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An *ex vivo* study of the effects of retained coronal dentine on the strength of teeth restored with composite core and different post and core systems

M. K. AL-Omiri & A. M. AL-Wahadni

Department of Restorative Dentistry, Faculty of Dentistry, Jordan University of Science and Technology, Irbid, Jordan

Abstract

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Aim To investigate the fracture resistance and fracture patterns of teeth restored with composite cores supported by different pre-fabricated post systems and different heights of remaining coronal dentine.

Methodology Four groups of 30 single rooted teeth were used. Each group was divided into three subgroups of 10 teeth each and restored with carbon fibre, glass fibre, or Radix titanium posts luted with dual cure resin cement. The control group A had no retained coronal dentine. Groups B, C and D had 2, 3 and 4 mm of retained buccal and lingual coronal dentine, respectively. Teeth were tested to failure using an Instron Universal Testing Machine. Subsequently, the fracture mode of specimens was recorded.

Results Teeth with retained dentine were more resistant to fracture ($P = 0.001$). Tooth fracture resistance was not significantly different between groups B, C and D. Within group A, titanium posts were associated with higher fracture resistance than fibre posts. Within the other groups, tooth fracture resistance was not related to post material. Within groups C and D, fracture resistance of teeth restored with carbon fibre posts was significantly higher than those restored with glass fibre posts. The dominant fracture mode in group A was core and vertical oblique root fracture whilst a combination of core, coronal dentine and root fracture occurred in the other groups.

Conclusions Fracture resistance of teeth increased with the presence of retained coronal dentine. The use of glass and carbon fibre posts did not improve the fracture resistance or the fracture pattern of teeth when compared with metal titanium posts regardless of the presence of retained coronal dentine. The dominant fracture pattern of teeth was not related to the amount of retained dentine if it was >2 mm high.

Keywords: coronal dentine, fracture resistance, pre-fabricated post and core.

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Introduction

Dental professionals have been searching for the best way to restore root filled teeth whilst protecting the remaining dental tissues. A variety of post and core systems are available for the restoration of such teeth but there is no consensus on which systems are best suited for clinical use.

Root filled teeth are weaker than intact ones due to decreased dentine moisture, loss of dental structure and root canal preparation (Helfer *et al.* 1972, Trope *et al.* 1985, Reech *et al.* 1989, Gutmann 1992). This will limit tooth deformation capacity under loading and thus will increase the potential for tooth fracture (Tidmarsh 1976).

The concept of tooth reinforcement using endodontic posts was proposed during the 1960s and 1970s

Correspondence: Dr Mahmoud K. AL-Omiri, BDS, PhD, FDS RCS (Eng), Jordanian Board, Department of Restorative Dentistry, Faculty of Dentistry, Jordan University of Science and Technology, PO Box 3030, Irbid 22110, Jordan (Tel.: 00962795571629; fax: 0096227095115; e-mail: alomirim @yahoo.co.uk).

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(Frank 1959, Silverstein 1964, Lau 1976). This concept was not supported by scientific studies and was then questioned and rejected (Ross 1980, Sorensen & Martinoff 1984, McDonald 1994, Manning *et al.* 1995, Stewardson 2001).

Natural dentine is superior in terms of fracture resistance than any post and core restoration (Abou-Rass 1992). Tooth strength is directly related to the remaining tooth structure (Hunter & Flood 1989). This necessitates caution during tooth preparation for endodontic post insertion.

Restoration of root filled teeth with endodontic posts should preserve tooth structure and reduce loss of dental tissues, allow and maintain a suitable apical seal and decrease damaging stresses (Sokol 1984, Weine 1996, Nergiz *et al.* 1997).

