Load capacity of simulated flared root canal restored with different fiber reinforced composite post

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Background. This study aimed to evaluate the load capacity of maxillary central incisors with simulated flared root canal restored with different fiber reinforced composite (FRC) post and resin cement.

Methods. Sixty-five extracted maxillary incisors were decoronated, its canal were artificially flared and randomly categorized into group 1 (tapered FRC post) (n=22), group 2 (multi-FRC post) (n=21), and group 3 (direct individually shaped-FRC (DIS-FRC) post) (n=22), which were further subdivided based on cementation resin. The posts were cemented and a standardized resin core was constructed. After thermocycling, the samples were loaded statically to fracture and the maximum load was recorded.

Results. The load capacity was found to be influenced by the different FRC posts and not the resin cement (p=0.289), and no significant interaction was found. Group 1 (522.9N) yielded a significantly higher load capacity compared to group 3 (421.1N). Overall, 55.4% favorable fracture pattern was observed and this was not statistically significant.

Conclusion. Within the limitation of the study, prefabricated FRC posts outperformed DIS-FRC post in the load capacity.

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Abstract

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Keywords: Post and core technique, Resin cements, Scanning electron microscopies

Introduction

Special attention and consideration are required when restoring an endodontically treated tooth to its initial form and function; due to its inherent structural weakness post-endodontic treatment (Fráter et al. 2017). It is particularly challenging when dealing with endodontically treated tooth which has a flared root canal. Traditionally, the treatment of choice for a flared root canal is the casted post and core (Clavijo et al. 2009; Plasmans et al. 1986). This approach requires multiple visits, produces sub-optimal aesthetics, has higher laboratory costs, is technically invasive; and is also associated with a higher degree of catastrophic failures (Gehrcke et al. 2017; Hegde et al. 2012; Zicari et al. 2011).

The introduction of the fiber reinforced composite (FRC) post system was regarded as a breakthrough. The elastic modulus of the FRC post is close to dentin (13-34 GA), allowing a similar rate of flexion upon loading on the tooth (Lassila et al. 2005; Sorrentino et al. 2016). It is therefore considered to be advantageous in reducing catastrophic tooth fracture when compared to the casted post and core with regards to long term survival (Sorrentino et al. 2016). However, FRC posts have a pre-fixed post size, which may require excessive root dentin removal to facilitate its accommodation to the root canal. This can potentially weaken the tooth (Bittner et al. 2010; Dietschi et al. 2008; Singh et al. 2012). Unfortunately, even the largest FRC post size may not fit well in flared root canal conditions. Hence, various clinical techniques were introduced for the usage of prefabricated FRC post in the flared canal. One of the techniques requires the use of a single FRC post and remaining spaces were then filled with accessory prefabricated FRC posts (Bonfante et al. 2007; Li et al. 2011). However, the *in-vitro* data for this technique was inconclusive (Bonfante et al. 2007; Latempa et al. 2014; Li et al. 2011; Talal et al. 2010).

A novel FRC post system was introduced allowing chairside customization known as the direct individually shaped-fiber reinforced composite (DIS-FRC) post; marketed as everStick post by GC Corporation, Japan (Lassila et al. 2005). The unidirectional E-glass fibers are embedded into the uncured resin matrix allowing the application of additional posts which are then molded and shaped according to the final canal configuration. This minimally invasive FRC post system requires minimal to almost no post space preparation; thereby reducing the risk of canal over preparation (Bell-Rönnlöf et al. 2005).

Despite the improvements in the fiber post systems, the debate on the restoration of a flared root canal tooth remains. Therefore, this study aims to investigate the load capacity of teeth with flared canals restored with different chairside FRC posts cemented with different resin luting cements and its mode of failure. The null hypotheses in this study include: i) there were no difference in the fracture resistance when a maxillary central incisor with simulated flared canal was restored with different FRC post, ii) there were no difference in fracture resistance when self-adhesive or self-etch resin cement was used for post cementation, and iii) there were no difference in the resultant mode of fracture.

Materials & Methods

Samples preparation

This is an *in-vitro* experimental study, obtained ethical approval from the university's ethiques review board, Jawatankuasa Etika Penyelidikan (Manusia) JEPeM, Universiti Sains Malaysia with protocol code USM/JEPeM/18100577. Written consent was taken from the eligible patient who was planned to have their maxillary central incisor extracted. Extracted sound maxillary central incisors with straight, crack-free roots were collected and stored in 0.9% normal saline under room temperature. The teeth were cleaned with an ultrasonic scaler (Newtron P5XS, Satelec Acteon, Merignac, France) and a number 11 surgical blade (Aesculap, B. Braun, Tuttlingen, Germany). The anatomical crown was sectioned at the cementoenamel junction (CEJ) to produce a root length of 17±1 mm. Its pulp tissue was then removed with a barbed broach size ISO 25 (Dentsply, Ballaigues, Switzerland). The roots were then ensured to have a mesio-distal dimension within 5.0-5.5 mm and 7.0-8.0 mm labio-palatally which was measured at 2.0 mm below the sectioning line for standardization purposes (Hegde et al. 2012). A total of 65 maxillary central incisors were prepared according to the inclusion criteria. The canal flare was simulated using a standardized tapered diamond cutting bur number 103R (Shofu, Kyoto, Japan) which was inserted into the canal up to 7.0 mm depth under copious water irrigation. This resulted in a flared root canal with the widest opening of 2.2 mm in diameter at the coronal opening (Hegde et al. 2012). A shoulder margin of 1.0 mm depth and 2.0 mm height was prepared to resemble a ferrule.

