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Original Research

Failures in cementation techniques of glass fiber posts with application of 3D digital prototyping and post-processing CBCT Software

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Failures in the cementation technique of intraradicular posts can pose risks for root canal treatment failure and crown loss. **Aim:** This study assessed cementation failures of glass fiber post systems using two techniques with application of 3D digital prototyping and post-processing CBCT software. **Methods:** Seventy-two maxillary central incisors were 3D-printed and divided into groups: 1. Splendor-SAP posts; 2. anatomical posts; 3. conventional glass fiber posts (control). Two cementation techniques were employed: manual and self-mixing. CBCT scans were taken, and root canal third images were analyzed using e-Vol DX software. The Chi-square test was applied at a significance level of 0.05%. **Results:** Regardless of the cementation technique used, a statistically significant difference was observed among the post systems. Group 2 showed the best results, while Group 1 exhibited the worst. The cementation technique did not significantly affect the presence of gaps (voids) in Groups 2 or 1 across the three evaluated areas. For all post systems and both cementation techniques, there was a significant difference among the three thirds, except for Group 1 using manual cementation. **Conclusions:** Irrespective of the cementation technique, significant differences were noted among various glass fiber post systems. The cementation technique did not impact the occurrence of voids in anatomical or Splendor-SAP glass fiber posts. However, with conventional glass fiber posts, the self-mixing cementation technique had a positive effect on reducing voids.

Keywords: Post and core technique. Cementation. Dental cements. Endodontics.

Introduction

Indirect restorations involving extensive coronal destruction often necessitate intraradicular anchorage, typically achieved with the use of posts[1,2]. Glass fiber posts offer several advantages, including a similar elastic modulus to dentin, compatibility with adhesive systems and resin cements, and ease of removal compared to metallic posts[3]. They are cost-effective, easier to handle, resistant to corrosion, and allow for preparation and cementation in a single session[1,4-6].

The use of fiberglass posts offers a significant advantage due to their less invasive nature. This is important because excessive preparation of the space for the post can compromise the remaining dentin, increasing the risk of root perforations or fractures. Therefore, a thorough understanding of the endodontic system anatomy is crucial for successful treatment, helping to avoid these risks and ensure the preservation of a safe dentin zone[7,8].

Direct use of glass fiber posts in wide canals or weakened roots requires a thick layer of cementing agent between the post and the root canal walls, which can decrease the fracture resistance of the post/root filling[9-14]. Moreover, excessive cement thickness may lead to the formation of gaps and voids, increasing the risk of post debonding[11].

Several techniques for cementing glass fiber posts have been proposed, with the choice of technique being a critical factor in cementation quality. The use of self-adhesive mixing tips for resin cement insertion can improve canal filling and reduce irregularities and void formation[13].

Cone-beam computed tomography (CBCT) is a non-invasive imaging exam with clinical utility, particularly in evaluating gaps and voids within the canal using a three-dimensional (3D) perspective[14]. Despite technological advancements in CBCT, software interpretation of acquired images often faces limitations, such as limited navigation tools and inadequate filters for overcoming artifacts. The e-Vol DX software[14] package addresses these challenges by providing high-resolution images, dynamic multi-plane navigation, adjustable volume parameters, and data correction capabilities through filters and manipulation of brightness and contrast[15].

Given the diversity of cementation techniques for glass fiber posts, evaluating variations and void formation within the cement using tomographic images offers potential clinical applications. This study assessed cementation failures of glass fiber post systems using two techniques with application of 3D digital prototyping and post-processing CBCT software. Three null hypotheses will be tested: firstly, regardless of manual or self-mixing cementation techniques, there is no significant difference among glass fiber post systems; secondly, cementation technique does not affect void formation in the cementation line; and thirdly, there is no difference among the thirds evaluated in each post system for both cementation techniques.

Material and Method

Making the 3D digital prototype

For the prototype of this study, a sound maxillary central incisor was selected, with a root length of 14mm, devoid of any curvature, measured with a digital caliper (Fowler/Sylvac Ultra-Cal Mark IV Electronic Caliper, Crissier, Switzerland) from the root apex. The tooth, extracted for different reasons, was obtained from the Dentistry Department Urgency Clinic at the Federal University of Goiás and properly stored in 0.1% thymol throughout the duration of the experiment. This study received approval from the ethics committee of the Federal University of Goiás, Brazil (# 06486919.0.0000.5083).

Tooth model preparation

To prepare the tooth model, a standard access cavity was created using a round diamond bur (#1012, KG Sorensen, Barueri, Brazil) attached to a high-speed handpiece with air and water spray cooling. Odontometric analysis was conducted by inserting a No.15 K-File (Dentsply Maillefer, Ballaigues, Switzerland) into the apical foramen, followed by a 1 mm setback, and root canal preparation was carried out using manual K-File instruments (Dentsply Maillefer) up to a No.60 instrument. For root canal filling, the lateral condensation technique was employed with gutta-percha cones (Tanari®, Manacapuru, AM, Brazil) and MTA Fillapex® sealer (Angelus, Londrina, Paraná, Brazil). Subsequently, the sample was placed in a dental oven (ECB, 1.3 digital, Odontobrás, Ribeirão Preto, SP, Brazil) at 37°C for 48 hours.

