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Adaptability of glass fiber posts fabricated by chair side versus in lab CAD/CAM technology

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Abstract:
***Background**: The passive fit of the endodontic post and the presence of a homogenous cement layer surrounding it can prevent harmful torque and levers on the tooth structure that might predispose it to fracture. If posts are not well adapted to the root canals, a thicker layer of resin cement is necessary to fill them, increasing the shrinkage stresses induced by the polymerization of this material. Since the post adaptation was a crucial factor for successful endodontic restoration, therefore the aim of this in-vitro study will be directed to compare the adaptation of glass fiber posts fabricated by chair side versus in lab CAD/CAM technology.*
***Materials and Methods**: A human maxillary central incisor was selected. The selected tooth crown was separated vertical to the tooth-long axis achieving a standardized length of 14 mm. The root canal was endodontically treated and the post space was prepared length of 9 mm. The prepared root was scanned with a CT scanner to generate a 3D image of the root in DICOM file format. An STL file was created from the DICOM file and used by 3D dental printer to generate thirty standard and identically prepared resin root models which randomly distributed into three groups (n=10 per group) according to the impression technique: acrylic pattern lab scanning group (ALS), vinylpolysiloxane lab scanning group (VLS) and chair-side scanning group (CS). STL files of the scanned patterns of all previous groups were opened in exocad DentalCAD software for designing the post and core restorations. A fiber-reinforced composite disc (Trilor) was milled to fabricate 30 glass-fiber post and core restorations. Prepared resin root models were embedded in methacrylate resin molds. A self-etch, self-adhesive dual-cure resin cement (TheraCem®) was used for post and core cementation. Models were sectioned longitudinally to their long axis. The sectioned models were examined with a scanning electron microscope (SEM) and the gap width was measured at three locating marks in coronal, middle, and apical areas. Data were collected, tabulated and analyzed using one-way analysis of variance (ANOVA).*
***Results:** The adaptability of CAD/CAM glass fiber posts was significantly affected by the fabrication technique ($P<0.05$). The highest overall gap width was found in ALS group (58.623 ± 16.797 µm) followed by CS group (53.483 ± 14.111 µm) while the VLS group has the lowest overall gap width (33.890 ± 4.936 µm).*
***Conclusion:** The adaptability of CAD/CAM glass-fiber posts was significantly affected by the fabrication technique. VLS technique had the highest adaptability and its overall gap width was significantly lower than other studied techniques. However, there was no significant difference in the overall gab width between CS and ALS fabrication techniques.*
***Key Word:** Glass fiber post, post adaptation, 3D dental printer, CAD/CAM, Trilor, TheraCem, scanning electron microscope, gap width.*

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I. Introduction

The restoration of endodontically treated teeth aims to replace the missing tooth structure, protect the remaining tooth structure from being fractured, and to avoid reinfection of the root canal after treatment. Root-filled teeth with inadequate coronal dental structures need posts to retain the cores and support the final prosthetic restoration to withstand the occlusal loads. [1] Since earlier, many materials have been used for post-fabrication ranging from wooden posts of the 18th-century to metal posts and, more recently, carbon fiber, glass fiber, and ceramic posts. [2]

Anterior maxillary teeth are subjected to heavy flexural stresses, and fiber posts are often luted to increase the biomechanical properties and produce a pleasant aesthetic appearance to the final prosthetic restoration. [3] Retention depends on the degree of adaptability of the post to the canal wall and the amount of luting agent present between them. A well-adapted post will have better retention. If posts are not well adapted to the root canals, a thicker layer of resin cement is necessary to fill them. This thick cement layer would increase the shrinkage stresses induced by the polymerization of this material, causing post debonding. The custom-made post has more retention as it has better adaptability to the canal wall and is made as per the shape of the canal. The post will resist torsion forces which will help indirectly in giving better retention. [4] A custom-made post can be made from a direct pattern fabricated in the patient's mouth, or an indirect pattern can be manufactured in the dental laboratory. For single root canals, the direct technique using the auto-polymerized, light-polymerized resin or inlay wax pattern is suggested, while for multiple canals, the indirect method is more applicable. With the development of computer-aided design and computer-aided manufacturing (CAD/CAM) technology, the fabrication of custom-made glass-fiber posts and cores were introduced. [5] Lately, the usage of intraoral digital scanners to make digital impressions has enabled clinicians to reduce the use of impression materials, identify margins for preparation, assess interocclusal clearance, and design the prostheses. [6] The accuracy of the digital impression is similar to that of the conventional impression and can be regarded as a clinical alternative to a fixed dental prosthesis. [7]

II. Material And Methods

This prospective comparative study was carried out on 3D printed prepared resin root models and approval for this research was obtained from Research Ethics Committee, Faculty of Dentistry, Tanta University. The design and procedures of the present study were accomplished according to the research guidelines published by Research Ethics Committee, Faculty of Dentistry, Tanta University, from October 2018 to January 2020. A total 30 Glass fiber post-and-core restorations were for in this study.

