Nihon University School of Dentistry
Journal of Oral Science

Influence of different scanning techniques on in vitro performance of CAD-CAM-fabricated fiber posts

Journal:	*Journal of Oral Science*
Manuscript ID	JOS-17-0254.R1
Manuscript Type:	Original Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Tsintsadze, Nino; University of Siena, Department of Medical Biotechnologies Juloski, Jelena; University of Belgrade, Clinic for Paediatric and Preventive Dentistry; University of Siena, Department of Medical Biotechnologies Carrabba, Michele; University of Siena, Department of Medical Biotechnologies Goracci, Cecilia; University of Siena, Department of Medical Biotechnologies Vichi, Alessandro; University of Siena, Department of Medical Biotechnologies Grandini, Simone; University of Siena, Department of Medical Biotechnologies Ferrari, Marco; University of Siena, Department of Medical Biotechnologies
Keywords:	CAD-CAM, scanning techniques, fiber post, post retention, nanoleakage, cement thickness

TITLE PAGE

Influence of different scanning techniques on *in vitro* performance of CAD-CAM-fabricated fiber posts

Nino Tsintsadze[1), Jelena Juloski[1,2)], Michele Carrabba[1)], Cecilia Goracci[1)], Alessandro Vichi[1)], Simone Grandini[1)], Marco Ferrari[1)]

[1)] Department of Medical Biotechnologies, University of Siena, Italy

[2)] Clinic for Paediatric and Preventive Dentistry, University of Belgrade, Serbia

Corresponding author: Jelena Juloski, Policlinico Le Scotte, Viale Bracci, Siena 53100, Italy

fax: +39(0577)233117

E-mail address: jelenajuloski@gmail.com

CONFLICT OF INTEREST

All the authors deny any conflict of interest.

ABSTRACT

The study assessed push-out strength, cement layer thickness and interfacial nanoleakage of luted fiber posts fabricated with CAD-CAM technology following three different scanning techniques: direct scanning of the post space (DS); scanning of a polyether impression of the post space (IS) and scanning of a plaster model of the post space (MS). Thirty premolars were randomly assigned to 3 groups according to the scanning technique. Posts were computer-designed and milled from experimental fiber-reinforced composite blocks. The mean and standard deviation values of push-out strength and cement thickness, respectively, were: DS) **17.12 ± 7.73** MPa and **162 ± 24** μm; IS) **10.66 ± 4.56** MPa and **187 ± 50** μm; MS) **12.03 ± 7.17** MPa and **258 ± 78** μm. Median values of interfacial nanoleakage scores (interquartile range) were: DS) 3; (2-4) IS) 2.5 (2-4); MS) 3 (2-4). Fiber posts fabricated following DS technique demonstrated superior performance compared to posts fabricated upon IS and MS, in terms of the post retention. **The cement thickness** did not differ between DS and IS, whereas in MS group the cement layer was significantly thicker then in the other two groups. **Scanning technique** did not influence the sealing ability, as all groups showed comparable nanoleakage.

Keywords: CAD-CAM; scanning techniques; fiber post; post retention; nanoleakage; cement thickness.

Introduction

Functional and aesthetic rehabilitation of endodontically treated teeth with a significant loss of tooth structure often requires a post-retained fixed prosthetic restoration (1,2). Fiber-reinforced composite posts (i.e fiber posts) are widely used due to their good esthetics and elasticity close to that of dentin, which allows for uniform stress distribution within a root and lowers the possibility of non-restorable root fractures (3,4). However, debonding of the post has been reported as the most frequent mode of failure observed in fiber post-retained restorations (5).

Shape of the root canal and cement thickness around the post represent some of the main factors influencing the retention of fiber posts (6-8). It has been reported that thicker cement layer around the post decreased the bond strength of fiber post to root dentin **(8-12)**. Thus, inserting circular prefabricated fiber post into the oval-shaped root canal is questionable as using an undersized fiber post leads to the excessive resin cement thickness (**8**,13). Bonding to apical thirds in such case is even more challenging (13). Good post fitting and low cement thickness in oval-shaped canals can be obtained using a fine grit oval tip combined with oval posts, in particular in the apical third (**8**). However, fracture resistance was not increased when oval posts were luted in the oval post spaces (14). Therefore, custom fabrication of fiber posts has been proposed as it may improve the adaptation of the post to the irregularly shaped, flared or root canals of a large diameter. Different authors have offered various techniques to custom fabricate the fiber post, such as chair-side fabrication of posts using polyethylene fibers and composite resin (15), combining a fiber post with a dual-curing resin cement to create an “anatomical post” (16), laterally compacting several small fiber posts (17) or customizing a fiber post to canal anatomy by using a diamond-coated bur (18,19). However, the main disadvantages of these techniques are that they are not easy to perform and they are time-consuming.