Subsequently, a coronal preparation was performed using a No.4138 diamond bur (KG Sorensen, São Paulo, Brazil), leaving a 2mm ferrule around the entire coronal perimeter of the tooth. Intraradicular preparation began with a No.1 Largo bur (Dentsply-Maillefer, Ballaigues, Switzerland), removing a portion of the gutta-percha and creating space for the post. This preparation was calibrated to a depth of approximately 9mm, using the measurement of the tooth's working length as a reference. Following this, a No.2 Largo bur was used to widen the canal and complete the preparation.

Obtaining the 3D digital prototype and printing the standardized specimens

The next step involved obtaining CBCT images using the CS 8100 3D CBCT system (Carestream, Marne-la-Valée, France), which was calibrated to a thickness of 0.15 mm, with a FOV (Field of View) of 8x5 cm and a voxel size of 75. The tube voltage was set at 90 kVp, and the tube current was maintained at 3mA, with an exposure time of 15 seconds. The acquired tomographic data were then converted into DICOM (Digital Imaging and Communications in Medicine) format. Subsequently, the images were interpreted using e-Vol DX software (CDT Software, São José dos Campos, SP, Brazil) and then converted into STL (Standard Triangle Language) format to generate a 3D digital model of the tooth (Figures 1A and 1B).

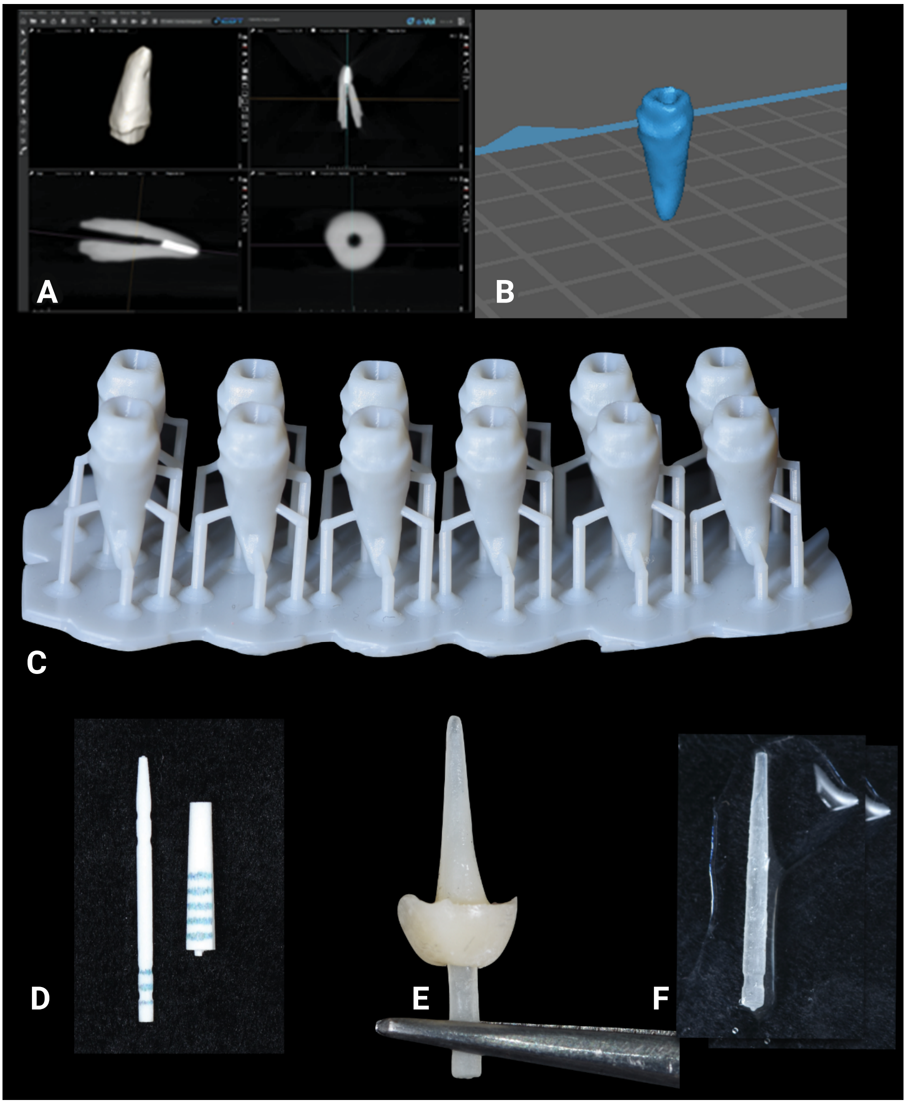

Figure 1. (A) CBCT scans of the model tooth in DICOM format as viewed in e-Vol DX software; (B) Image of the model tooth in STL format; (C) Group of teeth impressions after the full resin cleaning process; (D) Splendor-SAP system (Angelus, Londrina, Brazil) comprising a fiberglass sleeve and post used in Group 1; (E) No. 1 Exacto post (Angelus, Londrina, Brazil) utilized in the Control Group immersed in 24% H2O2 (Fitofarma, Goiânia, Brazil); (F) Anatomical post employed in Group 2.