Study Design: Prospective open label observational study.

Study Location: Fixed Prosthodontics Department, faculty of dentistry/ Tanta university, Egypt.

Study Duration: October 2018 to January 2020

Sample size: 30speicmens of Glass fiber post-and-core restorations.

Subjects & selection method: The study was done between from October 2018 to January 2020. This study consists of thirty prepared resin root models were randomly distributed into three groups (n=10 per group) according to the impression technique as follows:

Group I -Acrylic pattern lab scanning group (ALS) (n=10).

Group II -Vinyl polysiloxane lab scanning group (VLS) (n=10).

Group III -Chair-side scanning group (CS) (n=10).

Table 1: Materials used in the study are presented with their main composition and manufacturer.

Material	Manufacturer	Composition
elite HD+ (putty soft and light body)	Zhermack, Rovigo, Italy	Hydrophilic addition silicone (vinylpolysiloxane) for high precision impressions
DuraLay Inlay Pattern Resin	Reliance Dental Mfg. Co., Alsip, USA	Powder: Polymethyl Methacrylate, Diethyl Phthalate, Benzoyl Peroxide, and Titanium Dioxide Liquid: Methyl Methacrylate monomer
DuraLay PLASTIC PINS FOR POST AND CORE	Reliance Dental Mfg. Co., Alsip, USA	Serrated and tapered plastic pins
TRILOR® Fiber Disc	Bioloren S.r.I., Italy	Technopolymer consisting of an epoxy resin matrix reinforced by a network of bidirectional glass fibers
ADSEAL™ root canal sealer	Meta Biomed, Inc., Chungbuk, Korea	Base: Epoxy oligomer resin, Ethylene Glycol Salicylate, Calcium phosphate, Bismuth Subcarbonate, and Zirconium oxide Catalyst: Poly Aminobenzoate, Triethanolamine, Calcium Phosphate, Bismuth Subcarbonate, Zirconium oxide, and Calcium oxide
TheraCem® Self-Adhesive Resin Cement	Bisco, Inc. USA	Base: Portland Cement, Ytterbium with Barium Glass, Ytterbium Fluoride, and BisGMA Catalyst: 10-Methacryloyloxydecyl Dihydrogen Phosphate, 2-Hydroxyethyl Methacrylate, and Tert-butyl Perbenzoate

Procedure methodology

A freshly extracted human maxillary central incisor was included in the study as a model for specimen replicas. It was cleaned of debris and calculus using a periodontal scaler and stored in distilled water with 0.1% thymol disinfectant at room temperature. [8] The crown of the selected tooth was sectioned perpendicular to the long axis 2 ± 1 mm coronal to the cementoenamel junction using a low-speed diamond disc, to achieve a standardized length of 14 mm.[9] Access to the root canal was gained with a diamond rotary cutting instrument. Then, the canal was endodontically instrumented at a working length of 1 mm from the apex. Root canal preparation was carried out by a crown-down preparation technique using PROTAPER rotary endodontic files and ended with file size F3 (Dentsply-Maillefer, Ballaigues, Switzerland). A #2 Gates Glidden drill was inserted several millimeters into the canal to flare the coronal and middle third of the canal. This step was repeated with #3 and #4 drills. [10] The root canal was irrigated at each change of instrument with 2 ml of 1.0% sodium hypochlorite solution (about 5 min in total). After canal preparation, irrigation was performed with 5 ml 17% EDTA acid solution for 5 min, followed by 5 ml of distilled water for 5 min and dried with absorbent paper points. [11] ADSEAL root canal sealer (Meta Biomed, Inc., Chungbuk, Korea) was carried out to the prepared canal using a lentulo spiral. A master gutta percha cone with size F3 (Dentsply-Maillefer, Ballaigues, Switzerland) was coated with sealer and fully seated to the working length. Then, the root canal was obturated with gutta-percha cones using the lateral condensation technique. Excess gutta-percha coronal to the canal orifice was removed with a warm plugger. Canal orifice was sealed with temporary cement. The root canal filled tooth was left for 72 hours to ensure a complete set of the sealer. [12] Peso reamer of size #2 was used to remove gutta-percha points, leaving 5 mm of the gutta-percha intact at apical 1/3rd of the root and creating a standard post space length of 9 mm from the coronal surface. Initial enlargement of the root canal was done with peso reamers of size #3,4. Final post space preparation was made with EXACTO bur #3 (Angelus Indústria de Produtos Odontológicos S/A, Brazil) to gain adequate length and diameter for the post. Undercuts were eliminated from the post space, and the edge of the root orifice was rounded with a high-speed extra-fine diamond stone (Dia-Burs, TR-13EF; Mani, Inc, Japan) to facilitate the scanning and milling process. The root canal was cleaned with deionized water for 15 seconds and dried with absorbent paper points. [5] The root canal was enlarged with a diamond stone no.4137 (MICRODONT, Sao Paulo, Brazil) in a low-speed handpiece limited to a 9-mm vertical length to obtain a simulated wide flared canal with approximately a 1.5 mm width of the coronal root dentin wall.[10]

