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The Bond of Different Post Materials to a Resin Composite Cement and a Resin Composite Core Material

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Clinical Relevance

When selecting endodontic post materials, clinicians should be aware that fiber-reinforced composite (FRC) posts do not achieve a chemical bond to resin composites. The surfaces of different FRC posts need to be roughened by grit blasting with aluminum oxide particles to optimize micromechanical bonding.

SUMMARY

Purpose: To investigate the bond of endodontic post materials, with and without grit blasting, to a resin composite cement and a core material using push-out bond strength tests.

Materials and Methods: Fiber-reinforced composite (FRC) posts containing carbon (C) or glass (A) fiber and a steel (S) post were cemented into cylinders of polymerized restorative composite without surface treatment (as controls) and after grit blasting for 8, 16, and 32 seconds. Additional steel post samples were sputter-coated with gold before cementation to prevent chemical interaction with the cement. Cylindrical composite cores were bonded to other samples. After sectioning into discs, bond strengths were determined using push-out testing. Profilometry and electron microscopy were used to assess the effect of grit blasting on surface topography.

Results: Mean (standard deviation) bond strength values (MPa) for untreated posts to resin cement were 8.41 (2.80) for C, 9.61(1.88) for A, and 19.90 (3.61) for S. Prolonged grit blasting increased bond strength for FRC posts

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but produced only a minimal increase for S. After 32 seconds, mean values were 20.65 (4.91) for C, 20.41 (2.93) for A, and 22.97 (2.87) for S. Gold-coated steel samples produced the lowest bond strength value, 7.84 (1.40). Mean bond strengths for untreated posts bonded to composite cores were 6.19 (0.95) for C, 13.22 (1.61) for A, and 8.82 (1.18) for S, and after 32 seconds of grit blasting the values were 17.30 (2.02) for C, 26.47 (3.09) for A, and 20.61 (2.67) for S. FRC materials recorded higher roughness values before and after grit blasting than S. With prolonged grit blasting, roughness increased for A and C, but not for S.

Conclusions: **There was no evidence of significant bonding to untreated FRC posts, but significant bonding occurred between untreated steel posts and the resin cement. Increases in the roughness of FRC samples were material dependent and roughening significantly increased bond strength values ($p<0.05$). Surface roughening of the tested FRC posts is required for effective bonding.**

INTRODUCTION

The most frequent mode of failure reported for post-retained crowns is loss of retention of the post[1,2]; therefore, much research into post-retained crowns has focused on the factors that increase post retention.[3] In addition, with prefabricated posts, effective bonding of the post to the root may result in reduced stress in the root.[4,5] Prefabricated posts made from fiber-reinforced composite (FRC) materials are now available in addition to traditional metal posts. Manufacturers have suggested that FRC posts will bond to composite resins, both as luting cements and as core materials, and this is given as one of the principal reasons for choosing FRC posts in preference to metal posts. However, because prefabricated FRC posts are thoroughly cured in an industrial process, there may be little potential for chemical bonding to resin composite cements or cores. Therefore, the attachment of resins to FRC posts is likely to be through mechanical interlocking alone. The surfaces of metal prefabricated posts have large-scale features, such as serrations and indentations, which are incorporated to increase the retention of cements to posts.[6] FRC posts, with a few exceptions, do not have macroscopic retention features as these weaken the composite structure. Microroughening of metal posts using airborne particle abrasion (grit blasting) increases their retention[3,7] and has therefore also been used to enhance the retention of FRC posts to resin composite cements and cores.[8,9] The degree of roughness is likely to affect the retention produced and needs to be quantified if the effects on post retention are to be related to different surface treatment methods. To the authors' knowledge, in only one study to date has the roughness produced on the surface of posts by grit blasting been measured.[10] The degree of roughening will depend on many factors, including type of abrasive material and particle size, air pressure, distance between the grit-blasting nozzle and the target surface, nozzle aperture, angle of incidence of the particle jet and duration of abrasion. Comparing those studies where details of the grit-blasting method are given, there is little consistency in the pressures, durations, and distances selected, and there are no descriptions of how the abrasion around the cylindrical surface was managed.[8,9,11,12] As FRC materials contain different fibers, the roughening effects are likely to be material dependent. Grit blasting may damage the surface fibers, introduce flaws, and reduce the flexural strength of the post material. If the grit blasting is prolonged, a significant amount of material may be removed, thereby decreasing the post diameter and resulting in increased flexibility of the post.

The resin cements used to lute posts may be described as conventional composite cements based on bis-GMA (bisphenol glycidyl methacrylate) or as adhesive cements that contain additional functional monomers such as 4-META (4-methacryloyloxyethyl trimellitate anhydride) or MDP (10-methacryloyloxydecyl dihydrogen phosphate). These agents bond to metal oxides and are included to increase the affinity to calcified tissues and to metallic restorations.[13] Such cements would be expected to develop a chemical bond with the oxide layer formed on the surface of non-precious metal posts. The type of fiber used in many glass fiber composite posts is E-glass (electrical), which contains aluminum and calcium oxides.[14] Chemical bonding could occur between these oxides and the MDP. It is important for clinicians to understand how to achieve effective bonding of posts so as to improve retention and reduce the risks of root fracture. Therefore, it is necessary to investigate the bond of resin composites to currently available prefabricated post materials and examine the effect of surface roughening of post materials on their adherence. Many investigations compare the retention of different posts luted with different cements in natural roots and rank the different combinations according to the load required to dislodge the post.[15,16] Failure may have occurred between the post and the cement, within the cement, or between the cement and the root. If the aim is to compare just the bond of a cement to a post, then a test setup is required in which the bond of the cement to the root is reliable and is the strongest interface. Alternatively, to test the bond of cement to root, then the cement/post bond must be the strongest link. Push-out tests in natural roots reveal only which combination of materials resists removal; they do not test specific interfaces. The objectives of this study were

1. to investigate the bond of different prefabricated endodontic post materials by comparing the push-out bond strength of three selected endodontic post materials bonded to a resin luting cement and to a resin composite core material;
2. to quantify the effect of grit blasting on the post materials; and
3. to assess the effect of grit blasting for periods of 8, 16, and 32 seconds on the bond strength of the post materials.

METHODS AND MATERIALS

Samples of a carbon fiber (Composipost, RTD, Grenoble, France) and a glass fiber (Aesthetiplus, RTD) endodontic post material and stainless steel (Arenastock, Letchworth, UK) were obtained as rods 100-mm long and 2 mm in diameter. These were then cut using a diamond disc into lengths appropriate for the tests as described in the sections that follow.

