angle to the horizontal line using PMMA resin (Palapress Vario Transparent; Kulzer, Wehrheim, Germany; Rosentritt *et al.* 2004). Using a measuring plate in a parallelometer (DeguDent, Hanau, Germany), the crowns were sectioned approximately 2 mm above the cemento-enamel junction with a disc. A 1 mm deep chamfer finishing line lying on enamel was prepared. The root canals were enlarged using Hedström file sizes 15–40 (Roeko, Langenau, Germany) using the stepback technique, then cleaned and dried with paper points. The root canals were filled with gutta–percha points (Dentsply Maillefer, Ballaigues, Switzerland) and endodontic sealer (AH Plus; Dentsply DeTrey, Konstanz, Germany) with the lateral compaction technique. After 24 h post preparation was performed with reamers (FRC post steel reamer, apical dimension: 1.0 mm; Ivoclar-Vivadent, Schaan, Liechtenstein) to a length of 10 mm. The posts (FRC Postec; Ivoclar-Vivadent) were cleaned with 36% phosphoric acid gel and silaned (Monobond S; Ivoclar-Vivadent). In order to bond the post to the root canal walls, the dentine was etched with 36% phosphoric acid, rinsed after 15 s and dried with paper points. The posts were luted with a dual curing composite system and the corresponding matching bonding system (Variolink 2, Syntac classic; Ivoclar-Vivadent). Table 1 provides an overview of the materials used. Standardized conditions were provided for posts (length 10 mm, apical diameter 1.0 mm), and cores (h = 5 mm × w = 3 mm × l = 5 mm) with the aid of a transparent polyethylene mould (Ercolen 0.7 mm, Erkodent, Pfalzgrafenweiler, Germany). The crown geometry was: h = 8 mm × mesial-distal = 7 mm × bucco-palatal = 6 mm. The experimental core materials were comparable to the compositions

Table 1 Materials of posts, cores, crowns and cementation

Group	1 control	2	3	4	5	6
Post (length/diameter) luting system	FRC Postec[a] (1.75mm/10mm) Syntac/Variolink 2[a]					
Core material	Tetric Ceram[a]	Exp.core in layers[a]	Exp.core high viscosity[a]	Exp.core low viscosity[a]	Rebilda DC[b]	Multicore HB[a]
Core luting system	Syntac[a]	Syntac[a]	Syntac[a]	Syntac[a]	Solobond Plus[b]	Adhese[a]
Material crown	Empress 2[a]					
Crown cementation	Syntac/Variolink 2[a]					

[a] Ivoclar-Vivadent, Schaan, FL.
[b] Voco, Cuxhaven, G.

of commercial materials, which are based on a mixture of methacrylates (Urethanedimethacrylate, bis-phenol-dimethacrylate and triethyleneglycoldimethacrylate) with inorganic glass and SiO_2 fillers. The filler content of the low viscosity material (group 3) was 15 weight% and of the high viscosity material (group 4) approximately 30 weight%. The materials used in groups 4 and 5 were identical formulations, but the cores of group 5 were built-up in layers. All core materials were dual curing except for the light curing restorative Tetric Ceram (3 × 40 s; Elipar-Trilight; 3M Espe). Two systems were used with their corresponding bonding system (Rebilda DC & Solobond Plus; Multicore & Adhese), and all other systems were bonded with Syntac classic (Table 2).

All crowns (Empress 2; Ivoclar-Vivadent) were etched using hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar-Vivadent), treated with bonding agent (Monobond S; Ivoclar-Vivadent), adhesively luted using a matching bonding system (Syntac classic; Ivoclar-Vivadent) and a dual curing composite resin cement (Variolink 2, high viscosity; Ivoclar-Vivadent).

