AMERICAN COLLEGE OF PROSTHODONTISTS
Your smile. Our specialty.

A Novel Computer-Aided Method to Fabricate a Custom One-Piece Glass Fiber Dowel-and-Core Based on Digitized Impression and Crown Preparation Data

Zhiyu Chen, DDS,[1] Ya Li, MSD,[2] Xuliang Deng, DDS, PhD,[3] & Xinzhi Wang, DDS, PhD[1]

[1]Department of Prosthodontics, Peking University School and Hospital of Stomatology, Beijing, China
[2]Department of Dentistry, The First Hospital of Shijiazhuang City, Hebei, China
[3]Department of VIP Dental Services, Peking University School and Hospital of Stomatology, Beijing, China

Keywords
CAD/CAM technique; optical 3D digitization; sectional dual-arch impression.

Correspondence
Xinzhi Wang, Department of Prosthodontics, Peking University School and Hospital of Stomatology, #22 Zhongguancun South Street, HaiDian District, Beijing 100081, China. E-mail: xinzwang@sina.com

Funded by the Research Fund for the Doctoral Program of Higher Education of China. No. 20090001110099.

The authors deny any conflicts of interest.

Accepted July 10, 2013

doi: 10.1111/jopr.12102

Abstract

Purpose: Fiber-reinforced composite dowels have been widely used for their superior biomechanical properties; however, their preformed shape cannot fit irregularly shaped root canals. This study aimed to describe a novel computer-aided method to create a custom-made one-piece dowel-and-core based on the digitization of impressions and clinical standard crown preparations.
Materials and Methods: A standard maxillary die stone model containing three prepared teeth each (maxillary lateral incisor, canine, premolar) requiring dowel restorations was made. It was then mounted on an average value articulator with the mandibular stone model to simulate natural occlusion. Impressions for each tooth were obtained using vinylpolysiloxane with a sectional dual-arch tray and digitized with an optical scanner. The dowel-and-core virtual model was created by slicing 3D dowel data from impression digitization with core data selected from a standard crown preparation database of 107 records collected from clinics and digitized. The position of the chosen digital core was manually regulated to coordinate with the adjacent teeth to fulfill the crown restorative requirements. Based on virtual models, one-piece custom dowel-and-cores for three experimental teeth were milled from a glass fiber block with computer-aided manufacturing techniques. Furthermore, two patients were treated to evaluate the practicality of this new method.
Results: The one-piece glass fiber dowel-and-core made for experimental teeth fulfilled the clinical requirements for dowel restorations. Moreover, two patients were treated to validate the technique.
Conclusion: This novel computer-aided method to create a custom one-piece glass fiber dowel-and-core proved to be practical and efficient.

Dowels are usually required to retain cores to restore missing coronal tooth structure during prosthetic treatment. Despite being considered the gold standard,[1] traditional cast metal dowels have been associated with concentrating stress, risking fracturing the root beyond repair.[2] The same shortcoming is also found in dowels made from zirconium oxide.[3] An ideal dowel material should possess physical and mechanical characteristics similar to dentin, be biocompatible, offer reliable adherence to the tooth,[4] and fulfill esthetic demands. Glass- or quartz-fiber reinforced composite meet these requirements and have been recommended for clinical use. Compared to various alloys and dental ceramics, the elastic moduli of glass- or quartz-fiber dowels are closer to those of dentin,[5] and this physical superiority has been confirmed by both in vivo and in vitro studies. The stress was found to be distributed uniformly,[6] root fracture was less likely, and the failure mode was more favorable.[7] Moreover, when endodontic retreatment is necessary, fiber dowels are easily removed.[8] However, as root canals are not regularly circular or tapered, a precise fit cannot be obtained when preformed dowels are used. To adapt root canals to dowels, clinicians must modify the root canal shape using preformed drills. Large amounts of healthy tissue are removed in this manner, eventually weakening the fracture resistance of teeth.[9,10] Moreover, in wide, noncircular, or extremely tapered root canals, the discrepancy between the canal and dowel results in a thicker layer of cement, especially at the coronal portion, which leads to a high level of polymerization stress.[11] Weak areas develop within the cement material after the formation of bubbles or voids, which may compromise dowel retention.[12]

Figure 1 Experimental die stone cast containing three prepared natural teeth.