Fabrication of prepared root models

The prepared root was fixed horizontally on its proximal side, a small piece of modeling wax. A fan computed tomography (CT) scanner (GE Revolution EVO 128 slice, GE Medical Systems, USA) was used to scan the prepared root and generate a three-dimensional (3D) images of the root including the prepared post space. The helical CT imagining was performed as follows: slice thickness 0.625 mm, Display field of view (DFOV) 5 cm, tube voltage: 120 kV, and tube current: 349 mA. The resulted CT images had a DICOM file format.

A stereolithography (STL) file was created from the X-ray file (DICOM) of the prepared root to be recognized by the 3D printer using special software (InVesalius 3, CTI Renato Archer, Sao Paulo, Brazil). The STL file was imported in exocad DentalCAD software v2.2 (exocad GmbH, Darmstadt, Germany). A small notch was then made in the coronal portion of the root canal to serve as an anti-rotational element. The notch was located on one of the proximal surfaces of the tooth and extended from the canal orifice vertically to a length of 2 mm and a depth of 0.5 mm. [13] The STL file was used by Dent2 3D dental printer (Mogassam co., Egypt) (Fig. 4-10) to generate thirty standard and identically prepared resin root models (Snow White, Fun To Do., Alkmaar, Netherlands).

Models grouping

Thirty prepared resin root models were randomly distributed into three groups (n=10 per group) according to the impression technique:

Group I -Acrylic pattern lab scanning group (ALS) (n=10).
Group II -Vinyl polysiloxane lab scanning group (VLS) (n=10).
Group III -Chair-side scanning group (CS) (n=10)**.**

In acrylic pattern lab scanning group (ALS)**,** an autopolymerizing acrylic resin (DuraLay Inlay Pattern Resin, Reliance Dental Mfg. Co., Alsip, USA) was used to fabricate post pattern. The canal was lubricated with a separating medium (petroleum jelly). **Error! Bookmark not defined.** The autopolymerizing acrylic resin powder and liquid were mixed in a dappen dish to a runny consistency and placed on the plastic post (DuraLay PLASTIC PINS FOR POST AND CORE, Reliance Dental Mfg. Co., Alsip, USA) with a brush Size #2 (DuraLay, Reliance Dental Mfg. Co., Alsip, USA). The plastic post was entirely placed into the canal and maintained in position for

5-10 seconds until the acrylic resin reached the dough stage. The acrylic pattern was moved in and out of the canal to ensure that it was not locked into any undercuts in the canal. After the resin polymerization, the post was removed to determine if the entire anatomy of the canal was recorded. More acrylic resin was then applied to defective areas, and the post was placed back into the canal before it completely polymerized. The post was moved in and out of the canal until it easily inserted and removed. The produced acrylic post and core pattern was sprayed with an extraoral powder scan spray (MarmoScan Spray Basic, SILADENT Dr.Böhme & Schöps GmbH, Germany) then scanned with the lab scanner (Swing™, DOF Inc., Seoul, South Korea). The scanned data were processed with the lab scanner software to develop a digital 3D model of the post.

Vinyl polysiloxane lab scanning group (VLS): The 3D prepared resin root replica was placed in a typodont teeth model (Ramses, Egypt). The primary impression was taken by a partial plastic tray (Diling, Jiangsu, China) filled with putty (elite HD+ putty soft, Zhermack, Rovigo, Italy). After the impression setting, additional light silicone (elite HD+ light body, Zhermack, Rovigo, Italy) was injected into the canal by a dispensing gun (Dispenser D2, Zhermack, Rovigo, Italy). A plastic pin (DuraLay, PLASTIC PINS FOR POST AND CORE, Reliance Dental Mfg. Co., Alsip, USA) was adjusted to the post space length and fitted into the post space. Secondary impression was then taken by the putty tray. Finally, the post space impression was sprayed and scanned as in the acrylic pattern lab scanning group.