Thermal cycling and mechanical loading (TCML, Rosentritt *et al.* 2006) was performed to simulate a 5-year period of oral service (parameters: 6000 thermal cycles 5°C/55°C, 1.2×10^6 mastication cycles with 50 N) using human opposing teeth. After TCML, the restorations were loaded to failure in a universal testing machine ($v = 1$ mm min^{-1}; Zwick 1445; Zwick, Ulm, Germany). In order to distribute the force evenly and avoid force peaks, a 0.3 mm thick piece of tin foil was placed between the sample and the loading point. The failure modes were divided into the following categories (i) crown fracture, (ii) combined root fracture and marginal gap, (iii) combined root fracture and the absence of a marginal gap and (iv) combined root fracture and failure of the post cement.

Table 2 Batch numbers of the used materials

Material	Batch numbers
Syntac primer[a]	E34592
Syntac adhesive[a]	E30794
Heliobond[a]	E33931
Tetric Ceram[a]	E25623
Variolink 2[a]	Base: E31588 Catalyst: E34696
Liquid Strip[a]	C52046
Hydrofluoric acid[a]	C05457
Monobond S[a]	D01060
Exp. core high viscosity[a]	RZC169
Exp. core low viscosity[a]	Base: KG11481 Catalyst: KG11472
Total etch[a]	F51841
Solobond plus primer[b]	E20425
Solobond plus adhesive[b]	E20425
Rebilda DC dentin[b]	E2013
Vococid Ätzgel[b]	E10525
Multicore HB[a]	Base: F30158 Catalyst: F30159

[a] Ivoclar-Vivadent, Schaan, FL.
[b] Voco, Cuxhaven, G.

In the semi-quantitative analysis of marginal adaptation, the margins restoration/cement and tooth/cement were examined using a scanning electron microscope (Stereoscan 240, magnification: 200–800×; working distance 18 mm; Cambridge Instruments, Cambridge, UK). Replicas (Epoxy VP 1031; Ivoclar-Vivadent) of the crowns were made before and after artificial aging. The palatal marginal adaptation was measured and classified using image analysis software (Optimas 6.2; Optimas Co., Orange, CA, USA). Marginal quality was defined using the following criteria: (i) 'intact margin' with smooth transition and no interruption of continuity, and (ii) 'marginal gap' showing separation of the components due to cohesive or adhesive failure (Table 3).

For statistical analysis the Kruskal–Wallis and Mann–Whitney *U*-test were calculated. The nonparametric, *post hoc* Mann–Whitney *U*-test allows for the assessment of the difference in medians between two samples. Kruskal–Wallis one-way analysis of variance by ranks is a nonparametric method for comparing three or more groups. The significance level was set at $P \le 0.05$ (Brosius & Brosius 1995).

Results

Fracture resistance

The highest median of fracture resistance (Fig. 1) was found for crowns with Multicore [group 6, 1094 N

Table 3 Pairwise comparison of marginal adaptation before and after thermal cyclic and mechanical loading (TCML) (*P*-values)

	Pairwise comparison of marginal adaptation before and after TCML	
	Tooth/cement	Crown/cement
Tetric Ceram (control)	0.520	0.746
Rebilda DC	0.901	0.129
Exp. low viscosity	0.073	0.383
Exp. high viscosity	0.043*	0.043*
Exp. in layers	0.028*	0.015*
Multicore	0.423	0.012*

*Significant differences ($P \le 0.05$).

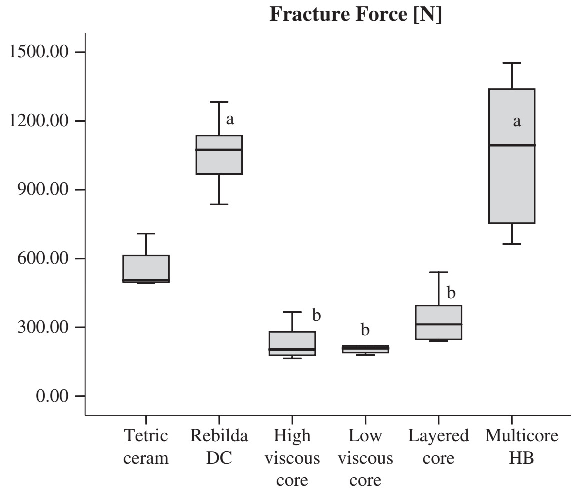

Figure 1 Boxplot: Fracture Force [N] (median, 25%, 75% and outlier) after thermal cyclic and mechanical loading (identical letters indicate no statistical significant differences $P \leq 0.05$).