Recently, the use of CAD-CAM-fabricated post and core restorations has been suggested, and several authors have investigated CAD-CAM-fabricated zirconia post and core (20-24). However, it is nearly impossible to retrieve zirconia post if fracture occurs, which leads to an irreversible tooth failure (**21**). Therefore, Lee et al. suggested the combination of prefabricated fiber post and zirconia core, as to avoid catastrophic failure caused by zirconia posts and achieve esthetic results by using zirconia core (**23,24**). Furthermore, fiber-reinforced composite blocks were used to CAD-CAM-fabricate the fiber posts for irregularly shaped or large root canals (25,26). Liu et al. (25) successfully restored a front tooth with CAD-CAM-fabricated fiber post and core and examined radiographically. Chen et al. (26) validated this technique by inserting one-piece glass fiber dowel-and-core fabricated using CAD-CAM technology in two patients. Additionally, two recent studies by Chen et al. tested von Misses stress level in dentine of extracted maxillary canines restored with CAD-CAM glass fiber posts and lithium disilicate crowns (27,28). However, scientific evidence regarding the performance of CAD-CAM-fabricated fiber posts into the oval-shaped root canals either *in vitro* or *in vivo* is still scarce.

Furthermore, according to the literature, digital images of the prepared tooth required for CAD-CAM-fabrication of the restoration can be obtained in three ways: by direct intraoral scanning, by scanning the impressions or by scanning the stone models (25-29). Studies show that both impressions and stone replicas can be digitized with a high reliability (30). It has also been reported that intraoral digital impression systems offer more adequate accuracy and precision than indirect digitization of either polyether impressions or stone casts (31,32). Patient movement, limited intraoral space, intraoral humidity, and saliva flow are listed as important patient-related factors that strongly influence the scanning quality, causing high deviation in intraoral scans (**32**). However, there is no scientific evidence regarding to which of the three available procedures would be the most appropriate for scanning the post space and CAD-CAM fabrication of the fiber posts.

Therefore, the present study aimed to assess the *in vitro* performance of CAD-CAM-fabricated fiber posts into the oval-shaped root canals, fabricated using 3 different digital data acquisition procedure. Three null hypotheses were tested: there are no statistical differences in 1) the push-out bond strength of the post, 2) the cement thickness surrounding the post and 3) the interfacial nanoleakage among different data acquisition techniques used for CAD-CAM-fabrication of the fiber posts.

Materials and Methods

Specimen preparation

Thirty human single-rooted premolars extracted due to orthodontic reasons were collected from patients upon informed consent was obtained. Teeth were decoronated and endodontically treated using Reciproc rotary instruments (VDW, Munich, Germany) and warm vertical gutta-percha technique, Beefill 2 in 1 (VDW) in combination with resin root canal sealer AH Plus (Dentsply, Konstnaz, Germany). All roots were sealed with **glass ionomer cement** Fuji VII (GC, Tokyo, Japan) and stored in water at 37˚C. After one week, oval-shaped post space preparations **10 mm** in depth were made using size #6 largo burs. The roots were randomly assigned to 3 groups (**n = 10**), which differed by the digital data acquisition procedure for the fabrication of the fiber posts using CAD-CAM technology:

Group 1: Direct scanning of the post space (DS). Post space was covered with scan spray (VITA, Bad Säckingen, Germany) and scanned with inEos scanner (Sirona, Bensheim, Germany). Digital 3-D model of the post was designed using inLab 3.88 software (Sirona) and fiber post was milled from the experimental fiber-reinforced composite blocks (RTD, St. Egrève, France) using inLab MC XL CAD-CAM milling unit (Sirona). Vinyl polyether silicone material (Black fit checker, GC) was used to control fit of all fabricated fiber posts.