Chair-side scanning group (CS) included a direct optical impression of the post space, which was taken by an intraoral scanner (TRIOS, 3Shape, Copenhagen K, Denmark). As in the VPS lab scanning group, the 3D prepared resin root was placed in the typodont teeth model (Ramses, Egypt) to mimic the natural tooth in the oral cavity and to be recognized by the intraoral scanner software (TRIOS, 3Shape, Copenhagen K, Denmark). The scanning began from the right canine cusp tip and moved to the left canine cusp tip, continued in the reverse direction through the buccal side, and finally from the palatal side of the right canine to the palatal side of the left canine. The printed resin root wasn't sprayed before the scanning step as it made from highly scannable acrylic resin (Snow White, Fun To Do., Alkmaar, Netherlands). After completing the scanning procedure, a virtual 3D model was created representing the printed resin root, including the post space and the adjacent teeth.

Designing and milling of the post and core restorations

STL files of the scanned patterns of all previous groups were imported in exocad DentalCAD software v2.2 (exocad GmbH, Darmstadt, Germany). The cores were made 2 mm in height and had flat occlusal tables with a central sectioning orientation groove extending labio-palatally to a depth of 0.5 mm, dividing the restoration equally into two halves. A fiber-reinforced composite disc (Trilor, Bioloren S.r.I., Italy) was milled using ARUM 5X-400 milling machine (Doowon ID Co., Ltd., Republic of Korea) to fabricate 30 glass fiber post and core restorations.

Cementation of the posts

Prepared resin root models were embedded in methacrylate resin molds. The glass fiber posts of all groups were cemented with self-etch, self-adhesive dual-cure resin cement (TheraCem®, Bisco, USA) per manufacturer's instructions. The resin cement was mixed and inserted into the post space with #40 lentulo spiral (Dentsply-Maillefer, Ballaigues, Switzerland). The posts were seated immediately and held in place under a static load of 3 kg for 5 min using a custom-made device. Light curing was made through the cervical portion of the root for 30 seconds. Excess luting material was then removed with explorer. [14]

Adaptation evaluation

Models were sectioned longitudinally to their long axis after cementation of the posts, guided by the post sectioning orientation groove, with Isomet® 4000 saw (Buehler, Lake Forest, IL) under constant water cooling and at 2500 rpm blade speed in two halves and polished until a uniform and flat surface was obtained. Three locating marks for a standardized examination of the gab width were made, by a scalpel perpendicular to the long axis of the sectioned specimen at 2 mm, 5 mm, and 8 mm from the post-core interface toward the apex to form the coronal, middle, and apical areas, respectively. [15] The sectioned models with the proximal notch were mounted on aluminum stubs and gold-sputter coated by an ion sputtering device (JFC-1100E, JEOL, Tokyo, Japan). The gap width was evaluated by scanning electron microscope (SEM) (JSM-IT200, JEOL, Tokyo, Japan) using x400 magnification. It was obtained by measuring the perpendicular distance between the outer post surface and the edge of the internal canal wall at the previously marked areas.

Statistical analysis

All the data were collected, tabulated, and statistically analyzed using one-way analysis of variance (ANOVA) to find the interaction between the different variables.

III. Results

Mean ± standard deviations (SD) of gap width values (µm) were calculated and analyzed statistically with descriptive statistics and one-way analysis of variance (ANOVA) test was used to evaluate whether there is a difference in the gap width values among the different studied groups or not (Table 2) (Figure 1).

Table 2. Comparison of the different studied groups as regards the gap width (µm) at three different root canal sections using the one-way ANOVA test and Tukey post hoc test:

Root section	Gap width (µm)	Groups			ANOVA		TUKEY'S Test		
		CS	ALS	VLS	F	P-value	CS & ALS	CS & VLS	ALS &VLS
Apical	Range	65 - 76	67.5 - 90.5	28.5 - 37	211.21	<0.001**	0.005*	<0.001**	<0.001**
	Mean ±SD	70.42 ± 3.84	78.49 ± 7.61	33.42 ± 3.05					
Middle	Range	46.7 - 58	46.5 - 64.5	18 - 40	44.26	<0.001**	0.113	<0.001**	<0.001**
	Mean ±SD	51.37 ± 4.12	56.85 ± 6.08	33.18 ± 7.07					
Coronal	Range	31 - 48.5	35 - 44	30.5 - 44	3.43	0.047*	0.655	0.225	0.040*
	Mean ±SD	38.66 ± 6.47	40.53 ± 2.89	35.07 ± 4.10					

CS: Chair-side scanning group
ALS: Acrylic pattern lab scanning group
VLS: Vinyl polysiloxane lab scanning group
** A highly significant difference.
* Significant difference.

