

RESEARCH AND EDUCATION

Internal adaptation of cobalt-chromium posts fabricated by selective laser melting technology



Wei Liu, MSD,^a Hai Qing, DDS, PhD,^b Xibo Pei, DDS, PhD,^c and Jian Wang, DDS, PhD^d

The evolution of digital technologies has led to rapid developments in dentistry, especially in prosthetic dentistry.¹ The recently introduced selective laser melting (SLM) technique has become attractive for dental applications. SLM is an additive manufacturing technique which fabricates 3-dimensional (3D) metal structures by using a high-powered laser beam to melt and fuse metallic powders.² The 3D digital data used for the manufacturing processes can be obtained through a computer-aided design (CAD) system or from an intraoral scanner. After data are sliced into layers, the metallic powders are melted selectively by a laser beam to form the sliced layers one by one until the structure is complete.³

In addition to SLM, conventional lost-wax casting technique and CAD-computer-aided manufacturing (CAM) milling have also been used to produce metal dental prostheses. Compared with conventional casting, both CAD-CAM milling and SLM reduce manufacturing time, eliminate

ABSTRACT

Statement of problem. Selective laser melting (SLM) has become popular in prosthetic dentistry. However, only limited information is available for the internal adaptation of cobalt-chromium (Co-Cr) posts fabricated by SLM.

Purpose. The purpose of this in vitro study was to investigate the internal adaptation of Co-Cr metal posts fabricated by SLM technique.

Material and methods. Thirty-six Co-Cr metal posts were fabricated by conventional casting, subtractive computer-aided design and computer-aided manufacturing (CAD-CAM), and additive CAD-CAM, by making an impression from a standardized model of a tooth with a single root canal. Posts and the dies were bonded with cement. Specimens were then sectioned horizontally by using a grinding and polishing machine, and 3 different cross-sections of each post were chosen to represent the apical, middle, and coronal regions. The areas of cement were photographed by using a stereomicroscope at an original magnification of $\times 32$ and measured using image-measuring software. From each group, 1 specimen was randomly selected and observed by using scanning electron microscopy. One-way ANOVA and Tukey honestly significant difference test were performed to identify differences among groups with regard to internal adaptation ($\alpha=.05$).

Result. The internal adaptation of the SLM group did not differ from that of the CAD-CAM milling group at 3 cross-section levels ($P>.05$). At the apical and coronal cross-section levels, the cement area of SLM group was smaller than that of the cast group ($P<.05$). However, at the middle cross-section level, the cement area of the cast group was significantly smaller than that of the SLM group ($P<.05$). Use of scanning electron microscopy showed both the SLM group and the CAD-CAM milling group exhibited homogeneous microstructures. However, the cast group showed a typical discontinuous dendritic solidification microstructure.

Conclusions. The internal adaptation of SLM was not inferior to that of the CAD-CAM milling group or the cast group. The SLM technique seems a promising choice for fabricating dental posts. (J Prosthet Dent 2019;121:455-60)

interoperator variation, and improve overall accuracy of products.⁴ Unlike the subtractive milling manufacturing method, SLM offers a higher rate of material use and

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^aPostgraduate student, Department of Prosthodontics, West China School/Hospital of Stomatology, Sichuan University, Chengdu, PR China.

^bAssistant Professor, Department of Restorative Dentistry, Temple University Kornberg School of Dentistry, Philadelphia, Pa.

^cAssociate Professor, Department of Prosthodontics, West China School/Hospital of Stomatology, Sichuan University, Chengdu, PR China.

^dProfessor, Department of Prosthodontics, West China School/Hospital of Stomatology, Sichuan University, Chengdu, PR China.

