Comparison Between Accuracy of Posts Fabricated Using a Digital CAD/CAM Technique and a Conventional Direct Technique

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Purpose: To compare the accuracy of posts fabricated using a conventional direct technique with casting to the accuracy of posts fabricated using a fully digital protocol with CAD/CAM technology and selective laser melting.

Materials and Methods: Ten extracted permanent maxillary incisors were endodontically treated and prepared for a post. For each tooth, two metal posts were fabricated, one by casting (Group C) and one by a fully digital protocol (Group D). Accuracy of fit was analyzed with computed microtomography (μCT) to compare the space volume, the space area, and the distance between the post and the prepared root canal wall among posts.

Results: The mean and SD values of the overall space volume and the distance between the post and the prepared root canal wall, respectively, were: Group C: 2.22 ± 1.35 mm³ and 53.66 ± 23.39 μm; Group D: 3.82 ± 0.45 mm³ and 89.47 ± 19.30 μm. The values for the Group C posts were significantly lower (P = .002). All space volume values in all measured sections were significantly lower for the Group C posts. The mean distance and the space area between the post and the prepared root canal wall in the apical sections 3 (P < .001 for both) and 4 (P = .0019; P = .004, respectively) were significantly lower in Group C. No significant differences were calculated in cervical sections 1 and 2.

Conclusion: Both methods of post manufacturing were similarly accurate in the cervical part of the prepared root canal; however, a significant difference regarding the accuracy of both methods was determined for the apical parts of the posts. Int J Prosthodont 2021;34:212–220. doi: 10.11607/ijp.6502

Endodontically treated teeth (ETT) with a substantial loss of coronal tooth substance have inferior mechanical properties and a higher risk of clinical failure. Many different techniques and materials are used for restoring such teeth. A post-and-core restoration is a commonly accepted prosthodontic technique used for the replacement of missing coronal tooth structure and for ensuring support and retention for the placement of the final prosthodontic restoration (crown).

Different systems and materials for fabricating posts and cores are available. Prefabricated posts are a modern and widely accepted system for restoring ETT. Despite the various available materials, enhanced mechanical properties, and rapid and less complicated fabrication, teeth with a missing coronal tooth structure or lack of a ferrule effect are less suitable for restoration with prefabricated posts and direct builds. Custom-casted posts and cores are of interest, as they conform better to the root canal anatomy and the prepared surface. According to a survey among dentists, they are still commonly used in clinical practice. For casting, mostly precious and nonprecious nickel-chrome (Ni-Cr) or cobalt-chrome (Co-Cr) alloys with sufficient corrosion resistance, hardness, and biocompatibility are used.
With the digitalization of dentistry, new possibilities for prosthodontic restorations can be considered. Different CAD/CAM methods have been introduced and are now used in fully digital protocols or in partly digital protocols in combination with classic clinical and laboratory procedures. Selective laser melting (SLM) was developed for the additive manufacturing of metal restorations, mostly from Co-Cr alloys. The technology behind SLM involves a high-powered optical laser developed for melting metal powder in 10- to 30-µm-thick layers based on a virtual model of the restoration. Major advantages of digitalization as described in the literature are lower costs of manufacturing, faster and more time-effective processing, reduction of possible human errors, and improved accuracy.

The first case of incorporating CAD/CAM technology into post-and-core fabrication was described by Awad and Marghalani. The post and core were milled from a zirconia monoblock based on an extraoral scan of an acrylic pattern that was fabricated using a direct method. Liu et al combined CAD/CAM with an indirect method and milling of fiber-reinforced composite (FRC) blocks. Both methods are partly digital, combining a digital workflow with a direct clinical pattern fabrication or intraoral impression. Lee proposed a different approach: clinical and laboratory procedures that combined intraoral scanning of the prepared coronal part of the tooth and of the FRC post inserted in the prepared canal. A CAD/CAM ceramic core was fabricated according to the scan data and then luted with an FRC post directly on the prepared tooth using adhesive luting cement. The first fully digital CAD solution for designing a one-piece post-and-core restoration was based on using special Scan Posts (3Shape) for capturing post position and depth in a prepared root canal. Scan Posts are available in different shapes and lengths and can be used intraorally or in a dental laboratory. After two intraoral scans (a scan of the prepared tooth and root canal and a scan with the Scan Post inserted in the prepared canal), a corresponding CAD software is used for design of the final restoration according to the space available concerning the antagonistic and adjacent teeth (Fig 1). At the end, the post and core can be fabricated using any different available material or CAM technology.