Group 2: Scanning of the impression of the post space (Impression Scanning, IS). Impression of the post space was **made** with polyether impression material (Parmadyne Garant 2:1, 3M ESPE, Neuss, Germany) in combination with silicon impression material (Pentamix 2, 3M ESPE) using stainless steel impression trays (Asa Dental, Bozzano, Italy). Impression was covered with scan spray (VITA). Scanning of the impression and fabrication of the fiber post were the same as described for the Group 1. Vinyl polyether silicone material (Black fit checker, GC) was used to control fit of all the fabricated fiber posts.

Group 3: Scanning the stone model of the post space (Model Scanning, MS). Impression was **made** following the same procedure as described for the Group 2. Then, stone model was poured with type 4 stone. Scanning of the model and fabrication of the fiber post followed the same protocol as described for the Group 1. Vinyl polyether silicone material (Black fit checker, GC) was used to control fit of all the fabricated fiber posts.

In all the groups, posts were cemented using Gradia Core dual-cure **resin** cement in combination with Gradia Core self-etching bond (GC). All the materials were handled according to the manufacturer's instructions

Thin-slice push-out test and cement thickness measurement

Twenty-four hours after the cementation 6 specimens per group were randomly selected for thin-slice push-out test. All the roots were sectioned with cutting machine (Isomet; Buehler, Lake Bluff, NY, U.S.A) using diamond disc at slow-speed (250 rpw) under water-cooling. Six 1-mm thick sectiones were obtained per root, 2 sections from coronal, middle and apical thirds, respectively. Each section was marked with a permanent marker on its apical surface. Thickness of each slice was individually measured using a digital caliper (OrteamS.r.l., Milan, Italy) with accuracy of 0.01 mm. Specimens were mounted on the jig with apical surface upward to the punsh-out rod. Thin-slice push-out test was conducted using a universal testing machine (Triax Digital 50, Controls, Milan, Italy) at the cross-head speed of 0.5 mm/min until failure occurred. The load was applied at the center of the post, in the apico-coronal direction to push each post toward the larger post space diameter. The load at failure was recorded in Newtons and bond strength was calculated in MPa. Digital images of all specimens were taken with a digital microscope (Nikon Shuttle Pix, Tokyo, Japan) and cement thickness around the post within each group was measured using Digimizer software (MedCalc, Mariakerke, Belgium).

Interfacial nanoleakage test

Remained 4 roots per group were subjected to interfacial nanoleakage test. Six 1-mm thin slices were obtained per root and covered with red nail polish leaving exposed just dentin-cement-post interfaces and immersed in silver nitrate solution (1 ml silver nitrate in 4 ml water) using 0.22 nanometer filter (Carrigtwohill, County Cork, Ireland). All specimens were left in the darkness for 24 hours, then rinsed with water for 30 minutes and immersed in the photo developing solution (3 ml in 10 ml water, Kodak, Rochester, NY) for 8 hours. After 8 hours slices were rinsed with water for 30 minutes and subjected for polishing. Polishing was performed using 600 to **4,000**-grit SiC papers in an ascending order until the root sections achieved mirror-like appearance. All the specimens were observed under the light microscope (Nikon SMZ645, Tokyo, Japan) to evaluate the nanoleakage score. Digital images were also taken using digital microscope (Nikon Shuttle Pix). Nanoleakage was analyzed depending on the percentage of black silver nitrate depositions along the post-cement-dentin interfaces following the nanoleakage scoring system proposed by Saboia et al. (33):

Score 0: no nanoleakage.

Score 1: < 25% of the interface showing nanoleakage.

Score 2: 25 - 50% of the interface showing nanoleakage.

Score 3: 50 - 75% of the interface showing nanoleakage.

Score 4: > 75% of the interface showing nanoleakage.

Statistical analyses

Push-out bond strength

The finding of a normal distribution of push-out strength data allowed the use of a Two-Way Analysis of Variance, with push out strength as the dependent variable, scanning technique and root level as factors. Assessment of statistically significant differences in push-out strength among different scanning techniques was followed by Tukey test for post hoc comparisons.

Cement thickness

The use of a Two-Way Analysis of Variance, with cement thickness as the dependent variable, scanning technique and root level as factors was ruled out by the occurrence of a non-normal data distribution. Thereby, the influence of the two factors on cement thickness had to be separately analyzed. Statistically significant differences in cement thickness among scanning techniques were assessed with the Kruskal-Wallis Analysis of Variance, followed by the Dunn's Multiple Range test for post hoc comparisons, as the data did not meet the requirement of normal data distribution. For the assessment of statistically significant differences among root levels within direct scanning group, the One-Way Analysis of Variance was applied, followed by the Tukey test for post hoc comparisons as data was normally distributed. For the assessment of statistically significant differences among root levels within impression scanning and model scanning groups, Kruskal-Wallis Analysis of Variance was applied, followed by the Dunn's Multiple Range test for the post hoc comparisons, as the data was did not meet requirement of normal data distribution.