The samples were then randomly categorized into three main groups (Fig 1A-C); group 1 (control), restored with a single tapered prefabricated FRC post (RelyX Fiber Post, 3M Deutschland GmbH, Neuss, Germany); group 2 restored with multi-FRC post technique consisting of one main parallel-sided prefabricated FRC post (Reforpost, Angelus, Londrina, Brazil) with an additional prefabricated accessory FRC post (Reforpin, Angelus, Londrina, Brazil); and group 3 restored with a DIS-FRC post (everStick post, GC Europe, Leuven, Belgium). These teeth were further subdivided into two different resin cement; subgroup a for ParaCore (Coltene, Altstatten, Switzerland) and subgroup b for RelyX U200 (3M Deutschland GmbH, Neuss, Germany).

Post preparation

Group 1

Post space was prepared sequentially using RelyX Fiber post drill (3M Deutschland GmbH, Neuss, Germany) up to size 3 drill at 12.0 mm depth. Next, a blue coded Ø1.9 mm RelyX Fiber Post (3M Deutschland GmbH, Neuss, Germany) was cut at its coronal end producing a 15.0 mm post length; with 12.0 mm of it in the canal and the remaining 3.0 mm at its coronal end to retain the composite core.

Group 2

Post space preparation was done sequentially until size 5 Largo drill (Angelus, Londrina, Brazil) corresponding to a 1.1 mm post diameter at 12.0 mm depth. One size 3 Ø1.1 mm parallel-sided prefabricated FRC post (Reforpost, Londrina, Brazil) was inserted to the desired length followed by a passive addition of one accessory prefabricated FRC post (Reforpin, Londrina, Brazil). The posts were cut to 15.0 mm length.

Group 3

Post space was prepared sequentially using ParaPost drills (Coltene, Altstatten, Switzerland) up to Ø1.25 mm. The canal was then dried with paper points (Meta Biomed, Chungcheongbuk-do, Korea). A Ø1.2 mm everStick post (GC Europe, Leuven, Belgium) was removed from its protective packaging, cut at 15.0 mm length and inserted into the canal. Additional Ø0.9 mm everStick post (GC Europe, Leuven, Belgium) was added to the main post and manipulated in a lateral condensation technique using a finger spreader until the canal was filled by the uncured post. The bundled DIS-FRC post using everStick post (GC Europe, Leuven, Belgium) was coated with StickRESIN (GC Europe, Leuven, Belgium) and protected from the light source before bonding via the “direct technique” where the post and the resin cement were cured concurrently (Makarewicz et al. 2013).

Cementation protocol

All the canals were irrigated with 2.5% sodium hypochlorite (Pharmaceutical Unit, USM, Kota Bharu, Malaysia) in between instrumentations followed by a final rinse of 17% ethylenediaminetetraacetic acid (EDTA) (Meta Biomed, Chungcheongbuk-do, Korea).

Subgroup a

Non-rinse conditioner (ParaBond, Coltene, Altstatten, Switzerland) was applied into the canal for 30 seconds; following which the conditioner was removed and dried with a gentle airstream for 2 seconds. ParaBond adhesive A and B (Coltene, Altstatten, Switzerland) was mixed in a mixing well and applied into the canal for 30 seconds using a microbrush. The excess adhesive was removed. Then, ParaCore cement (Coltene, Altstatten, Switzerland) was transferred into the canal with the designated automix tip followed by gentle insertion of the post to its full seating. It was then light-cured for 40 seconds with a calibrated LED light-curing device (Mini LED, Satelec Acteon, Merignac, France).

Subgroup b

Self-adhesive resin cement RelyX U200 (3M Deutschland GmbH, Neuss, Germany) was ejected, mixed carefully on a mixing pad, and the post was coated before gently being inserted into the canal, followed by a light-curing of 40 seconds.

Composite core constructions and thermocyclic ageing

Composite core was made with ParaCore (Coltene, Altstatten, Switzerland) using a standardized thermoplastic mold based on the bonding protocol described for ParaBond (Coltene, Altstatten, Switzerland). All samples underwent 500 thermocycles at temperatures of 5^{o}C to 55^{o}C with a dwell time of 30 seconds and a transfer time of 5 seconds using an automated transfer dipping machine (ATDM T6 PD, AMMP Centre, Kuala Lumpur, Malaysia).