Surface Treatment of Posts

The surface of samples was roughened by grit blasting with 50 μm aluminum oxide powder and a Danville microetcher (Danville Engineering, San Ramon, CA, USA) connected to the main compressed air supply of a dental unit at a pressure of 2.3 to 2.4 bars. Each of the post materials was cut into 50-mm lengths, and nylon cubes with central holes 2 mm in diameter were pushed onto either end. In the lid of a transparent plastic box, a 50-mm long slot was cut, and samples were secured with soft wax inside the box below and parallel to the slot. The slot width was approximately the same as the width of the nozzle of the grit-blasting unit. This allowed the nozzle to be moved along the length of the post at a constant separation of 10 mm. After initial trials, it was possible to repeatedly maintain the time taken to pass the nozzle from one end of the slot to the other by hand, to approximately 1 second. After one aspect had been treated, the sample was rotated by 90°, and grit blasting was repeated until each aspect had been abraded for 2, 4, or 8 seconds (giving a total of 8, 16, or 32 seconds per sample)

For the stainless steel material, additional samples of untreated stainless steel were coated with a 150-nm film of gold using a sputter-coating machine, Emitech K550x (Emitech Ltd, Ashford, UK) to prevent any chemical bond from occurring between the metal oxides and the MDP in the Panavia 21. This would allow the researchers to separate the contribution of chemical bonding to the adhesion of the steel posts from the effect of surface roughening.

Evaluation of Surface Roughness

Qualitative assessment of the post surfaces before and after the different abrasion times was made with a scanning electron microscope (SEM, JEOL 5300, Jeol Ltd, Tokyo, Japan). Roughness was quantitatively measured using a profilometer (FormTalysurf Series 2, Taylor Hobson Ltd, Leicester, UK). Samples of the posts were secured while the ruby stylus was drawn around the circumference for a distance of 0.8 mm, and the average roughness, R_A, was measured at four sites along the sample on one surface and four sites measured after the sample was rotated through 180°. Eight measurements were made on each of four samples of each post before (as controls) and after the three grit-blasting periods chosen, and the mean roughness was compared.

Push-Out Bond-Strength Testing

To evaluate the bond between the three different post materials and the luting cement, resin composite cylinders approximately 50 mm in length were produced from Tetric composite shade A2 (Ivoclar Vivadent, Schaan, Liechtenstein). The material was expressed into thin-walled (0.8 mm) glass tubes with an internal diameter of 6.7 ± 0.05 mm and then polymerized in a light-curing oven (Visio-Lux, 3M/ESPE, St Paul, MN, USA) for 14 minutes. The irradiance of this unit was calculated as 67.6 ± 3.1 mW/cm^2.[17] After one week's storage at room temperature (23°C) and humidity (45% to 50%), these were then cut into 10-mm lengths using a water-cooled slow-speed saw (Isomet, Buehler, Lake Bluff, IL, USA). A central hole was cut through each cylinder using a 2.1-mm steel twist drill in a bench press. The walls of this post space were roughened to create a frictional key for the cement lute with a coarse-grade silicon carbide grinding paste (Anglo Abrasives Ltd, Manchester, UK) applied for 30 seconds using the smooth shank of a 1.6-mm twist drill from which the cutting flutes had been removed. The channel was cleaned with an alcohol-containing gel (Purell, GOJO industries, Milton Keynes, UK), followed by copious amounts of tap water. After drying, the channel walls were coated with Panavia 21 (Kuraray, Kurashiki, Japan), a resin cement containing MDP as an adhesion promoter. A spiral root filler was used to ensure even coating of the walls.[18,19] Fifteen-millimeter lengths of the stainless steel, Composipost, and Aesthetiplus post materials, untreated as controls or grit-blasted for 8, 16, or 32 seconds, were luted into four cylinders and allowed to cure for 48 hours. Gold-coated steel post samples were also cemented into an additional four composite cylinders. To hold the cylinders for sectioning, 10-mm nylon cubes were fabricated and a 2-mm hole was prepared through the center. The portion of post material protruding from the composite cylinder was pushed into the hole in the cube, which could then be gripped in the sample holder of a water-cooled slow-speed saw and each composite cylinder cut into five discs approximately 1.4-mm thick. Twenty disc samples of each material were produced.

Samples were also created to derive the push-out bond strength between the post materials and a composite resin core. Four 15-mm lengths of the posts were secured into nylon cubes, coated with a bonding agent (Excite, Ivoclar Vivadent, Schaan, Liechtenstein), air thinned, and polymerized in the light-curing oven for one minute. Next, four 10-mm-long sections were cut from transparent cylindrical plastic pipettes (LP Italiana SPA, Milan, Italy) with an internal diameter of 7 mm and lightly lubricated with petroleum jelly and placed around the posts resting on the nylon cubes. This mold was carefully filled with Tetric composite shade A2 and polymerized and stored as described before for one week. Each sample was then cut into five slices as described earlier (20 for each post material). To compare the push-out bond strength of grit-blasted posts to core composite with that of untreated (control) posts, each post material was abraded for a single period of 32 seconds, and cores were built up and cured as described previously and subsequently sectioned to produce 20 sample discs. It was decided to grit-blast the samples bonded to core composite for only a single time of 32 seconds after observing the limited effect that shorter durations of grit blasting had had on push-out bond strength to the luting cement.

A jig was constructed to carry out the push-out tests; it consisted of a steel plate attached to the base of an Instron universal testing machine (model 5544, Instron UK, High Wycombe, UK). In the center of the plate was a 3.25-mm-diameter hole over which the sample disc was placed. A 3-mm-long, 1.5-mm-diameter steel punch was attached to the upper part of the machine and aligned with the center of the hole in the base plate. The punch was lowered at a crosshead speed of 0.5 mm per minute and the load required to dislodge the post from the composite disc was recorded.

The push-out bond strength was calculated using the following equation:[20]

$$\text{Bond strength} = F_{\max} \div \pi DH$$

where $F_{\max}$ was the load required to dislodge the post (Newtons), D was the mean diameter, and H the mean thickness of the disc (millimeters); the value of π was taken as 3.142.

After failure, each sample was examined under the SEM to identify where failure had occurred, and images were obtained of representative examples.