Interfacial nanoleakage

The interfacial nanoleakage scores were analyzed using Kruskal Wallis Analysis of Variance, followed by the Dunn's Multiple Range test for post-hoc comparisons.

In all the analyses the level of significance was set at $\mathbf{p < 0.05}$ and calculations were handled by the Sigma Plot 11 statistical software (Systat Software, Inc., San Jose California USA).

Results

For each group the mean values ± standard deviation (SD) for push-out bond strength in MPa were: Group 1) 17.12 ± 7.73; Group 2) 10.66 ± 4.56; Group 3) 12.03 ± 7.17 and the mean values for cement thickness ± SD in micrometers (μm) were: Group 1) 162 ± 24; Group 2) 187 ± 50; Group 3) 258 ± 78. The median values (interquartile range) of nanoleakage scores were: Group 1) 3 (2 - 4); Group 2) 2.5 (2 - 4); Group 3) 3 (2 - 4). Statistical analysis revealed that scanning technique was a significant factor for the push-out bond strength, whereas the post level was not statistically significant factor (Two Way ANOVA). Posts fabricated following DS achieved strongest retention (**$p < 0.001$**), while IS and MS group fiber posts showed comparable results (Table 1).

Furthermore, statistically significant differences in cement thickness were recorded among the scanning techniques. Significantly thicker cement layer was observed in MS group compared to DS and IS groups (**$p < 0.001$**), which demonstrated comparable cement layer thicknesses (Table 2). No statistically significant differences in cement thickness emerged among the root levels in any of the groups (Table 3).

In addition, statistical analysis found no significant differences in interfacial nanoleakage among the three groups (Table 4). Representative digital images of nanoleakage assessment for each group are shown in **Fig. 1**.

Discussion

The tested null hypothesis 1 was rejected, as statistically significant differences emerged in push-out bond strength among the groups. Specifically, the fiber posts fabricated following DS technique achieved higher retention compared to IS and MS techniques. No significant differences were found between two indirect data acquisition procedures, i.e. IS and MS procedures, in terms of post retention into the oval-shaped root canals.

To the best of our knowledge, no study available in the current scientific literature investigated on the direct scanning method of the post space. Several studies used different indirect techniques for digital data acquisition of the post space (**23-28,34**). Lee et al. scanned stone model of the post space to custom fabricate fiber post and core restoration (**23,24**). In the study by Liu et al. (25) the wax pattern prepared from the stone model of the post space was digitized to design the 3-D model of fiber post and core. Chen et al. (26) scanned vinylpolysiloxane impressions taken from the die stone model to CAD-CAM-fabricate fiber posts. In the study by Bittner et al. (34), acrylic resin patterns were scanned to CAD-CAM-fabricate zirconia post and core. Moreover, in the recent studies on CAD-CAM glass fiber posts by Chen et al. no information regarding the utilized scanning methods can be collected (27,28). However, no scientific information regarding the efficacy and comparison of different digital acquisition procedures of the post space in particular could be found in the literature.

When focusing on the digitizing of full arches and single unit crown or fixed dental prostheses preparations, the information regarding the accuracy and effectiveness of the direct and indirect digital scanning methods vary. Direct digital scanning has been recommended as the more logical solution compared to scanning polyether impressions (**31**). Additionally, the direct acquisition systems are described as less invasive, quicker, and more precise than the indirect methods (35). Moreover, significantly higher accuracy was achieved with the direct digitalization compared to the indirect digitalization of the impressions and the gypsum casts (36). Syrek et al. (37) also showed statistically significant superior marginal fit of the single crowns received from the direct data capturing compared to the indirect digitization. Although, these studies did not investigate scanning procedures of the post spaces, results of the present study are in agreement with their findings in terms of accuracy of the direct and indirect digitalization methods.