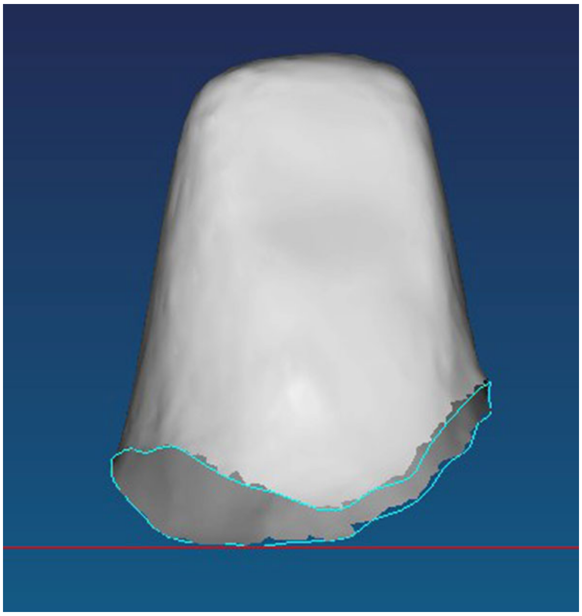

Figure 2 A 3D lateral incisor core: data outside the CL1 (blue-green curve) were cut off through the lowest point on CL1, and a plane (red plane) perpendicular to the Z-axis was constructed.

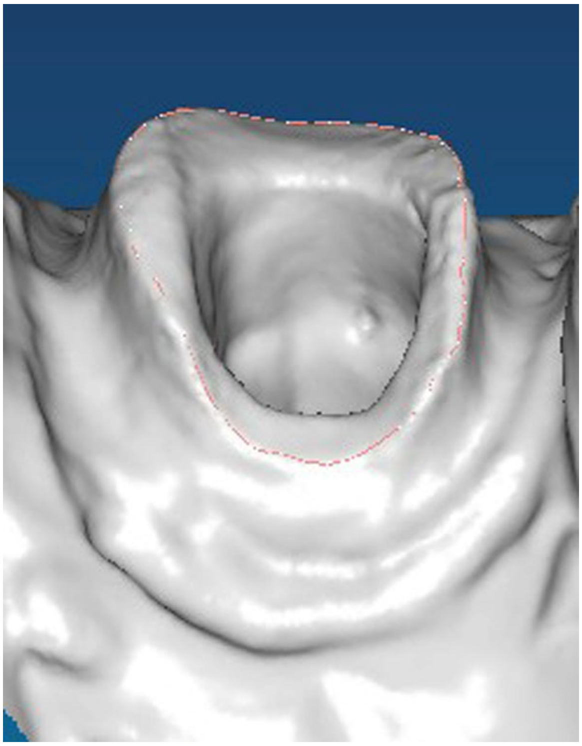

Figure 3 3D data of the residual tooth structure (lateral incisor) and fixed curve TL3 (red curve).

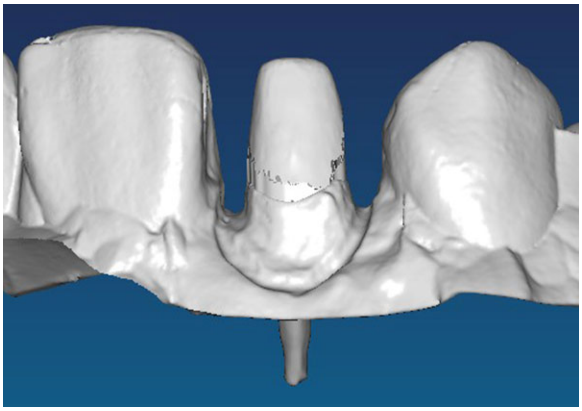

Figure 4 A rudimentary core (lateral incisor) remained in the proper position after the Boolean operation.

Several anatomical fiber dowel forms have been developed that aim to achieve precise dowel adaption without a reduction in fracture resistance. These include preformed oval-shaped glass fiber dowels,[13] custom-modified dowels from large diameter preformed ones,[10] siliceous fiber dowels covered with a layer of composite resin,[14] and the glass or polyethylene fibers directly into the root canal with a dual-cure resin.[15] However, the addition of a composite resin core to the dowel remains necessary for all these methods. Because of the difference in chemistry, the methacrylate-based resin of the composite cannot chemically bond with the epoxy resin of the fiber dowel matrix,[16] and this weak link is partially responsible for the high failure rate encountered in preformed fiber dowel-and-core systems.[17] To prevent interface failure, the dowel and the core should be integrated as a whole.