Many factors can influence the clinical survival rate of post-and-core restorations and affect the prognoses of the restored teeth. The most frequent complications or failures in the case of post-and-core restorations are the loss of post retention and root fracture. The frequency of such complications and their further prognoses depend on different factors, including the optimal fit of the post to the prepared root canal and the optimal cement thickness for the chosen luting agent. An optimal post fit can contribute significantly to better retention of the post and a greater fracture resistance of the restored teeth and is most important in the cervical part. A greater cervical cement thickness is also related to a higher microleakage, which has a negative effect on the prognosis of a post-and-core restoration.

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**Fig 1** CAD workflow. (a) Sample of prepared tooth for first 3D scan. (b) Sample of tooth with Scan Post inserted into prepared canal for second 3D scan. (c) Virtual 3D working model. (d) Selection of Scan Post used in the CAD software. (e) Three-point alignment. (f) Marginal line of preparation. (g) Design of post. (h) Design of core. (i) 3D model of post.
Most of the research studies testing or comparing different post-and-core restorations are designed as in vitro studies and aimed at testing the post retention, the bond strength, or the fracture resistance of the restored tooth. There are few studies designed to compare the accuracy of the post fit to the prepared root canal.

One of the most recent and sophisticated nondestructive methods used in dental research for measuring the accuracy of fit is computed microtomography (µCT), which is based on x-ray tomographic technology with a resolution of up to 1 µm. This method has already been successfully used in dental research for measuring the distance, volume, and microstructure of inner and outer tooth structures and restorative materials.\textsuperscript{19–23} Rayyan et al used µCT analysis to evaluate the accuracy of fit of casted posts fabricated using direct and indirect techniques. They compared the space area in the coronal, middle, and apical sections, the overall volume, and the volume at the end of the post and found no significant differences.\textsuperscript{19}

The accuracy and clinical success rate of CAD/CAM post-and-core restorations are not well known. There are only two comparative studies of posts fabricated with CAD/CAM technologies found in the literature: one assessing the fracture resistance of teeth restored with custom-casted, milled, and SLM-fabricated posts,\textsuperscript{10} and one comparing the accuracy of the post fit for Co-Cr posts fabricated by casting, milling, and SLM technology.\textsuperscript{24}

The purpose of the present study was to compare the accuracy of the fit of posts fabricated using a conventional direct technique and posts fabricated using digital CAD/CAM technology. The hypothesis was that the fabrication of a post with the use of Scan Posts, intraoral scanning, and SLM technology would be as accurate as the fabrication of posts with a conventional direct technique using an acrylic resin pattern and casting.

**MATERIALS AND METHODS**

This research complies with the World Medical Association Declaration of Helsinki and the Code of Medical Ethics of Slovenia. Ethical approval was obtained from the Slovenian National Medical Ethics Committee (0120-304/2017-4, KME 48/06/17).

Ten extracted noncarious permanent maxillary incisors were collected for this research. These teeth were chosen because their round cross-sections would minimize the influence of root canal anatomy on the canal preparation. They had no anatomical or pathologic root deviations. Endodontically treated or prosthetically restored teeth were excluded. The teeth were examined using magnifying loupes to exclude any possible vertical or horizontal cracks. All the teeth were extracted for medical reasons within a 6-month time frame. After extraction, the teeth were rinsed under running water, cleaned with curette and gauze, and stored in sterile distilled water in a fridge (4°C to 5°C) until the end of the research. The water was changed every week.\textsuperscript{25} For the entire research period, a strict handling protocol for the prevention of dehydration and cracking was followed. When out of the distilled water, all teeth were handled in wet gauze, except for during the µCT analysis.

