REVIEW ARTICLE

Computer-aided Design/Computer-aided Manufacturing (CAD/CAM) Machines With Scanning and Milling Capabilities for Fabricating Custom Posts and Cores: A Narrative Review

Nor Faharina Abdul Hamid, Rohana Ahmad

Centre of Restorative Studies, Faculty of Dentistry, Universiti Teknologi MARA, Jalan Hospital 47000 Sungai Buloh, Selangor.

ABSTRACT

Custom cast metal posts and cores are time-consuming to make, requiring several clinical and laboratory stages and the use of gold, cobalt-, or nickel-chromium. Aside from the numerous stages involved, a cast metal post and core has a significantly higher modulus of elasticity than the dentinal root structure and, as a result, is more likely to cause root fracture. Furthermore, the metal colour of the post and core, which always appears as a dark shadow beneath a ceramic crown, is an aesthetic concern. Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) of posts and cores is a potential fabrication option for overcoming the issues associated with cast metal posts and cores. Some of the time-consuming clinical and laboratory procedures can be eliminated by using a CAD/CAM machine, and tooth-colored materials can be milled to create custom posts and cores. The marginal and internal adaptation of the CAD/CAM produced posts and cores to the tooth structure, on the other hand, is highly dependent on the scanning accuracy and milling capability of the CAD/CAM machine. Because the majority of studies on dental CAD/CAM have concentrated on the fabrication of fixed and removable prostheses, data on the marginal accuracy and internal adaptation of CAD/CAM produced posts and cores is limited. As a result, the aim of this review paper is to determine the current state of the market's CAD/CAM machines in terms of their scanning and milling capability to produce custom posts and cores that match the marginal and fitting accuracy of cast metal posts and cores.

Keywords: Computer-aided design, Computer-aided manufacturing, Core, Milling, Post

Corresponding Author:
Nor Faharina Abdul Hamid, M. Rest.Dent
Email: faharina@uitm.edu.my
Tel: +603-6126 6593

INTRODUCTION

In the case of substantial loss of coronal tooth structure following root canal treatment, a post is recommended to provide retention to the core and crown of the tooth (1). Although there are many different types of posts, they can all be categorised by how they are made: ready-made (prefabricated) or custom-made. Prefabricated post can yield great outcomes in a case of adequate dentinal wall bulk; however, in the situation of substantial tooth structure loss, custom-made post and core is preferable since it allows for better post-canal wall adaption (2-5). Fabrication of custom-made post and cores traditionally entails a number of clinical and laboratory stages. It can be done in a clinical setting using either a direct method, which involves the fabrication of an auto polymerizing or light-polymerized acrylic resin pattern build up, or an indirect method, which involves the impression of the canal space with polyvinylsiloxane (PVS). The metal post and core are then constructed in the laboratory using the lost-wax-casting technique. This traditional procedure is considered technique-sensitive, necessitates many appointment visits, and adds to clinical and laboratory time. Furthermore, dimensional changes in the resin pattern, impression, investment material, and casting alloy can have a substantial impact on the precision of the final prosthesis (6, 7).

One of the biggest drawbacks of custom-made post and core is the scarcity of suitable materials. Gold, cobalt-chromium, or nickel-chromium are the most common materials used for custom built post and cores. Although these materials have a high success rate and a good long-term prognosis (8-10), the main disadvantages are the variation in elasticity modulus and colour. The considerable elasticity differential between the post material and the root dentine causes non-homogeneous stress in the tooth structure, resulting in catastrophic root fracture (9, 12). Furthermore, corrosion of custom-made post and core from non-noble alloys causes an aesthetic problem when used in conjunction with an all-ceramic crown system, as it can generate a blue-grey look (13).

The advancement of computer-aided design/computer-aided manufacturing (CAD/CAM) technology in dentistry has brought an alternate solution in producing post and cores to traditional impression making and casting procedures (14). CAD/CAM technology can be utilised in conjunction with tooth-colored materials to meet the aesthetic requirements of dental restorations in a single day. It provides a wide range of material possibilities, allowing clinicians to select materials with similar modulus of elasticity. Despite the fact that all CAD/CAM materials on the market are intended for extracoronal restorations, researchers and clinicians have attempted to use ceramic (lithium disilicate-reinforced glass-ceramic, zirconia-reinforced lithium silicate glass-ceramic, zirconium oxide, hybrid glass ceramic) (15, 16), resin (polymer infiltrated ceramic network (PICN), nano ceramic (17, 18), and experimental fibre reinforced composite (FRC) (4, 19, 20) to fabricate CAD/CAM post and core.