Tooth supporting tissues simulation

The periodontal ligament and alveolar bone simulations were made using the transition wax technique (Soares et al. 2005). Dipping wax (GEO Rewax, Renfert, Hilzingen, Germany) was heated up to 60^{o}C and the root of each sample was dipped into the wax for 2 seconds up to 3.0 mm apical to the prepared margin. The samples were then embedded onto the self-curing acrylic (Vertex, Zeist, The Netherlands) up to 2.0 mm apical to the prepared margin. Upon initial setting of the acrylic, the samples was then removed and the wax layer was completely removed. The space created between the root and acrylic was filled with polyvinylsiloxane (Express light body, 3M Deutschland GmbH, Neuss, Germany) which simulates the periodontal ligament.

Fracture load testing

All the samples were mounted on a designated platform and subjected to static load using a universal testing machine (AG-x plus, Shimadzu, Kyoto, Japan) at 135° angle simulating a class I incisor relationship with a cross-head speed of 0.5 mm/min at 2.0 mm below the incisal edge (Fig 1D). The maximum load capacity was recorded in Newton (N).

Assessment of fracture mode

Under operating binocular loupes with a magnification of 3.0× (Surgitel, USA), each sample was assessed and categorized to either to favorable fracture (fracture line not extending below the level of the acrylic block, core fracture, post-fracture or post debonding) or unfavorable fracture (fracture line extended below the acrylic level) (Fig 2).(Hegde et al. 2012)

Scanning electron microscopy analysis

Two representative samples from each group were randomly selected for further analysis using SEM. Two grooves were carefully made on the mesial and distal root surface. The root was then split into half which was then air-dried, sputter-coated with gold powder, and viewed under SEM (Quanta FEG 450, FEI, USA) with secondary electrons 5.00kV.

Data analysis

The collected data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 26.0 (IBM Corp, USA). The descriptive data were analyzed and it met the normality and homogeneity of variances assumptions hence, parametric Two-way ANOVA analysis and the Least Significant Difference (LSD) post-hoc test were used to analyze the maximum fracture load. The mode of fracture was analyzed using the chi-square test for differences. The level of significance was set at α=0.05.

Results

A total of 65 samples completed the tests and were eligible for data analysis. *Table 1* summarizes the mean maximum load capacity and its standard deviation. Following the Two-way ANOVA analysis, no interactions found between the type of post and the type of resin cement in the load capacity, $F(2, 59) = 1.268$, p=0.289 (p>0.05). However, the load capacity was significantly affected by the type of posts (p=0.046, p<0.05). Therefore, the LSD *post-hoc* test only applies to the main effect; the types of post which revealed a statistical difference between group 1 (522.9N) and group 3 (421.1N).

With regards to the mode of fracture, the percentage of favorable and unfavorable fracture were almost equal. Samples in group 1b demonstrated the most favorable fracture pattern (82%) and this was statistically significant (χ^2 (1):4.455(1); p=0.035, p<0.05) (*Table 2*). However, other groups did not show any significant differences in terms of mode of fractures.

In the SEM analysis, at the coronal region (Fig 3) most of the resin cement was seen adhering and covering the post surfaces. An exceptionally thick resin cement was evident in the post in group 1; with a sign of cement delamination and cracks exposing the post surface. However, its fibers within the post were seen attached to its matrix. Also, various cracks were observed horizontally and vertically on the cement surface and root dentin. There were gaps and microporosities across most of the samples. Meanwhile, resin tags were observed at the mid root region (Fig 4). Its morphology however, did not exhibit observable differences between the two different types of cement used. The DIS-FRC post (group 3) revealed signs of fiber detachment from its matrix. At the apical region, resin tags were also present with a higher degree of gaps and microporosities observed (Fig 5). In this region, more DIS-FRC post fiber detachments were observed leaving concave surfaces on its matrix known as scalloping.

Discussion

Based on the results, different FRC posts resulted in a different maximum load capacity on maxillary central incisors with a flared root canal. This finding was consistent with previous *in-vitro* studies (Hazzaa et al. 2015; Hegde et al. 2012; Kıvanç et al. 2009; Sary S et al. 2019; Talal et al. 2010). Therefore, the first null hypothesis was rejected. Group 2 yielded the highest load capacity value (522.9N) and this technique was previously shown to be comparable to the metal cast post and core *in-vitro* (Li et al. 2011; Talal et al. 2010). In our study, this was not significantly different compared to the positive control group 1. Group 3 performed the worst among the groups, with the lowest load capacity recorded (421.1N). Nevertheless, all the recorded load capacity values were higher than the maximum bite force (80N) at the anterior region in a normal healthy person (Hattori et al. 2009).