A total of 72 standardized specimens were fabricated by 3D printing the digital model using TR250 LV acrylic resin (Phrozen, Hsinchu City, Taiwan). The STL file was imported into the 3D printing software (Chitubox, Guangdong, China), and the specimens were printed with the buccal side facing towards the right side of the platform in a standardized manner. Each group comprised 12 samples arranged in 2 rows of 6 samples each, with approximately 10mm spacing between the apex of one tooth and the next, and 7mm spacing between the first and second rows. The specimens were printed using a Phrozen Mini 4K 3D printer (Phrozen Mini 4K, Taiwan) with a layer thickness setting of 0.06mm and an exposure time of 6 seconds per layer (Figure 1C).

Following printing, the specimens underwent immersion in a 99.80% isopropyl alcohol solution (Quimidrol, Joinville, Brazil) within an ultrasonic bath (Tecnodent, Indaiatuba, Brazil) for 2 minutes. They were then dried using absorbent paper towels and air jets before being transferred to an ultraviolet light-curing chamber (Otoflash G171, NK-OPTIK, Baierbrunn, Germany), programmed for 2 cycles at a rate of 1000 flashes per minute.

The printed specimens were allocated into three experimental groups (n=24) based on the type of post utilized:

Group 1 – Splendor-SAP single adjustable glass fiber posts (Angelus, Londrina, Brazil) (Figure 1D). Group 2 – Exacto anatomical glass fiber posts (Angelus, Londrina, Brazil) anatomized and mounted with Harmonize composite resin (Kerr, Bioggio, Switzerland) (Figure 1E). Group 3 – Control Group: conventional glass fiber posts (Exacto, Angelus, Londrina, Brazil) (Figure 1F).

Each group was further subdivided into two subgroups, A and B (n=12), based on the cementation techniques employed: Subgroup A: Manual mixing utilizing a glass plate and No.24 spatula, with cement insertion performed using a straight exploratory probe (Golgran, São Caetano do Sul, Brazil) and LM-ErgoMax composite resin mini spatula (Quinelato, Rio Claro, Brazil); Subgroup B: Cement insertion accomplished with self-mixing tips and intracanal cannula (Sulzer Mixpak, Haag, Switzerland).

For each of the aforementioned methods for preparation and cementation of the intraradicular posts, one of the three experimental groups was utilized:

Group 1 - Splendor-SAP glass fiber posts (Angelus, Londrina, Brazil), comprising two components - a parallel post and a conical sleeve. The post was conditioned with 24% hydrogen peroxide (H2O2) (Fitofarma, Goiânia, Brazil) for 60 seconds, thoroughly washed for 20 seconds, and air-dried. Subsequently, silane primer (Kerr, Orange, USA) was applied and left for 60 seconds. The root canal was abundantly irrigated with saline solution and dried with No. 60 absorbent paper points (Dentsply, Ballaigues, Switzerland). After post and root canal preparation, the self-adhesive resin cement U200 (3M Espe, Neuss, Germany) was handled according to each subgroup as follows:

Subgroup A - The self-adhesive resin cement U200 (3M Espe, Neuss, Germany) was dispensed onto a glass plate and manipulated for 10 seconds with the aid of a No. 24 spatula (Golgran, São Caetano do Sul, Brazil). The cement was introduced into the root canal with a straight exploratory probe (Golgran, São Caetano do Sul, Brazil), and the post was coated with cement using a composite resin spatula (Quinelato, Rio Claro, Brazil). First, the post was inserted into the root canal, and then the sleeve was positioned over it, removing the excess. After 6 minutes of curing, photoactivation was performed for 60 seconds (Valo Cordless, Ultradent, Utah, USA) parallel to the long axis of the tooth.

Subgroup B - Resin cement was inserted into the root canal with the aid of a self-mixing tip with an intracanal cannula (Sulzer Mixpak, Haag, Switzerland), and then the post was inserted into the root canal, followed by positioning the sleeve over it and removing the excess. As in Subgroup A, after 6 minutes of curing, photoactivation was performed for 60 seconds (Valo Cordless, Ultradent, Utah, USA).

For Group 2, to perform anatomization with composite resin, the Exacto post (Angelus, Londrina, Brazil) underwent similar treatment to Group 1. After silanization, a first layer of Opti-Bond FL adhesive was actively applied (Kerr, Orange, USA) for 15 seconds, followed by evaporation with air jets for 10 seconds. Subsequently, a second layer of adhesive was applied, and light curing was conducted for 20 seconds using a high-power unit (Valo Cordless, Ultradent, Utah, USA). Root canal preparation involved lubricating it with water-soluble gel (KY, Johnson & Johnson, São José dos Campos, SP, Brazil), and excess was removed with a No.50 paper point (Diadent, Burnaby, Canada). The post was coated with a single application of Harmonize (Kerr, Orange, USA), inserted into the canal, and light-cured for 2 seconds (Valo Cordless, Ultradent, Utah, USA). The set was removed and repositioned inside the canal, and curing was repeated three times with exposure times of 2 seconds. After anatomization, light curing was performed on the post-resin composite outside the canal for 60 seconds, with the light source perpendicular to the long axis of the post and on all its faces.