Apart from being aesthetically pleasing and having better mechanical qualities, the materials can bond to root dentin, resulting in better stress distribution throughout the tooth structure. Because of the potential to produce a monobloc effect due to the comparable composition of material, the one-piece post and core unit provides good adaptability because minimal post-core separation is expected (21). Bittner et al., further claimed that the monobloc post and core can prevent core delamination because there are no interfaces between the two materials (11). With the advancement of CAD/CAM technology, the types of dental restorations that may be made utilising this technique are practically limitless. Overall, CAD/CAM aids in the simplification of restorative procedures, the reduction of clinical chair time, and the achievement of clinical success (11, 22-24). However, the majority of scanners, milling machines, and other CAD/CAM equipment currently on the market are specifically intended for extra coronal restorations, not for intracoronal restorations such as posts and cores. Although CAD/CAM is well known for its ability to streamline clinical and laboratory procedures, it is also critical to have a scanner and milling machine that can properly scan posts and cores in order to make high-quality prostheses with good fitting precision. Previous research has shown that CAD/CAM produces equivalent or better results than traditional fabrication methods since it eliminates many fabrication phases in the course of the procedure (24-26). However, there is a scarcity of data on the marginal accuracy and internal adaption of CAD/CAM-produced posts and cores. The question is, “Are the CAD/CAM scanners and milling machines that are currently available on the market well-suited for scanning and machining the posts and cores?” As a result, the aim of this paper is to provide a review of current CAD/CAM scanner and milling machine capacity for scanning and milling posts and cores based on published literature.

CAD/CAM (COMPUTER AIDED DESIGN/COMPUTER AIDED MANUFACTURING)

In general, CAD/CAM systems are divided into chairside and laboratory systems, with the latter being further divided into open and closed systems based on data sharing (27). In close systems, no interchangeability of data, design, or production between different systems from different companies was allowed, however open systems will allow digital data to be accepted by CAD software and CAM machines from other companies (27). A CAD/CAM system consists of three primary components: a scanner that converts the geometry of the receptor (tooth) into digital data, CAD software for designing the prosthesis, and a milling machine for fabricating the final restoration (28).

CAD/CAM SCANNER

CAD/CAM scanners has been extensively used and investigated in fixed prostheses such dental veneers, onlays, crowns, bridges, and implant-supported restorations, as well as removable prostheses. However, only a few studies have looked into the scanners for CAD/CAM posts and cores (Table I). Current review shown that most of scanners used are laboratory scanner. Laboratory scanners can be optical scanners that use a laser or mechanical scanners that read the master cast with a ruby ball. In 2013, 3shape™ (Trios®, Denmark) announced the launch of a new intraoral scanner called 3shape Scan Posts™, which consists of a variety of forms and sizes of scan bodies designed exclusively for scanning the post and core. The technology was created with the goal of facilitating and capturing the detailed depth of post and core restorations. It can be used at the chairside or in the laboratory (29). Despite the fact that it had been on the market for 8 years, there was very little in vitro and clinical study on the scan post bodies.

SCANNING TECHNIQUE AND ACCURACY OF CAD/CAM POST AND CORE

In 2007, Awad and Marghalani were the first clinicians to introduce a step-by-step clinical technique for post and core fabrication utilising CAD/CAM. They gave an excellent illustration of ideal post and core design, which included a large post-core junction and coronal portion, a round internal angle, and a good ferrule design (15). However, no common tooth preparation recommendations for CAD/CAM generated post and core were created after that. Following that, multiple attempts were made to create CAD/CAM post and core using various technologies.