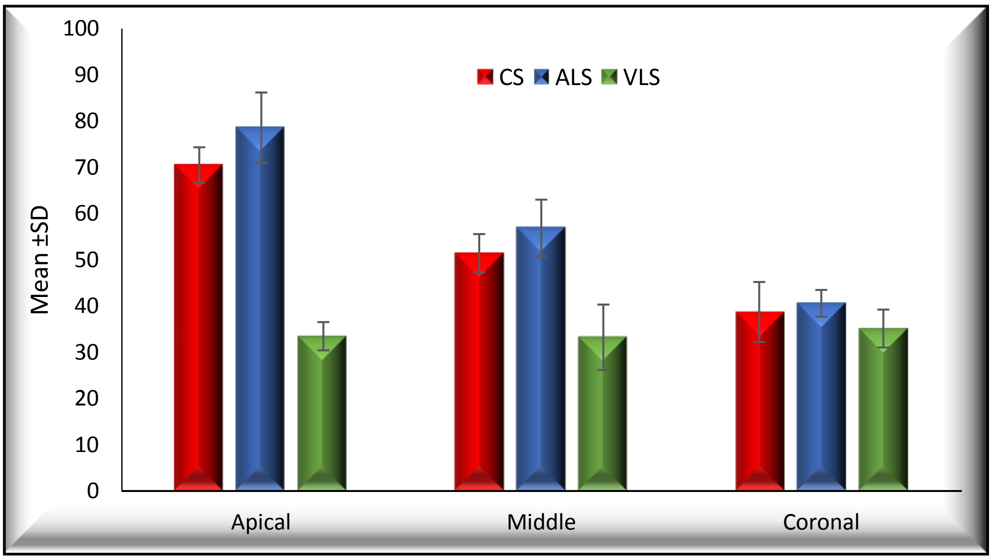

Figure 1. Mean of gap width values of the different studied groups at different root canal sections

Table 2 showing that the apical root canal section of Acrylic pattern lab scanning group (ALS) has the highest mean gap width (78.490 ± 7.613 µm) while the middle root canal section of Vinyl polysiloxane lab scanning group (VLS) has the lowest mean gap width (33.180± 7.072 µm). One-way ANOVA test showed a high statistically significant difference ($P<0.001$) among the different studied groups at the apical and the middle root canal sections and significant difference ($P<0.05$) at the coronal root canal section.

Tukey's post-hoc test was employed to compare pairs of groups. It revealed a significant difference ($P=0.05$) between the ALS and CS groups at the apical root canal section. However, the middle and coronal root canal sections were not significantly different. Tukey's test also showed a high statistically significant difference ($P<0.001$) between the VLS group and CS or ALS groups at the apical and middle root canal sections. At the coronal root section, a significant difference ($P<0.05$) was found between the ALS and VLS groups, whereas there was no significant difference between the CS and the VLS.

In table 3, the one-way ANOVA test showed a high statistically significant difference (P<0.001) among the different root canal sections in both CS and ALS groups while the VLS group has no significant difference. Tukey's post-hoc test was applied to the CS and ALS groups and revealed a high statistically significant difference (P<0.001) between the different pairs of root canal sections in both groups.

Table 3. Comparison of the different root canal sections as regard the gap width (µm) in each studied group using one-way ANOVA test and Tukey post-hoc test:

Groups	Gap width (µm)	Root section			ANOVA		TUKEY'S Test		
		Apical (A)	Middle (M)	Coronal (C)	F	P-value	A & M	A & C	M & C
CS	Range	65-76	46.7-58	31-48.5	103.93	<0.001**	<0.001**	<0.001**	<0.001**
	Mean ±SD	70.42±3.84	51.370±4.123	38.66±6.47					
ALS	Range	67.5-90.5	46.5-64.5	35-44	105.22	<0.001**	<0.001**	<0.001**	<0.001**
	Mean ±SD	78.49±7.61	56.850±6.088	40.53±2.89					
VLS	Range	28.5-37	18-40	30.5-44	0.41	0.663	0.994	0.747	0.683
	Mean ±SD	33.42±3.05	33.18±7.07	35.07±4.10					

** A highly significant difference

The overall gap width mean values of the studied groups were also calculated and analyzed statistically with descriptive statistics (Table 4) (Figure 2). The highest overall gap width was found in ALS group (58.623 ± 16.797 µm) followed by CS group (53.483 ± 14.111 µm) while the VLS group has the lowest overall gap width (33.890 ± 4.936 µm). One-way ANOVA test revealed a high statistically significant difference (P<0.001) for the experimental groups. Using the Tukey's post-hoc test, a high statistically significant difference (P<0.001) was found between the VLS group and CS or ALS groups. However, there was no significant difference between CS and ALS groups.