The incorporation of accessory posts around the main FRC post in group 2 was to improve its fibre to resin composition in order to enhance the fracture resistance and to reduce the resin cement thickness (Latempa et al. 2014; Li et al. 2011; Talal et al. 2010). Also, the increased fiber content optimizes stress distribution within the root canal (Latempa et al. 2014). Although the fiber/resin composition in the group 3 was favorable, the increase in load capacity was not observed in our study as previously reported (Hazzaa et al. 2015; Talal et al. 2010). This was due to the low elastic modulus and flexural strength in the DIS-FRC post (Gao et al. 2010). Moreover, the water sorption and hydrolytic degradation between E-glass fibers to the semi-interpenetrating network matrix reduces its flexural strength to up to 35% after thermocycling (Almaroof et al. 2019; Lassila et al. 2005).

The type of resin cement did not affect the load capacity in our study. Therefore, the second null hypothesis was accepted. The main effect analysis indicated that cementation of FRC post with a higher filler content resin cement ParaCore (68% inorganic filler by weight) resulted in no differences in the load capacity among all samples. This observation implies that a high filler content resin cement was favorable in cementing DIS-FRC post as it enhances its mechanical properties. This result is debatable as Alshahrani et al. (2020) did not observe any significant role of filler content in resin cement in terms of increasing the fracture resistance. However, the related samples were not in a flared root canals for that study.

Although the overall mode of failure demonstrates a favorable fracture pattern, the results were not statistically significant. This finding contradicted many other studies which revealed minimal or no root fracture when a tooth was restored with FRC post systems (Beltagy 2017; Doshi et al. 2019; Fráter et al. 2017; Hegde et al. 2012; Maccari et al. 2007). Nevertheless, our result was in agreement with few other studies that also failed to indicate the protective effects of the FRC posts *in-vitro* (Bell-Rönnlöf et al. 2011; Fokkinga et al. 2006; Fráter et al. 2020; Li et al.

2011; Magne et al. 2017). This was postulated to be due to the thin root dentin in the samples and that the tooth failed prior to the mechanical failure of the post (Maccari et al. 2007). Due to this reason, no incidence of post fracture or debonding were observed in this.

Davis et al. (2010) described the DIS-FRC post fibers detachment from the matrix. This was also consistent in our sample observations in this study. The poor coupling and adhesion between the E-glass fibers to the matrix contributed to the reduced physical strength of the post (Davis et al. 2010). Other *in-vitro* studies revealed a higher degree of cohesive failures within the DIS-FRC post (Alnaqbi et al. 2018; Bell-Rönnlöf et al. 2005). However, such an event was not readily observed in the prefabricated FRC post. Despite luting cement delamination and post surface exposure in the samples in group 1, the fibers within the post have strongly adhered to its matrix.

There was a large standard deviation observed in our data. Natural human teeth are highly subjected to variations due to the wear and anatomical variations (Bell-Rönnlöf et al. 2011; Bolay et al. 2012; Yoldas et al. 2005). Also, the collection of maxillary central incisors was challenging due to its aesthetic value, hence the eligible samples were lacking than the required sample size which resulted in an unbalanced distribution of samples within the groups in this study (Bell-Rönnlöf et al. 2011). Despite that, the final power of this study was 79.78% which was still acceptable. Endodontic treatment was not performed in view of the possible contamination by the secondary smear layer during gutta-percha removal which could prevent proper bonding of the post to the root dentin (Bell-Rönnlöf et al. 2011; Elkassas et al. 2010). Furthermore, endodontic procedures would not affect the load capacity of the samples (Johnson et al. 2000). Crown restoration was also avoided in this study to prevent confounding effects and to evaluate better the role of a post in fracture resistance along with its fracture mode (Annadurai et al. 2019; Beltagy 2017; Fráter et al. 2017; Kivanç et al. 2010). Since a crown is considered as a definitive restoration, the load capacity may be potentially higher (Annadurai et al. 2019; Beltagy 2017; Gehrcke et al. 2017; Sary S et al. 2019).

Conclusions

Within the limitations of this study, it can be concluded that prefabricated FRC posts outperforms DIS-FRC posts in the load capacity of a simulated flared root canal regardless of the luting techniques used. All the tested fiber post systems did not show any protective effect in terms of the failure mode.

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Figure 1

Types of fiber posts used.

(A) single tapered prefabricated FRC post in group 1, (B) parallel prefabricated FRC post with accessory post in multi-FRC post technique in group 2, (C) DIS-FRC post (everStick post) in group 3, and (D) the schematic diagram of experimental setup in universal testing machine.