The fabrication of CAD/CAM posts and cores can be divided into two categories: direct digitalization and indirect digitalization. Direct digitalization is an ideal technique because it allows the clinician to rapidly identify the preparation margin and design the prosthesis at the chairside, eliminating the need for a laboratory process. Although direct digitalization may simplify the whole fabrication process by minimising clinical and laboratory procedures, such techniques

Table I: Type of scanner used, post length, scanning method and milling machine used in CAD/CAM post and core based on clinical case report/case series

References	Scanner			Milling machine		
	Manufacturer	Post length	Scanning method	Manufacturer	Types of milling machine	Axis
Awad and Marghalani 2007 (15)	Cercon; DeguDent GmbH	NS	Resin pattern-ID of resin pattern	Cercon; DeguDent	Laboratory	3-axis
Streacker, and Geissberg-er,2007 (49)	CEREC inLab	NS	Resin pattern-ID of resin pattern	CEREC inLab	Laboratory	3-axis
Liu and Wang 2010 (48)	SmartVision; Gim-mafei Tech	8 mm	Impression-gypsum-resin patten-ID of resin pattern	VMC 850s	Laboratory	4-axis
Vinothkumar, Kandas-wamy,and Chanana 2011(21)	CEREC InLab 3D	NS	Impression-gypsum-ID of gypsum	NS	NS	NS
Kumar and Patil, 2012(50)	Amann Girrbach	NS	Impression-gypsum- ID of resin pattern	Amann Girrbach	Laboratory	Not known
Chen et al, 2014 (51)	Activity 102; Smar-tOptics	NS	Impression-gypsum- ID of gypsum	HSC 20 linear, DMG	Laboratory	5-axis
Lee 2014 (31)	TRIOS Color Pod; 3Shape	NS	Impression-gypsum- ID of gypsum	Ceracube CM5	Laboratory	5-axis
Lee, Sohn, and Lee 2014 (53)	D800; 3Shape	NS	DD-3D printing to make polyurethane cast-core design based on contralateral teeth.	Ceracube CM5	Laboratory	5-axis
Gьlnahar, Soygun, and Bo-layır 2016 (54)	Dental Wings	NS	Resin-pattern-ID with resin pattern	Dental Wings	Laboratory	5-axis
Spina et al. 2018 (55)	Ceramill Map400	NS	Impression-ID impression	Ceramill Motion 2	Laboratory	5-axis
Lee 2018 (23)	Identica Blue	NS	Impression-ID impression	Arum 5X-200	Laboratory	5-axis
Libonati et al. 2020 (32)	Trios,3shape	9 mm	DD	Roland DWX-50	Laboratory	5-axis
Farah, Aloraini, and Al-Haj Ali 2020 (42)	Artica Autoscan	NS	Impression-ID impression	inLab MC X5	Laboratory	5-axis

*NS- non specify *DD-Direct digitalization * ID- Indirect digitalization

have failed to address the problem of narrow root canal detection during scanning using the present CAD scanner technology (30). According to the findings of a preliminary in vitro investigation, the existing CAD system was unable to achieve consistent reading depth due to difficulties encountered by light beams when attempting to reach the deepest point of the post space, which resulted in only partial post space scanning. Another in vitro study demonstrated that the intraoral CEREC (Chairside Economical Restoration of Esthetic Ceramics) system can only scan post space lengths of less than 10 mm in length (13). Other than these few studies, data on scanning accuracy of post space is severely lacking as the majority of publications on CAD/CAM posts and cores are case reports focusing on the clinical procedures only. Table 1 listed the manufacturer of the CAD/CAM scanners, the length of the posts, and the scanning method that had been employed in prior studies. Lee made the first attempt to use direct digitalization when developing the post and core, incorporating fibre reinforced composite post and quick prototype process (31). Following that, only one case study reported using direct digitalization to a depth of 9 mm, with apical seals of 6–7 mm gutta percha (32). Because prior in vitro studies have shown that direct digitalization can only scan up to 10 mm or less, it is vital to remember that the crown-to-root ratio is important during post and core fabrication. Previous research has shown that posts with a length equal to two-thirds of the root length, or at least the same length as the crown height, have a better success rate clinically (33, 34). As a result, case selection was critical while preserving the concept, as it is critical to give resistance to occlusal forces as well as aid in stress distribution to the remaining tooth structure (35).

