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INFLUENCE OF MICRO-GUIDED ENDODONTICS IN A CONSERVATIVE ACCESS CAVITY ON FRACTURE RESISTANCE

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ABSTRACT

Aim: compare traditional access cavity (TAC) and conservative access cavity (CAC) using micro-guided endodontics, by measuring the volume of dentin removed (VDR) using cone beam computed tomography (CBCT) and fracture resistance (FR) test. **Methods:** Sixty unidentified extracted human maxillary premolar teeth were collected and divided into three groups: group A subjected to TAC, group B subjected to CAC using micro-guided endodontics, and a control group which remained sound without access cavity preparations. Groups A and B were scanned pre-operatively and post-operatively by CBCT, then subjected to a fracture resistance test using an Instron® universal testing machine after access cavity preparations with a control group. The Mann-Whitney test was used to compare VDR between groups, and the one-way ANOVA test was used to compare fracture resistance between groups. **Result:** There was no discernible difference in fracture resistance between the CAC and control groups. However, a significant difference was noted between the TAC, CAC, and control groups. FR considerably decreased when VDR increased, and vice versa, indicating a significant negative association between the two variables. There was no discernible difference in fracture resistance between the CAC and control groups. However, a notable distinction was noted between the TAC, CAC, and control groups. VDR and FR showed a substantial negative association, declining significantly when VDR rose and vice versa. **Conclusion:** According to the study's limitations, the CAC via micro-guided endodontics approach improved the fracture resistance of endodontically treated teeth contrasted to TAC.

INTRODUCTION

Access cavity preparation is one of the most crucial phases in root canal therapy. For many years, the conventional method of access cavity preparation has not changed. But it has a problem: It removes more tooth structure, weakening the tooth. This decreases fracture resistance, which could eventually lead to tooth extraction [1, 2].

Recently, conservative access cavity designs were introduced, where a minimal amount of tooth is removed, these designs are like the truss access cavity preparation, where the operator opens the access directly above the location of the orifices, the operator can achieve free-handed by the experience and knowing the tooth morphology [3, 4].

Truss access cavity could also be achieved with the aid of modern technologies like dental microscopy and cone beam computed tomography (CBCT) to accurately locate the canal orifices [3- 5].

A new access cavity technique was introduced and known as the Ninja access cavity, where the operator opens a small opening occlusal, and then performs the cleaning and shaping with flexible files projecting them to the location of canal orifices [1].

The conservative access cavity preparations preserve more tooth structure, guiding to expanding the fracture resistance of the tooth, and then decreasing the liability of the tooth to be extracted later. The obstacle was that the mentioned access cavity designs took a long time, especially if there were pulp calcifications, besides the need for an experienced operator to perform them [6].

The obstacle was overcome by the introduction of a novel technique called guided endodontics, a technique transferred from the dental implant field, where the images of CBCT of a tooth and images of surface scanner are merged, then designing a virtual path extending from the tooth occlusal surface till the orifice, then transferring these data to be fabricated by a 3D printer, producing eventually a guide, where the operator could use to gain access cavity with high accuracy, in a short time, and without the need for prior experience [7, 8].

Guided endodontics aids also in overcoming pulp canal obliterations, where a special drill is used to remove the calcifications, thus creating a patent canal, when the drill used has a minimal diameter, the technique is called micro-guided endodontics [9].

This novel technique increases the fracture resistance (FR) of the tooth significantly, by decreasing the volume of dentin removed (VDR) from the tooth during access cavity preparation [10].

In this study, the micro-guided endodontics technique was performed on premolars, then other premolars accessed by traditional cavity design, the two groups were then compared in the means of the volume of dentin removed, and then they were compared to sound premolars in the means of fracture resistance.

The current study aimed to compare the fracture resistance of TAC and CAC utilizing micro-guided endodontics and to close the knowledge gap regarding the relationship between VDR and fracture resistance in maxillary premolar teeth.

There is no difference in fracture resistance between teeth reached by CAC employing micro-guided endodontics and teeth accessed by TAC, according to the study's null hypothesis.

MATERIALS AND METHODS

Power analysis and sample size calculation

This research was approved by the ethical committee of the Faculty of Dentistry, Suez Canal University, Egypt (211 /2019). All methods were carried out according to relevant guidelines and regulations. Before the extraction, each patient signed a written informed consent form.

Based on the findings of a prior study by Plotino et al. [1], in which the authors discovered a significant difference in the number of fracture resistance between three different access cavity designs using a similar study design, a power analysis was conducted using computer software (G* Power) to verify the appropriate sample size. The sample size calculation yields a total of 51 samples (17 samples/ each group) using the One-way ANOVA test. The sample size was increased by about 20% (by adding 9 samples) to account for possible damaged samples. Therefore, the total sample size becomes 60 samples (20 samples/group), (Effect size=0.684, 2. Pooled SD=260, 3. Alpha (α)=.05, 4. Power (β)=.99)

Collection of samples:

Sixty freshly unidentified extracted human maxillary premolar teeth were collected. Upper premolar teeth with completely formed apices, having two roots, (buccal and palatal roots), and each root contains type I root canal morphology according to Vertucci classification, which was detected by digital radiographs (Myray, Italia).

The study did not include teeth with root caries, calcified root canals, internal or external root resorption, prior endodontic treatment, root fracture, or cracking symptoms [1].

Preparation of Samples:

After using a curette to scrape away any remaining tissue from the exterior root surfaces, the teeth were disinfected for an hour using 2.5% sodium hypochlorite. To avoid dehydration, the teeth were then kept in a daily cleansable saline solution until test time.