With the advent of copy-milling technology, a dowel-and-core that can fit any root canal can be custom-made in a single piece.[18,19] Using indirect dowel wax-pattern scanning, Liu et al described a procedure to fabricate a custom one-piece glass fiber dowel-and-core[20] and found that the fracture load of this new form fiber dowel was higher than that of prefabricated ones.[21] To construct a 3D model of the dowel-and-core in traditional copy-milling technology, a direct or indirect wax or acrylic resin pattern must be made. These steps are both time- and material-consuming and often require cooperation with a dental laboratory, and the risk of introducing errors throughout the complex process also increases. To avoid these shortcomings, the

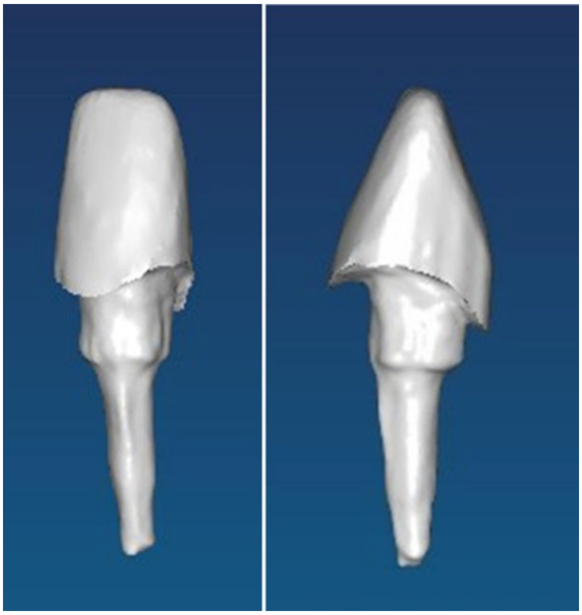

Figure 5 The created virtual model of custom dowel-and-core (lateral incisor) viewed from the labial (left) and distal (right) sides.

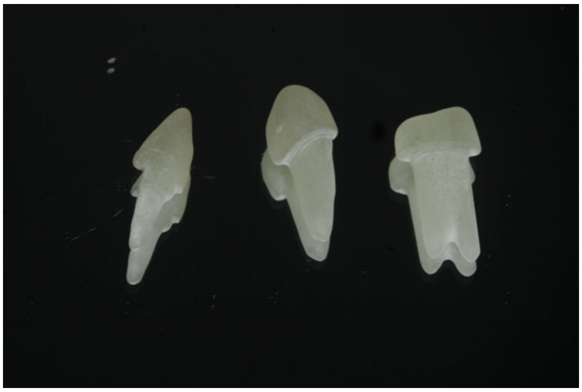

Figure 6 Three custom one-piece glass fiber dowel-and-cores were milled for experimental teeth.

Figure 7 The residual tooth structure was insufficient to support a crown, and a dowel was needed.

Figure 8 The dowel-and-core seated on remaining tooth structure showing good adaptation (buccal view).

Figure 9 The dowel-and-core seated on remaining tooth structure showing good adaptation (occlusal view).

Figure 10 A golden metal-ceramic crown was placed.

number of operative steps should be minimized. The immediate digitization of dowel impressions and the rapid CAD/CAM of a single-piece dowel-and-core in the dental office may be beneficial. This is especially the case where restorative treatments must be completed within a few visits, in which a provisional crown must be placed at the first visit, and preformed dowels would not be sufficient. Furthermore, the prompt placement

Figure 11 The left maxillary central incisor was fractured, and the lateral incisor had a crossbite.

Figure 12 The custom one-piece dowel-and-core was made and prepared to correct the crown palatal inclination.

Figure 13 An all-ceramic crown was placed.

of dowels can reduce the risk of root canal reinfection due to coronal leakage after dowel preparation.

The aim of this in vitro study was to introduce a novel CAD/CAM procedure to fabricate a custom-made one-piece glass fiber dowel-and-core using dowel impression scanning data and clinical standard crown preparation data. Furthermore, the practicality of this new method was also evaluated in clinical conditions.