As previously mentioned, 3Shape created chairside intraoral Scan Posts™ to make post and core scanning easier (29). Despite the fact that the systems have been on the market for some time, in vitro research and clinical validity are still lacking, with just three studies evaluating the system and assessing the marginal and internal gap of CAD/CAM post and core in relation to scanning technique (36-38). Moustapha et al., compared direct digitalization procedures employing several types of scanners (intraoral scanner and laboratory scanner) to indirect digitalization techniques in a previous study (using resin pattern or silicone impression). They came to the conclusion that direct digitalization was more adaptable and accurate than indirect digitalization. This is owing to the availability of data obtained during intraoral post scanning, which allows CAD/CAM software to trim the post to suit the canal if there is an undercut. Furthermore, the indirect digitalization technique is said to have additional variables during the fabrication process (37). This study would have been more meaningful if the researchers had included a control group of traditional custom-made post and core for comparison. As a result, a study was conducted to compare traditional, direct digitalization, and indirect digitalization strategies for gaining access to the apical gap of CAD/CAM post and core (38). In terms of the apical gap, they discovered that traditional procedures were more accurate than direct or indirect digitalization techniques (38). A recent study confirmed previous findings that direct digitalization using a scan post causes a larger apical gap in CAD/CAM post and core, concluding the superiority of traditional custom-made cast post and core, which offers better adaptation coronally and apically in both round and oval root canals (36). Jafarian et al., (2020) also pointed out the limitations of their study, which was primarily laboratory-based, and urged that more research be done to incorporate other clinical measures including saliva and temperature.

Apart from direct digitalization, indirect digitalization was used to create CAD/CAM post and cores, which involved the impression of the post space with a resin pattern, gypsum material, or PVS impression, all of which had advantages and disadvantages. The use of a resin pattern may lengthen the clinical procedure and increase the risk of residual material becoming lodged inside the canal, as well as polymerization shrinkage (39). A recent study found that errors in scanning or machining could jeopardise the final product, with the author reporting a 3.59 percent inaccuracy during post copy milling (40). In addition, laboratory costs and the possibility of dimensional changes in gypsum products are potential disadvantages of employing the indirect digitalization process with gypsum (41). Although PVS can save more clinical chairside time, it is critical to check the passivity of the PVS post and core pattern before milling to avoid unwanted chairside changes (42). For indirect digitalization techniques to be used in conjunction with clinical adaptation, Perucelli et al., acknowledged that indirect digitalization or "half-digital workflows" approaches might provide a clinically acceptable range in terms of adaptation, emphasising the advantages of being less time demanding than traditional techniques of fabricating of posts and cores (43). On the basis of a survey of existing research, the possible scanning approaches for the posts and cores are summarised in Figure 1.

Based on the facts presented in this section, it is proposed that, with current technology, direct digitalization may not be the best method for producing CAD/CAM post and core in clinical settings when longer post length is required. This is especially true in the case of longer teeth like incisors or canines, as research shows that direct digitization can only scan up to 10 mm in length. There is no consensus on the best scanning and designing system for CAD/CAM post and core based on the available scientific evidence; however, indirect digitalization can provide a fabrication alternative for CAD/CAM post and core in clinical settings where it is needed, as direct digitalization is not yet fully established. As a result, more research should be done, with a

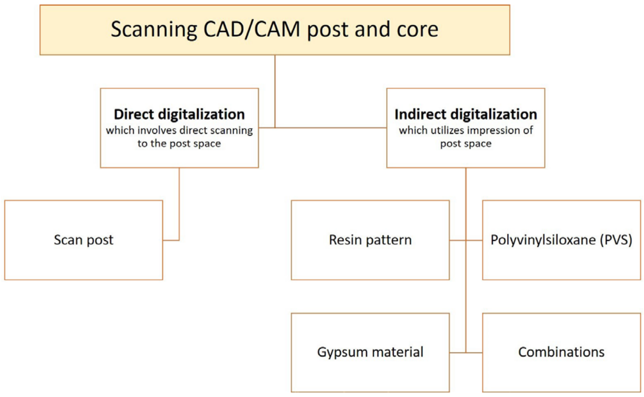

Figure 1: CAD/CAM post and core scanning

focus on developing direct digitalization techniques so that they may be used fully for chairside applications. Furthermore, in a future study, the evaluation of marginal gap and internal adaptation after fabrication of CAD/CAM posts and cores to validate accuracy should be highlighted. Although marginal gaps are lessening with the advancement of CAD/CAM techniques, the current data available is primarily for extra coronal restoration. The scientific evidence currently available does not allow for definitive conclusions to be reached about the superiority of a CAD/CAM scanner in terms of posts and cores fabrication. However, in aesthetically challenged teeth with large flared root canals, CAD/CAM posts and cores can be a viable treatment alternative (21, 32, 44).