All of the teeth were cut 2 mm above the cementoenamel junction (CEJ). The remaining pulp and cervical third of the root canals were cleaned and prepared using the crown-down technique with a Gates Glidden Size 2 drill (Kerr Dental). The remaining part of the root canal was cleaned and prepared using the step-back technique with hand files and reamers to ISO 35. During instrumentation, the canals were extensively irrigated with 2.5% sodium hypochlorite (NaOCl). After preparation, the smear layer was removed with 17% ethylenediaminetetraacetic acid (EDTA; Calcinate, Lege Artis) for 40 seconds. The root canals were once again rinsed with 2.5% NaOCl and dried with paper points (Roeko). Endodontic obturation was carried out with the cold lateral compaction technique using master and accessory gutta-percha points (Roeko) and epoxy resin sealer (AH Plus, Dentsply Sirona). Any excess material was removed with a warm excavator and a plugger. The apical and coronal openings were sealed with an adhesive system (Excite, Ivoclar Vivadent) and a flowable composite (Tetric EvoFlow, Ivoclar Vivadent) for appropriate sealer polymerization during the storage period in distilled water. Teflon was put over the obturation before the composite application.

After 1 to 2 weeks, 10 mm of obturation was removed with a Gates Glidden Size 2 drill. All of the teeth were carefully prepared for the best possible fit of the chosen Scan Post (1.7 APL, 3Shape) with a dimensionally suitable penetration and calibration drill (no. 110, Maillefer, Dentsply Sirona). All teeth were invested in Plexiglas tubes in an autopolymerizing, transparent, acrylic resin cylindrical block (ProBase Cold, clear, Ivoclar Vivadent). The axis of each prepared canal was in line with the axis of the tube used.

For each tooth, two custom metal posts were fabricated: one using the direct technique with casting, and one using the digital CAD/CAM technique with SLM technology.

For the direct technique (Group C), the post-and-core pattern was fabricated using autopolymerizing acrylic resin (Pattern Resin LS, GC America). The prepared root canal was isolated in a thin layer of liquid paraffin applied with a paper point. The acrylic resin was mixed and applied with a spiral root canal instrument (Lentula Spiral, Maillefer, Dentsply Sirona). A plastic post (UniClip, Maillefer, Dentsply Sirona) was inserted, and the core was formed. All the acrylic patterns were invested...
(Fujivest, GC) and casted from a Co-Cr alloy (Biostar S, Aurodent) with a precision metal-casting technique using a centrifugal casting machine.

For each tooth, a second post and core were fabricated using the 3Shape post-and-core CAD solution and SLM technology (Group D). A TRIOS intraoral scanner (3Shape) was used according to the manufacturer’s instructions (Fig 1). The coronal part and the prepared root canal of each tooth were scanned in the first scan, and a second scan was made with the chosen Scan Post (1.7 APL) passively inserted into the prepared root canal. The CAD software Dental System (3Shape) was used for the post-and-core design with a 5-µm cement gap. The file was exported into stereolithographic format (STL) and sent for 3D printing (3Dmed, Maribor, Slovenia). All the posts and cores in Group D were fabricated from Co-Cr alloy (Remanium star CL, Dentaurum) using SLM technology (Mlab Cusing, Concept Laser).

After printing, the fabrication was tested for accuracy. All the posts and cores were scanned with a laboratory scanner (Identica T300, Medit), with every scan superimposed on the corresponding STL file (Inspect, GOM) and assessed on a color deviation map.

The posts from both groups were airborne particle-abraded with aluminum oxide particles (Korox 110, Bego), cleaned with steam and 70% ethanol, air dried, and tested for passive fit in the corresponding prepared root canal. In the case of discrepancies or failure, the post and core would be reprinted or recasted.

Each tooth was analyzed with µCT (MicroXCT-400, Xradia) separately with the corresponding Group C and Group D inserted posts. The device settings were the same for all samples (same tooth with both posts). For the teeth, the beam energy was 80 kV and 7 W, and for the posts, it was 140 kV and 10 W. The µCT was equipped with a x0.39 magnification optical lens. The other settings were: field of view (6 x 6 mm²), number of projection images (2,000), and exposure time (4 seconds per projection for the tooth and 2 seconds for the post). With all these settings, the resolution of the images was 13 µm per pixel.