Materials and methods

Three intact teeth, a maxillary lateral incisor, canine, and second premolar, that had been extracted for periodontal disease or orthodontic reasons were selected for this study. Radiographic and microscopic examinations were carried out to determine the root canal shape and exclude the presence of possible cracks. Conventional endodontic treatment was performed using manual K-files (Dentsply Maillefer, Ballaigues, Switzerland). After root canal and cavity filling, the teeth were stored in normal saline for 2 weeks. Then, they were mounted in a standard maxillary cast made of high-strength die stone (Royal Rock; Pemaco, Inc., St. Louis, MO) according to the tooth position, with the autopolymerizing acrylic resin enveloping the roots up to the cementoenamel junction (CEJ) as an artificial gingiva. To simulate natural occlusion, experimental maxillary and mandibular casts were mounted on an average value articulator. The teeth were decoronated at 1.5 mm coronal to the most incisal/occlusal point of the CEJ with the aid of high-speed diamond bur water irrigation. The residual (TF-12; Mani Inc., Utsunomiya, Japan) under coronal structure was prepared to eliminate undercuts and to gain a clear shoulder at the CEJ level. Dowel space preparation was performed with Peeso reamers (Mani, Inc.) according to the clinical criteria for cast metal dowels. Weak dentin walls and acute angles were eliminated during preparation, especially at the root orifice, using the same TF-12 high-speed diamond bur (Fig 1).

Vinylpolysiloxane (VPS; Flexi-Time; Heraeus Kulzer GmbH, Hanau, Germany) impressions that included each experimental tooth along with two adjacent teeth on either side were obtained using a sectional plastic dual-arch impression tray (3-in-1, Premium Plus, Brooklyn, NY). A single-step dual-viscosity impression technique was used in accordance with the manufacturer's recommendations. The light-bodied impression material was automixed by a hand dispenser system (Dispensing Gun 2; Heraeus Kulzer GmbH) and syringed into and around the root canal. A low-speed metal spiral conveyer was used to transport material into the root canal, and a metal pin was inserted to resist deformation when the impression was removed. Simultaneously, the heavy-bodied material was mixed with an automated machine (Dynamix; Heraeus Kulzer GmbH) and dispensed into both sides of the dual-arch tray. Once the

Figure 14 Radiograph of incisor after 8 months.

tray was seated, the articulator was closed with a constant pressure imposed from the top to simulate an occlusal force. The impression was taken off after a 6-minute period for setting (1 minute longer than stated by the manufacturer's instructions).

A total of 107 (maxillary lateral incisors, n = 36; canines, n = 26; premolars, n = 45) stone casts for metal-ceramic or all-ceramic crowns were collected from the dental clinic at the Department of Prosthodontics, Peking University School, and from the Hospital of Stomatology. Only preparations with clear shoulders, a desirable shape, smooth surfaces, and an ideal space for a definitive crown were included.

A high-precision optical scanner (Activity 102; SmartOptics, Bochum, Germany)[22] was used for 3D digitization. The digitizer has a documented accuracy of up to 10 μm. The scanner projects an array of blue light bands onto the surface of an object, where the light bands would be deformed if the surface were not perfectly flat. A high-resolution charge-coupled device (CCD) captures the resulting band pattern, and the accompanying software automatically processes the images and decodes the surface topography using a triangulation algorithm. Partial data obtained during the digitization from different directions can be aligned and sliced to reconstruct the complete profile of the scanned object. To obtain a complete exposure of the scanning field, redundant impression material was trimmed with a scalpel. The impressions and stone casts were spray coated with a layer of white powder (Arti-Spray, Bausch, Koeln, Germany) at the scanning zone and fixed on a rotation plate in the scanner, which can rotate 360° along a linear axis and tilt. Each object was scanned automatically to provide an overview, and the interest zone was then marked and scanned in detail by manually altering the view angles. Then, data from multiple views were aligned and sliced using the scanner software until a perfect virtual model of the object was reconstructed. The results were exported and saved in the STereo Lithography (STL) format.