Statistical Analysis

Statistical analysis of all data was carried out using the statistical package SPSS (version 16, SPSS Inc, Chicago, IL, USA). The data were first examined using Shapiro-Wilk and Levene's tests, which confirmed a normal distribution and homogeneity of variance. The mean loads were then compared for statistically significant differences using independent samples t-tests or one or two-way analysis of variance (ANOVA), as appropriate, with post hoc Scheffé tests (α=0.05).

RESULTS

Surface Roughness

Comparison of the surfaces as seen under the SEM showed that the untreated steel presented a relatively smooth surface with a few shallow indentations and linear grooves (Figure 1). After grit blasting for 8 seconds there was a widespread but apparently superficial increase in roughness. There was a more obvious increase in roughness after 16 seconds but little additional increase in roughness was obvious after 32 seconds of grit blasting.

The surface of the Composipost samples showed little change after 8 seconds of grit blasting compared with untreated (plain) samples (Figure 2). Surface changes become more apparent after 16 seconds but it was difficult to differentiate between the roughness observed after 16 seconds or 32 seconds. The increase in irregularity appears to be

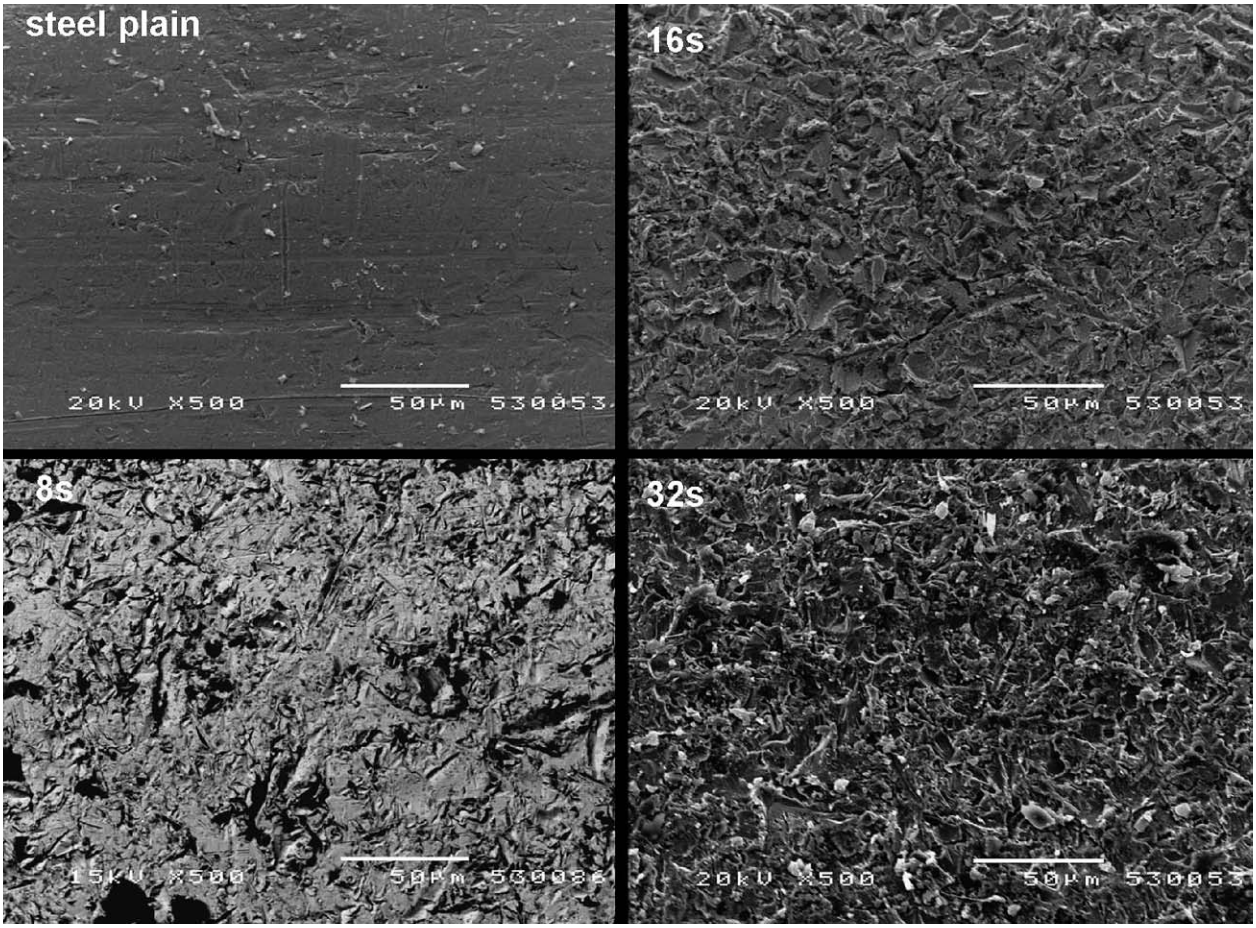

Figure 1. *Representative SEM images of stainless steel, untreated and after grit blasting for 8, 16 , and 32 seconds.*

due in part to the creation of surface voids by the loss of sections of fibers from the surface.

The samples of the untreated Aesthetiplus material had a more irregular surface than the Composipost, which is composed of smaller-diameter fibers. After 8 seconds of grit blasting there was a noticeable change in the surface appearance. After 16 seconds the roughness became more apparent but little difference could be seen between the surfaces after 16 seconds or 32 seconds. As with Composipost, loss of some superficial fibers produced furrows on the surface but these were of a greater diameter in the Aesthetiplus (Figure 3).

Profilometry

The mean roughness determined by the profilometer for each material and grit-blasting time is shown in Figure 4. It may be seen that Aesthetiplus had the highest mean R_A before and after each period of grit blasting, and grit blasting produced a proportionally smaller increase in roughness on the stainless steel than occurred for either FRC material. Analysis with one-way ANOVA and post hoc Scheffé tests ($p=0.05$) showed that for both FRC materials there was a significant increase in mean R_A after 8 seconds and again after 16 seconds of grit blasting ($p<0.005$) but there was no significant difference in the roughness between 16 seconds and 32 seconds ($p=0.858$ Composipost; $p=0.875$ Aesthetiplus). The stainless steel showed a significant difference in mean R_A after grit blasting for 8 seconds ($p<0.001$) but there was no significant difference in roughness after 16 seconds ($p=0.969$) or after 32 seconds ($p=0.083$).