Clinical Implications

A cobalt-chromium post fabricated by selective laser melting is a promising alternative to that fabricated by conventional casting or CAD-CAM milling.

avoids material waste.⁵ Furthermore, SLM metal production has been reported to exhibit better corrosion resistance and surface properties.⁶

SLM is currently used to manufacture different restorations, including crowns and post-and-core restorations. A post-and-core is needed when an endodontically treated tooth cannot provide adequate resistance and retention for a crown.⁷ Custom metal posts are still indicated in various clinical situations.⁸ Adaptation has been reported to be a key factor in the clinical success of the post and can affect the thickness of the cement.⁹ Various *in vivo* studies have suggested that an excessively thick cement layer can be a negative factor for the long-term success of post-retained restorations and may be related to higher frequencies of post debonding.^{10,11} A post that is better adapted to the canal wall will have a minimum thickness of cement.¹²

Co-Cr alloy has a long history of use in prosthodontics, including for post-and-cores. It also has many excellent properties in terms of mechanical strength, corrosion resistance, and biocompatibility.¹³⁻¹⁵ Currently, the SLM technique can be used to fabricate Co-Cr metal posts. The mechanical characteristics and adaptation of metal crowns fabricated by this new method have been reported. After examining 330 single-unit metal-ceramic crowns, Huang et al¹⁶ reported that the marginal fit of SLM Co-Cr crowns was better than that of the cast Co-Cr crowns. Tamac et al¹⁷ reported that the metal-ceramic crowns fabricated by SLM, CAD-CAM milling, and conventional casting had similar clinical marginal adaptations. A recent study focused on the fracture resistance of teeth restored with metal posts fabricated by SLM and concluded that SLM Co-Cr posts and cast Co-Cr posts showed similar levels of fracture resistance.¹⁸ However, the authors are unaware of reports of the internal adaptation of Co-Cr metal posts manufactured by the SLM technique.

The purpose of this *in vitro* study was to compare the internal adaptation of Co-Cr metal posts fabricated by SLM with those of posts fabricated by conventional casting and CAD-CAM milling. The null hypothesis was that the 3 different techniques would have no influence on the internal adaptation of Co-Cr posts.

MATERIAL AND METHODS

To avoid variables of different natural teeth, a standardized tooth model with a single root canal was selected.

The model was a composite resin die manufactured by 3D printing technology. By using 3D CAD software (AutoCAD v20.0.51.0; Autodesk), we were able to simulate a maxillary central incisor prepared for a metal post-and-core restoration by drawing a standard tessellation language (STL) file. The height of the resin die was 12.0 mm, and the depth of the post space was 8.0 mm. In the model, the remaining vertical marginal tooth substance available for ferrule preparation was 1.5 mm high, and the taper of the post was 6 degrees (Fig. 1).^{19,20} The STL file was input to a 3D printer (Projet MJP 3600; 3D Systems), and 36 resin models were fabricated according to the same STL file.

Randomization of this study was achieved by using computer-generated randomization (Excel 2016; Microsoft Corp). After resin dies were numbered, they were randomly divided into 3 groups: cast group, milling group, and SLM group. Each group consisted of 12 dies. However, before dies were grouped, a die was randomly chosen to make the impression of the post-and-core. A light body polyvinyl siloxane impression material (ExpressXT; 3M ESPE) was mixed and injected into the post space, followed by an impression tray with the heavy-body material, which was mixed at the same time. The impression was first digitized by using a digital scanner (inEos X5; Dentsply Sirona) to obtain an STL file of the post (Fig. 2). It was then poured with Type 4 dental stone (Die-Keen; Kulzer GmbH) to make a dental cast. To produce the cast posts, the wax patterns were completed on the stone cast with the melted wax (Ultra-Waxer 2; Kerr Corp) and then invested with a phosphate-bonded investment (Bellavest SH; BEGO) and cast in Co-Cr alloy (Co, 63%wt; Cr, 24%wt; W, 8.1%wt; Mo, 2.9%wt; Si, 1.1%wt; Nb, 0.9%wt; Solibond C plus; Yeti Dental) in a casting machine (Ducatron S3) according to the manufacturer's instructions. From the STL file, the milling machine (inLab MC XL; Dentsply Sirona) milled a Co-Cr metal block (Co, 61 ±2%wt; Cr, 26 ±2%wt; W, 6.5 ±1%wt; Mo, 4.5 ±1%wt; Jinbego DC; Nantong Today High-Tech Material) by simultaneous, double 4-axis processing to manufacture the milled posts. SLM posts were produced by the SLM system (M1 cusing; Concept Laser). With a spot size of 0.09 mm and a power of 160 W, a laser beam scanned on a 30- μ m-thick layer of metal powder (Co, 63.9%wt; Cr, 24.7%wt; W, 5.4%wt; Mo, 5.0%wt; and trace amounts of Fe and Si; Wirobond C+; BEGO) and melted the powder layer by layer to fabricate the posts according to the CAD data. After posts were fabricated using the 3 techniques, they were airborne-particle abraded with 250- μ m Al₂O₃ (Korox; BEGO) under a pressure of 0.4 MPa.