The virtual models of stone casts were processed by Imageware (version 11.0; EDS, Palo Alto, CA) to create the core data. The inner boundary line of the shoulder (line 1 of the core, CL1), meaning the conversion line between the shoulder and the axial surface, was drawn by connecting a series of manually fixed interval points, and data outside this line were cut off. The 3D coordinates of the virtual model were then adjusted until the long axis of the core became parallel to the Z-axis, and the positive/negative directions were the same; this new position of the core model was fixed with the coordinate system. From the lowest point on CL1 along the Z-axis, a plane perpendicular to the Z-axis was constructed (Fig 2). The projection of CL1 onto this plane created another circle (line 2 of the core, CL2). From CL2, the largest diameter of the core in the mesiodistal/buccolingual direction and the perimeter of CL2 were measured. The impression was processed in a similar way, where the long axis of the ideal crown for the experimental teeth was determined by referring to the neighboring mesial and distal teeth, and a line (TL1) similar to CL1 on experimental teeth and its projecting line (TL2) were drawn as stated above. The largest diameter in the mesiodistal/buccolingual direction and the perimeter of TL2 were also measured. Finally, the conversion line (TL3) between the top and the axial surface of the residual tooth structure was drawn by connecting a series of manually fixed points (Fig 3). All 3D data were recorded and saved.

According to the values measured, the most suitable and preferably the largest available core was selected for each experimental tooth. The core data were imported into the coordinate system fixed with the impression virtual model. The core was manually regulated (moved and rotated) to an ideal position to meet the requirements of the crown preparation. The height of the core was determined by referring to the occlusion curve deduced from neighboring teeth. The core was visually checked from different directions to ensure correct orientation and appropriate space for the subsequent crown. It was then fixed on top of the experimental tooth, and generally there would be a remaining gap between the core and tooth. Then, TL3 was extended along the Z-axis in the direction of occlusion by a 5 to 6 mm length at a 2° taper. The extension surface was computerized to create a point cloud and a subsequent intuitive STL format virtual model; this surface intersected the core data in a closed junction curve. Then the Boolean operation[23] of Imageware was applied to exclude the data outside the junction curve along the Z-axis, allowing only a rudimentary core to remain (Fig 4). Dowel data were extracted through TL3 from the impression virtual model, maintaining the same spatial relationship between the dowel and the rudimentary core. Finally, Imageware software was used to fill the small holes between/on the virtual dowel-and-core model and to smooth the surface of the core to eliminate any acute angles. The created virtual models of the dowel-and-core were imported and saved in the STL format (Fig 5).

On the basis of these virtual models, one-piece glass fiber dowel-and-cores (Fig 6) were milled from glass fiber blocks (Ouyaruikang Co., Ltd., Beijing, China) with a milling machine (HSC 20 linear, DMG, Seebach, Germany) and used for each canal. Under the guidance of a color indicator (Arti-Spray, Green, Bausch) to test fit, any interference was eliminated with a high-speed finishing diamond bur (Dia-Burs, TR-13EF; Mani Inc.). When the fiber dowel-and-cores were completely seated, a general evaluation of the dowel-and-core adaptation was carried out.

Clinical application 1

A 31-year-old female referral patient from the Department of Endodontics attended the prosthodontic clinic for a metal-ceramic crown of her right first maxillary premolar. Root canal treatment of the tooth had been completed 2 weeks previously, and outcomes were confirmed by clinical and radiographic examinations. Temporary filling material was then removed, and the preliminary preparations for the crown were made. As the residual dentin walls were insufficient to support a crown (Fig 7), a dowel was necessary. The root canal was oval, and the preformed dowel could not be precisely adapted. The patient preferred a nonmetal dowel, and therefore a one-piece glass fiber dowel-and-core was planned. The root canal was prepared to eliminate undercuts. A posterior sectional dual-arch impression was made using VPS, and a custom glass fiber dowel-and-core was designed and fabricated as described above (Figs 8, 9). The root canal was cleaned with 75% alcohol and dried by air stream and paper points. The dowel-and-core was rinsed with an ultrasonic cleaner (VS350; Silfradent Srl, Santa Sofia, Italy) and air dried before being secured with resin cement (RelyX Unicem Aplicap; 3M ESPE, Seefeld, Germany) in a similar manner to that recommended for conventional fiber dowels. The tooth preparation procedures were performed, and the definitive metal-ceramic crown was made as standard (Fig 10). The patient was recalled 6 months after the crown placement, and no complications were noted in either the clinical or radiographic examinations.