Each sample was composed of three separate scans: a scan of the tooth, a scan of the tooth with an inserted Group C post, and a scan of the tooth with an inserted Group D post. Fixation of the teeth during the analysis was ensured with a thermoplastic material (Iso Function-al, GC) used for locking the tube on the device carrier.

Raw-format (.raw) images (Figs 2a and 2b) were imported into the computer software Avizo Fire (FEI Visualization Sciences Group) for 3D reconstruction and measurements. Images of the same tooth with and without each post were superimposed, and the pixels on the margin of the tooth were checked for a mismatch. A 100% match needed to be determined to proceed with the analysis. With the software function “Interactive thresholding,” segmentation was made to determine the air/post and air/canal margins. With the software function “Surface view,” 3D models of the tooth and both posts without the tooth were designed (Figs 2c to 2e). The 3D model of the tooth and each post were combined. The following measurements were made on the 3D model of the space between the post surface and the prepared root canal wall:

- The overall volume of the space between the post surface and the prepared root canal wall for each post
- The areas of the four different sections of space between the post surface and the prepared root
canal wall (sections 1 and 2 = cervical; sections 3 and 4 = apical) (Fig 3a).

• The volume of the cervical (C), middle (M), and apical (A) segments (Fig 3b) of the space between the post surface and the prepared root canal wall for each post.

• The distances between the post surface and the prepared root canal wall at four sites in each of the four sections (buccal [B] at 0 degrees; the approximal right [AR] at 90 degrees; the palatal [P] at 180 degrees; and the approximal left [AL] at 270 degrees) (Fig 3c).

All the segments and sections were the same for each sample. Each measurement was repeated and checked twice to avoid inconsistencies. Statistical analyses of the data were performed with SPSS software (SPSS Statistics 22, IBM) using Shapiro-Wilk test for distribution of the numeric variables. A two-way statistical test was used because of the small number of samples (n = 10). Because of the normal distribution of the numeric variables, parametric Student t test was used. One-way analysis of variance (ANOVA) with post hoc Bonferroni correction was used for comparison of the mean distances among the different sections in the same group of posts. A statistically significant difference was confirmed when the P value (calculated to three decimals) was less than .05.

RESULTS

According to computer software analysis of the 3D models for both groups, the space volume, space area, and distance between the post and prepared canal wall were measured. The mean and SD values and the range of data with minimum and maximum values of the overall space volume and the space volume between the post and the prepared canal wall of segments C, M, and S are summarized in Table 1. All the mean space volume measurements were significantly lower for the Group C posts compared to the Group D posts (overall: \( P = .002 \); segment C: \( P = .023 \); segment M: \( P < .001 \); segment A: \( P < .001 \)).

The mean and SD values and the minimum and maximum values of the space area, the distance in sections 1, 2, 3, and 4, and the distance of all the sections together between the post and the prepared canal wall are summarized in Table 2. No significant differences were observed between the space area or the mean distance between the post and the prepared canal wall in sections 1 or 2. The mean values of the distances of all the sections together (\( P = .002 \)), the mean distances in sections 3 (\( P < .001 \)) and 4 (\( P = .019 \)), and the space area in sections 3 (\( P < .001 \)) and 4 (\( P = .004 \)) were significantly lower for the Group C posts compared to the Group D posts. Charts showing mean values and...
the distribution of the data of space area and distance between the post and the prepared canal wall in sections 1, 2, 3, and 4 are shown in Figs 4 and 5.

DISCUSSION

The null hypothesis that the fabrication of posts using Scan Posts, an intraoral scanner, and SLM technology would be as accurate as fabrication using a direct technique with casting was not fully rejected. According to the measurements of the space area and the distance between the post and the prepared root canal, the posts of both groups were comparably accurate in the cervical part of the prepared root canal. However, in other parts of the prepared root canal and for all the volume measurements of the space between the post and the prepared root canal wall, the Group C posts had a significantly more congruent form in comparison to the Group D posts.