Posts were randomly assigned to the dies in each group. After being evaluated, both the posts and root canals of the dies were cleaned with 70% ethanol and air dried. A dual-polymerized composite resin cement

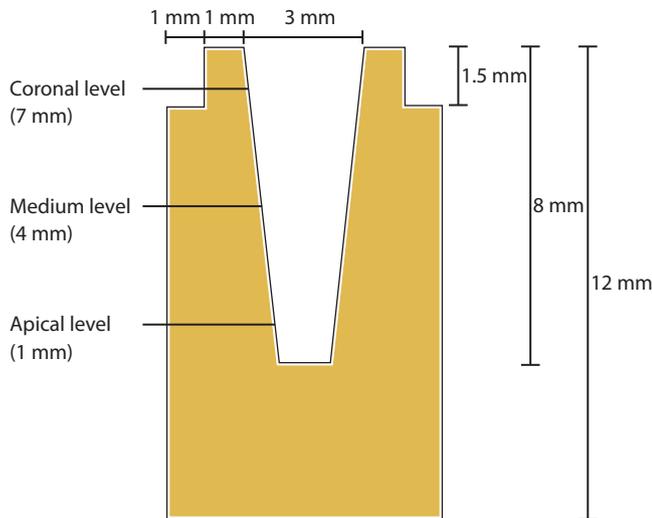


Figure 1. Longitudinal section of standardized tooth model with single root canal.

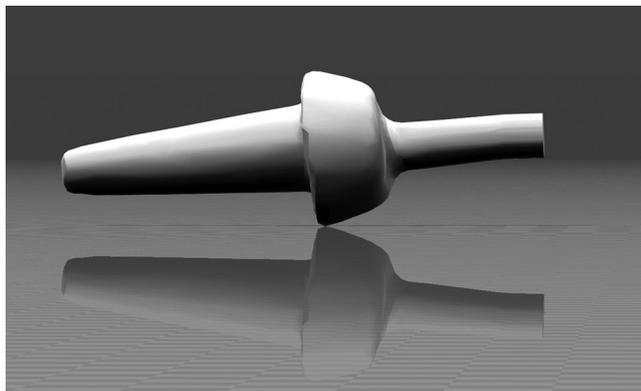


Figure 2. Three-dimensional image of silicone impression of post.

(Maxcem Elite; Kerr Corp) was used to bond the posts and the dies. According to the manufacturer’s instructions, the cement was dispensed onto the post and into the canal space with the root canal tips (Maxcem Elite; Kerr Corp). The post was rotated slightly upon insertion to avoid trapping air, and finger pressure was applied to the core in the vertical direction until the post-and-core was fully seated. The excess cement was then removed from the margin and polymerized with a light-emitting diode (LED) light (LED.B; Woodpecker) for 20 seconds on each surface. Specimens were embedded in epoxy resin and then ground with a machine (LaboPol-6; Struers) in the horizontal axis. Three cross-sectional levels of the post were chosen to represent the apical, middle, and coronal regions, which were 1, 4, and 7 mm, respectively, from the bottom of the post (Fig. 1). Each cross-sectional level was digitally photographed using stereomicroscopy (SZX16; Olympus Corp) at an original magnification of $\times 32$, and the area of the cement layer

was measured on the images (Fig. 3) with image-measuring software (Digimizer v4.6.1; MedCalc Software). The investigator (X.P.) who measured the images was blinded to the information regarding the images.

Additionally, 1 specimen was randomly selected from each group for microstructural observation. Three specimens were sequentially polished with SiC papers (200 to 2000 grit) using a grinding and polishing machine (LaboPol-6; Struers) and ultrasonically cleaned in ethanol and deionized water. Each specimen was etched in a mixture of hydrochloric acid/hydrogen peroxide (80:20, v/v) for 30 seconds at room temperature and observed using scanning electron microscopy (Inspect F; FEI).