Clinical application 2

A 26-year-old female patient attended the Department of Prosthodontics for the restoration of her fractured left maxillary central incisor. Root canal treatment of the tooth had been carried out at the Department of Endodontics 1 month previously. After clinical and radiographic examinations, a glass fiber dowel and an all-ceramic crown for the fractured tooth were planned with the agreement of the patient. As the original crown was mildly lingually inclined, the use of a preformed fiber dowel may have led to a thin resin layer surrounding the dowel on the lingual side of the core, or even dowel exposure after preparation. Therefore, a custom one-piece glass fiber dowel-and-core was adopted. The patient's left maxillary lateral incisor had a cross bite (Fig 11), and therefore the long axis of the created core was determined under the guidance of residual dentin walls considering the symmetry of the central incisors. With a lateral incisor core that was proportionally enlarged in 3D, a customized one-piece dowel-and-core was designed and made, and the lingual inclination of the crown was rectified (Fig 12). The subsequent restorative steps were conducted according to clinical standards until an all-ceramic crown was placed (Fig 13). The patient was recalled 8 months after treatment, no complications occurred, and periapical radiography demonstrated that the fiber dowel-and-core remained well adapted to the dowel space (Fig 14).

Results

Three one-piece glass fiber dowel-and-cores were designed and manufactured for the experimental teeth. The impression digitization and dowel-and-core CAD process usually required 12 to 15 minutes for each step individually. After necessary modifications were made to eliminate interference, all three dowel-and-cores fitted the root canal accurately without undue mobility, and the margin adaptation conformed to clinical principles. The long axis of the core was correct, and the restorative space for a subsequent crown was appropriate. In addition, the shade and translucency of the core were compatible with natural dentin. As a result of the resin property, the core was easier to modify than metal or ceramic.

Two patients were treated, and both received their dowel treatment on their first appointment. The custom-made dowel adapted satisfactorily, and the integrated resin core was sufficient to support a crown. No failure or complication was detected after more than 6 months of follow-up.

Discussion

The present study proposes a rapid procedure to make a custom one-piece glass fiber dowel-and-core with the aid of CAD/CAM technology. The created dowel fit root canals precisely, resulting in a relatively thin and uniform cement layer. The composite resin core was strengthened by being integrated with the dowel and reinforced by glass fibers. Direct digitization of dental impressions made it unnecessary to make a positive stone replica and a restoration wax pattern, thus shortening the treatment time and reducing the amount of required materials. With this simplified method, the entire digitization and design process were accomplished in the dental office after dowel impressions were obtained. The designed virtual models can be transferred to the CAM center through the Internet, and the real dowel can be produced quickly.

The 107 standard crown preparations that form the core database were collected from clinical practice through a restricted selection process, which combined the principles of crown preparation and individual tooth shapes. Although the tooth shape and size varied across gender and race, studies have verified there were normal tooth dimension ranges for specific populations. Many tooth diameter standards have been developed for different populations, including for the Chinese.[24,25] These regular patterns have provided the theoretical possibility of a standard crown preparation database. Although the core could be 3D enlarged or shrunk proportionally to achieve the ideal fit, the insufficient database in the present study frequently led to large discrepancies between the core and defective tooth, highlighting the need for a comprehensive detailed database with an efficient selection index for Chinese populations.

Glass fiber reinforced composite was recommended as an ideal dowel material because its flexural properties are similar to those of dentin,[26] and the bond strength of the FRC dowel to root dentin proved to be more fatigue-resistant than rigid (zirconia) dowels.[27] To make a custom one-piece glass fiber dowel-and-core, CAD/CAM was the only appropriate method. The glass fiber block used in the present study was made of an epoxy polymer matrix appropriate for milling that keeps the fibers together during the milling process. The manufacturer purports that the flexural modulus of this material is 25.0 to 45.0 GPa, which is similar to that of dentin (range of 10 to 30 GPa[28]). D'Arcangelo et al found that when resin cement thickness was 0.1 to 0.3 mm, high bond strengths were obtained for the fiber-reinforced dowels.[29] In the present study, the dowel-and-core can be cut back to its original size in the CAD process or milled to smaller sizes using the CAM procedure to ensure an ideal resin cement thickness.