CAD/CAM MILLING MACHINE

Prior to restoration fabrication, the CAD software will process the data and create a digital 3-dimensional (3D) model of the prosthesis (4). Milling, often known as machining, is the final production process of a dental CAD/CAM block that uses subtraction manufacturing technology (27). To meet the requirements for accuracy, high milling accuracy helps to eliminate prosthesis adjustment and modification of internal adaption (45). Figure 2 depicts the milling machine categorization, which is divided into two categories: wet processing and dry processing, as well as the number of axes (three, four, or five) (28).

In this review, milling machines are discussed based on the number of axes. A three-axes milling machine moves in three spatial directions: X, Y, and Z, but a four-axes milling machine moves in three spatial directions while rotating around the X axes. Apart from the three spatial directions, there is an additional rotation at the X and Y axes for five axes (27, 28). Extraoral prosthesis such as veneers, inlays, onlays, crowns, or fixed partial dentures are commonly milled on three- or four-axis milling machines in dental clinics. Five-axis milling machines, on the other hand, are more typically seen in dental laboratories and are utilised for more complicated restorations such as post and core, telescope crowns, splints, models, bars, surgical drill guides, implant

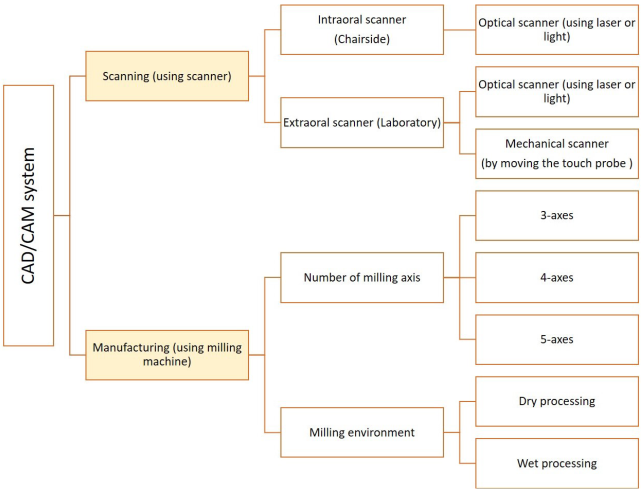

Figure 2: CAD/CAM systems

abutments, or screw retained implant crowns (27). The milling procedure's purpose is to create an exact replica of the prosthesis that was developed digitally. In this situation, the milled prosthesis' entire surface should be comparable to the original CAD data set, indicating excellent milling quality (45). The type of milling machine used can have a big impact on the final adaption of a restoration (27, 46), especially when it comes to post and core restorations with complicated geometry and internal angles compared to extra coronal restorations. Furthermore, the size and shape of the rotary instrument in the milling machine can have an impact on the final restoration's adaptability (46). Bosch, Ender, and Mehl (2014) found that 5-axis milling machines have a higher trueness than 4-axis milling machines when assessing the trueness of partial crowns using different milling units. They also recommended using a smaller diameter rotary cutting device, which would result in a more precise milling technique (45). A more recent study looked at the accuracy of milling machines, taking into account various milling machines, milling techniques, milling strategy, and instrument geometry. Kirsch et al., backed up an earlier study that found that five-axis milling devices produce high trueness of prosthesis, whereas extra-fine mode in a four-axis milling machine (MCXL) produces results comparable to five-axis milling machines, implying that chairside fabrication could be possible (46).

CAD/CAM POST AND CORE MILLING

Although the choice between chairside digital fabrication and laboratory-based fabrication is dependent on materials, manufacturer recommendations, and clinician preferences (47), the majority of milling machines used in CAD/CAM post and core studies were laboratory-based milling machines (Table I). The milling machine with five axes can mill vertical and steep walls, as well as small angles in the presence of undercuts from various directions (27, 46). These extra axes are required to mill the post and core complicated designs, as they must spin in additional axes (37, 47, 48). Libonati et al., also suggested reducing vibration during the milling process by utilising a slower, lower-stress milling machine can reduce inaccuracy and failure (32). To avoid post-breakage, Moustapha et al. proposed coordinating the machining procedure with an extra-fine milling approach (37). Over milling with less than the diameter of the milling rotary instrument might result in a less precise prosthesis and could damage the restoration complex, therefore accuracy of the milling technique is critical (27, 46).