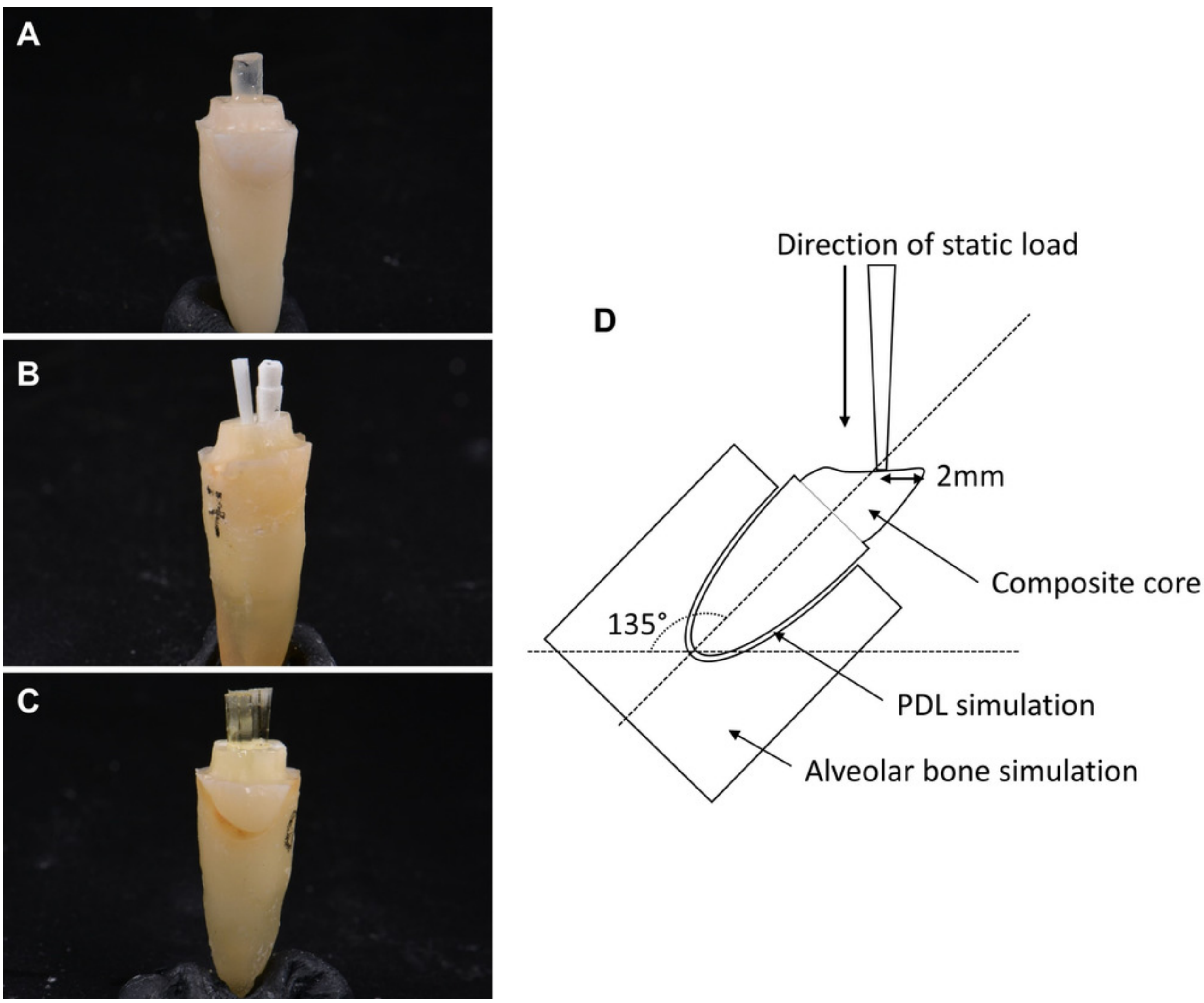

Figure 2

Assessment of the mode of fracture.

(A) favorable fracture, (B) unfavorable fracture, red arrow=crack/fracture line (note that the sample was lifted from the acrylic block to allow better visualization of the crack extension).