Nevertheless, according to the other authors, due to its technical features the extraoral scanning has higher accuracy than the intraoral digitization (**32**,38). Patient related factors such as patient movement, limited intraoral space, intraoral humidity, and saliva flow could cause deviations in the intraoral scans (**32**). The mentioned patient-related factors could not apply to the direct scanning technique in the present laboratory study, as the specimens were not scanned in the intraoral environment. However, even in the clinical practice, when directly scanning the post spaces, unlikely the scanning of the crown/fixed dental prostheses preparations, some of the patient related factors such as the intraoral humidity and saliva flow can be eliminated by using the tooth isolating systems.

The tested null hypothesis 2 was also rejected. In terms of cement thickness measured around the posts, the least accurate was MS method. Significantly thicker cement layer was observed around the posts in the MS group compared to IS and DS groups, which showed comparable results. This finding is, to a certain extent, in line with the study by Güth et al. (36), although not related to the posts, where more accurate results were achieved by digitization of the polyether impressions compared to the digitization of the gypsum casts. However, literature is not consistent regarding this issue either. No significant differences were found in precision between two techniques of scanning impressions and scanning stone replicas of the master dies prepared for the crowns (30).

The tested null hypothesis 3 was accepted. With regard to the interfacial nanoleakage expression, no statistically significant differences were found among the tested groups in the present study. Teeth from all three groups showed considerable nanoleakage (interquartile range 2-4, Table 4; Fig. 1), leading to the conclusion that the sealing ability in root canal dentin is a matter of concern. Also, based on this finding it could be assumed that bond strength and cement thickness do not correlate with the nanoleakage, as significant differences were observed in the push-out bond strength and cement thickness among the groups. Previous investigations found no statistically significant differences in the interfacial nanoleakage expression comparing different luting materials for bonding the fiber posts to the intraradicular dentine, despite existing differences in push-out strength (39). In addition, no significant correlation between cement thickness and interfacial nanoleakage has been found as well (40).

Regarding the premature failures, debonding prior to testing or catastrophic fractures occurred during the preparation of the specimens in impression scanning and model scanning groups (Tables 1-4). All the premature failures came from the apical portion of the root, which supports the fact that post adhesion is most challenging into the deepest part of the root canal (13). Since prematurely failed specimens could not be tested for push-out strength or nanoleakage expression, it has been decided to exclude them from the statistical calculations. Reporting, but excluding premature failures from the statistical analyses has been supported by the recent literature (41,42).

Various experimental models, scanners and accuracy measurement procedures used in different studies could explain contradictory information regarding the efficacy of different digital data acquisition techniques. In this study push-out bond strength, cement layer thickness and interfacial nanoleakage expression were measured to assess the accuracy of different digital data acquisition techniques used to CAD-CAM-fabricate fiber reinforced composite posts. Bittner et al. (34) compared marginal gap distance between the tooth and the acrylic resin patterns and between the tooth and the definite zirconia post-and-core restoration to assess the scanning procedure accuracy. Other studies assessing the accuracy of the different digitization procedures are based on comparing deviations between test and reference datasets by analyzing distances between Euclidean points (33) or on the repeated measurements where the model rendered from the first scan serves as the control surface for the consecutively acquired models (**32**). Currently, new reference scanners are used to test the precision and trueness of the digital impression (43). Therefore, more laboratory and clinical studies need to be conducted to test the efficacy of direct and indirect digital data acquisition techniques used to scan the irregularly shaped root canals.

Regarding the limitations of the present study, it should be mentioned that it was not possible in the *in vitro* study to take into account the mentioned patient-related factors. Also, the operator's skill, experience and knowledge might affect the clinical results. However, the relevance of using CAD-CAM-fabricated fiber posts in clinical practice lies in the possibility to combine the advantages of traditionally custom made posts and the prefabricated fiber posts. Such posts may have better fit to the post space as well as the modulus of elasticity close to that of dentin, which is considered one of the main advantages of fiber-reinforced composite material. Nevertheless, CAD-CAM fabrication of the fiber

posts would require a longer appointment for scanning of the post space, an additional clinical step for the cementation of the post, and a main prerequisite is a chair-side CAD-CAM device in the dental office. Therefore, fabrication of fiber posts may represent an additional option for the practitioners already working with a CAD-CAM chair-side system and also for the dental laboratories using the digital workflow.

Within the limitations of this study, it can be concluded fiber posts fabricated following DS technique demonstrated superior performance compared to posts fabricated upon IS and MS, in terms of post retention. With regard to the thickness of the cement layer, it did not differ between DS and IS, whereas in MS group the cement layer was significantly thicker than in the other two groups. Different scanning techniques did not influence the sealing ability, as all tested groups showed comparable nanoleakage.