Data were analyzed using statistical software (IBM SPSS Statistics, v19.0; IBM Corp). One-way ANOVA and Tukey honestly significant difference tests were used to compare the areas of cement layers among groups (Cast group, Milling group, and SLM group) ($\alpha=.05$ for all tests).

RESULTS

The mean cement areas of the different groups are reported in Table 1. Statistically significant differences were found among the 3 groups on the apical cross-section ($df=2$, $F=12.357$; $P<.001$), medium cross-section ($df=2$, $F=11.001$; $P<.001$), and coronal cross-section ($df=2$, $F=12.457$; $P<.001$). For the apical cross-section, the cast group presented a larger cement area than the milling group or the SLM group ($P<.05$). No significant differences were found between the milling group and the SLM group ($P>.05$). The same statistical results were found at the coronal cross-section level. The milling group showed no differences from those of the SLM group ($P>.05$), and the mean cement area of the cast group was significantly larger than those of the other 2 groups ($P<.05$). Results of the middle cross-section levels are presented in Table 1. No significant differences were found between the milling group and the SLM group ($P>.05$), whereas the mean cement areas of the 2 groups were both significantly larger than that of the cast group ($P<.05$).

Figure 4 shows the microstructure of the specimens fabricated by the 3 techniques. The cast specimen (Fig. 4A) observed at an original magnification of $\times 1000$ showed a typical discontinuous dendritic solidification microstructure. This structure was inhomogeneous and consisted of dendrites (Fig. 4A, light regions) and interdendritic areas (Fig. 4A, dark regions). In addition, a series of dark micropores were found in the light regions at magnification $\times 10\,000$ (Fig. 4D). At magnification $\times 1000$, the structures of the milling specimen (Fig. 4B) and the SLM specimen (Fig. 4C) were not clearly observed. Nevertheless, the milling specimen exhibited a homogeneous block structure at magnification $\times 10\,000$ (Fig. 4E). For the SLM

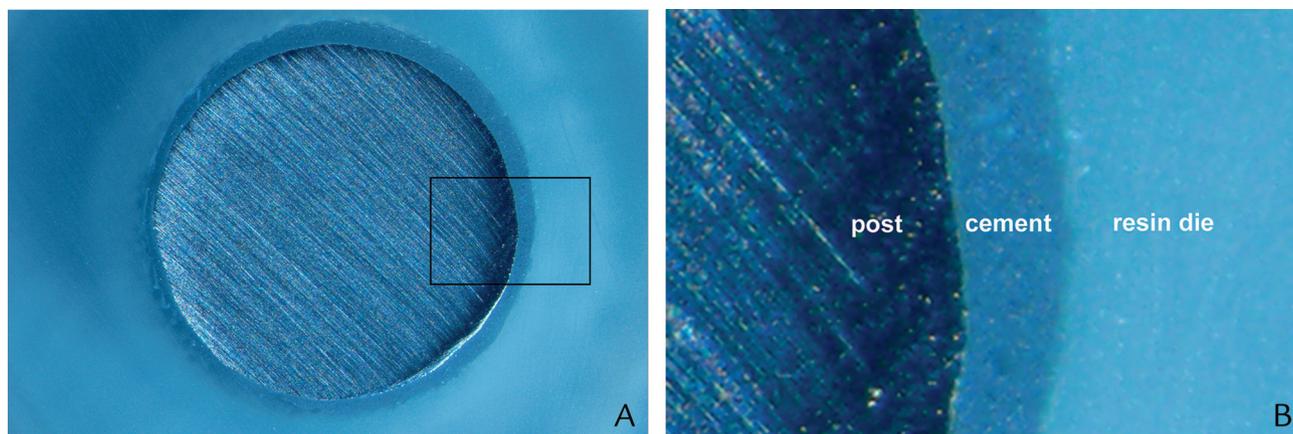


Figure 3. A, Stereomicroscope image of cross-section (original magnification $\times 32$). B, Magnified image showing post, cement, and resin die.