Table 4. Comparison of the overall gap width mean values (µm) of the studied groups using one-way ANOVA test and Tukey post-hoc test:

GAP	Groups			ANOVA		TUKEY'S Test		
	CS	ALS	VLS	F	P-value	CS & ALS	CS & VLS	ALS & VLS
Range	31-76	35-90.5	18-44	30.321	<0.001**	0.280	<0.001**	<0.001**
Mean ±SD	53.483±14.111	58.623±16.797	33.890±4.936					

** A highly significant difference.

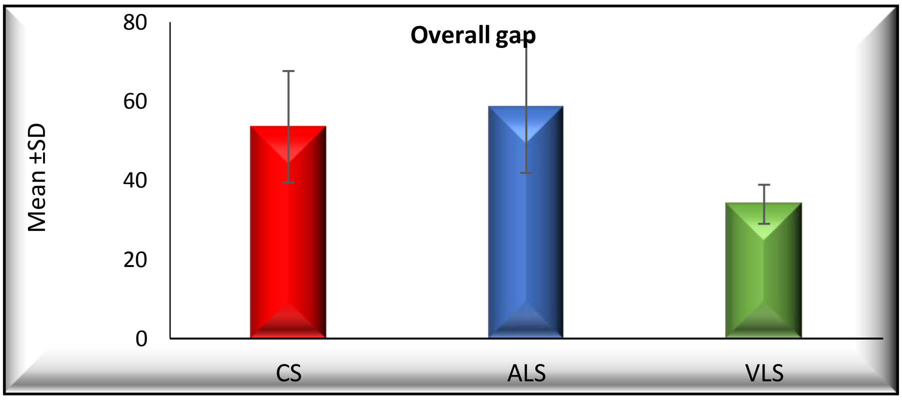

Figure 2. Mean of overall gap width values of the different studied groups

IV. Discussion

The primary purpose of a post is retaining a core in a tooth with insufficient coronal tooth structure. Anterior maxillary teeth must resist lateral and shearing types of forces, as they are responsible for disocclusion guide and food incision. However, their pulp chambers are too small to provide adequate retention and resistance of the prosthetic restoration, which indicates using the post and core. [16] Thus, glass fiber material was chosen in the current study as it has nearly modulus of elasticity of dentin, and stresses would be more uniformly distributed in the root, reducing root fractures. Additionally, it has highly fluorescent characteristics that improve the final aesthetic outcome of the restoration. [17]

TRILOR® Fiber Disc was selected for post and core fabrication as it consists of an epoxy resin matrix reinforced by a network of bidirectional glass fibers. [18] Maxillary central incisor was chosen in this study as it has a long, nearly straight, and round canal, providing a superior sealing ability compared to oval canals with abnormalities. The tooth was kept in a 1% thymol solution at room temperature. [8] Thymol has an antifungal effect, less impact on adhesive mechanisms compared to alternative storage media, and has been mentioned repeatedly in other studies. [19]

The tooth was endodontically treated with a crown-down preparation technique in the current study. The canal was washed with EDTA and NaOCl solutions due to their documented efficiency in eliminating the smear layer. [11] The root canal irrigation was finalized with the application of distilled water to remove the chemical agents and neutralize their effects. This final irrigation would prevent the development of a precipitating coating from the sodium hypochlorite crystallization after the canal walls drying. [20]

Fan beam CT scanner was used in the present study to scan and generate a three-dimensional (3D) image of the prepared root. It has less artifact incidence, less distortion, better signal-to-noise ratio, and greater capacity to distinguish low contrast structures. In contrast, the cone-beam CT scanner is more susceptible to scattering, beam hardening, artifacts, and images are grainier and less smooth. [21]

Self-etch, self-adhesive dual-cure resin cement was used in this study to reduce the number of the luting steps and overcome the problems associated with improper cement polymerization in the most apical portion of the root canal. This incomplete polymerization could arise from the difficulty of light penetration along the length of the post. [22]

High adaptation of the post to the root canal would result in thinner cement layer. This thinner cement layer would lead to higher bond strength between the post and the dentin. Also, it would generate less tensile stress at the adhesive dentin interface due to its lower polymerization shrinkage stress and would have few defects to cause a cohesive fracture. Su et al. found that the CAD/CAM produced one-piece glass fiber post-and core had an excellent adaptation to root canal in comparison with conventional fiber posts. It was also able to achieve strong bonding properties in the canal to prevent dislodgement by minimizing the cement thickness. These features made the CAD/CAM glass fiber post-and core especially suitable in restoring the flared roots or defected teeth with incomplete ferrule. [23]

Gap width measurement was widely used to evaluate the adaptation of the restoration. [24] The adaptation level of prostheses fabricated by CAD/CAM technology has been assessed by various methods such as direct viewing with light microscopy, [25] impression replica technique, [26] evaluation of the sectioned restoration with electronic microscopy, [27] and microtomographic technology. [28] The scanning electron microscope was used in the current study to evaluate the adaptation of glass fiber posts. It has great resolution, large depth of field, and high magnification at the interface. Furthermore, it allows better visualization of different structures, with different heights, without alternation of the focus, and generates data in digital form. [29]