The amount of remaining tooth tissue around a post determines fracture resistance (Tjan & Whang 1985, Assif & Gorfil 1994, Marchi *et al.* 2003). Although most reports have recommended retaining coronal tooth structure to improve retention and stress distribution, the effect of retained coronal dentine on the strength of root filled teeth remains controversial. Some studies have suggested that it increases resistance to tooth fracture (Standlee & Caputo 1988, Barkhordar *et al.* 1989, Milot & Stein 1992, Fan *et al.* 1995, Al-Wahadni & Gutteridge 2002) whilst others have concluded that it does not (Tjan & Whang 1985, Sorensen & Engelman 1990, Patel & Gutteridge 1996, Saupe *et al.* 1996, Al-Hazaimeh & Gutteridge 2001).

Moreover, no previous studies have investigated the effect of different heights of remaining coronal dentine on the fracture resistance of root filled teeth restored with pre-fabricated metal and nonmetal post systems. Further investigation is required in this regard.

This laboratory study aimed investigate the effect of different heights of remaining coronal dentine on the fracture resistance of teeth restored with composite cores and three types of pre-fabricated posts. The mode of fracture of teeth restored with those posts was also studied. The hypothesis was that the fracture resistance and mode of fracture of teeth will differ according the type of pre-fabricated post used.

Materials and methods

A total of 270 single rooted teeth, including pre-molars, canines and incisors were collected from the Dental Teaching Centre, Jordan University of Science and Technology, Irbid, Jordan, and stored in a solution of water and 5% thymol at room temperature (Al-Wahadni & Gutteridge 2002). Thymol solution has an antifungal action and was used to store the specimens during the period of tooth collection for this study.

A digital caliper (Angilia, stMicroelectronics, Edinburgh, UK) was used to measure mesiodistal and buccolingual dimensions of each tooth at the tooth cementoenamel junction to secure similar size distribution of different teeth included in the study groups.

Teeth were examined under 2× magnification to exclude teeth with caries, cracks, or restorations that might jeopardize their resistance to fracture under experimental loading. All teeth were assessed by the two examiners and the decisions of both investigators were 100% coincident.

A total of 220 teeth selected from the initial 270 teeth were allocated to four groups A, B, C and D (Fig. 1). Each group consisted of 30 teeth. Teeth within groups A, B, C and D were allocated so that they would be prepared to have zero, 2, 3 and 4 mm height of

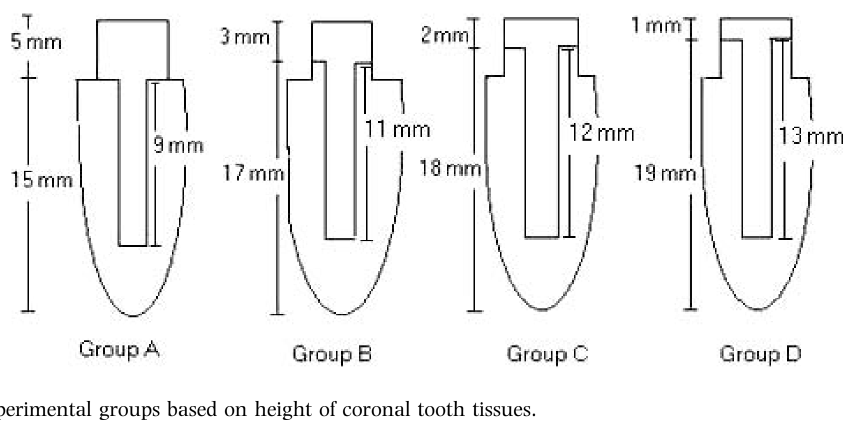

Figure 1 The experimental groups based on height of coronal tooth tissues.

retained coronal dentine, respectively. Each group was then subdivided into three subgroups of 10 teeth each. Each subgroup was restored with one type of prefabricated post systems including Radix prefabricated titanium metal posts (Radix–Anker–Standard; Dentsply Maillefer, Ballaigues, Switzerland), carbon fibre endodontic posts (C-Post; Bisco Inc., Schaumburg, IL, USA), or glass fibre endodontic posts (GF; J. Morita, Irvine, CA, USA). All teeth were restored by the same operator.