For cementation of the anatomized post, the root canal was abundantly irrigated with saline solution and dried with No.50 absorbent paper points (Diadent, Burnaby, Canada). The post was washed with a jet of air and water, and silane was again applied and left for 60 seconds. The cement application procedure occurred as previously described for Subgroups A and B.

For Group 3, the Control Group, the Exacto post (Angelus, Londrina, Brazil) was initially positioned inside the root canal to assess stability and select its diameter. Following this test, a No.1 post diameter was chosen and immersed in 24% hydrogen peroxide (H2O2) (Fitofarma, Goiânia, Brazil) for 60 seconds, then washed with a jet of water and air for 20 seconds, and dried with a jet of air. Subsequently, silane primer (Kerr, Bioggio, Switzerland) was applied to the entire post structure and left for 60 seconds. The root canal was irrigated abundantly with saline solution and dried with No. 50 absorbent paper points (Dentsply, Ballaigues, Switzerland). After post and root canal preparation, the self-adhesive resin cement Relyx U200 (3M espe, Neuss, Germany) was used according to each subgroup (A or B).

Image acquisition and analysis

CBCT image acquisition and analysis were conducted utilizing the CS 8100 3D system (Carestream, Atlanta, Georgia, USA), calibrated to a thickness of 0.15 mm, with a FOV (Field of View) of 8x5 cm and a voxel size of 75. The tube voltage was set at 90kVp, and the tube current was maintained at 3mA, with an exposure time of 15 seconds. Tomographic data acquired after cementation were converted into DICOM format. Subsequently, root canal systems were reconstructed in 3D following the software manufacturer’s instructions.

The DICOM calibration was performed using e-Vol DX software (CDT Software, São José dos Campos, SP, Brazil), and the resulting images were analyzed by two radiologists on a workstation equipped with an Intel Core i7-10750H Comet Lake processor, 10th Gen, 2.6Ghz (Intel Corp., Santa Clara, CA, USA), NVIDIA GeForce RTX 2060 GPU Cached Video Card (NVIDIA Corporation, Santa Clara, CA, USA), and an EIZO-Flexscan S2000 monitor with a resolution of 1600X1200 pixels (EIZO NANAO Corp., Hakusan, Japan). The workstation operated on a Windows 10 Pro OS (Microsoft Corp., Redmond, WA, USA).

The noise elimination filter (BAR 2) was applied, and the scan commenced at the apical end of the post and terminated at the coronal limit of the tooth. Evaluations were conducted on the three tomographic planes, with the coronal and sagittal planes serving as references for positioning in relation to the cervical, middle, and apical thirds of the canal. Assessments on the axial plane analyzed the following areas to determine relative scores. On the axial plane, each specimen was divided into areas A, B, C, and D, and classified into scores ranging from 0 to 4[16] (Figure 2). Scores were assigned for the apical, middle, and cervical thirds of the root canal. Voids within these thirds were identified in the coronal and sagittal planes, and their locations were measured in millimeters from the cervical ends of the tooth to the center of the voids, considering that each third of the root canal had an approximate length of 3mm (Figure 3).

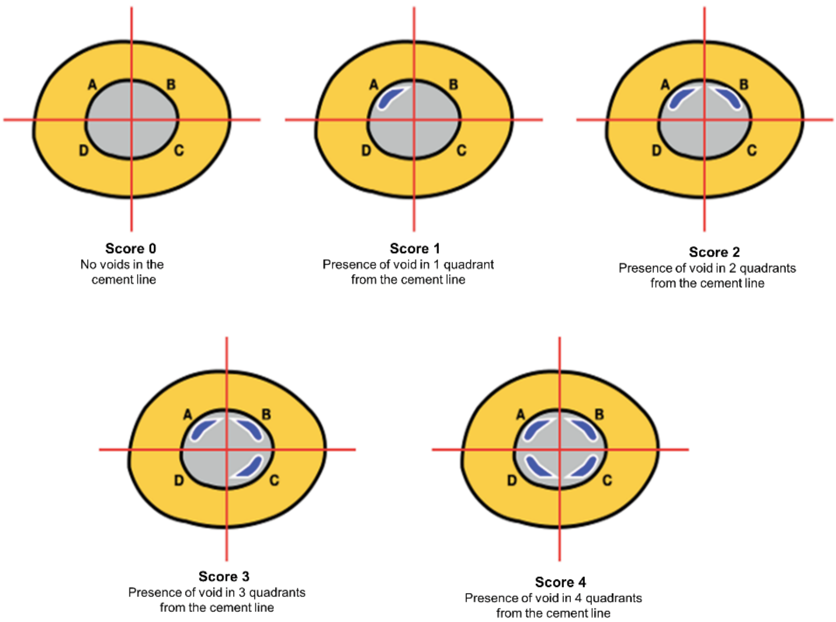

Figure 2. (A) Schematic representation illustrating the division of the root canal into areas (A, B, C, and D) and the classification system utilized to evaluate the presence or absence of voids (gaps) at the adhesive interface between the post and root canal.

Figure 3. (A) 3D model displaying the post-cement filling of a specimen from Group 3 Subgroup B using e-Vol DX software, revealing the presence of large voids in the middle third (indicated by the red arrow). (B), (C), and (D) depict voids in the axial, sagittal, and coronal sections, respectively, with the axial section serving as a reference for classification as a Score of 3. The sagittal section (E) and coronal sections (F) and (G) are presented with linear measurements to determine the void's location in the apical, middle, and coronal thirds in three different specimens from Groups 1, 2, and 3, respectively.