(771/1334)] and Rebilda [group 2, 1063 N (889/1113)]. Crowns using the restorative core Tetric Ceram [group 1, 509 N (498/614)] resulted in significantly lower fracture values than crowns with Rebilda or Multicore cores. There were no statistically significant differences between the experimental core materials irrespective of whether they were applied in layers [group 5, 313 N (251/375)] or were high viscosity [group 4, 208 N (194/217)] or low viscosity [group 3, 204 N (183/262)]. Most systems showed a combined fracture of root and core (groups 1, 3, 4 and 6), but only root fractures were seen with Rebilda (group 5) and root fracture with post-luxation were found in all cases with Multicore (group 6).

Marginal adaptation

Figures 2 and 3 show the results of the semi-quantitative evaluation of marginal quality at the interface cement/crown and cement/tooth with changes before and after artificial ageing. At the interface cement/crown more than 95% of specimens in all groups had intact margin. There were no statistically significant differences between the different materials before TCML. After TCML, only Multicore (group 6) provided significant differences compared to Rebilda (group 5, $P = 0.001$) and the experimental layered system (group 2, $P = 0.002$). The high viscosity experimental material (group 3), the layered material (group 2) and Multicore (group 6) were all affected significantly by TCML. Before TCML, the layered system (group 2) showed statistically significant poorer marginal adaptation at the cement–tooth interface compared to all other systems. After TCML, there was a significant

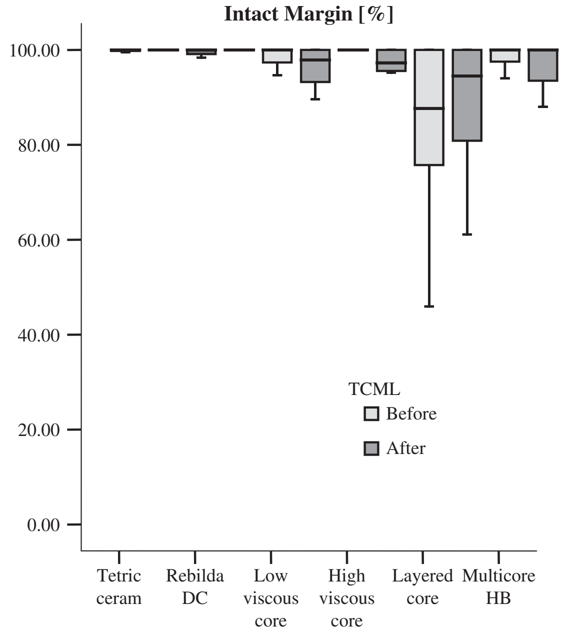

Figure 2 Boxplot: Intact margin [%] at the interface cement/tooth (median, 25%, 75% and outlier) before and after thermal cyclic and mechanical loading (TCML).