There is no information in this area about the impact of various milling methods on the accuracy of milled CAD/CAM post and core. As a result, future study should focus on the necessity of a precise milling process for a well-fitting restoration, as it aids in the improvement of the finishing and polishing processes, as well as the production of fewer marginal gaps, which leads to increasing restoration lifespan. Following that, once the CAD/CAM milling machine has attained consistent quality and accuracy, it aids in reducing laboratory intensity and producing less expensive prosthesis than conventionally produced post and core.

CONCLUSION

The following conclusions can be drawn based on the findings of this review:

1. Direct digitization using currently available CAD scanners is still limited, as it can only capture canal features for post lengths of 10 mm or less.
2. Indirect digitalization can be employed as a backup option in any clinical scenario with a post length of more than 10 mm.
3. The optimum milling machine for CAD/CAM post and core fabrication is an extra-fine milling machine with 5-axes and a slow and low-stress machining technique. However, because this is based on assumption information from extra coronal restoration, more research is needed to verify the statement.
4. Due to the limited data available, no conclusive conclusions on the marginal gap and adaptation on the superiority of CAD/CAM technology for post and core can be reached.

In short, while tooth-colored CAD/CAM blocks have good aesthetic and mechanical compatibility, continuous development and improvement of CAD/CAM scanners and milling machines is essential for producing high-quality CAD/CAM post and core restorations. The number of CAD/CAM post and core studies is expected to increase in the future. As a result, future research should focus on the development of CAD/CAM systems capable of accurately scanning and recording the entire length of canal depth prior to milling of CAD/CAM post and core.

ACKNOWLEDGEMENT

We would like to acknowledge the Fundamental Research Grant Scheme for Research Acculturation of Early Career Researchers (FRGS-RACER) 600-IRMI/ FRGS-RACER 5/3 (020/2019) for the support.