The comparison between the posts, the different cementing methods, and the various regions of the root canal concerning the scores was evaluated using the chi-square test with a significance level of 5% employing the Statistical Package for the Social Sciences software version 20 (SPSS, Chicago, IL, USA).

Results

In Table 1, a statistically significant difference ($p<0.05$) was observed between the three types of posts in the three thirds evaluated, irrespective of whether the manual or self-mixing cementation technique was employed.

For the conventional glass fiber posts (Control Group), a significant difference between the two cementation techniques was noted in the cervical and apical thirds, with a higher prevalence of the lowest scores observed for the self-mixing cementation. However, in the middle third, no significant difference was found, with a predominance of score 2 for both cementation techniques.

Regarding the formation of voids, no significant difference was observed with the anatomical posts (Group 2) and Splendor-SAP posts (Group 1), regardless of the third evaluated, regardless of the cementation technique used (Table 2).

For all three post systems, no significant difference was found between cementation techniques when evaluated in the cervical, middle, and apical thirds, except for the Splendor-SAP posts fixed with manual cementation. In this case, a significant difference ($p<0.05$) was observed, with a higher prevalence of scores 0 and 2 in the cervical third and scores 3 and 4 in the apical third (Table 3) (Figure 4).

Table 1. Comparison between the different post systems with the two cementation techniques regarding the cervical, middle, and apical thirds.

Manual cementation							Self-mixing cementation						
Cervical Third							Cervical Third						
Post / Score	**Score 0**	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p****	**Post / Score**	**Score 0**	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p****
Fiberglass post	0	0	10	2	0	0.000	Fiberglass post	6	3	2	0	1	0.000
Anatomical post	12	0	0	0	0		Anatomical post	12	0	0	0	0	
Splendor-SAP post	5	1	6	0	0		Splendor-SAP post	2	1	9	0	0	
Middle Third							Middle Third						
Post / Score	**0**	**1**	**2**	**3**	**4**	***p****	**Post / Score**	**0**	**1**	**2**	**3**	**4**	***p****
Fiberglass post	1	9	0	2	0	0.000	Fiberglass post	1	2	9	0	0	0.000
Anatomical post	12	0	0	0	0		Anatomical post	12	0	0	0	0	
Splendor-SAP /post	2	0	7	3	0		Splendor-SAP /post	0	0	9	2	1	
Apical Third							Apical Third						
Post / Score	**0**	**1**	**2**	**3**	**4**	***p****	**Post / Score**	**0**	**1**	**2**	**3**	**4**	***p****
Fiberglass post	0	1	9	2	0	0.000	Fiberglass post	2	5	4	0	1	0.000
Anatomical post	11	1	0	0	0		Anatomical post	10	2	0	0	0	
Splendor-SAP post	0	0	4	5	3		Splendor-SAP post	0	1	6	3	2	

*Chi-square test.

Table 2. Effect of cementation technique (CT) on different fiberglass post systems.

Fiberglass post							Anatomical post							Splendor-SAP post						
Cervical Third							Cervical Third							Cervical Third						
CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**	CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**	CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**
Manual cementation	0	0	10	2	0	0.002	Manual cementation	12	0	0	0	0	1.000	Manual cementation	5	1	6	0	0	0.390
Self-mixing cementation	6	3	2	0	1		Self-mixing cementation	12	0	0	0	0		Self-mixing cementation	2	1	9	0	0	
Middle Third							Middle Third							Middle Third						
CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**	CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**	CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**
Manual cementation	1	0	9	2	0	0.261	Manual cementation	12	0	0	0	0	1.000	Manual cementation	2	0	7	3	0	0.327
Self-mixing cementation	1	2	9	0	0		Self-mixing cementation	12	0	0	0	0		Self-mixing cementation	0	0	9	2	1	
Apical Third							Apical Third							Apical Third						
CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**	CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**	CT / Score	Score 0	Score 1	Score 2	Score 3	Score 4	*p**
Manual cementation	0	1	9	2	0	0.048	Manual cementation	11	1	0	0	0	0.537	Manual cementation	0	0	4	5	3	0.552
Self-mixing cementation	2	5	4	0	1		Self-mixing cementation	10	2	0	0	0		Self-mixing cementation	0	1	6	3	2	

*Chi-square test.

Table 3. Comparison of the cervical, middle, and apical thirds of the root canal using the different fiberglass post systems with the two cementation techniques.