This in vitro study was conducted in a controlled and standardized laboratory environment for an optimal accuracy assessment. Even though in vitro conditions cannot replicate the clinical situation completely, they are more appropriate for studying accuracy using methods not applicable for a clinical study (µCT).

The CAD software 3Shape Post and Core Solution used in this study is the only fully digital option for post-and-core fabrication currently available on the market.15 The main advantages of fully digital CAD/CAM methods are that they are patient-friendly and provide faster and more time-effective clinical procedures, as well as cost-effective laboratory procedures.11 Other methods described in the literature are combinations of CAD/CAM and classic impression techniques12,13,26,27 or combinations of prefabricated posts and CAD/CAM cores.14,28

According to the literature, the indications for using metal cast posts and cores is limited to restoring teeth with substantial coronal tooth loss.1,2 When restoring

Table 1

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<th>Section</th>
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<th>Mean</th>
<th>SD</th>
<th>Maximum</th>
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<td>0.80</td>
<td>0.19</td>
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<tr>
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All values between groups were statistically significant (P<.05) and are in bold.

Table 2

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<th>Distance (µm)</th>
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SD = standard deviation; sections 1 and 2 = cervical; sections 3 and 4 = apical. Statistically significant (P<.05) values are in bold.
anterior teeth with translucent ceramic crown restorations, gray metal substructures (such as Co-Cr alloy) usually compromise the esthetic outcome. If a custom-casted metal post and core is indicated, gold or gold alloy posts and cores in combination with ceramic crown restorations can offer a good esthetic result with an excellent long-term prognosis and can be fabricated with milling or SLM technologies. For the present study, Co-Cr alloy was used because of the almost equal composition of casting and SLM alloy.

For the µCT analysis and evaluation of the accuracy of the post fit, the same tooth was used for both groups (C and D). In this way, the variables were better standardized, and the influence of the root canal anatomy on the obtained results was minimized. This method was similar to the study of Rayyan et al.

The use of µCT for evaluation and comparison of the post fit in this research proved this nondestructive diagnostic tool to be very useful, accurate, and applicable. Its advantage is the 3D software reconstruction from thousands of two-dimensional radiographic images, which enabled a broad spectrum of different measurements, which is not possible using traditional methods. The resolution of 13 μm and the contrast between the root canal wall and the post’s surface was sufficient for optimal visualization and for the measurements used to evaluate the accuracy. Different research studies evaluating the µCT method and comparing it to classic microscopy showed that µCT analysis is a reliable and accurate research method.

When x-rays impinge on metal, reflection or scattering can occur, causing the emergence of artifacts in the vicinity of the metal’s surface. For this reason, marginal filters can be applied later in the software to change the grayness of the pixels in contact with the metal based on different mathematical algorithms. Liedke et al radio graphically compared the gingival gaps of metal crowns by applying different filters and concluded that filters can significantly influence the accuracy of the results. In order to reduce the need to apply a filter, the described method was modified with the use of three separate scans: a scan of the tooth, a scan of the tooth with an inserted Group C post, and a scan of the tooth with an inserted Group D post. Separating the 3D models of the posts and combining them with the 3D model of the tooth scanned separately enabled reduction of the influence of artifacts and avoidance of the use of filters.

To the present authors’ knowledge, the only study in the literature related to measuring the volume of the space between the root canal wall and the post’s surface was published by Rayyan et al. The mean volume for the direct technique was 12.25 mm³, which is six times greater than the mean volume for the direct technique measured in the present research (2.22 mm³ for Group C and 3.82 mm³ for Group D). Even though Rayyan et al used premolars and 2-mm–longer posts, another possible explanation for such a difference could be the use of a 52% beam reduction.