REFERENCES

1. Girotto LPS, Dotto L, Pereira GKR, Bacchi A, Sarkis-Onofre R. Restorative preferences and choices of dentists and students for restoring endodontically treated teeth: A systematic review of survey studies J Prosthet Dent. 2020; Article in press.
2. Soares LP, de Souza PG, Garcia C, Barino B. Designing a custom-made post and core using CAD/CAM technology's CEREC system. CJRDP. 2014;7(3):40-8.
3. Plasmans P, Visseren L, Vrijhoef M, KΔyser A. In vitro comparison of dowel and core techniques for endodontically treated molars. J Endod. 1986;12(9):382-7.
4. Pang J, Feng C, Zhu X, Liu B, Deng T, Gao Y, et al. Fracture behaviors of maxillary central incisors with flared root canals restored with CAD/CAM integrated glass fiber post-and-core. Dent Mater J. 2019;38(1):114-9.
5. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod. 2004;30(5):289-01.
6. Gelbard S, Aoskar Y, Zalkind M, Stern N. Effect of impression materials and techniques on the marginal fit of metal castings. J Prosthet Dent.1994;71(1):1-6.
7. Blackman R, Baez R, Barghi N. Marginal accuracy and geometry of cast titanium copings. J Prosthet Dent. 1992;67(4):435-40.
8. Bergman B, Lundquist P, Sjo U. Restorative and endodontic results after treatment with cast posts and cores. J Prosthet Dent. 1989;61(1):10-5.
9. Fraga R, Chaves B, Mello G, Jr JS. Fracture resistance of endodontically treated roots after restoration. J Oral Rehabil. 1998;25(11):809-13.
10. Martinez-Insua A, Da Silva L, Rilo B, Santana U. 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. 1998;80(5):527-32.
11. Bittner N, Hill T, Randi A. Evaluation of a one-piece milled zirconia post and core with different post-and-core systems: An in vitro study. J Prosthet Dent. 2010;103(6):369-79.
12. Akkayan B, Gьlmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent. 2002;87(4):431-7.
13. Kalyoncuoğlu E, Ural З, Aydemir H, Aslan MA, Balkaya V. Effect of 1-piece post and core fabrication techniques on fracture strength. J Appl Biomater Funct Mater. 2015;13(3):253-8.
14. Rosentritt M, Furer C, Behr M, Lang R, Handel G. Comparison of an vitro fracture strength of metallic and tooth coloured posts and cores. J Oral Rehabil. 2000;27(7):595-601.
15. Awad MA, Marghalani TY. Fabrication of a custom-made ceramic post and core using CAD-CAM technology. J Prosthet Dent. 2007;98(2):161-2.
16. Dede DO, Celik E, Tulga A, Sariyilmaz E, Cakici F, Cakici EB, et al. Fracture strength of endodontically treated teeth restored with novel CAD/CAM ceramic post systems. Ann Med Res. 2021;28(2):267-74.
17. Alkhatri R, Saleh ARM, Kheder W. Impact of post and core materials on the apical extension of root fracture in root canal treated teeth. J Mater Res Technol. 2021; 10:730-7.
18. Borzangy SS, Saker SM, Al-Zordk WA. Effect of restoration technique on resistance to fracture of endodontically treated anterior teeth with flared root canals. J Biomed Res. 2019;33(2):131-8.
19. Tsintsadze N, Juloski J, Carrabba M, Tricarico M, Goracci C, Vichi A, et al. Performance of CAD/CAM fabricated fiber posts in oval-shaped root canals: An in vitro study. Am J Dent. 2017;30(5):248-54.
20. da Costa RG, Freire A, Caregnatto de Morais EC, Machado de Souza E, Correr GM, Rached RN. Effect of CAD/CAM glass fiber post-core on cement micromorphology and fracture resistance of endodontically treated roots. Am J Dent. 2017;30(1):3-8.
21. Vinothkumar TS, Kandaswamy D, Chanana P. CAD/CAM fabricated single-unit all-ceramic post–core–crown restoration. J Conserv Dent 2011;14(1):86-9.
22. Meyenberg KH, Luthy H, Scharer P. Zirconia posts: a new all-ceramic concept for nonvital abutment teeth. J Esthet Restor Dent. 1995;7(2):73-80.
23. Lee JH. Fabricating a custom zirconia post-and-core without a post-and-core pattern or a scan post. J Prosthet Dent. 2018;120(2):186-9.
24. Hamid NFA, Bakar WZW, Ariffin Z. Marginal gap evaluation of metal onlays and resin nanoceramic computer-aided design and computer-aided manufacturing blocks onlays. Eur. J. Dent. 2019;13(01):017-21.
25. Abdel-Azim T, Rogers K, Elathamna E, Zandinejad A, Metz M, Morton D. Comparison of the marginal fit of lithium disilicate crowns fabricated with CAD/CAM technology by using conventional impressions and two intraoral digital scanners. J Prosthet Dent. 2015;114(4):554-9.
26. Dolev E, Bitterman Y, Meirowitz A. Comparison of marginal fit between CAD-CAM and hot-press lithium disilicate crowns. J Prosthet Dent. 2019;121(1):124-8.
27. Alghazzawi TF. Advancements in CAD/CAM technology: Options for practical implementation. J. Prosthodont. Res. 2016;60(2):72-84.
28. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br. Dent. J.