Table 1. Mean \pm standard deviation areas of cement layers in different cross-sections with 3 techniques

Group	Area of Cement Layers (mm^2)		
	Cast	Mill	SLM
Apical	0.59 ± 0.09^a	0.45 ± 0.12^b	0.41 ± 0.05^b
Middle	0.30 ± 0.09^c	0.39 ± 0.07^d	0.43 ± 0.05^d
Coronal	0.77 ± 0.22^e	0.53 ± 0.08^f	0.53 ± 0.07^f

SLM, selective laser melting. Data within rows followed by same superscript letter not significantly different ($P > .05$).

specimen, a closely arranged honeycomb microstructure was observed at magnification $\times 10\,000$ (Fig. 4F).

DISCUSSION

On the basis of the results of the present study, the null hypothesis that the 3 different techniques would have no influence on the internal adaptation of Co-Cr metal posts was rejected. Table 1 shows that the SLM group demonstrated an internal adaptation similar to that of the milling group at every cross-sectional level. Furthermore, the results of these 2 groups revealed a better internal adaptation than that of the cast group on the apical and coronal cross-sectional levels. Conversely, the cast Co-Cr metal posts exhibited a small volume of expansion at the middle cross-section level, which caused a statistical difference from the other 2 groups in internal adaptation. The nonuniform casting shrinkage that occurred at the cast Co-Cr metal posts was most likely caused by the thermal and setting inhomogeneous expansions of investment materials, a disadvantage of the conventional lost wax casting technique.^{21,22} In the wax pattern of a crown, because of the different volumes of the different aspects, the occlusal aspect offers different amounts of resistance to the forces of expansion than the thin cervical aspect.²³ Takahashi et al²⁴ found that phosphate-bonded investment caused nonuniform setting expansion, which may inevitably lead to the distortion of the pattern, especially in a horizontal direction. In the

present study, the obvious differences between the cross-section levels of the cast posts indicated the instability of the casting technique. However, unlike the conventional casting technique, the laboratory procedures of both the milling and SLM techniques can be standardized by CAD, and the manufacturing steps can be simplified, which may have a positive effect on the accuracy of the Co-Cr posts.

Scanning electron microscopy images showed the microstructures of the casting, the CAD-CAM milling, and the SLM techniques. The differences among the microstructures which showed different processing characteristics of the 3 methods might have been the cause of the significant differences in the internal adaptation of posts. At magnification $\times 1000$, the cast group exhibited a typical discontinuous dendritic solidification microstructure (Fig. 4A). At magnification $\times 10\,000$, microporosity was found in the light region, which was caused mostly by the nonuniform solidification shrinkage of the casting metal (Fig. 4D).²⁵ However, the microstructures of the other 2 groups revealed no clear grains (Fig. 4B, C). The honeycomb microstructure found in the SLM group at magnification $\times 10\,000$ (Fig. 4F) was arranged closely and less than $1\ \mu\text{m}$ in diameter. Moreover, in the CAD-CAM milling group at magnification $\times 10\,000$ (Fig. 4E), the block microstructure represented similar characteristics as well. In the current study, SLM posts were fabricated layer by layer. With the local melting and rapid solidification of the metal powder, the SLM technique can provide a relatively homogeneous honeycomb microstructure. In summary, the milling and SLM techniques provided smaller grains and more compact structures than the conventional cast technique. Furthermore, these homogeneous structures can have a positive influence on the internal adaptation of posts. This study has pointed out that the internal adaptation of SLM is not inferior to that of the casting and the milling techniques, which is in accordance with other studies.^{17,26}