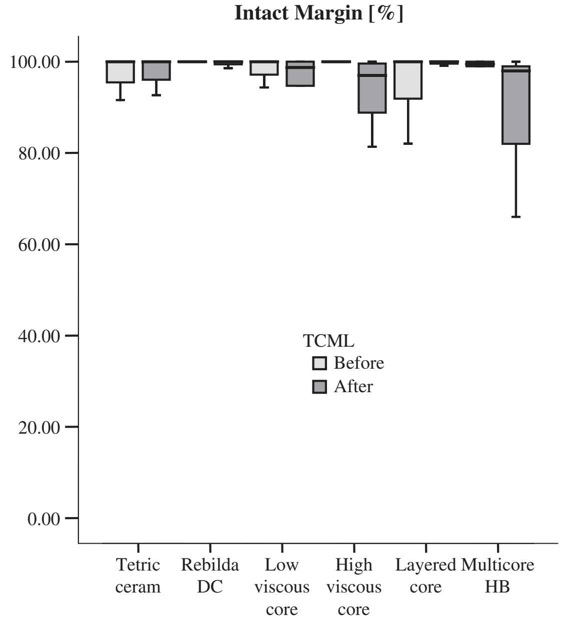

Figure 3 Boxplot: Intact margin [%] at the interface cement/crown (median, 25%, 75% and outlier) before and after thermal cyclic and mechanical loading (TCML).

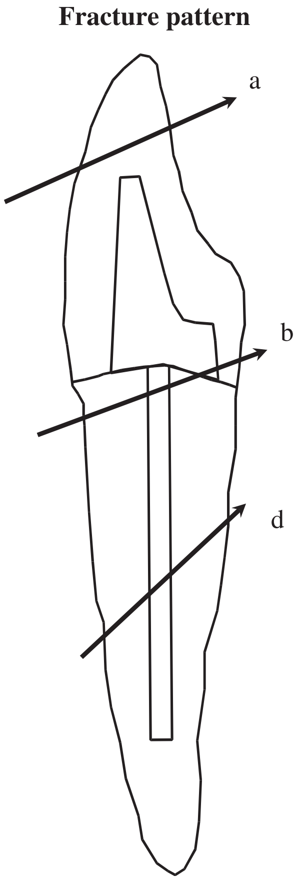

Figure 4 Types of observed fracture pattern: (a) Crown fracture, (b) combined root fracture and marginal gap, (c) combined root fracture and the absence of a marginal gap and (d) combined root fracture and the absence of a marginal gap.

difference in marginal adaptation only between the layered material (group 2) in comparison with Rebilda (group 5, $P = 0.015$) and the control (group 1, $P = 0.007$). The crowns with the high viscosity core material (group 3) as well as the crowns with the high viscosity experimental cores (group 2) were affected by TCML.

Discussion

An *in vitro* study was conducted to examine the influence of the core material on fracture strength and marginal adaptation of maxillary central incisors, which were restored with glass fibre-reinforced composite posts, various composite build-up materials and all-ceramic crowns. Fracture strength depended on the core material used, while marginal adaptation was influenced by the method of application of the core material (Figs 4 and 5).

After TCML, deterioration in marginal quality was found for two experimental materials and one commercial core system, a finding which coincides with previous results (Rosentritt *et al.* 2006). Nevertheless, the high proportion of intact margins was greater than 95% at both interfaces, suggesting that adequate performance may occur clinically. Only the group with the layered core at the cement–tooth interface provided unexpectedly significantly poorer results: approximately 80–90% intact margins with a broad range of values. Insufficient marginal seal may lead to penetration of bacteria, result in caries (Goracci *et al.* 1995) or may reduce the bond between crown and tooth. In general, observable effects of marginal adaptation on fracture resistance could not be found for the systems tested.

The highest fracture strength was achieved by the two core materials Multicore with its adapted bonding agent Adhese (1094 N) and Rebilda DC with Solobond Plus (1063 N). The results of all commercial core materials were higher than the suggested values for application in anterior teeth (Al Wazzan 2002). However, clinically unfavourable fracture patterns such as root fracture (Rebilda) or fracture of root and composite core (Multicore, Tetric Ceram) still occurred. The results were comparable to, or even exceeded, values with light curing composite cores and titanium posts (365 N), zirconia posts (580 N) or FRC posts (505 N) (Rosentritt *et al.* 2004). Heydecke *et al.* (2002) found fracture values of 1047, 1100 or 500 N for metal crowned incisors, composite cores and zirconia posts.