Between materials, the surface of the untreated Aesthetiplus was significantly rougher than the other two untreated materials, which were not significantly different from each other. After 8 seconds and after 16 seconds of grit blasting, the mean R_A for each material was significantly different from the others ($p<0.01$). After 32 seconds, stainless steel was significantly less rough than the

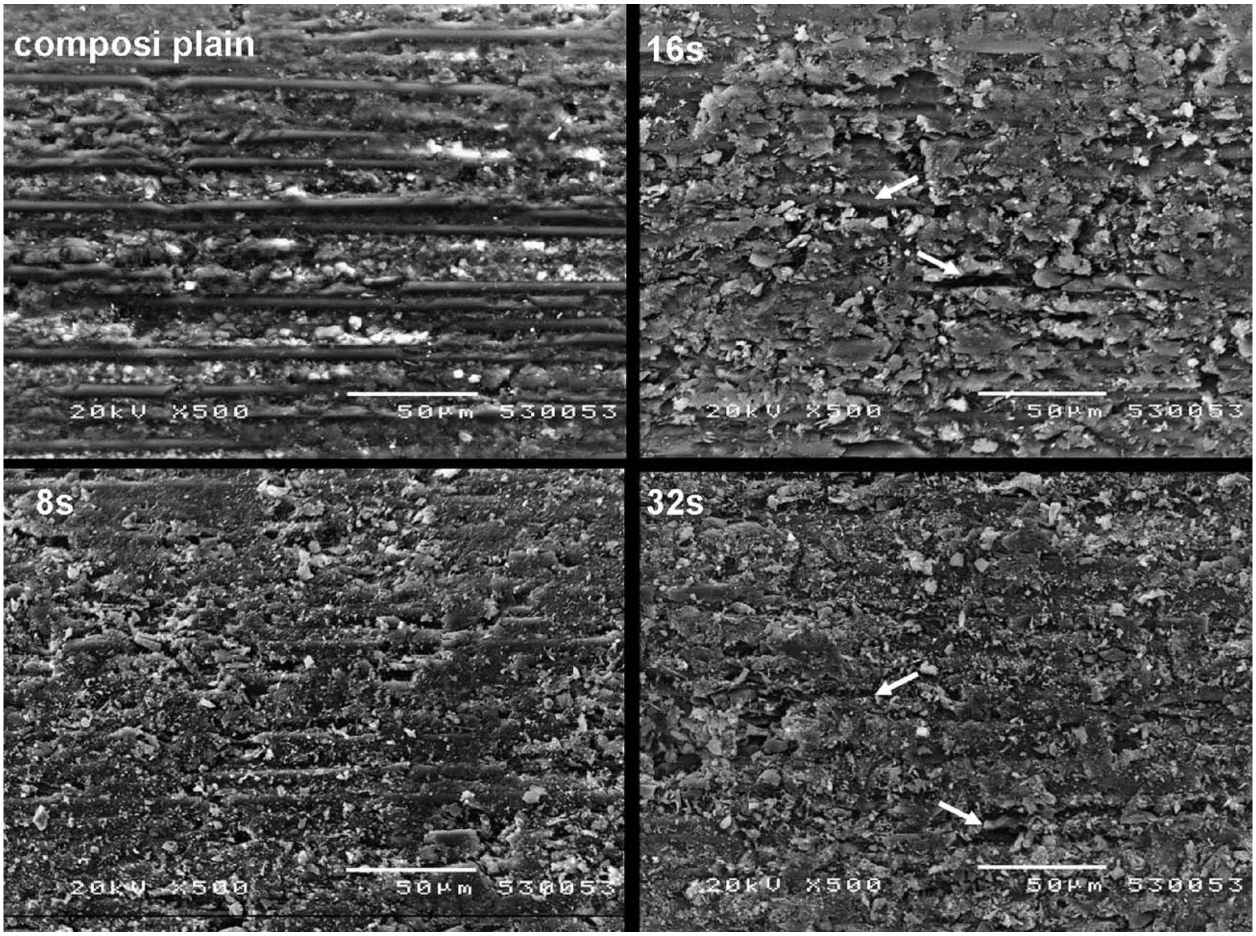

Figure 2. *SEM images of the surface of samples of Composipost before and after grit blasting for 8, 16, and 32 seconds. Arrows indicate areas where short sections of fibers may have been plucked from the surface of the sample.*

FRC materials ($p<0.001$), which showed no significant difference between them ($p=0.06$).

Push-Out Bond Strengths to Luting Cement

The mean values for push-out bond strengths of the post materials luted into the composite cylinders are recorded in Table 1. After the FRC posts received grit blasting, the bond strengths increased with increasing abrasion time. The plain steel posts recorded much higher strength values than the plain FRC post, and grit blasting of the steel posts was associated with only a slight further increase in mean push-out bond strength. Increasing durations of grit blasting were associated with increases in push-out bond strengths for the FRC posts. The gold-coated steel samples recorded the lowest mean bond strength values.

Statistical analysis using two-way ANOVA ($p=0.05$) showed significant main effects for both material ($p=0.007$) and post surface treatment ($p=0.003$) and a significant interaction between material and surface treatment ($p<0.001$). One-way ANOVA and post hoc Scheffé tests were then performed. The push-out bond strengths of the untreated FRC posts showed no statistically significant difference ($p=0.41$) but both were significantly lower than that of untreated steel ($p<0.001$). Comparing the effects of the surface treatment used, after 8 seconds of grit blasting, the shear strength of Composipost had increased but was significantly lower than that of Aesthetiplus ($p=0.032$), which was lower than that of steel ($p<0.001$). After 16 seconds of grit blasting, the bond strength of Composipost was lower but not significantly lower than that of Aesthetiplus ($p=0.055$). The latter mean bond strength value was significantly lower than that for the steel posts ($p<0.001$). After 32 seconds there was no significant difference among the mean bond strengths of the materials ($p>0.05$).