Measurements of the space volume, space area, and mean distance were made on different sections of the teeth for a more detailed evaluation of both methods. Some discrepancies were expected in the apical part of the Group D posts in comparison to the Group C posts because congruence of a custom-shaped post can only be expected in the scanned parts of the root canal. In the cervical part, the accuracy of both methods was comparable, with no significant difference in the mean distance or space area in sections 1 and 2 but a significantly greater space volume for the Group D posts. These results show that the intraoral scanner used can accurately scan down to 4 mm in the root canal.

In segments M and A, and in sections 3 and 4, all the measurements were significantly different and more than two-times greater for the Group D post. The fit of the post there depends on the primary fit of the scan post and the precision of the preparation, which are mostly related to the drill system used. According to the manufacturer’s specifications and the instruction manual, Scan Posts come in various shapes and sizes, but without any corresponding drills offered or specified by the company. Even though the most suitable drilling system was chosen in this study, it had a major impact on the apical accuracy of the Group D posts, in which the measurements showed the greatest discrepancies between the groups. Six out of 10 posts from Group D were shorter than the prepared root canal, contributing to a greater volume of space between the post and the canal wall in the apical segment and influencing the measurements of distance and area in Section 4.

In Figs 4 and 5, the distance between the post and the canal wall and the area of the space in all four sections can be seen and compared between both groups. Contrary to expectations, neither the distance between the post and the canal wall nor the space area decreased from section 1 to section 4. The smallest distance and space area were measured in sections 2 or 3 of both groups. A possible reason for this is the choice of the section height. The most apical part (section 1) was chosen, where the cervical margin was probably slightly damaged during the insertion and removal of the posts, contributing to a reduced accuracy. In the most apical part (section 4), the posts of Group C were not very congruent with the canal walls because of the endodontic filling material, the remnants of the isolating solution, and the acrylic resin’s polymerization. Contrary to the findings of the present study, Liu et al found a better cervical and apical internal adaptation of Co-Cr posts fabricated with SLM and milling in comparison to casted posts. They measured the space area in the apical, cervical, and middle cross-sections using stereomicroscopy.
and computer software analysis. For the casted post, the mean values of the space area were 0.59 mm$^2$ apically, 0.30 mm$^2$ in the middle, and 0.77 mm$^2$ cervically; and for the SLM group, 0.41 mm$^2$ apically, 0.43 mm$^2$ in the middle, and 0.53 mm$^2$ cervically. The different findings can be explained by the different CAD method used by Liu et al., as they used a partially digital method, combining a silicone impression of the post preparation and CAD/CAM technologies. According to the authors, the obtained differences in the cervical cross-sections between both groups can be explained by the nonuniform setting expansion of the casted metal. The post’s fit or accuracy is an important clinical parameter that contributes to a greater fracture resistance and to an increasing clinical success rate for the final prosthodontic restoration.

According to Kious et al., measurements of the thicknesses of different cements under constant load in different time frames after mixing showed that in 2-minute intervals, the thicknesses of the tested cements were 25 µm or less. These results are important when considering the minimum space or distance from the post to the canal wall for the post’s cementation. The optimal distance or the cement thickness differ according to the cementation technique used. When phosphate cements were used, a thicker cement layer of composite cements had no influence, even up to 316 µm, and the highest retention was measured for a thickness of 150 µm.

From the results of the present study, it can be concluded that the accuracy of the post fit from both experimental groups was clinically acceptable. The conclusion was made according to the optimal cement thickness in relation to different cementation techniques. Both post groups had a comparable cervical accuracy, which is the most important for optimal post retention and fracture resistance.

In the opinion of the present authors, further research is needed to investigate and compare different drilling systems, retention with different cementation techniques, fracture resistance, and the long-term clinical success rates of restorations manufactured using digital CAD/CAM methods. These results represent a basis and indicate possibilities for further improvement of the digital method.
CONCLUSIONS

Within the limitations of this study, it can be concluded that in the cervical part (sections 1 and 2), where the accuracy of the post fit is the most important, the prepared canal was successfully scanned using an intraoral scanner. No significant difference between groups in the distance or space area between the post and the canal wall was observed; however, in the apical part, the direct technique with casting of the post was significantly more accurate than the digital CAD/CAM technique with SLM technology, even though the null hypothesis could not be entirely rejected.

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