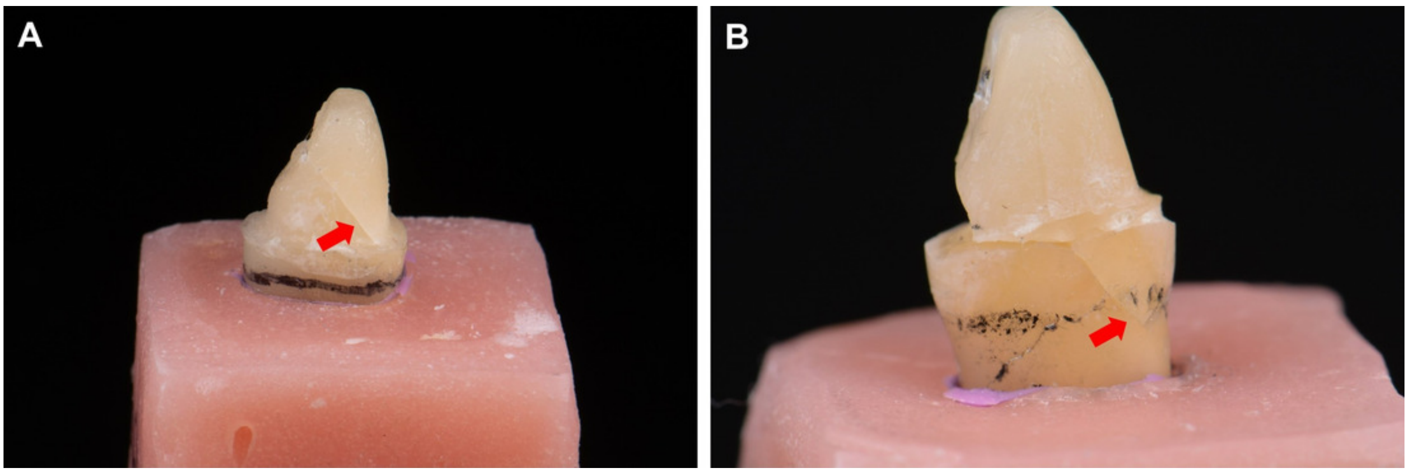

Figure 3

SEM images at coronal region.

P=post surface, D=dentin surface, red arrow=crack, blue arrow=resin tag and green arrow=gaps and microporosities.

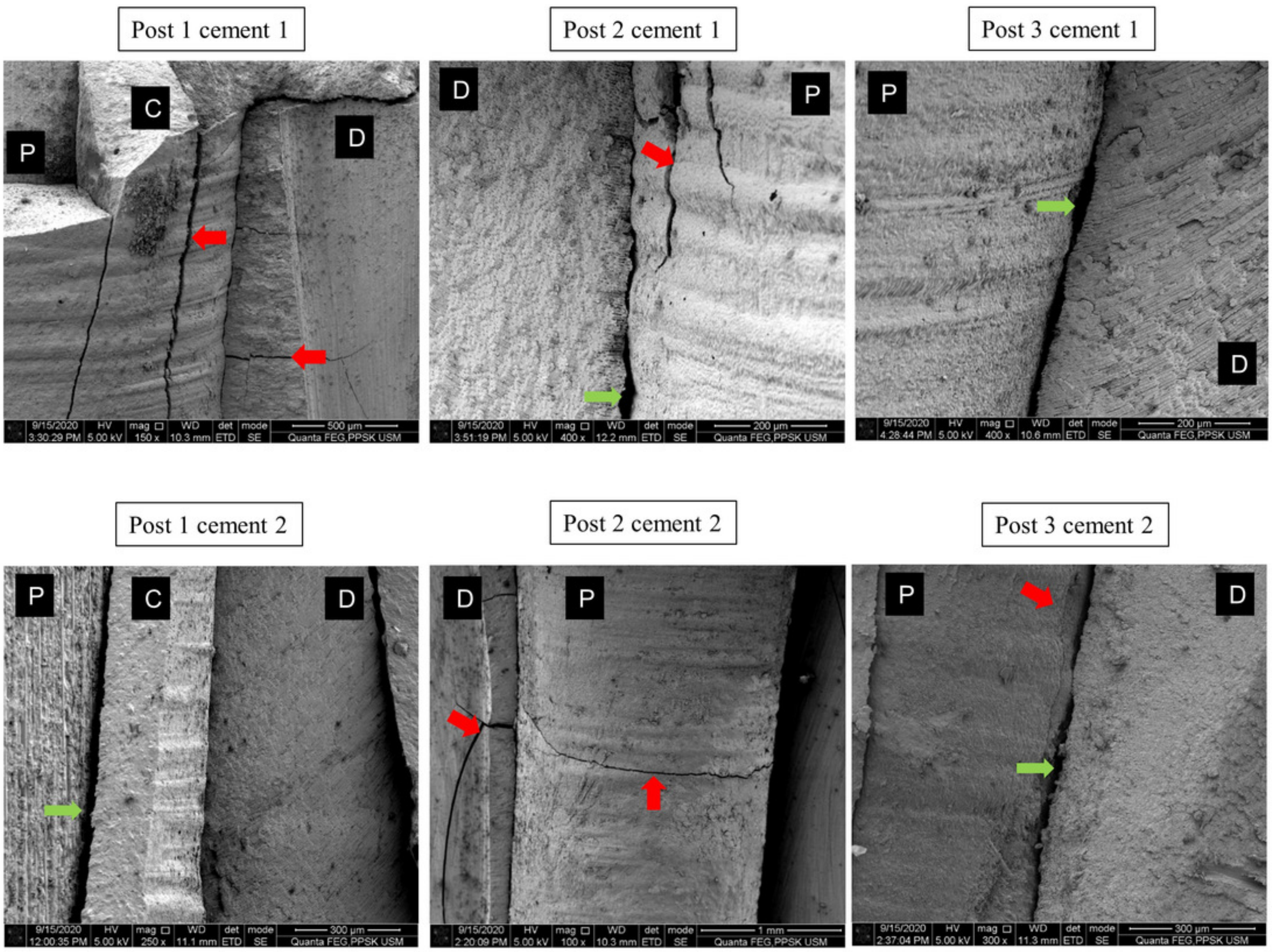

Figure 4

SEM images at mid root region.