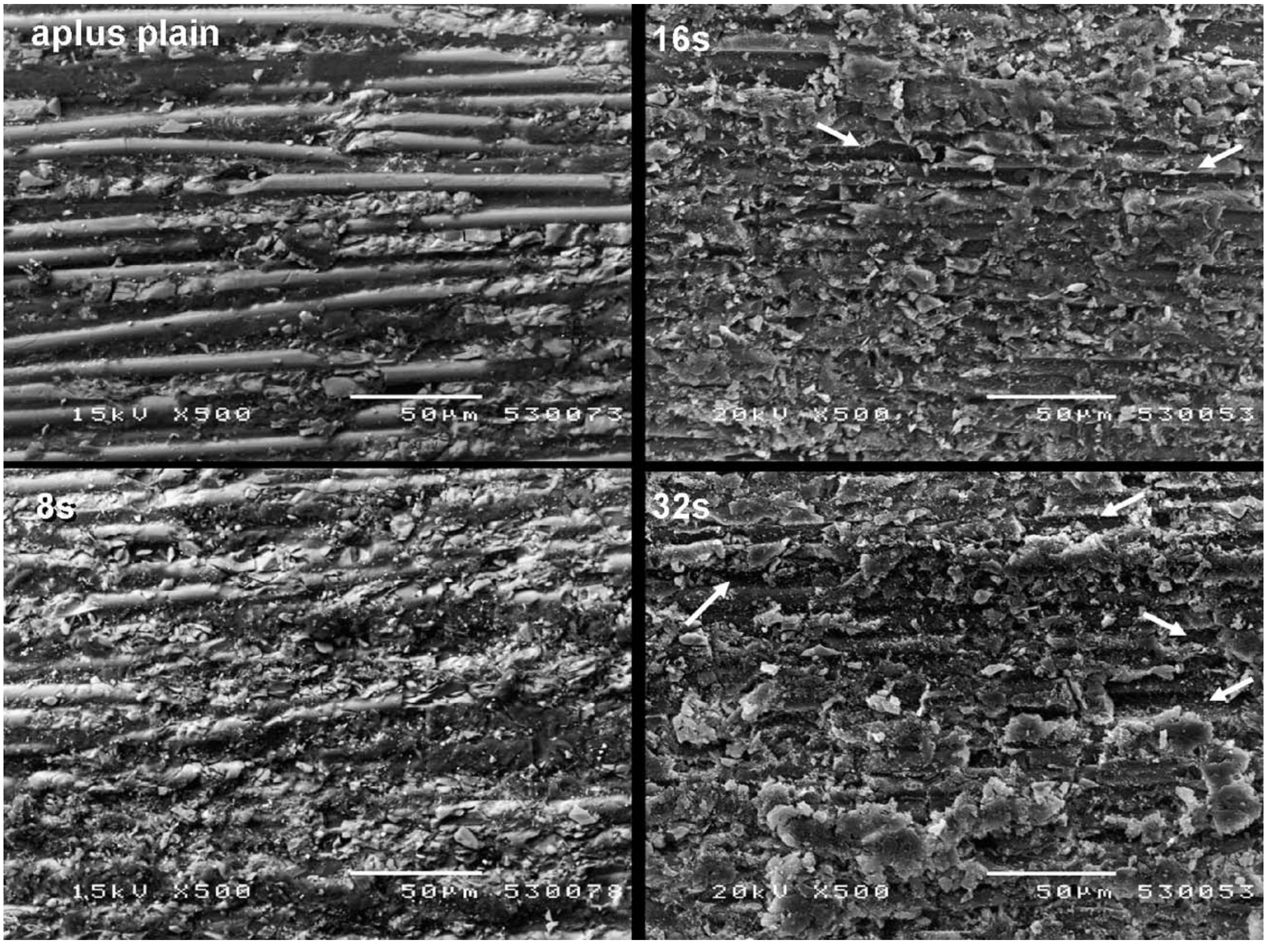

Figure 3. *Images of the surface of samples of Aesthetiplus before and after grit blasting for 8, 16, and 32 seconds. Arrows indicate furrows remaining where fibers may have been lost.*

The increase in bond strength showed different trends among the materials. For stainless steel, push-out bond strength was not significantly increased after 8 seconds of grit blasting (p=0.893). The difference in bond strength between 8 seconds and 16 seconds just reached significance (p=0.039) but there was no significant difference between the bond strength after 16 seconds and after 32 seconds (p=0.999). The push-out bond strength of Compositpost after 8 seconds of grit blasting was not significantly different from that of the untreated material (p=0.205). There was a significant increase between 8 seconds and 16 seconds (p=0.003) and again between 16 seconds and 32 seconds (p=0.02). For Aesthetiplus, there was a significant increase in bond strength after 8 seconds of grit blasting (p=0.001) and between 8 seconds and 16 seconds of grit blasting ($p<0.001$) but no significant difference in the bond strength between 16 seconds and 32 seconds (p=0.829).

Examination of the samples after push-out testing showed that almost no cement was present on either dislodged untreated FRC post, suggesting that failure had occurred at the interface of the FRC post and the lute (Figure 5A,B) On the stainless steel samples the post surfaces were entirely covered with cement, and failure appeared to have occurred between the cement and the composite cylinder surface (Figure 5C). A mixture of appearances was observed on the failed push-out samples of grit-blasted Aesthetiplus. Among the samples treated for 8 seconds, surface fibers were visible, and there were only small areas of cement attached, suggesting that failure had occurred between the cement and the post. On the samples treated for 32 seconds, a thick layer of cement could be seen over most of the surface with little remaining attached to the composite cylinder (Figure 5D). Failure appeared to be predominantly the result of separation of the cement from the composite. Samples abraded for 16 seconds showed a mix of the two appearances. With increas-

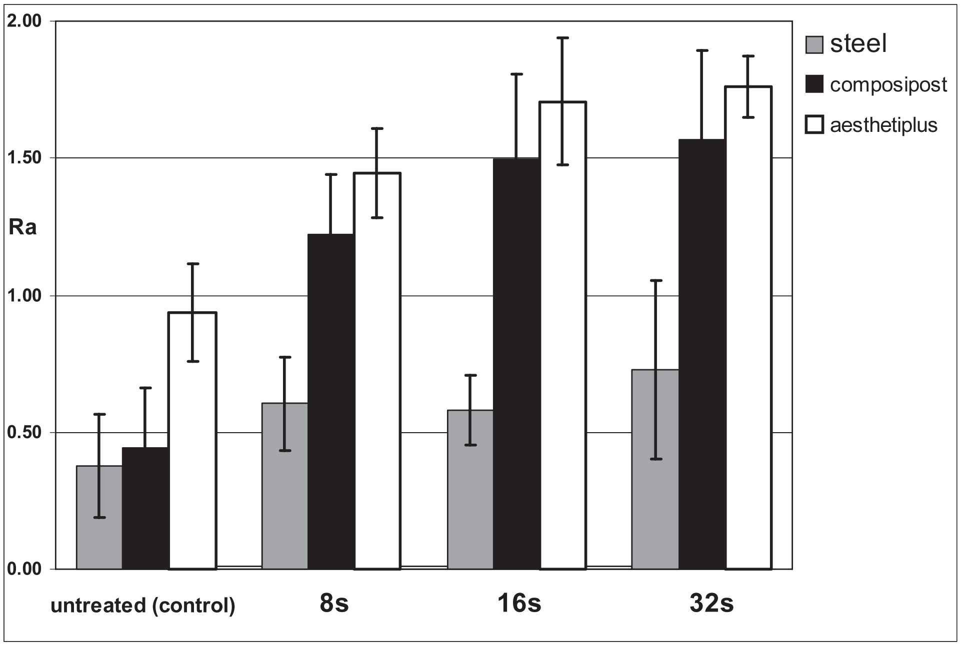

Figure 4. *Graph comparing the average roughness values (R_A) for the post materials before (control) and after grit blasting for 8, 16, and 32 seconds. Error bars indicate standard deviation.*