Teeth within group A were sectioned 2 mm above the cementoenamel junction (Al-Wahadni & Gutteridge 2002). This allowed the roots to be embedded within stone but allow the sectioned surface (finish line) to be 3 mm and the cementoenamel junction 1 mm above the stone surface, this simulated the root position and bone levels *in vivo* and ensured standard preparation and loading of all specimens (Patel & Gutteridge 1996). Teeth within groups B, C and D were sectioned 17, 18 and 19 mm from the apex, respectively.

Under constant irrigation with saline, post channels 1.5–1.6 mm in diameter were prepared using a sequence of burs provided with each system according to the manufacturers instructions to create post spaces 9, 11, 12 and 13 mm in length within groups A, B, C and D, respectively. Post channels in groups B, C and D extended 9 mm below the level of finish line and 2, 3 and 4 mm above the finish line, respectively, in accordance with the height of the retained coronal dentine. The coronal portion of the Radix titanium post has a length of 5 mm and a diameter of 3.5–4 mm whilst the radicular portion has a length of 9 mm and a diameter of 1.6 mm. Therefore, the cervical 2, 3 and 4 mm of the coronal section of the Radix titanium posts were reduced to 1.6 mm diameter to allow the insertion of Radix titanium posts of 1.6 mm diameter and 11, 12 and 13 mm height in groups B, C and D, respectively. The apical 5 mm of the root canal was left undisturbed (Al-Hazaimeh & Gutteridge 2001, Al-Wahadni & Gutteridge 2002) to simulate the presence of intact apical portion of root filling *in vivo* (Mattison *et al.* 1984, Zillich & Corcoran 1984, Peroz *et al.* 2005).

The thickness of remaining coronal dentine was standardized via the construction of a cast Ni–Cr metal jig in the form of a flat central button covering the root face dentine and extending 1.5 mm buccally, 1.5 mm lingually, 1 mm mesially and 1 mm distally from the post channel toward outer surface of the tooth (Al-Wahadni & Gutteridge 2002). Using a shoulder diamond bur (Intensiv, Grancia, Switzerland) a shoulder was prepared on the remaining coronal dentine 15 mm from the apex in groups B, C and D. A shoulder of approximately 1 mm width was obtained for all teeth and measured by the digital calibre.

The post channels were irrigated with saline, dried with cotton paper points (Absorbant Paper Points; Dream Dental Co., Pusan, South Korea) and then acid etched for 30 s using 30% phosphoric acid solution (Gluma, Bayer Dental, Leverkusen, Germany). They were then irrigated with distilled water and dried with cotton paper points. According to the manufacturer's instructions, the posts were luted inside the post channels using adhesive resin luting cement (Bistite II DC; J. Morita, Irvine, CA, USA).

All specimens were restored with a composite core material (Shade A 3.5 Estelite composite; J. Morita) over the posts. The tooth surface and the post portion that projected from the canal were acid etched and treated using the Bistite II DC adhesive resin cement according to the manufacturer's instructions. A cellulose mould was used during core build up for each tooth to ensure standardized core size as well as to exclude voids and deficiencies within the core material. A small indentation was included at the inner surface of the cellulose mould to provide a standardized point of load application. Dental curing light (3M ESPE 2500 Curing Light Unit; 3M, St Paul, MN, USA) was used to cure the composite for 30 s.

Each tooth was then embedded within a specially made stainless steel tube filled with die stone (Begostone, BEGO Bremer Goldschlgereiaeilh, Bermen, Germany). The tooth was aligned parallel to the outside of the stainless steel tube using a surveyor (Degussa, AG, Geschaftsbereich Dental, Fankfort II, Germany) where the analysing rod was positioned parallel to the side of the core and the outside of the tube.

Each specimen was then mounted within an Instron Universal testing machine (Instron 1195; Instron Limited, High Wycombe, Buckinghamshire, UK). The load was applied at the lingual surface of the tooth and was set at 130° from the horizontal by mounting the specimen within a specially designed retaining arm of the Instron machine. The angle of 130° has been demonstrated to clinically mimic the angle of loading in anterior teeth (Eshelman & Sayegh 1983, Volwiler *et al.* 1989, Patel & Gutteridge 1996, Al-Wahadni & Gutteridge 2002).