P=post surface, D=dentin surface, red arrow=crack, blue arrow=resin tag and green arrow=gaps and microporosities.

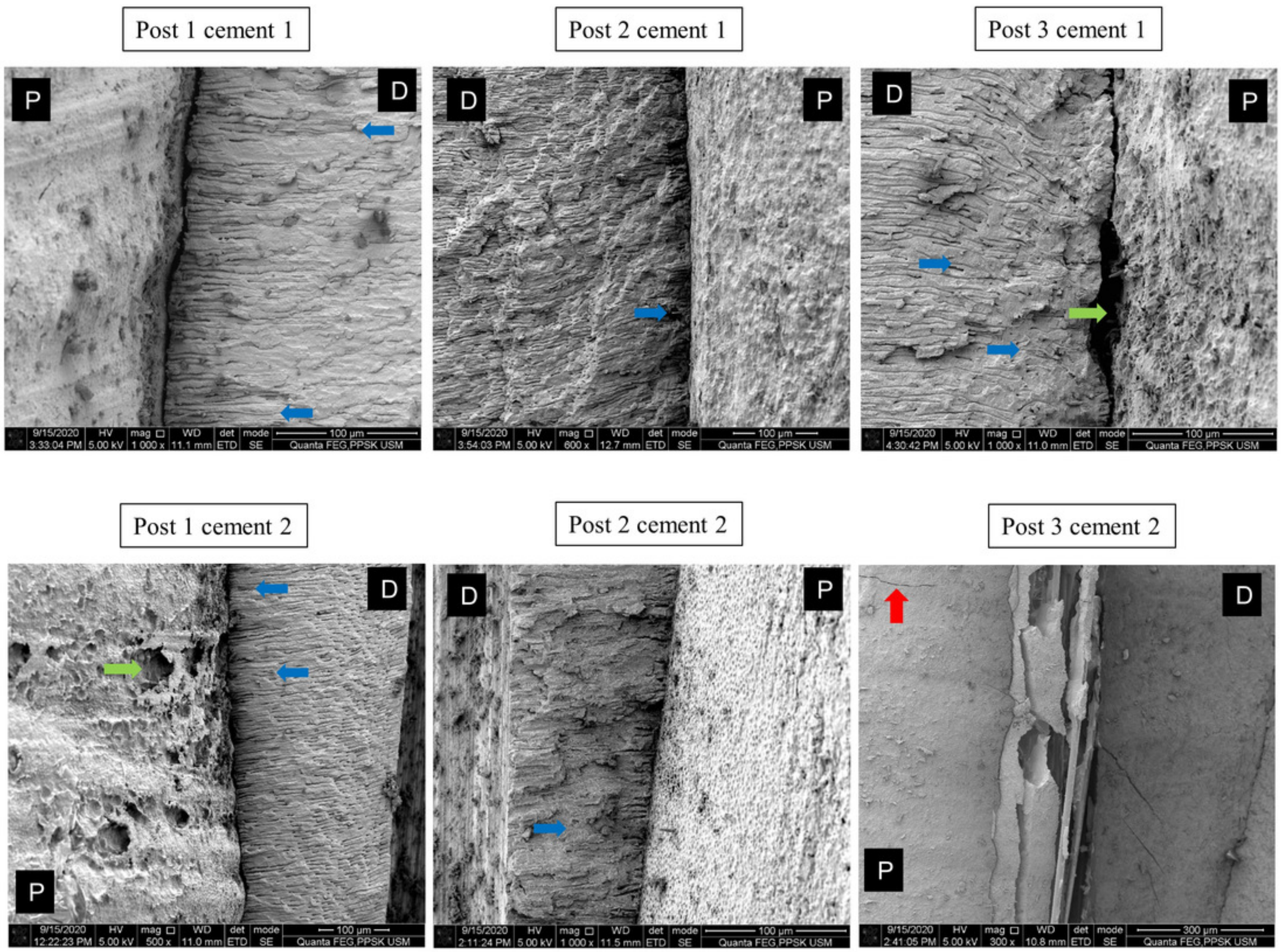

Figure 5

SEM images at apical region.

P=post surface, C=cement, D=dentin surface, S=scalloping, H=hackle lines, F=fiber, green arrow=gaps and microporosities, and blue arrow=resin tag.