References

1. Ferrari M, Cagidiaco MC, Grandini S, De Sanctis M, Goracci C (2007) Post placement affects survival of endodontically treated premolars. J Dent Res 86, 729-734.

2. Zadik Y, Sandler V, Bechor R, Salehrabi R (2008) Analysis of factors related to extraction of endodontically treated teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 106, e31-e35.

3. Martínez-Insua A, da Silva L, Rilo B, Santana U (1998) Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon fiber post with a composite core. J Prosthet Dent 80, 527-532.

4. Torres-Sánchez C, Montoya-Salazar V, Córdoba P, Vélez C, Guzmán-Duran A, Gutierrez-Pérez J.L, et.al. (2013) Fracture resistance of endodontically treated teeth restored with glass fiber reinforced posts and cast gold post and cores cemented with three cements. J Prosthet Dent 110, 127-133.

5. Cagidiaco MC, Radovic I, Simonetti M, Tay F, Ferrari M (2007) Clinical performance of fiber post restorations in endodontically treated teeth: 2-year results. Int J Prosthodont 20, 293-298.

6. Ferrari M, Vichi A, Mannocci F, Masson PN (2000) Retrospective study of clinical performance of fiber posts. Am J Dent 13, B15-B18.

7. Peters OA (2004) Current challenges and concepts in the preparation of root canal systems: A review. J Endod 30, 559-567.

8. Coniglio I, Garcia-Godoy F, Magni E, Carvalho CA, Ferrari M (2009) Resin cement thickness in oval-shaped canals: oval vs. circular fiber posts in combination with different tips/drills for post space preparation. Am J Dent 22, 290-294.

9. Egilmez F, Ergun G, Cekic-Nagas I, Vallittu PK, Lassila LV (2013) Influence of cement

thickness on the bond strength of tooth-colored posts to root dentin after thermal cycling. Acta Odontol Scand 71, 175-182.

10. Mirmohammadi H, Gerges E, Salameh Z, Wesselink PR (2013) Effect of post diameter and cement thickness on bond strength of fiber posts. Quintessence Int 44, 801-810.

11. Özcan E, Çetin AR, Tunçdemir AR, Ülker M (2013) The effect of luting cement thicknesses on the push-out bond strength of the fiber posts. Acta Odontol Scand 71, 703-709.

12. Gomes GM, Rezende EC, Gomes OM, Gomes JC, Loguercio AD, Reis A (2014) Influence of the resin cement thickness on bond strength and gap formation of fiber posts bonded to root dentin. J Adhes Dent 16, 71-78.

13. Dietschi D, Duc O, Krejci I, Sadan A (2008). Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). Quintessence Int 39, 117-129.

14. Krastl G, Lorch H, Zitzmann NU, Addison O, Dietrich T, Weiger R (2014) Do oval posts improve fracture resistance of teeth with oval root canals? Dent Traumatol 30, 232-235.

15. Singh A, Logani A, Shah N (2012) An ex vivo comparative study on the retention of custom and prefabricated posts. J Conserv Dent 15, 183–186.

16. Grandini S, Sapio S, Simonetti M (2003) Use of anatomic post and core for reconstructing an endodontically treated tooth: a case report. J Adhes Dent 5, 243-247.

17. Porciani PF, Coniglio I, Magni E, Grandini S (2008) Fiber post fitting to canal anatomy: a review of the morphology and shape of root canal system. Dent SA 10, 52-58.

18. Grande NM, Butti A, Plotino G, Somma F (2006) Adapting fiber-reinforced composite root canal posts for use in non circular-shaped canals. Pract Proced Aesthet Dent 18, 593-600.

19. Plotino G, Grande NM, Pameijer CH, Somma F (2008) Influence of surface remodeling using burs on the macro and micro surface morphology of anatomically formed fiber posts. Int Endod J 41, 345-355.

20. Awad MA, Marghalani TY (2007) Fabrication of a custom-made ceramic post and core using CAD-CAM technology. J Prosthet Dent 98, 161-162.

21. Ozkurt Z, Işeri U, Kazazoğlu E (2010) Zirconia ceramic post systems: a literature review and a case report. Dent Mater J 29, 233-245.