For each specimen, testing loads were applied onto a standard point at the middle of the lingual-occlusal line angle of the core, at a level of 5 mm height from the finish line, corresponding to a small indentation at the inner surface of the cellulose mould that was used to construct the composite core.

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The Instron machine cross-head speed was 10 mm min^{-1}, which is comparable to chewing speed (Patel & Gutteridge 1996), and the chart speed was 1000 mm min^{-1}. Fracture resistance testing results were registered as force at failure (N). The pattern of tooth fracture was recorded photographically at the start of the failure of each specimen as the value of failure force dropped suddenly.

Statistical analysis

The Statistical Package for Social Sciences (SPSS) computer software version 11.0 (SPSS, Inc., Chicago, IL, USA) was used to conduct data analysis. Descriptive statistics including means, standard deviations, and frequency distribution were calculated for each group. A Pearson's correlation test was used to correlate variables within the same group. Results from the four test groups were compared and analysed using one-way ANOVA test and the *post-hoc* least significant difference (LSD) test to demonstrate differences between pairs of groups. Probability values of $P \leq 0.05$ were set as the reference for statistically significant results.

Results

The mesiodistal dimension of the teeth ranged from 4.0 to 6.0 mm whilst the buccolingual dimension ranged from 4.5 to 8.5 mm. Table 1 presents the means and standard deviations of mesiodistal and buccolingual dimensions of the test teeth. Using ANOVA, the mean buccolingual and mesiodistal dimensions of teeth in the four groups were not statistically different from each other ($P = 0.358$ and 0.301, respectively).

Table 2 discusses the fracture loads of teeth within the four test groups and relevant subgroups. Group A, B, C and D had mean fracture loads of 462.5, 619.2, 660.63 and 758.7 N, respectively. The increased amount of remaining dentine was associated with higher fracture loads. Using ANOVA, the groups were significantly different in terms of fracture loads ($P = 0.001$). When pairs of groups were compared together, fracture loads of teeth within groups B, C and D were significantly higher than those of teeth within group A ($P = 0.031$, 0.007 and 0.000, respectively) (Table 3). However, no statistically significant difference was found between groups B and C, B and D, or C and D (Table 3).

The analysis of variance between different subgroups (different types of posts) within each main group revealed significantly different fracture loads within subgroups of groups A and D and when all the test teeth were considered together ($P = 0.000$, 0.045 and 0.012, respectively). However, no significant differences between the subgroups were detected when groups B and C were considered ($P = 0.552$ and 0.099, respectively).

Within group A, fracture loads of teeth restored with Radix titanium posts were significantly higher than those associated with carbon and glass fibre posts ($P = 0.000$ and 0.004, respectively) (Table 4). However, fracture loads of teeth restored with carbon fibre posts were not significantly different from those restored with glass fibre posts ($P = 0.211$) (Table 4).

Table 2 Means, standard deviations, minimum and maximum fracture loads of teeth in the four test groups and relevant subgroups

		Fracture load (*n*)			
Group	Post type	Mean	SD	Minimum	Maximum
A	Glass fibre	381.2	104.190	231	556
	Carbon fibre	435.7	101.637	311	608
	Radix	570.6	77.433	495	685
	All	462.5	122.440	231	685
B	Glass fibre	574.6	312.430	229	1135
	Carbon fibre	571	379.280	100	1330
	Radix	712	278.280	280	1060
	All	619.2	321.600	100	1330
C	Glass fibre	527.2	273.965	229	1016
	Carbon fibre	744.7	268.665	347	1070
	Radix	710	123.198	530	960
	All	660.63	224.585	229	1070
D	Glass fibre	569.9	220.730	395	1147
	Carbon fibre	964.2	438.134	500	1570
	Radix	742	308.502	390	1320
	All	758.7	362.190	390	1570