ing grit blasting there was some increase in the amount of cement fragments adherent to the surfaces of the Composipost samples after failure. However, even after 32 seconds of grit blasting there were several areas where fibers were clearly visible on the post surface, indicating little attachment of cement at these points (Figure 5E). Most of the cement layer was also identifiable attached to the surrounding composite, indicating that the mode of failure was mainly adhesive between the cement and the Composipost surface with some cohesive failure within the cement. When the steel posts had been gold-coated and tested, there was no cement visible on the post surface after failure (Figure 5F).

Push-Out Bond Strengths to Core Composite

The mean push-out bond strength values for the samples are shown in Table 2. Statistical analysis using independent samples t-tests showed that there was a significant difference between the bond strengths of the untreated and the grit-blasted samples of each material ($p<0.001$).

One-way ANOVA and post hoc Scheffé tests indicated that the bond of the core composite to the untreated Composipost was significantly weaker than to stainless steel ($p<0.001$) and that the bond with the steel was significantly weaker than that of the plain Aesthetiplus ($p<0.01$). After grit blasting for 32 seconds, the same significant differences between push-out bond strength values were also identified ($p<0.001$).

DISCUSSION

In this study, a push-out test was used to evaluate post retention. A variety of other methods have been employed to test the retention of posts; pull-out tests[21] produce a nonuniform distribution of stresses and are difficult to carry out on FRC posts because the post will be damaged by the gripping jaws of the loading machine. Microtensile testing has been adapted to evaluate the bond between posts cemented into tooth roots and between posts and core materials. However, the samples produced in this situation do not have planar surfaces arranged perpendicular to the separating force.[22,23] The interface is curved, and the stress field across the surface will be different from that in a standard microtensile test.

Push-out tests have also been used to calculate bond strength values[20] and can allow the bond at different depths within a post space to be compared. The preparation of samples is less technique sensitive than for microtensile testing[24]; there is less variability in the data[25] and a more uniform distribution of stress occurs.[26] In this study, samples were stored for one week to ensure that polymerization of the self-cure cement was complete. No immersion or artificial aging of samples was carried

Table 1: *Comparison of Push-Out Bond Strengths to Panavia 21 for Each of the Post Materials Before and After Grit Blasting*

Material	Treatment	Mean Push-Out Bond Strength (MPa)	SD
Steel	Untreated	19.90[de]	3.61
Steel	Grit blasting for 8 s	20.43[de]	3.09
Steel	Grit blasting for 16 s	23.21[e]	2.37
Steel	Grit blasting for 32 s	22.97[e]	2.87
Steel	Gold coated	7.84[a]	1.40
Composipost	Untreated	8.41[a]	2.80
Composipost	Grit blasting for 8 s	11.18[ab]	3.13
Composipost	Grit blasting for 16 s	16.29[cd]	4.67
Composipost	Grit blasting for 32 s	20.65[de]	4.91
Aesthetiplus	Untreated	9.61[ab]	1.88
Aesthetiplus	Grit blasting for 8 s	13.93[bc]	3.07
Aesthetiplus	Grit blasting for 16 s	19.51[de]	4.36
Aesthetiplus	Grit blasting for 32 s	20.41[de]	2.93

out as the aim of this study was to assess the potential for post materials to bond to a resin composite core and cement. Therefore, no attempt was made to simulate a clinical environment. Had the results revealed strong bonding for the FRC posts, it would then have been appropriate to challenge the samples with, for example, a thermocycling regimen before using the results to predict clinical performance.

The results of the push-out bond strength tests and the examination of the failed samples show that the Panavia resin cement developed a greater bond to the stainless steel material than to either of the FRC materials. This is likely because of a chemical reaction occurring between the cement and the steel as, when the steel was coated with gold, the bond strength value decreased below that recorded for the FRC materials. The gold coating will have prevented the MDP component of the cement from reacting with the base metal surface oxides. The post also had a relatively smooth surface and so very little mechanical locking could have occurred to increase bonding. The higher elastic modulus of the steel may also have been a contributing factor because it has been demonstrated that bond strength values can be affected by the difference in modulus of the two bonded materials.[27] However, the push-out bond strength values of the posts to either the core composite or the composite cement showed no direct relation with the modulus of the post because the untreated Composipost, which has an intermediate modulus,[28] recorded lower bond strength than either the steel or untreated Aesthetiplus materials.

The untreated FRC posts recorded low bond strengths, and although this was not statistically significant, the bond strengths correlated with the surface roughness determined for the untreated FRC posts and the gold-coated steel. From this and the observation that failure occurred between the cement and the post, it may be assumed that, in contrast to steel, no significant chemical bonding occurred between the Panavia cement and the untreated FRC materials. The push-out bond strengths also increased in conjunction with the increase in surface roughness produced by the grit blasting. The surface roughness of the steel was not greatly increased by this treatment and little increase in bond strength was noted. However, in view of the already high bond strengths noted for untreated steel and the proportion of fractures in the composite cylinder to which they were attached, it is unlikely that higher values could be achieved in this test setup without exceeding the ultimate strength of the composite. The increase in push-out bond strength produced by grit blasting is consistent with similar increases in retention reported in pull-out tests[8] and push-out tests[29] of grit-blasted glass fiber posts.