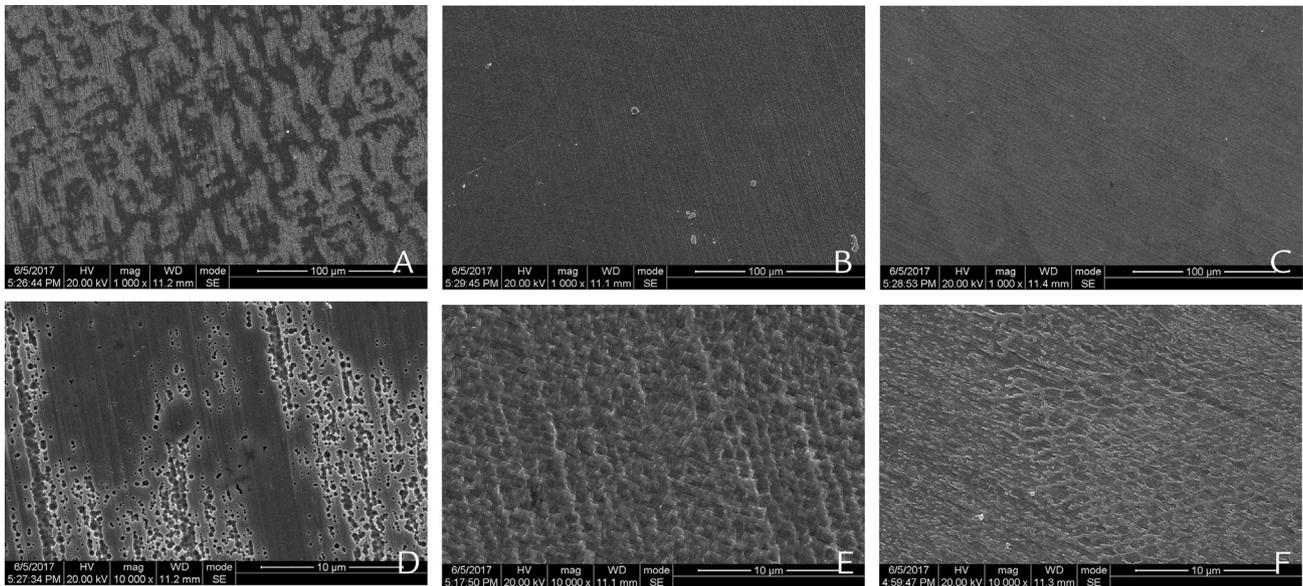


Figure 4. Scanning electron microscope images of microstructure. A, D, Cast. B, E, Milled. C, F, selective laser melted. Original magnification A-C, $\times 1000$; D-F, $\times 10\,000$.

Different methods have been used to evaluate the internal adaptation of dental restorations, including intraoral measurement, silicone replica technique,¹⁷ and direct measurements.^{27,28} However, opinions still differ as to which method is most suitable for measuring internal adaptation. The intraoral measurement is closely related to daily clinical situations, but it is not easy to make an accurate measurement. In the silicone replica technique, the thickness of silicone impression material is used to represent the internal adaptation of restorations. Owing to the larger height and smaller diameter of the post compared with those of the crown, the silicone layer is too difficult to preserve during post removal. Accordingly, the silicone replica technique is typically used to measure the internal adaptation of the crown rather than that of the post. Direct measurement has also been adopted by many researchers to examine the internal adaptation. The thickness of the cement layer can be directly measured, and there are only a few simple steps in this method. Thus, in this study, internal adaptation was measured directly by using a stereomicroscope after specimens were sectioned, which were embedded in epoxy resin.

This research did not focus on the oxide layer, which usually covers the surface of metal restorations. Xin et al²⁹ found that the oxide layers on the cast specimens and the SLM specimens were approximately 3.3 and 3.6 nm thick, respectively, much less than the thickness of cement. Therefore, the oxide layer has a negligible impact on the internal adaptation of the post. To simulate real clinical practice, finger pressure was used by 1 investigator while seating the posts. A

previous study also found that the possible difference in seating forces did not result in significantly different cement layers.²⁶

This study, which focused on the internal adaptation of posts fabricated by using 3 different techniques, has some limitations, including the different numbers and different sizes of root canal. Further investigations of these aspects should be performed to comprehensively evaluate the internal adaptation of metal posts.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Co-Cr metal posts fabricated by SLM had similar internal adaptation to those fabricated by the CAD-CAM milling method and did not exhibit inferior adaptation compared with the conventionally cast posts.
2. Fewer microporosities were observed in the posts fabricated by the SLM and CAD-CAM milling techniques than in the posts fabricated by the conventional casting technique.
3. The SLM technique is a promising alternative to conventional casting for metal post-and-core fabrication.

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Corresponding author:

Dr Jian Wang
 Department of Prosthodontics
 West China School of Stomatology, Sichuan University
 No.14, Section 3, South Peoples Rd, Chengdu 610041
 PR CHINA
 Email: ferowang@hotmail.com

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