It has been shown that the fracture strength of crowns is dependent on the modulus of elasticity of the tooth or alternative tooth material for laboratory testing (Scherrer & De Rijk 1993). The fracture strength of the two commercial systems was not significantly different, although the materials possess different properties with respect to the modulus of elasticity (Multicore HP: 18 GPa; Rebilda DC: 10 GPa). Comparable fracture resistance values were found for the experimental systems with a modulus of 9 or 18 GPa and despite different viscosities, they nonetheless had comparable fracture resistance.

The layering technique improved the fracture resistance by approximately 30% over the bulk technique, although this difference was not statistically significant. This decreased fracture rate may be a result of improved condensing of the individual layers or a

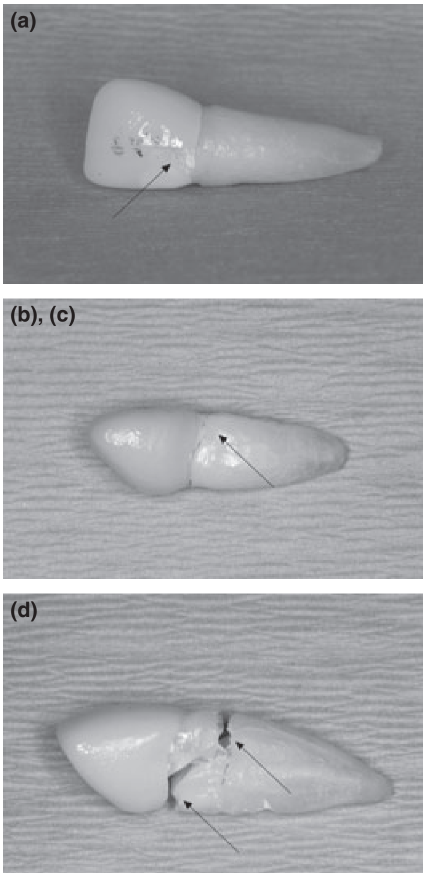

Figure 5 Examples of typical failure pattern.

better adaptation of the core material on dentine and post.

The light curing core material Tetric Ceram improved the restorative system in comparison with the chemical dual curing experimental systems, despite a comparable or lower modulus of elasticity (Tetric Ceram approximately 10 GPa). These observations may be explained by the effect of light curing: Syntac classic and its bonding agent require light activation and therefore may benefit from the light curing of Tetric Ceram. Composite cores with primer and bonding achieve reliable bond strengths to dentine between 11 and 28 MPa (Boschian Pest *et al.* 2002). The bonding may suffer without proper light activation due to a thick core layer or a thick layer of oxygen inhibition (Rueggenberg & Margeson 1990). This could explain the comparably poor results of the experimental materials and the improved results of the two systems using Adhese or Solobond bonding, where the bonding is adapted to the chemical curing nature of the core. It should be mentioned that the results may suffer as a result of the varying quality of dentine, where an increased amount of coronal dentine may improve the fracture resistance of root-filled teeth (Jefferson *et al.* 2006). In addition, acid etching may produce different effects in different regions (Le Bell *et al.* 2005) or different directions/cuts of the dentine tubuli (Arnold *et al.* 2001). The post luxation of the experimental layered group may have occurred as a result of the hindered light curing of the adhesive system in the root canal, the quality of root dentine, air inclusion in the root canal or insufficient fit of the posts. Improved fracture resistance may be found with chemically curing adhesives, which establish a strong bond to the root canal walls after dentine conditioning (Ferrari *et al.* 2000).

Conclusions

Fracture strength was dependent on the type of core material used, whereas marginal adaptation was not related to the core materials. The properties of the restoration were not affected by core properties (modulus of elasticity), but presumably by the bonding between core and tooth tissue. The use of chemically curing cores with adapted bonding systems provided the highest fracture strength and the restorative composite achieved sufficiently positive results for clinical use.

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