Table 1 Means and standard deviations of buccolingual and mesiodistal dimensions of the study teeth

	Group				
	A	B	C	D	All teeth
Mean mesiodistal dimension (mm)	5.53	5.13	5.16	5.23	5.26
Standard deviation (mm)	0.31	0.29	0.35	0.37	0.36
Mean buccolingual dimension (mm)	7.05	6.73	6.95	7.04	6.94
Standard deviation (mm)	0.43	0.79	0.95	0.83	0.78

Table 3 *Post hoc* least significant difference (LSD) test for comparison of the fracture load between pairs of groups

Compared groups	Mean difference	SE	Significance	95% confidence interval Lower bound	Upper bound
A versus B	−156.7	71.813	0.031*	−298.93	−14.47
A versus C	−198.13	71.813	0.007*	−340.37	−55.90
A versus D	−296.2	71.813	0.000*	−438.43	−153.97
B versus C	−41.43	71.813	0.565	−183.67	100.80
B versus D	−139.5	71.813	0.054	−281.73	2.73
C versus D	−98.07	71.813	0.175	−240.30	44.17

*Significant relation ($P \leq 0.05$).

Table 4 *Post hoc* least significant difference (LSD) test for the comparison of the fracture load between pairs of different types of posts used in the study

Group	Compared post types	Mean difference	SE	Sig.	95% Confidence interval Lower bound	Upper bound
A	GF versus CF	−54.50	42.569	0.211	−141.84	32.84
	GF versus RX	−189.40	42.569	0.000*	−276.74	−102.06
	CF versus RX	−134.90	42.569	0.004*	−222.24	−47.56
B	GF versus CF	3.60	145.810	0.980	−295.58	302.78
	GF versus RX	−137.40	145.810	0.354	−436.58	161.78
	CF versus RX	−141.00	145.810	0.342	−440.18	158.18
C	GF versus CF	−217.50	104.056	0.046*	−431.01	−3.99
	GF versus RX	−182.80	104.056	0.09	−396.31	30.71
	CF versus RX	34.70	104.056	0.741	−178.81	248.21
D	GF versus CF	−394.30	149.634	0.014*	−701.32	−87.28
	GF versus RX	−172.10	149.634	0.26	−479.12	134.92
	CF versus RX	222.2	149.634	0.149	−84.82	529.22
All test teeth	GF versus CF	−165.67	64.009	0.011*	−292.44	−38.91
	GF versus RX	−170.42	64.009	0.009*	−297.19	−43.66
	CF versus RX	−4.75	64.009	0.941	−131.52	122.02

GF, glass fibre; CF, carbon fibre; RX, Radix titanium; Sig., significance.
*Significant relation ($P \leq 0.05$).

Fracture loads of teeth within different subgroups of group B were not statistically significantly different ($P = 0.552$) (Table 4). Within group C, fracture loads of teeth restored with glass fibre posts were significantly lower than those restored with carbon fibre posts ($P = 0.046$) (Table 4). However, fracture loads were not significantly different between teeth restored with Radix titanium and those restored with carbon or glass fibre posts ($P = 0.741$ and 0.09, respectively). Within group D, fracture loads of teeth restored with glass fibre posts were significantly lower than those restored with carbon fibre ($P = 0.014$) (Table 4). However, fracture loads were not significantly different between teeth restored with Radix titanium and those restored with carbon or glass fibre posts ($P = 0.149$ and 0.26, respectively).

When all samples were considered as one group regardless of the amount of remaining dentine, the fracture loads of teeth restored with Radix titanium or carbon fibre posts were significantly higher than those restored with glass fibre posts ($P = 0.009$ and 0.011, respectively) (Table 4). However, fracture loads of teeth restored with Radix titanium were not statistically significantly different from those restored with carbon fibre posts ($P = 0.941$) (Table 4).