22. Marghalani TY, Hamed MT, Awad MA, Naguib GH, Elragi AF (2012) Three-dimensional finite element analysis of custom-made ceramic dowel made using CAD/CAM technology. J Prosthodont 21, 440-450.

23. Lee JH, Sohn DS, Lee CH (2014) Fabricating a fiber-reinforced post and zirconia core with CAD/CAM technology. J Prosthet Dent 112, 683-685.

24. Lee JH (2014) Accelerated techniques for a post and core and a crown restoration with intraoral digital scanners and CAD/CAM and rapid prototyping. J Prosthet Dent 112, 1024-1029.

25. Liu P, Deng XL, Wang XZ (2010) Use of a CAD/CAM fabricated glass fiber post and core to restore fractured anterior teeth: a clinical report. J Prosthet Dent 103, 330-333.

26. Chen Z, Li Y, Deng X, Wang X (2014) A novel computer-aided method to fabricate a custom one-piece glass fiber dowel-and-core based on digitized impression and crown preparation data. J Prosthodont 23, 276-283.

27. Chen A, Feng X, Zhang Y, Liu R, Shao L (2015) Finite element analysis to study the effects of using CAD/CAM glass-fiber post system in a severely damaged anterior tooth. Biomed Mater Eng 17, S519-S525.

28. Chen A, Feng X, Zhang Y, Liu R, Shao L (2015) Finite element analysis of stress distribution in four different endodontic post systems in a model canine. Biomed Mater Eng 17, S629-S635.

29. Boldt F, Weinzierl C, Hertrich K, Hirschfelder U (2009) Comparison of the spatial landmark scatter of various 3D digitalization methods. J Orofac Orthop 70, 247-263.

30. Persson AS, Oden A, Andersson M, Sandborgh-Englund G (2009) Digitization of simulated clinical dental impressions: virtual three-dimensional analysis of exactness. Dent Mater 25, 929-936.

31. Kurbad A (2011) Impression-free production techniques. Int J Comput Dent 14, 59-66.

32. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC (2013) Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop 144, 471-478.

33. Saboia VP, Nato F, Mazzoni A, Orsini G, Putignano A, Giannini M et al. (2008) Adhesion of two-step etch-and-rinse adhesive on collagen-depleted dentin. J Adhes Dent 10, 419-422.

34. Bittner N, Hill T, Randi AJ (2010) Evaluation of a one-piece milled zirconia post and core with different post-and-core systems: an in vitro study. Prosthet Dent 103, 369-379.

35. Galhano GÁ, Pellizzer EP, Mazaro JV (2012) Optical impression systems for CAD-CAM restorations. J Craniofac Surg 23, e575-e579.

36. Güth JF, Keul C, Stimmelmayr M, Beuer F, Edelhoff D (2013) Accuracy of digital models obtained by direct and indirect data capturing. Clin Oral Investig 17, 1201-1208.

37. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J (2010) Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active

wavefront sampling. J Dent 38, 553-559.

38. Luthardt RG, Kühmstedt P, Walter MH (2003) A new method for the computer-aided evaluation of three-dimensional changes in gypsum materials. Dent Mater 19, 19-24.

39. Marchesi G, Mazzoni A, Turco G, Cadenaro M, Ferrari M, Di Lenarda R et al. (2013) Aging affects the adhesive interface of posts luted with self-adhesive cements: a 1-year study. J Adhes Dent 15, 173-180.

40. Cantoro A, Goracci C, Vichi A, Mazzoni A, Fadda GM, Ferrari M (2011) Retentive strength and sealing ability of new self-adhesive resin cements in fiber post luting. Dent Mater 27, e197-e204.

41. Nikolaenko SA, Lohbauer U, Roggendorf M, Petschelt A, Dasch W, Frankenberger R (2004) Influence of C-factor and layering technique on microtensile bond strength to dentin. J Adhes Dent 20, 579-585.

42. Roulet JF, Van Meerbeek B (2007) Statistics: a nuisance, a tool, or a must? J Adhes Dent 9, 287-288.

43. Ender A, Mehl A (2014) Accuracy in dental medicine, a new way to measure trueness and precision. J Vis Exp 29, 51374.

Tables

Table 1. Push-out bond strength (MPa). N: number of specimens per group; PF: number of premature failures; SD: standard deviation. Asterisk (*) indicates the significant factor for push-out bond strength. Different upper case letters indicate statistically significant differences (Two-Way Analysis of Variance, Tukey test, **p < 0.001**).