Data acquisition is the first step in the CAD process. In practice, two main categories of 3D scanners were defined: contact and noncontact. Contact scanners cannot be used on flexible surfaces, such as impression materials, which would be either deformed or worn due to probe contact pressure.[30,31] As noncontact scanning methods were involved, intraoral digitization of the root canal appears to be impractical because of the narrow and deep canal form and the small space of the oral cavity. It was feasible to obtain an impression to duplicate the root canal shape and digitize it with an optical scanner in vitro. Impression digitization excluded possible errors introduced by stone cast and wax-pattern making. DeLong et al found that optical digitization of a VPS impression is surface angle dependent, and that a large digitizing angle (the angle of the impression surface relative to the digitizing head) led to poor digitizing performance.[32] To facilitate the scanning process and obtain accurate data, maximum exposure of the scanning field was important. To this end, all teeth were prepared to eliminate the undercuts before impression duplication was performed, and a wingless section dual-arch tray was used in the present study. The silicone materials blocking the digitization light could then be trimmed away. The accuracy and clinical reliability of dual-arch trays have been proved in many studies.[33-35] A sectional dual-arch tray was capable of covering the relevant teeth to fulfill the design requirements and generate impressions of the prepared teeth (dowel), the opposing teeth, and the interocclusal record simultaneously. This not only simplified the impression procedure, but also was a convenient method to introduce the occlusal relationship into the dowel design process.

There were some limitations to the present study. The proper position of the core was determined manually according to the occlusion curve deduced from adjacent teeth instead of a true occlusal relationship. Therefore, this novel method could not be applied for multiple missing teeth because the reference occlusion curve was lacking. For single-tooth defects, the neighboring teeth on both sides must be intact and in the appropriate position or orientation to accurately determine the core position; however, the opposing teeth and interocclusal record were duplicated by dual-arch trays, and occlusion relationships may still occur in a further improved design process. The core database in the present study contains only three tooth types, and it was therefore insufficient to fulfill the various needs in dental practice. More standard crown preparations are currently being collected and classified, and a specific retrieval index for the most fitting core data will be assessed in future studies.

Conclusions

This in vitro study describes the rapid CAD/CAM method of constructing a custom-made one-piece dowel-and-core based on direct dowel impression scanning and clinical standard crown preparation data. A simplified method was successfully used in two clinical cases, suggesting that this novel method is both practical and efficient.

References

1. Jung RE, Kalkstein O, Sailer I, et al: A comparison of composite post buildups and cast gold post-and-core buildups for the restoration of nonvital teeth after 5 to 10 years. Int J Prosthodont 2007;20:63-69
2. Assif D, Gorfil C: Biomechanical considerations in restoring endodontically treated teeth. J Prosthet Dent 1994;71:565-567
3. Eraslan O, Aykent F, Yücel MT, et al: The finite element analysis of the effect of ferrule height on stress distribution at post-and-core-restored all-ceramic anterior crowns. Clin Oral Investig 2009;13:223-227
4. Fernandes AS, Shetty S, Coutinho I: Factors determining post selection: a literature review. J Prosthet Dent 2003;90:556-562
5. Plotino G, Grande NM, Bedini R, et al: Flexural properties of endodontic posts and human root dentin. Dent Mater 2007;23:1129-1135
6. Yamada Y, Tsubota Y, Fukushima S: Effect of restoration method on fracture resistance of endodontically treated maxillary premolars. Int J Prosthodont 2004;17:94-98
7. Schmitter M, Rammelsberg P, Gabbert O, et al: Influence of clinical baseline findings on the survival of 2 post systems: a randomized clinical trial. Int J Prosthodont 2007;20: 173-178
8. Lindemann M, Yaman P, Dennison JB, et al: Comparison of the efficiency and effectiveness of various techniques for removal of fiber posts. J Endod 2005;31:520-522
9. Fuss Z, Lustig J, Katz A, et al: An evaluation of endodontically treated vertical root fractured teeth: impact of operative procedures. J Endod 2001;27:46-48
10. Plotino G, Grande NM, Pameijer CH, et al: Influence of surface remodelling using burs on the macro and micro surface morphology of anatomically formed fibre posts. Int Endod J 2008;41:345-355
11. Ferracane JL: Developing a more complete understanding of stresses produced in dental composites during polymerization. Dent Mater 2005;21:36-42
12. Grandini S, Goracci C, Monticelli F, et al: SEM evaluation of the cement layer thickness after luting two different posts. J Adhes Dent 2005;7:235-240
13. Signore A, Kaitsas V, Ravera G, et al: Clinical evaluation of an oval-shaped prefabricated glass fiber post in endodontically treated premolars presenting an oval root canal cross-section: a retrospective cohort study. Int J Prosthodont 2011;24: 255-263
14. Savi A, Manfredi M, Tamani M, et al: Use of customized fiber posts for the aesthetic treatment of severely compromised teeth: a case report. Dent Traumatol 2008;24:671-675
15. Piovesan EM, Demarco FF, Cenci MS, et al: Survival rates of endodontically treated teeth restored with fiber-reinforced custom posts and cores: a 97-month study. Int J Prosthodont 2007;20:633-639
16. Monticelli F, Toledano M, Tay FR, et al: A simple etching technique for improving the retention of fiber posts to resin composites. J Endod 2006;32:44-47
17. Vano M, Goracci C, Monticelli F, et al: The adhesion between fibre posts and composite resin cores: the evaluation of microtensile bond strength following various surface chemical treatments to posts. Int Endod J 2006;39:31-39
18. Streacker AB, Geissberger M: The milled ceramic post-and-core: a functional and esthetic alternative. J Prosthet Dent 2007;98:486-487
19. Awad MA, Marghalani TY: Fabrication of a custom-made ceramic post-and-core using CAD-CAM technology. J Prosthet Dent 2007;98:161-162
20. Liu P, Deng XL, Wang XZ: Use of a CAD/CAM-fabricated glass fiber post-and-core to restore fractured anterior teeth: a clinical report. J Prosthet Dent 2010;103:330-333
21. Liu P, Li YN, Jiang H, et al: In-vitro study of the fracture load of CAD/CAM one-piece glass fiber post and core. Beijing J Stomatol 2010;18:90-93(in Chinese)
22. Ayyildiz S, Sahin C, Akgün OM, et al: Combined treatment with laser sintering and zirconium: a case report of dentinogenesis imperfecta. Case Rep Dent 2013;2013, Article ID 745959, doi: 10.1155/2013/745959
23. Jiao T, Zhang F, Huang X, et al: Design and fabrication of auricular prostheses by CAD/CAM system. Int J Prosthodont 2004;17:460-463