Table 5 presents the fracture modes amongst test teeth in each group and subgroup. Within group A, the dominant fracture mode was core and vertical oblique root fracture (21 specimens). The fracture line originated at the core adjacent to the point of load application then passed toward the centre of the root surface and then propagated obliquely downward in a facial (buccal or labial) direction. All carbon fibre posts were associated with tooth fracture modes that involved both the core and the root. Titanium posts on the other hand were associated with fracture modes that involved both the core and the root or only the root. However, glass fibre posts were associated with different fracture modes including only core fracture, only vertical oblique root fracture, or core and vertical oblique root fracture.

Within groups B, C and D the dominant fracture mode was a combined coronal dentine–core–vertical oblique

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Table 5 Mode of fracture of the study specimens

Group	Post type	Fracture mode* and its frequency								Total
		1	2	3	4	5	6	7	8	
A	Glass fibre	–	–	–	–	6	–	2	2	10
	Carbon fibre	–	–	–	–	–	–	–	10	10
	Radix	–	–	–	–	1	–	–	9	10
	All	–	–	–	–	7	–	2	21	30
B	Glass fibre	–	–	–	9	1	–	–	–	10
	Carbon fibre	–	2	2	5	–	–	1	–	10
	Radix	–	2	–	7	–	1	–	–	10
	All	–	4	2	21	1	1	1	–	30
C	Glass fibre	1	–	–	3	6	–	–	–	10
	Carbon fibre	–	–	–	10	–	–	–	–	10
	Radix	–	–	2	8	–	–	–	–	10
	All	1	–	2	21	6	–	–	–	30
D	Glass fibre	–	–	1	9	–	–	–	–	10
	Carbon fibre	–	–	–	7	3	–	–	–	10
	Radix	–	–	–	8	–	2	–	–	10
	All	–	–	1	24	3	2	–	–	30
All	Glass fibre	1	–	1	21	11	–	4	2	40
	Carbon fibre	–	2	2	22	3	–	1	10	40
	Radix	–	2	2	23	1	3	–	9	40
	All	1	4	5	66	15	3	5	21	120

*1, coronal dentine; 2, coronal dentine and core; 3, coronal dentine and root; 4, coronal dentine-core-vertical oblique root; 5, vertical oblique root; 6, horizontal root; 7, core; 8, core and vertical oblique root.

root fracture (21, 21 and 24 specimens, respectively). The fracture line originated at the core adjacent to the loading point and passed through the coronal dentine and then propagated through centre of the root surface obliquely in an apical and buccal direction.

When all test teeth were considered as one group, the dominant fracture mode was a combined coronal dentine–core–vertical oblique root fracture (66 specimens). Teeth restored with carbon fibre posts demonstrated fracture modes including coronal dentine and core, coronal dentine and root, coronal dentine–core–root, vertical oblique root, or only core fracture modes. Teeth restored with titanium posts were associated with fracture modes including coronal dentine and core, coronal dentine and root, coronal dentine–core–root, vertical oblique root, or horizontal root fracture modes. However, teeth restored with glass–fibre posts demonstrated fracture modes including only coronal dentine, coronal dentine and root, coronal dentine–core–root, vertical oblique root, or only core fracture modes.

In all specimens, root fractures were catastrophic and beyond repair. Horizontal root fracture was only associated with titanium metal posts whilst only core fracture mode was associated with fibre posts. No specimen demonstrated fracture of the post.

Discussion

This study was performed on sound extracted natural teeth. Using natural teeth has various drawbacks since they vary in width, length, moisture content, calcification, size and position of the pulp, and presence of cracks and surface flaws (Kantor & Pines 1977, McDonald *et al.* 1990, Heydecke *et al.* 1999, Ottl *et al.* 2002). On the other hand, artificial roots cannot mimic natural dentine and their adhesion to the post is unrealistic and not similar to clinical situations (Mendoza *et al.* 1997, O'Keefe *et al.* 2000). Furthermore, natural teeth have higher fracture resistance than artificial ones (Strub *et al.* 2001).