Scanning technique *	**N**	**PF**	**Mean**	**SD**	**Post space level**	**N**	**PF**	**Mean**	**SD**
Direct scanning [A]	36	0	17.12	7.73	Coronal	12	0	18.30	7.52
					Middle	12	0	17.14	7.52
					Apical	12	0	15.91	8.61
Impression scanning [B]	36	0	10.66	4.56	Coronal	12	0	10.45	4.89
					Middle	12	0	10.40	3.60
					Apical	0	0	11.13	5.39
Model scanning [B]	33	3	12.03	7.17	Coronal	12	0	11.16	5.70
					Middle	12	0	11.44	6.81
					Apical	9	3	13.26	8.78

Table 2. Thickness of the cement layer surrounding the posts (μm). N: number of specimens per group; PF: number of premature failures; SD: standard deviation; 25%: 25th percentile (lower quartile); 75%: 75th percentile (upper quartile). Different upper case letters indicate statistically significant differences (Kruskal-Wallis Analysis of Variance, Dunn's Multiple Range test).

Scanning technique	**N**	**PF**	**Mean**	**SD**	**Median**	**25%**	**75%**
Direct scanning [A]	36	0	162	25	163	148	180
Impression scanning [A]	36	0	187	50	173	147	213
Model scanning [B]	33	3	259	78	236	187	314

Table 3. Thickness of the cement layer surrounding the posts (μm) by root canal level within each group. N: number of specimens per group; PF: number of premature failures; SD: standard deviation. Different upper case letters indicate statistically significant differences within each group separately († One-Way Analysis of Variance, ‡ Kruskal-Wallis Analysis of Variance).

Scanning technique	Post space level	N	PF	Mean	SD
† Direct scanning	Coronal [A]	12	0	171	25
	Middle [A]	12	0	160	22
	Apical [A]	12	0	156	25
‡ Impression scanning	Coronal [A]	12	0	181	61
	Middle [A]	12	0	195	49
	Apical [A]	12	0	184	42
‡ Model scanning	Coronal [A]	12	0	265	73
	Middle [A]	12	0	240	75
	Apical [A]	9	3	273	87

Table 4. Descriptive statistics for nanoleakage scores. N: number of specimens per group; PF: number of premature failures; 25%: 25th percentile (lower quartile); 75%: 75th percentile (upper quartile). Different upper case letters indicate statistically significant differences (Kruskal-Wallis Analysis of Variance, Dunn's Multiple Range test).

Scanning technique	**N**	**PF**	**Median**	**25%**	**75%**
Direct scanning [A]	24	0	3.0	2.0	4.0
Impression scanning [A]	22	2	2.5	2.0	4.0
Model scanning [A]	19	5	3.0	2.0	4.0

Figures

Figure 1

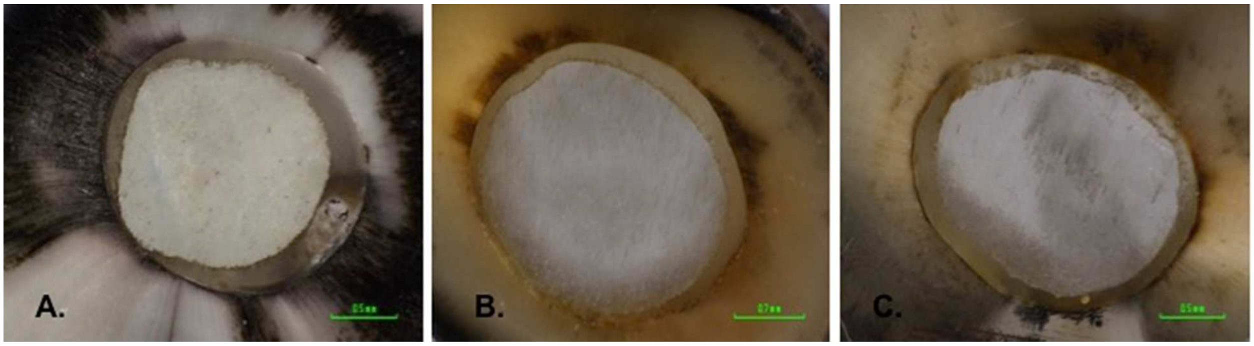

Figure legend

Figure 1. Microleakage evaluation. A. Direct scanning technique, score 3; B. Impresion scanning technique, score 2; C. Model scanning technique, score 3.