The method of grit blasting described did not ensure absolute consistency of treatment between samples but a greater degree of reproducibility was possible than that achieved with the methods described among other similar studies.[7–9] The glass fiber posts increased their roughness in less time than did the carbon fiber posts, which suggests that they are less resistant to the effects of grit blasting than the carbon fiber material, but with longer periods of grit blasting, the roughness produced was similar between the two materials. Although push-out bond strengths were also similar between the FRC posts after prolonged grit blasting, failure among the carbon fiber post samples appeared to

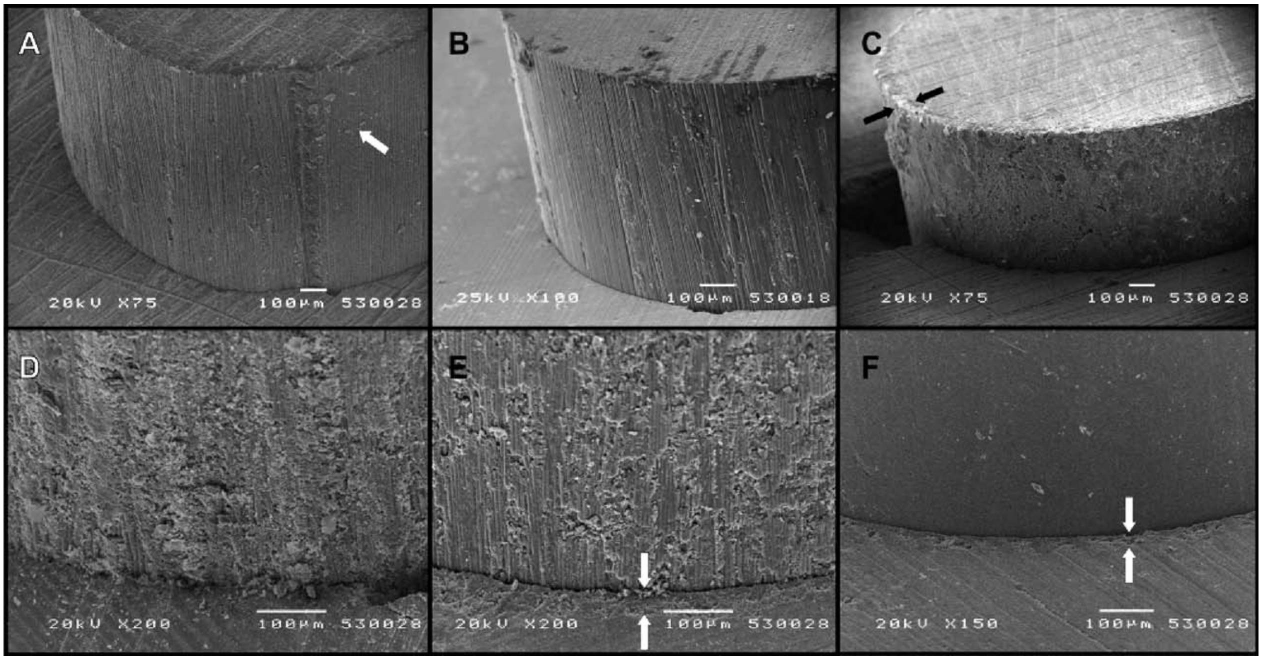

Figure 5. *SEM images of failed push-out test samples showing the following (A): Small areas of luting cement attached (arrowed) to untreated Aesthetiplus sample. (B): No significant attachment of luting cement to the post surface of untreated Composipost. (C): Untreated stainless steel push-out sample with fracture of surrounding composite cylinder. All the luting cement appears to be attached to the surface of the post (arrows). (D): Higher magnification image of grit-blasted Aesthetiplus with substantial attachment of cement to the post surface and no layer of cement attached to the surrounding composite. (E): Surface of grit-blasted Composipost sample with surface fibers visible and a luting cement layer attached to the composite disc (arrowed). (F): Gold-coated stainless steel sample showing the cement lute layer attached to the inner wall of the composite disc (arrowed) and no cement visible on the post surface.*

have occurred mainly between the post and the cement, whereas more of the glass fiber samples had failed between the cement and the composite. This could be because carbon fibers are less readily wetted than are glass fibers.[30]

Table 2. *Comparison of Push-Out Bond Strengths to the Core Composite of Each of the Post Materials Before and After Grit Blasting*

Material	Treatment	Mean Push-Out Bond Strength (MPa)	SD
Steel	Untreated	8.82	1.18
Steel	Grit blasting for 32 s	20.61	2.67
Composipost	Untreated	6.19	0.95
Composipost	Grit blasting for 32 s	17.30	2.02
Aesthetiplus	Untreated	13.22	1.61
Aesthetiplus	Grit blasting for 32 s	26.47	3.09

In the push-out tests of the posts bonded to core composite, bond strengths were not clearly related to the surface roughness of the posts. The untreated and grit-blasted glass fiber Aesthetiplus posts had rougher surfaces than the other materials and recorded higher bond strength to the core composite. However, the carbon fiber Composipost recorded the lowest bond strengths with and without grit blasting, despite having a rougher surface than the stainless steel posts. Surface roughness alone does not explain these results. Wetting differences among the materials or possible chemical interactions with components of the bonding agent may also have a part to play and requires further investigation.

The effect of grit blasting showed some differences between the materials. With the steel, there was little quantifiable increase in roughness even after 32 seconds of treatment. Both FRC materials showed a much greater increase in roughness with grit blasting, which was more pronounced with the glass fiber post. However, the effect on surface roughness appeared to be reaching its limit after 32 seconds. With both FRC posts, loss of surface material was becoming noticeable after 32 seconds, more so on the glass fiber samples. There would therefore seem to be an optimum duration for grit blasting at which significant roughness can be produced without significant destruction occurring. Other investigations have reported that grit-blasting procedures caused no significant effect on flexural properties of FRC posts[12,31] but in these studies the grit-blasting methods used appeared to be less aggressive than the 32-second protocol selected here. The use of more intensive applications or longer periods of grit blasting are unlikely to produce a significant further increase in surface roughness but could result in a progressive decrease in the diameter of FRC posts, an increase in their flexibility, and a reduction in the maximum load-bearing capacity of the post.