	Manual cementation							Manual cementation							Manual cementation					
	Fiberglass post							Anatomical post							Splendor-SAP post					
	Score 0	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p******		**Score 0**	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p******		**Score 0**	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p******
Cervical	0	0	10	2	0	0.667	Cervical	12	0	0	0	0	0.358	Cervical	5	1	6	0	0	0.015
Middle	1	0	9	2	0		Middle	12	0	0	0	0		Middle	2	0	7	3	0	
Apical	0	1	9	2	0		Apical	11	1	0	0	0		Apical	0	0	4	5	3	
	Self-mixing cementation							**Self-mixing cementation**							**Self-mixing cementation**					
	Fiberglass post							**Anatomical post**							**Splendor-SAP post**					
	Score 0	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p******		**Score 0**	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p******		**Score 0**	**Score 1**	**Score 2**	**Score 3**	**Score 4**	***p******
Cervical	6	3	2	0	1	0.056	Cervical	12	0	0	0	0	0.120	Cervical	2	1	9	0	0	0.229
Middle	1	2	9	0	0		Middle	12	0	0	0	0		Middle	0	0	9	2	1	
Apical	2	5	4	0	1		Apical	10	2	0	0	0		Apical	0	1	6	3	2	

*Chi-square test.

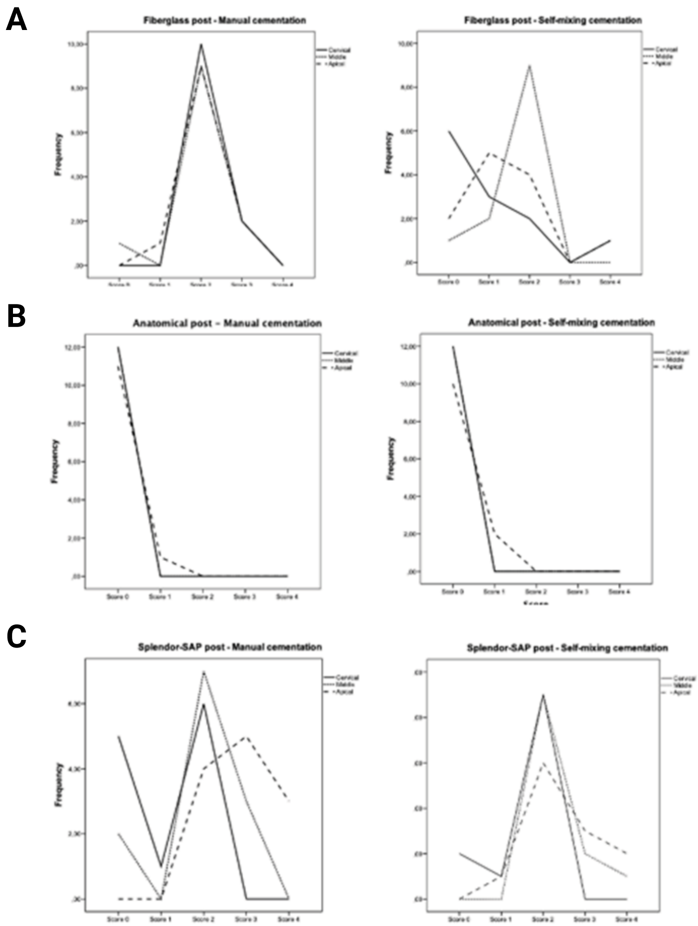

Figure 4. Linear graph illustrating the frequency of scores in the cervical, middle, and apical root canal thirds achieved with either manual and self-mixing cementation and with either conventional fiberglass posts (A), anatomical posts (B), or Splendor-SAP posts (C).

Discussion

The cement line of three types of glass fiber post systems to root canals using two cementation techniques was evaluated with the first null hypothesis, which assumed that there would be no significant difference among them in the areas examined, namely, the apical, middle, and cervical thirds. The first null hypothesis was rejected because, regardless of whether a manual or self-mixing cementation technique was employed, there was a statistically significant difference ($p<0.05$) observed between the three types of posts in the three evaluated thirds (Table 1).

The second null hypothesis, which assumed that neither the manual nor the self-mixing cementation technique used with the various post systems would influence the formation of voids in the cement line, was partially accepted after data analysis. The absence of a statistically significant difference in the quantity of voids between the two cementation techniques was observed only with the anatomical posts (Group 2) and with the Splendor-SAP posts (Group 1), regardless of the third evaluated. However, the conventional glass fiber posts (Control Group) presented a significant difference between the two cementation techniques in the cervical and apical thirds (Table 2).

The third null hypothesis assumed that there would be no difference between the apical, middle, or cervical thirds evaluated for each post system, nor between cementation techniques. This null hypothesis was partially accepted, as significant differences ($p<0.05$) among the apical, middle, or cervical thirds were observed with the Splendor-SAP posts using manual cementation (Table 3).

Several methodologies have been employed to analyze the adhesion between posts and intraradicular dentin. Traditionally, destructive methods involve sectioning samples and subjecting them to scanning electron microscopy for failure analysis[11]. However, in recent times, cone beam computed tomography (CBCT) has emerged as a robust tool for evaluating the internal morphology of dental materials and tissues[15]. As a non-destructive technique, CBCT offers a wealth of quantitative and qualitative information on various materials, enabling more comprehensive analyses[15,17-23].

Studies have demonstrated the value of this technology in investigating dimensional parameters and identifying internal and external flaws within the root canal[13,15]. However, traditional DICOM file viewing software has inherent limitations, particularly concerning artifacts. Recently, strategies have been implemented to mitigate artifacts during various CBCT imaging procedures, including acquisition, post-processing, and reconstruction[15,20-22]. In this regard, the novel tomographic software e-Vol DX has emerged as a remarkably innovative and beneficial tool[15]. Filters such as Blooming Artifact Reduction (BAR), designed to reduce white contrast artifacts or “blooming,” have been shown to enhance saturation and brightness in specific areas, unveil details in underexposed and overexposed regions, and improve image clarity and analytical capabilities[15].