It was difficult to collect sound extracted human teeth of similar dimension and this explains the use of different tooth types within this study (Patel & Gutteridge 1996, Al-Wahadni & Gutteridge 2002). The effect of the periodontium was not reproduced through this study and the specimens were directly embedded within stone (Libman & Nicholls 1995, Martinez-Gonzalez *et al.* 2001). The teeth were not embedded within silicon or wax since this might cause dislodgment of the teeth during loading and might not allow the study of actual behaviour of the materials used (Al-Hazaimeh & Gutteridge 2001, Martinez-Gonzalez *et al.* 2001). Furthermore, such materials have different elasticity than the periodontium and thus be unrepresentative of the clinical situation (Al-Hazaimeh & Gutteridge 2001). The root canals of the teeth were not filled with a root filling material for simplification and to avoid unnecessary destruction of the tooth structure. This was in concordance with previous studies (Al-Hazaimeh & Gutteridge 2001, Al-Wahadni & Gutteridge 2002).

Through this study, composite cores were used rather than metal cores (amalgam or cast metal) because it has been reported that failure modes were unfavourable when metal cores were used and favourable when composite cores were used (Pilo *et al.* 2002). Moreover, composite is considered a good core material to use, especially with fibre posts (Purton & Payne 1996, Peroz *et al.* 2005).

Loading was applied directly onto the core, as no crown was used in accordance with previous studies, for simplification purposes and to exaggerate the load effect on the tooth (Al-Wahadni & Gutteridge 2002). However, this might have affected the stress distribution within the tooth and thus the magnitude of fracture loads and the fracture modes of the specimens.

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Resin cements reduce potential stress as their elasticity approaches that of dentine (Eakle *et al.* 1992, Suh & Cincione 1992, Leinfelder 1993, Junge *et al.* 1998). Mendoza *et al.* (1997) concluded that root filled teeth restored with resin bonded endodontic posts were more resistant to fracture than teeth restored with zinc phosphate cemented posts. Love & Purton (1998) demonstrated that resin cements were superior, in terms of endodontic post retention, to glass ionomer. Dual cure resin cements are superior to light cured resin cements for luting glass fibre posts (Ferrari *et al.* 2001). Peroz *et al.* (2005) have recommended the use of adhesive cements for luting all types of posts as they were associated with higher success rates. Therefore, dual cure resin cement was used to lute the posts during this study.

The presence of remaining coronal dentine improved the fracture resistance of teeth restored with prefabricated metal and fibre reinforced resin posts. The use of composite cores, posts of different material, resin cements, and retaining coronal dentine buccally and lingually might be the reason behind such findings. The literature supports the concept that removing dentine is detrimental for root strength and resistance to fracture (Trabert *et al.* 1978). In order to avoid failure, it is critical to preserve tooth structure to optimize stress reduction (Sokol 1984, Halpern 1985, Hunter & Flood 1989, Weine 1996, Nergiz *et al.* 1997).

Previous studies have presented contradictory results regarding the failure rates and fracture resistance of teeth restored with metal posts compared with those restored with fibre posts. Some studies have demonstrated higher failure rates of teeth restored with metal posts in comparison with teeth restored with fibre posts (Duret *et al.* 1996, Isidor *et al.* 1996, Sidoli *et al.* 1997, Asmussen *et al.* 1999, Mannocci *et al.* 1999, Akkayan & Gulmez 2002, Ottl *et al.* 2002, Albuquerque *et al.* 2003). This was explained on the basis that favorable stress distribution and flow within the dentine requires a similar rigidity of the post and tooth (Assif *et al.* 1989, Torbjorner *et al.* 1996). Fibre reinforced resin posts have moduli of elasticity similar to dentine and thus meet the above requirement (Duret *et al.* 1996, Asmussen *et al.* 1999, Mannocci *et al.* 1999, Brown 2000, Stewardson 2001).