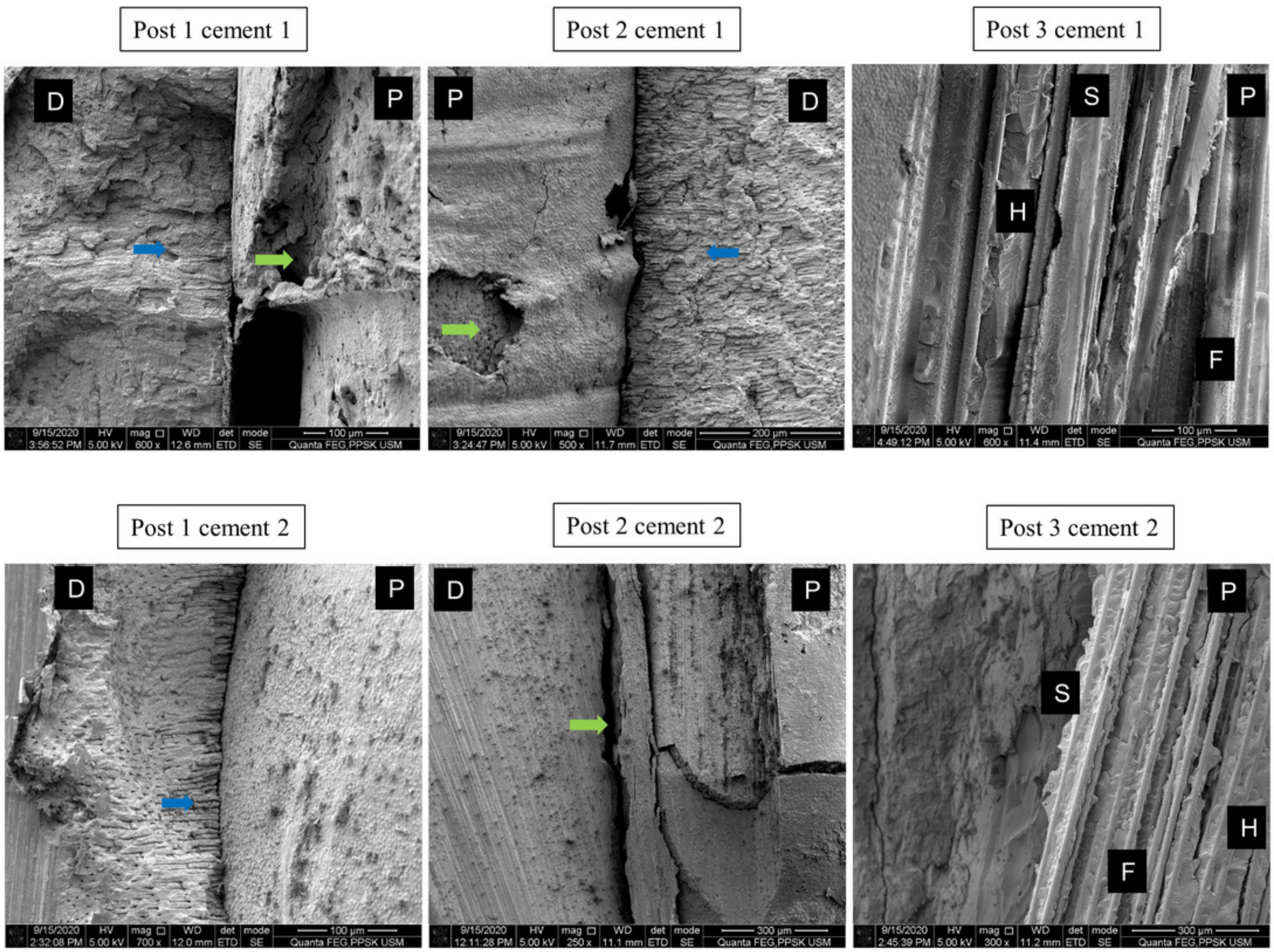

Table 1 (on next page)

Mean maximum load capacity.

Table 1. *Mean maximum load capacity.*

Group	n (number of samples)	Load capacity, N (SD)
1a	11	458.2 (91.8)[a]
2a	10	539.4 (161.3)[a]
3a	11	437.8 (211.9)[a]
1b	11	541.5 (119.1)[A]
2b	11	507.9 (127.5)[AB]
3b	11	404.3 (79.5)[B]

Different lower case superscript letters representing statistical difference in pairwise comparison using LSD post hoc test when comparing types of post within a single level (subgroup a).
Different upper case superscript letters representing statistical difference in pairwise comparison using LSD post hoc test when comparing types of post within a single level (subgroup b).
whereby p-value <0.05 is considered significant.
Load capacity in N (Newton).
SD= standard deviations.

Table 2 (on next page)

Mode of fracture and statistical analysis using chi-square test for differences.

Table 2. *Mode of fracture and statistical analysis using chi-square test for differences.*

Group	Mode of fracture		χ^2 (df)	*p*-value
	Favorable, n (%)	Unfavorable, n (%)		
Group 1a	7 (64%)	4 (36%)	0.818(1)	0.366
Group 1b	9 (82%)	2 (18%)	4.455(1)	0.035
Group 2a	4 (40%)	6 (60%)	0.400(1)	0.527
Group 2b	6 (55%)	5 (45%)	0.091(1)	0.763
Group 3a	4 (36%)	7 (64%)	0.818(1)	0.366
Group 3b	6 (55%)	5 (45%)	0.091(1)	0.763
Total	36 (55%)	29 (45%)	0.754(1)	0.385

* χ^2=chi-square test for differences, significance level set at $p<0.05$