The utilization of the BAR filter in the e-Vol DX software did not induce any dimensional alterations in CBCT scans of posts composed of low-fusion alloy, gold alloy, or anatomically customized glass fiber posts with composite resin. Validation was conducted by comparing these results with measurements of the original posts obtained using a micrometer[22]. In another investigation[23], mesiodistal and buccolingual linear measurements of low-fusing alloy posts and gold alloy posts were compared using two CT scanners (the PreXion 3D Elite, PreXion Inc, San Mateo, CA, USA, and the CS 9000C 3D, Carestream Health, Rochester, NY, USA). Images were processed and analyzed using two tomographic reconstruction software packages: the e-Vol DX software and the PreXion 3D Image Analysis System. Notably, there was no statistically significant difference between the linear tomographic measurements conducted by the e-Vol DX software in images acquired with the two scanners, even when compared with measurements obtained using a micrometer. Conversely, all measurements obtained with the PreXion3D Image Analysis System software exhibited a statistically significant difference when compared with those obtained using a micrometer or with the e-Vol DX software. These findings underscore the e-Vol DX software’s capability to mitigate the interference of blooming artifacts, thereby enhancing diagnostic accuracy, treatment planning, and clinical decision-making

The e-Vol DX software employed in this study provided high-resolution images, dynamic navigation across various planes, and the capability to adjust volume parameters such as thickness, data cuts, and corrections. The utilization of the BAR 2 filter to fine-tune brightness and contrast facilitated artifact reduction and facilitated image analysis and data tabulation[15].

The cementation of glass fiber posts within root canals ideally utilizes adhesive luting agents[24], although numerous factors can influence this process, potentially hindering the achievement of a homogeneous layer of resin cement. Therefore, the manner in which resin cement is applied can be considered one of the most crucial steps in ensuring proper cementation between the post and the root canal wall[25].

Voids or gaps in the cementation line can have adverse effects on adhesion and weaken areas within the material, thereby compromising durability and predisposing it to microleakage[26]. These voids can impact the longevity of the adhesive bond in several ways. Firstly, when located directly at the interface between dentin and cement, the area of adhesive contact is diminished. Secondly, as the mechanical properties of the bond are significantly influenced by the distribution of faults and the presence of voids, their existence is expected to diminish the strength of the cement and create sites where cracks can initiate and propagate. Thirdly, voids serve as stress concentration factors, reducing the bonding area and concentrating the highest stress peaks at the remaining intact interface[27].

Resin cement systems utilizing syringes to deliver cement through self-mixing tips directly into the root canal can yield a bubble-free cement mixture, as the catalyst and base paste remain isolated from contact with air[28].

In another investigation[29], it was observed that manually mixed resin cement dispensed with a Centrix dispensing gun resulted in a greater formation of voids compared to self-mixing resin cement injected with a conventional tip or Endotip (intracanal tip), indicating that the mixing method influenced bubble formation at the adhesive interface. Similar findings were reported by another study[30], which compared the presence of voids when different commercial cements were used to cement a single type of glass fiber post using both conventional application techniques (manual cement mixing) and self-mixing tips. A significant quantity of voids was identified when the conventional cementation technique was employed, whereas the use of self-mixing tips yielded a more homogeneous adhesive interface.

The results obtained from Group 3 (Control Group, conventional posts) indicate that manual mixing techniques resulted in a higher number of voids compared to self-mixing. Conversely, the cementation technique did not yield a significantly different quantity of voids with the Splendor-SAP posts (Group 1) or with the anatomical posts (Group 2), regardless of the specific third of the root that was evaluated. However, it is noteworthy to mention that although no significant difference was observed between the mixing techniques for these two post systems, their behavior exhibited distinct tendencies. While Group 1 displayed the highest number of voids, predominantly with scores of 3 and 4, Group 2 showcased superior performance with fewer voids and a higher incidence of 0 scores across all three sections of the root canal (Table 2).

Manually mixed resin cement exhibited the lowest porosity in the cervical third, followed by the middle third, with the highest porosity observed in the apical third, irrespective of the cement type used[31]. Conversely, the injection of resin cement aided by a self-mixing tip and an Endotip intracanal cannula, particularly in the deeper apical third regions of the root canal, led to reduced air retention within the root canal and minimized bubble formation. Moreover, the utilization of the Endotip alongside a self-mixing technique significantly diminished the porosity of all examined resin cements in the study. When the intracanal cannula is sufficiently thin to reach the bottom of the prepared root canal, thereby facilitating the insertion of resin cement from the apical to the cervical third, a marked reduction in porosity is observed in the cementation line. This engenders a more uniform cement layer along the entire root surface, enhancing the bond between the resin cement and the root dentin, while also promoting a more even distribution of stress along the interface of the post and dentin[27,32].