Stiffer posts have been associated with better stress distribution and greater fracture resistance (Manning *et al.* 1995, Stockton & Williams 1999). This was explained by the fact that fibre post flexibility causes stress direction toward the core or the post–tooth interface and thus decreases their success rates (Stockton & Williams 1999). Moreover, the use of carbon fibre post did not significantly alter the fracture resistance of teeth when compared with cast post and core systems and pre-fabricated metal post systems (Cormier *et al.* 2001, Raygot *et al.* 2001, Hu *et al.* 2003). Carbon fibre endodontic posts have inferior strength when compared with metal posts (Sidoli *et al.* 1997, Stockton & Williams 1999). This has led to the recommendation that carbon fibre endodontic post should be used when enough tooth structure is retained and when the crown restoration can be supported by natural tooth structure (Sidoli *et al.* 1997, Stockton & Williams 1999).

Using fatigue testing, fewer failures were reported when carbon fibre posts were used to restore teeth in comparison with metal posts (Isidor *et al.* 1996, Mannocci *et al.* 1999). However, under progressive loading fibre posts demonstrated failures at lower stress levels than metal posts (Sidoli *et al.* 1997, Martinez-Insua *et al.* 1998). The former situation is more representative of *in vivo* conditions.

With the presence of remaining coronal dentine, the use of fibre posts in this study did not significantly change the fracture resistance of teeth when compared with pre-fabricated titanium metal posts. However, fracture resistance of teeth restored with carbon fibre posts were found superior to those restored with glass fibre posts.

Without the presence of remaining coronal dentine, the use of metal titanium posts significantly increase the fracture resistance of teeth when compared with fibre posts. However, fracture resistance of teeth restored with carbon fibre posts were found similar to those restored with glass fibre posts.

The above findings do question the claims that fibre posts are associated with better fracture resistance than metal posts. Moreover, they support the idea that stiffer posts are associated with better stress distribution. However, different surface features of the posts used, presence of small threads on the outer surface of the Radix titanium posts compared with smooth surface of the fibre posts, and the uniform diameter of the Radix titanium posts in comparison with variable coronal and apical diameters of the carbon fibre posts might have affected the amount of prepared tooth structure and thus the fracture resistance of the teeth in this study.

This study has demonstrated that different post materials and various amounts of remaining dentine did not significantly alter the fracture patterns of single rooted teeth. All fractures that involved the roots were non-repairable. Such findings might be explained by

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the fact that fibre post flexibility has led to stress direction toward the core or the post–tooth interface and thus increased the failure rate (Stockton & Williams 1999). These findings coincided with the results of previous studies (Cormier *et al.* 2001, Raygot *et al.* 2001, Hu *et al.* 2003). However, this study contradicts Akkayan & Gulmez (2002) who reported favourable fracture patterns of teeth restored with glass fibre post system and unfavourable fracture patterns of teeth restored with titanium post system.

Vertical root fractures were dominant throughout this study and this coincided with the results of previous studies (Meister *et al.* 1991, Patel & Gutteridge 1996, Al-Hazaimeh & Gutteridge 2001, Butz *et al.* 2001, Fuss *et al.* 2001, Lertchirakarn *et al.* 2003).

Pilo *et al.* (2002) have concluded that using composite cores was associated with repairable root fracture. This was not supported in this study as all the root fractures were beyond repair.

Conclusions

Within the limitations of this study it can be concluded that

1. Fracture resistance of teeth with retained coronal dentine was better than teeth without retained coronal dentine. Although statistically insignificant, the higher the retained dentine the higher the fracture resistance.

2. The use of glass and carbon fibre posts did not improve the fracture resistance or the fracture pattern of teeth when compared with metal titanium posts regardless of the presence of retained coronal dentine.

3. Teeth restored with metal titanium post were more fracture resistant than those restored with fibre posts when teeth had no retained coronal dentine.

4. Teeth restored with carbon fibre posts were associated with greater fracture resistance than those restored with glass fibre posts.

5. The dominant fracture mode was core and root fracture in teeth without retained coronal dentine whilst combined coronal dentine–core–root fracture in teeth with retained coronal dentine. The fracture pattern of teeth was not related to the amount of retained dentine when it was >2 mm high.

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