The null hypothesis was rejected as the results of the current study revealed significant differences among the different impression techniques. The CAD/CAM glass fiber posts fabricated by the VLS technique had the least overall gab width and achieved higher adaptation compared to CS and ALS techniques. No significant differences were found between CS and ALS techniques in terms of overall gab width. Nevertheless, the mean gap value of all groups was in the range of 33.890 to 58.623 µm, which was in the clinically acceptable range (23.5 to 154.1 µm). [30]

Pitigoi-Aron et al. found that indirect technique using vinyl polysiloxane impression material provided fit and accuracy better than the direct technique with the acrylic pattern. Although this study was applied to cast posts, the results of the present study were in agreement with its findings in terms of the accuracy of the direct and indirect impression techniques. [31]

A similar conclusion was reached by Ender et al. when compared the precision of multiple intraoral scanner systems with conventional dental impressions. All the intraoral scanner systems were inferior to the elastomeric impression, and the highest precision was for the scanned vinyl siloxanether impression. [32] Jeong et al. also found that the vinyl polysiloxane impression was more precise than two intraoral scanner systems. [33] These conclusions support the results of the present study regarding the accuracy of the conventional vinyl polysiloxane impression.

Rayyan MR et al. investigated the effect of post pattern fabrication technique on the accuracy of post fit. µCT imaging was used in that study to investigate the fitting accuracy of posts by measuring the space between the post and the root canal wall at five different areas. It found using either a direct pattern acrylic resin or indirect post pattern fabrication technique with vinyl polysiloxane impression did not affect the accuracy of cast post and core fit. [34] Hendi AR et al. study compared the accuracy of posts and cores fabricated using conventional pattern acrylic resin, direct intraoral scanning (full-digital), and scanning elastomeric impression material (half-digital) techniques. In that study, only the apical gap between the remnant of gutta percha, and the tip of the posts was measured using parallel radiographs. It showed that the conventional acrylic resin pattern fabrication technique had the smallest gap, followed by the full-digital technique, while the half-digital technique had the biggest gab. [35] However, the findings demonstrated in these previous studies were contrary to the results of the present study. An explanation of this controversy could be the difference in post-fabrication techniques, the method used to measure the accuracy of post fit, sample size, and the number of measurements per specimen among the different studies.

Shimizu S et al. evaluated the accuracy of different digital intraoral and extraoral scanners for designing of fixed dental prostheses. The intraoral scanners were less accurate than the extraoral scanners. [36] This conclusion is consistent with what has been found in previous studies that investigated the precision of intraoral and extraoral digital scanning. [37,38] A similar pattern of results was obtained in the current research in terms of the accuracy of the chair-side and digital lab scanners.

The digital scanner type, whether it is an extraoral or intraoral, may have a high impact on the accuracy of produced dental restorations. Mandelli F et al. compared the accuracy of different extraoral laboratory scanners and found significant differences among them. [39] This result tied well with Emir F et al. study wherein extraoral blue-light scanners exhibited more accurate and consistent data than the laser and white light scanners in terms of trueness and precision. [40] Other studies evaluated the accuracy of different chair-side intraoral scanners and also exhibited significant differences in both trueness and precision among the scanners. [41,42] These findings could explain the considerable differences among the different groups in the current study.

Significant discrepancies in gap width, which found between different root sections in the chair-side scanning (CS) group, could be attributable to the accuracy of the intraoral scanner used in this experiment. Several studies revealed multiple variables that can influence the accuracy of intraoral scanners such as scanning distance, scanning sequence, stitching algorithm, and scanned surface morphology and composition. Kim M et al. study evaluated the effects of scanning distance on the accuracy of different intraoral scanners. The results showed that the accuracy was lowest at 0 mm and highest at a 2.5–5.0 mm interval, which implies that scanning distance could be an essential factor affecting scan accuracy. [43]

Scanning sequence and camera movement play a leading role in the accuracy of intraoral scanners. Diagonal orientations of the Cerec Bluecam camera were noticed to be more precise than the occlusal orientation. This difference can be attributed to better capturing of overlapping areas and significant features. Other systems (Lava™ COS and TRIOS®) benefited from the recording of the occlusal surface through the entire arch, followed by the buccal and palatal surfaces, respectively. On the contrary, more deviations were associated with rotating the camera around each tooth along the arch or recording half the arch on one side, followed by the other side. [44, 45] Muller et al. compared the trueness and precision of three scanning strategies for TRIOS. It was found that recording the occlusal surface of the whole arch, followed by palatal and buccal surfaces respectively, was superior to scanning the buccal surface, followed by occlusal and palatal or rotating the camera around each tooth. [46] Accordingly, the scanning strategy used in the current study could have a significant influence on the results of the chair-side scanning (CS) group.