The Splendor-SAP represents a glass fiber retainer system comprising a sleeve and post, offering an innovative solution to challenges encountered with traditional posts. Its adaptability to a range of root canal dimensions, from narrow to wide, without the need for various sizes and models of burs, renders it particularly versatile. This innovation fosters improved mechanical engagement with root canal walls, enhances chemical adhesion, and augments post retention within the canal. Additionally, it eliminates the necessity for anatomization with composite resin.

In the current study, no statistically significant difference was observed between the evaluated post systems across the cervical, middle, and apical thirds, or with either cementation technique, except for the Splendor-SAP post when utilizing manual cementation. Notably, this post exhibited lower scores in the cervical third and higher scores in the apical third. One plausible explanation for this discrepancy is the potential inability of manual cement insertion to fully access the deepest region of the root canal. Furthermore, the morphology of the Splendor-SAP post, characterized by greater overlap with the sleeve in the cervical and middle thirds, and a narrower apical diameter compared to conventional or anatomical posts, may result in reduced pressure on the cement during canal insertion, potentially leading to air entrapment in this region.

The cervical third of the conventional glass fiber post using manual cementation as well as the Splendor-SAP post using self-mixing cementation both showed a predominance of score 2. This may be considered a critical factor as it is in this region that the greatest masticatory forces are applied with all attendant biomechanical risks which may affect the success of the final restoration. Furthermore, from a biological point of view, voids in the cervical region can favor the infiltration of microorganisms from the oral environment into the periapical region[33].

In both the cervical third of the conventional glass fiber post with manual cementation and the Splendor-SAP post with self-mixing cementation, a predominance of score 2 was observed. This finding holds critical implications, as this region is subjected to the highest masticatory forces, along with associated biomechanical risks that could impact the success of the final restoration. Moreover, from a biological standpoint, voids in the cervical region may facilitate the ingress of microorganisms from the oral environment into the periapical region[33].

In recent studies of push-out bond strength and failure modes, the single adjustable Splendor-SAP post was compared with anatomical posts and computer-aided design/computer-aided manufacturing (CAD-CAM) posts[34,35]. In both studies, no significant difference was found among the post systems in terms of bond strength. However, regarding failure modes, one study did show a significant difference, with a predominance of adhesive failure at the post-resin cement interface for the Splendor-SAP post[35].

It is believed that the formation of voids and voids occurs less often when thin, uniform cement layers are used[11]. Glass fiber posts re-coated with composite resin (the anatomical post technique) will present a greater surface area to the root canal and thus improve retention through friction and reduce the chances of defects in the cement layer[36,37].

In a previous study[13], four groups were compared based on the type of post (conventional glass fiber posts and posts recoated with composite resin) and the method of cementation (manual or with the aid of ultrasonic vibration). Computed tomography scans were conducted before and after cementation, and the volume of voids was quantified. While the use of ultrasonic vibration did not yield significant results in this study, recoating posts with composite resin led to a notable reduction in void formation in the cement line. Similarly, other studies have corroborated that the anatomical post technique contributes to minimizing the number of voids at the adhesive interface[11,36].

The present study demonstrated superior performance with anatomical posts compared to other post systems, exhibiting consistent outcomes across both cementation techniques, with a prevalence of score 0 in the cervical, middle, and apical thirds of the canal. This suggests that the post's fit within the root canal may be a more influential factor in the quality of the cementation interface than the specific technique employed for cementation.

The limitations of this study include the use of only one type of resin cement, as different adhesives may perform differently with varying cavity preparations. Additionally, this study used standardized 3D-printed acrylic resin roots to ensure consistency in root canal volume across all groups. However, variations in cavity design and geometric principles could influence outcomes. Therefore, further research involving human or bovine teeth is needed to validate the correlations observed in this study.

It's important to note that this study introduces a preliminary experimental model leveraging 3D Digital Prototyping and Post-processing CBCT Software. It is imperative to acknowledge that the materials used may exhibit varied behaviors in dentin, necessitating cautious interpretation when extrapolating the results.

Based on the findings of this study, it is evident that there was a notable discrepancy between the various glass fiber post systems, irrespective of the cementation technique employed. Specifically, the Splendor-SAP and anatomical glass fiber post methodologies exhibited the highest and lowest levels of voids, respectively. Interestingly, the choice of cementation technique did not exert a discernible influence on the void quantity observed in the anatomical or Splendor-SAP glass fiber posts. However, for conventional glass fiber posts, the self-mixing cementation technique demonstrated a favorable impact on void quantities. Notably, the manual cementation technique exhibited a distinct effect on void distribution within each third of the root canals when utilized with Splendor-SAP posts.

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Conflict of Interest

The authors have no conflict of interest to disclose.

Data availability

Datasets related to this article will be available to the corresponding author upon request.

Author Contribution

Jorge Luiz de Oliveira Cruvinel Filho: Conceptualized of the study, data collection. **Sicknan Soares da Rocha:** Conceptualized of the study, statistical analysis, participated in manuscript editing. **Olavo Cesar Lyra Porto:** Conceptualized the study, data collection. **Mike dos Reis Bueno:** Conceptualized the study, developed of the software. **Lucas Rodrigues de Araújo Estrela:** Data collection, study writing, participated in manuscript editing. **Carlos Estrela:** Conceptualized the study, study writing, developed of the software, participated in manuscript editing. All authors actively revised and approved the final version of the manuscript.

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