CONCLUSIONS

The results of this study show that Panavia cement bonded effectively to smooth steel post materials but that no significant bonding occurred to FRC post materials. To enhance the retention of an FRC post when using Panavia cement, it is therefore necessary to roughen its surface. Grit blasting increases the micromechanical retention but the degree of roughening produced and the time needed to achieve sufficient surface roughening varies between different FRC materials.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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REFERENCES

1. Mentink AG, Meeuwissen R, Kayser AF, & Mulder J (1993) Survival rate and failure characteristics of the all metal post and core restoration *Journal of Oral Rehabilitation* **20(5)** 455-461.
2. Bergman B, Lundquist P, Sjogren U, & Sundquist G (1989) Restorative and endodontic results after treatment with cast posts and cores *Journal of Prosthetic Dentistry* **61(1)** 10-15.
3. Stockton LW (1999) Factors affecting retention of post systems: a literature review *Journal of Prosthetic Dentistry* **81(4)** 380-385.
4. Asmussen E, Peutzfeldt A, & Sahafi A (2005) Finite element analysis of stresses in endodontically treated, dowel-restored teeth *Journal of Prosthetic Dentistry* **94(4)** 321-329.
5. Mendoza DB, Eakle WS, Kahl EA, & Ho R (1997) Root reinforcement with a resin-bonded preformed post *Journal of Prosthetic Dentistry* **78(1)** 10-14.
6. Standlee JP, & Caputo AA (1993) Effect of surface design on retention of dowels cemented with a resin *Journal of Prosthetic Dentistry* **70(5)** 403-405.
7. Nergiz I, Schmage P, Platzer U, & McMullan-Vogel CG (1997) Effect of different surface textures on retentive strength of tapered posts *Journal of Prosthetic Dentistry* **78(5)** 451-457.
8. Balbosh A, & Kern M (2006) Effect of surface treatment on retention of glass-fiber endodontic posts *Journal of Prosthetic Dentistry* **95(3)** 218-223.
9. Radovic I, Monticelli F, Goracci C, Cury AH, Coniglio I, Vulicevic ZR, Garcia-Godoy F, & Ferrari M (2007) The effect of sandblasting on adhesion of a dual-cured resin composite to methacrylic fiber posts: microtensile bond strength and SEM evaluation *Journal of Dentistry* **35(6)** 496-502.
10. Nergiz I, Schmage P, Ozcan M & Platzer U (2002) Effect of length and diameter of tapered posts on the retention *Journal of Oral Rehabilitation* **29(1)** 28-34.
11. Soares CJ, Santana FR, Pereira JC, Araujo TS, & Menezes MS (2008) Influence of airborne-particle abrasion on mechanical properties and bond strength of carbon/epoxy and glass/bis-gma fiber-reinforced resin posts *Journal of Prosthetic Dentistry* **99(6)** 444-454.
12. Cheleux N, Sharrock P, & Degrange M (2007) Surface treatments on quartz fiber post: influence on adhesion and flexural properties *American Journal of Dentistry* **20(6)** 375-379.
13. Miller BH, Nakajima H, Powers JM, & Nunn ME (1998) Bond strength between cements and metals used for endodontic posts *Dental Materials* **14(5)** 312-320.
14. Wallenberger FT, Watson JC, & Li H (2001) Glass fibers In: Miracle DB, & Donaldson SL (eds) *ASM Handbook Volume 21*; Composites ASM International Materials Park, Ohio 27-34.
15. Perdigao J, Geraldeli S, & Lee IK (2004) Push-out bond strengths of tooth-colored posts bonded with different adhesive systems *American Journal of Dentistry* **17(6)** 422-426.
16. Kececi AD, Ureyen Kaya B, & Adanir N (2008) Micro push-out bond strengths of four fiber-reinforced composite post systems and 2 luting materials *Oral Surgery Oral Medicine Oral Pathology Oral Radiology Endodontology* **105(1)** 121-128.
17. Palin WM, Fleming GJ, & Marquis PM (2005) The reliability of standardized flexure strength testing procedures for a light-activated resin-based composite *Dental Materials* **21(10)** 911-919.
18. Turner CH (1981) Cement distribution during post cementation *Journal of Dentistry* **9(3)** 231-239.
19. Reel DC, Hinton T, Riggs G, & Mitchell RJ (1989) Effect of cementation method on the retention of anatomic cast post and cores *Journal of Prosthetic Dentistry* **62(2)** 162-165.
20. Dhert WJ, Verheyen CC, Braak LH, de Wijn JR, Klein CP, de Groot K, & Rozing PM (1992) A finite element analysis of the push-out test: influence of test conditions *Journal of Biomedical Materials Research* **26(1)** 119-130.

21. Gallo JR III, Miller T, Xu X, & Burgess JO (2002) In vitro evaluation of the retention of composite fiber and stainless steel posts *Journal of Prosthodontics* **11(1)** 25-29.

22. Mallmann A, Jacques LB, Valandro LF, Mathias P, & Muench A (2005) Microtensile bond strength of light- and self-cured adhesive systems to intraradicular dentin using a translucent fiber post *Operative Dentistry* **30(4)** 500-506.

23. Aksornmuang J, Foxton RM, Nakajima M, & Tagami J (2004) Microtensile bond strength of a dual-cure resin core material to glass and quartz fibre posts *Journal of Dentistry* **32(6)** 443-450.

24. Bouillaguet S, Troesch S, Wataha JC, Krejci I, Meyer JM, & Pashley DH (2003) Microtensile bond strength between adhesive cements and root canal dentin *Dental Materials* **19(3)** 199-205.

25. Goracci C, Tavares AU, Fabianelli A, Monticelli F, Raffaelli O, Cardoso PC, Tay F, & Ferrari M (2004) The adhesion between fiber posts and root canal walls: comparison between microtensile and push-out bond strength measurements *European Journal of Oral Sciences* **112(4)** 353-361.

26. Soares CJ, Santana FR, Castro CG, Santos-Filho PC, Soares PV, Qian F, & Armstrong SR (2008) Finite element analysis and bond strength of a glass post to intraradicular dentin: comparison between microtensile and push-out tests *Dental Materials* **24(10)**:1405-1411.

27. Della Bona A, & van Noort R (1995) Shear vs. tensile bond strength of resin composite bonded to ceramic *Journal of Dental Research* **74(9)** 1591-1596.

28. Stewardson DA, Shortall AC, Marquis PM, & Lumley PJ (2010) The flexural properties of endodontic post materials *Dental Materials* **26(8)** 730-736.

29. Bitter K, Priehn K, Martus P, & Kielbassa AM (2006) In vitro evaluation of push-out bond strengths of various luting agents to tooth-colored posts *Journal of Prosthetic Dentistry* **95(4)** 302-310.

30. Walsh PJ (2001) Carbon fibers In: Miracle DB, & Donaldson SL (eds) *ASM Handbook Volume 21*; Composites ASM International Materials Park, Ohio. 35-40.

31. D'Arcangelo C, D'Amario M, Vadini M, De Angelis F, & Caputi S (2007) Influence of surface treatments on the flexural properties of fiber posts *Journal of Endodontics* **33(7)** 864-867.