Any light scanning process is based on emitting light on the tooth surface and capturing the reflected light. Printed acrylic tooth used in the current study has different reflective and refractive properties than a natural tooth, which may affect the accuracy of the virtual model obtained from the intraoral scanner. This speculation is in line with previous studies which found scanned surface with different light properties than natural tooth was associated with image error and significant surface noise. [47, 48] Although the surface noise was eliminated by software filtering, the process can cause loss of surface details. Also, Excessive reflection in areas with poor access would influence the quality and the sharpness of the captured image. [49] Further, the light obstruction can cause shadowing and loss of the entire shadowed area. Other included studies had found that areas associated with shadowing such as steep surfaces, sharp edges, proximal areas, and gingival margins were more likely to suffer from more significant discrepancies. [50, 51] Regarding these studies, the scanning process of a shadowing area with limited light access as the post space would result in excessive reflection. This redundant reflection could be an important factor affecting the results of the chair-side scanning (CS) group in the present study.

The intraoral scanner cannot capture a large field or the whole arch with a single scan; multiple overlapping scans have to be taken and combined via stitching algorithm. As a consequence, every stitching process can introduce additional discrepancies. Eventually, the error will be propagated for every stitching process. [52] These multiple stitching processes may explain why significant differences in gab width were found between the different root sections in the chair-side scanning (CS) group. Unlike intraoral scanners, conventional impression and laboratory scanners do not necessitate numerous stitching so they can potentially be more precise. Although stitching is applied for laboratory scanners, it is automated and involves a larger overlap field that covers the whole arch length. As a result, the entire arch distortion is less significant than for intraoral scanners systems. [53]

Auto polymerizing acrylic resins have been indicated for direct post and core patterns since earlier. However, they are subjected to dimensional change due to the polymerization shrinkage of their methyl methacrylate base. [54] A study by Mojon P et al. showed that Duralay acrylic resin had a polymerization shrinkage of 7.9%, and eighty percent of the dimensional change appears before 17 minutes at room temperature. [55] Iglesias A et al. investigated the effect of acrylic resin pattern fabrication technique and storage time on the marginal fit of full-crown restoration. The results revealed the incremental pattern fabrication technique produced equal or smaller marginal gaps than the bulk technique for full-crown patterns. Also, the patterns measured at 1 hour had smaller marginal gaps than at 24 hours. [56] A similar finding was reported in Ghanbarzadeh J study, which found significant shrinkage in the Duralay post pattern diameter when it stored in a dry atmosphere at 25°C for 24 hours. [57] Overall, these results are in accordance with the Nosouhian S et al. study that demonstrated the polymerization shrinkage was more in the apical diameter of Duralay post pattern than the coronal one after 24 hours stored in air. It also recommended storing Duralay acrylic post pattern in water until laboratory fabrication of post and core. [58] Accordingly, factors that affected the dimensional stability of auto polymerizing acrylic resins as pattern fabrication technique, storage time, and media can contribute to the significant differences in gab width observed in the Acrylic pattern lab scanning group (ALS) group in the current study.

Regarding the limitations of the current study, it should be mentioned that this in vitro experiment had limited ability to represent the clinical situation. In the clinical environment, the scanning accuracy might be impaired by humidity and saliva, which leads to deviations in the intraoral scanning results. [59] Conventional impressions can also be challenging for dentists and patients. Clinical conditions such as gag reflex, risk of damaging the gingival tissues during the impression stages, thermal changes from the mouth to the laboratory, and deformation of the impression material while removing from the patient's mouth could affect the accuracy of impressions. [60,61] Further, the operator's skill, experience, and knowledge might affect the clinical results. [62] Another limitation of the present study involved using the longitudinal- sectioning method to evaluate the adaptation of glass fiber post under the scanning electron microscope. However, this is a 2-dimensional measurement method which restricted to preselected measure points and cannot reflect overall post adaptation. The 3D approach would have allowed measurements at numerous locations and result in uniform distribution of data with small standard deviations compared to the mean values. [63]

Various accuracy measurement methods, the experimental environment, skills of the operators, different die materials, and differences in the scanning design and milling devices used could explain contradictory information regarding the efficacy of different digital data acquisition techniques. Additional studies are therefore necessary to evaluate the presented findings under clinical conditions and to explore the impact of the CAD/CAM glass fiber post and core fabrication technique on other mechanical properties such as the survival rate and the fracture strength of these restorations. Also, it is preferred to use a larger sample size to obtain more conclusive results and consistent data with lower standard deviations.

V. Conclusions

Based on the recorded results and within the limitation of this in- vitro study, the following conclusions may be drawn:

- The gap values observed in the different studied groups were all within the clinically acceptable range.
- The fabrication technique greatly influenced the adaptability of CAD/CAM glass fiber posts.
- The vinyl polysiloxane lab scanning fabrication technique had the highest adaptability, and its overall gap width was significantly lower than other studied techniques.
- There was no significant difference in the overall gab width between chair-side scanning and acrylic pattern lab scanning fabrication techniques.

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