24. Uysal T, Sari Z: Intermaxillary tooth size discrepancy and mesiodistal crown dimensions for a Turkish population. Am J Orthod Dentofacial Orthop 2005;128:226-230
25. Ling JY, Wong RW: Tooth dimensions of Southern Chinese. Homo 2007;58:67-73
26. Dominic AS, Adrian CS, Peter MM, et al: The flexural properties of endodontic post materials. Dent Mater 2010;26:730-736
27. Bottino MA, Baldissara P, Valandro LF, et al: Effects of mechanical cycling on the bonding of zirconia and fiber posts to human root dentin. J Adhes Dent 2007;9:327-331
28. Kinney JH, Marshall SJ, Marshall GW: The mechanical properties of human dentin: a critical review and reevaluation of the dental literature. Crit Rev Oral Biol Med 2003;14:13-29
29. D'Arcangelo C, Cinelli M, De Angelis F: The effect of resin cement film thickness on the pullout strength of a fiber-reinforced post system. J Prosthet Dent 2007;98:193-198
30. Ireland AJ, McNamara C, Clover MJ, et al: 3D surface imaging in dentistry—what we are looking at. Br Dent J 2008;205:387-392
31. Quaas S, Rudolph H, Luthardt RG: Direct mechanical data acquisition of dental impressions for the manufacturing of CAD/CAM restorations. J Dent 2007;35:903-908
32. DeLong R, Pintado MR, Ko CC, et al: Factors influencing optical 3D scanning of vinyl polysiloxane impression materials. J Prosthodont 2001;10:78-85
33. Ceyhan JA, Johnson GH, Lepe X: The effect of tray selection, viscosity of impression material, and sequence of pour on the accuracy of dies made from dual-arch impressions. J Prosthet Dent 2003;90:143-149
34. Ceyhan JA, Johnson GH, Lepe X, et al: A clinical study comparing the three-dimensional accuracy of a working die generated from two dual-arch trays and a complete-arch custom tray. J Prosthet Dent 2003;90:228-234
35. Johnson GH, Mancl LA, Schwedhelm ER, et al: Clinical trial investigating success rates for polyether and vinyl polysiloxane impressions made with full-arch and dual-arch plastic trays. J Prosthet Dent 2010;103:13-22