2008;204(9):505-11.
29. 3Shape. 3Shape Releases CAD Solution for Post and Core Restorations Denmark 2013 Available from: https://www.3shape.com/en/press/2013/cad-solution-for-post-and-core-restorations (Accessed June 2021).
30. Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the current literature. BMC Oral Health. 2017;17(1):1-11
31. Lee JH. Accelerated techniques for a post and core and a crown restoration with intraoral digital scanners and CAD/CAM and rapid prototyping. J Prosthet Dent. 2014;112(5):1024-9.
32. Libonati A, Di Taranto V, Gallusi G, Montemurro E, Campanella V. CAD/CAM customized glass fiber post and core with digital intraoral impression: a case report. Clin Cosmet Investig Dent. 2020; 12:17-24
33. Braga NMA, Paulino SM, Alfredo E, Sousa-Neto MD, Vansan LP. Removal resistance of glass-fiber and metallic cast posts with different lengths. J Oral Sci. 2006;48(1):15-20.
34. Cecchin D, Farina AP, Guerreiro CAM, Carlini-Júnior B. Fracture resistance of roots prosthetically restored with intra-radicular posts of different lengths. J Oral Rehabil. 2010;37(2):116-22.
35. Santos-Filho P, Castro C, Silva G, Campos R, Soares C. Effects of post system and length on the strain and fracture resistance of root filled bovine teeth. Int Endod J. 2008;41(6):493-501.
36. Jafarian Z, Moharrami M, Sahebi M, Alikhasi M. Adaptation and Retention of Conventional and Digitally Fabricated Posts and Cores in Round and Oval-Shaped Canals. Int J Prosthodont. 2020;33(1):91-8.
37. Moustapha G, AlShwaimi E, Silwadi M, Ounsi H, Ferrari M, Salameh Z. Marginal and internal fit of CAD/CAM fiber post and cores. Int J Comput Dent. 2019;22(1):45-53.
38. Hendi AR, Moharrami M, Siadat H, Hajmiragha H, Alikhasi M. The effect of conventional, half-digital, and full-digital fabrication techniques on the retention and apical gap of post and core restorations. J Prosthet Dent. 2019;121(2):1-6.
39. Rosenstiel SF, Land MF. Contemporary fixed prosthodontics. 5th Edition ed: Elsevier Health Sciences; 2015.
40. Dayalan M, Jairaj A, Nagaraj K, Savadi RC. An evaluation of fracture strength of zirconium oxide posts fabricated using CAD-CAM technology compared with prefabricated glass fibre posts. J. Indian Prosthodont. 2010;10(4):213-8.
41. de Moraes AP, Neto VP, Boscato N, Pereira-Cenci T. Randomized clinical trial of the influence of impression technique on the fabrication of cast metal posts. J Prosthet Dent. 2016;116(1):47-51.
42. Farah RFL, Aloraini AS, Al-Haj SNA. Fabrication of Custom Post-And-Core Using a Directly Fabricated Silicone Pattern and Digital Workflow. J Prosthodont. 2020;29(7):631-5.
43. Perucelli F, da Costa RG, de Souza EM, Rached RN. Effect of half-digital workflows on the adaptation of customized CAD-CAM composite post-and-cores. J Prosthet Dent. 2020; Article in press.
44. Liu P, Deng X, Wang X. Use of a CAD/CAM-fabricated glass fiber post and core to restore fractured anterior teeth: a clinical report. J Prosthet Dent. 2010; 103:330-3.
45. Bosch G, Ender A, Mehl A. A 3-dimensional accuracy analysis of chairside CAD/CAM milling processes. J Prosthet Dent. 2014;112(6):1425-31.
46. Kirsch C, Ender A, Attin T, Mehl A. Trueness of four different milling procedures used in dental CAD/CAM systems. Clin. Oral Investig. 2017;21(2):551-8.
47. Blatz MB, Conejo J. The current state of chairside digital dentistry and materials. Dent Clin N Am. 2019;63(2):175-97.
48. 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(6):330-3.
49. Streacker AB, Geissberger M. The milled ceramic post and core: A functional and esthetic alternative. J Prosthet Dent. 2007;98(6):486-7.
50. Kumar R, Patil S. Forced orthodontic extrusion and use of CAD/CAM for reconstruction of grossly destructed crown: A multidisciplinary approach. J Conserv Dent. 2012;15(2):191-5.
51. Chen Z, Li Y, Deng X, Wang X. 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. 2014;23(4):276-83.
52. Lee JH, Sohn DS, Lee C-H. Fabricating a fiber-reinforced post and zirconia core with CAD/CAM technology. J Prosthet Dent. 2014;112(3):683-5.
53. Gьlnahar E, Soygun K, Bolayır G. The Customized Forming of the Applied Post-Core System: Case Reports. J Dent Probl Solut 2016;8418(3):31-4.
54. Spina DRF, da Costa RG, Correr GM, Rached RN. Scanning of root canal impression for the fabrication of a resin CAD-CAM-customized post-and-core. J Prosthet Dent. 2018;120(2):242-5.