The chosen teeth were placed in a rectangular plastic container and filled with epoxy resin that auto-polymerizes. It was ensured that the teeth' long axis was vertically oriented during the mounting process, 2mm below the tooth's cement-enamel junction, and that it was allowed to set completely for a full day.

Every ten teeth were put in one epoxy resin block, divided into two rows, each row containing 5 teeth, the dimensions of the block are 10×10 cm, these dimensions were chosen to provide enough surface for fracture resistance test after dividing the block into 10 separate teeth (**Figure 1, A**).

Each tooth in the block was coded by a number to facilitate data collection. To mark the buccal surface of teeth from the palatal surface, a metal ball was put in the epoxy resin from the buccal side.

Grouping of samples:

Twenty teeth (n=20) were randomly chosen and left with no access cavity preparation as a control group. The remaining 40 premolar teeth were distributed into 2 main groups each with 20 premolars (n=20 /group), according to the method of access cavity preparation.

Group A: Traditional endodontic access cavity (TAC), and Group B: conservative endodontic access cavity (CAC). Each group of teeth was mounted in 2 resin blocks such that 10 premolar teeth per block. (n=10/block).

Pre-operative scan

To evaluate the tooth's root canal morphology, pre-operative CBCT scans (Scanora 3D Soredex, Finnland) of each experimental group model were performed at 110 kVp, 3.0mA, with a field of view of 10x10 cm and a voxel size of 0.2mm. The scans were recorded as digital image communication files (DICOM). Using a high-resolution optical scanner (Open Technologies, Brescia, Italy) with an accuracy of 4μm as specified by the manufacturer, surface scans of every tooth were carried out.

Access cavity preparation:

Group A: Traditional endodontic cavities (TAC) were performed for 2 blocks containing 20 specimens. Round diamond bur was utilized in initial access cavity preparation leading to primary penetration of the pulp chamber. The occlusal enamel and dentin tissue between the buccal and palatal root canal orifices were then removed, and the access cavity preparation of the bucco-lingual oval-shaped structure was refined utilizing an Endo-Z-bur (DentSply, Malliefer, Ballaigues, Switzerland).

Straight access to canal orifices was made possible without coronal hindrance, and all orifices were visible in the same field of vision.

Group B: Using guided endodontics, the conservative endodontic cavity (CAC) was performed for 2 blocks containing 20 specimens. A path for the drilling bur was virtually designed, maintaining straight-line access up to the root canal orifice opening, after both image data sets DICOM images from the CBCT and the scanned images of the teeth were imported into the software, and surface scans were compared with the CBCT data by aligning the tooth crowns [10].

Finally, a guide for the drilling bur with two openings corresponding to the buccal and palatal canal orifices with 1.2 mm diameter and with a cylindrical corridor of 4 mm long to guide the bur was designed by special software (3diagnosys v 4.2 3diemme, Italy), and then a 3D printed endodontic guide was fabricated using the 3D printer (Form2, Formlabs, USA), where every 5 guides were printed together connected to a meshwork, when operating, single guide was separated from the meshwork to be placed over the tooth (Figure 1, B), slight dimensional mismatch may occur during the printing due to polymerization shrinkage, so a safety distance was done to compensate for the polymerization effect [8].

The teeth were fitted with the 3D endodontic guide. The access cavities were initiated using a Munce Discovery bur size 1 (CJM Engineering, Santa Barbara, CA, USA) (Figure 1, C) [9]. This round carbide bur is 34 mm long overall, with a 21 mm exposed shaft and a maximum diameter of 1 mm. Its head diameter is 0.8 mm, and its variable shaft diameter ranges from 0.7 to 1 mm. To pinpoint the precise location of the endodontic access cavity, the drill's point of entry on the tooth surface was noted. A diamond bur was then used to drill a tiny hole in the enamel, allowing the Munce bur to only come into touch with dentin tissue.

Low-speed drilling was carried out at 250 rpm in an endodontic headpiece (6:1) (Dentsply Sirona Endodontics, Germany) since cooling is challenging below the guide and in the drill path. After five teeth were prepared, the bur was replaced after the cavity had been cleansed and the bur's head was cleaned every 2mm of advancement. When the bur struck the guide's mechanical stopper, the final position was reached. Then, using a K-file size 10, access to each root canal was examined. (Germany: Dentsply Sirona Endodontics) (Figure 1, D). The final occlusal view implies a truss access cavity preparation maneuver where the dentin bridge is preserved in between access openings [3].

Cleaning, and Shaping:

The working length was then verified by CBCT. Root canal preparation was then carried out using Wave-One gold file 25/0.07 file (Dentsply, Maillefer, Ballaigues, Switzerland). Reciprocation parameters like angle and torque were pre-stetted in the endodontic motor. Sodium hypochlorite 2.5% was used for irrigation between each file alternating with 17% EDTA. Drying the root canals with adsorbent sterile paper points is done.

Post-Operative scan:

Post-operative scanning is done using the same machine where images were taken for the blocks and stored as digital images and communication (DICOM) files.

Volume of dentin removed (VDR) measurements:

Following access preparation and CBCT scanning of the specimens, the DICOM-formatted data were reconstructed with a 0.15 mm voxel size and exported as DICOM data sets. ITK-SNAP 2.4 (open-source software, www.itksnap.org) is a 3D picture semi-automatic segmentation and voxel-counting application that loads this data.

For the calculation of coronal dentine volume before and after access preparation in corresponding teeth in booth groups CAC and TAC (Figure 2).

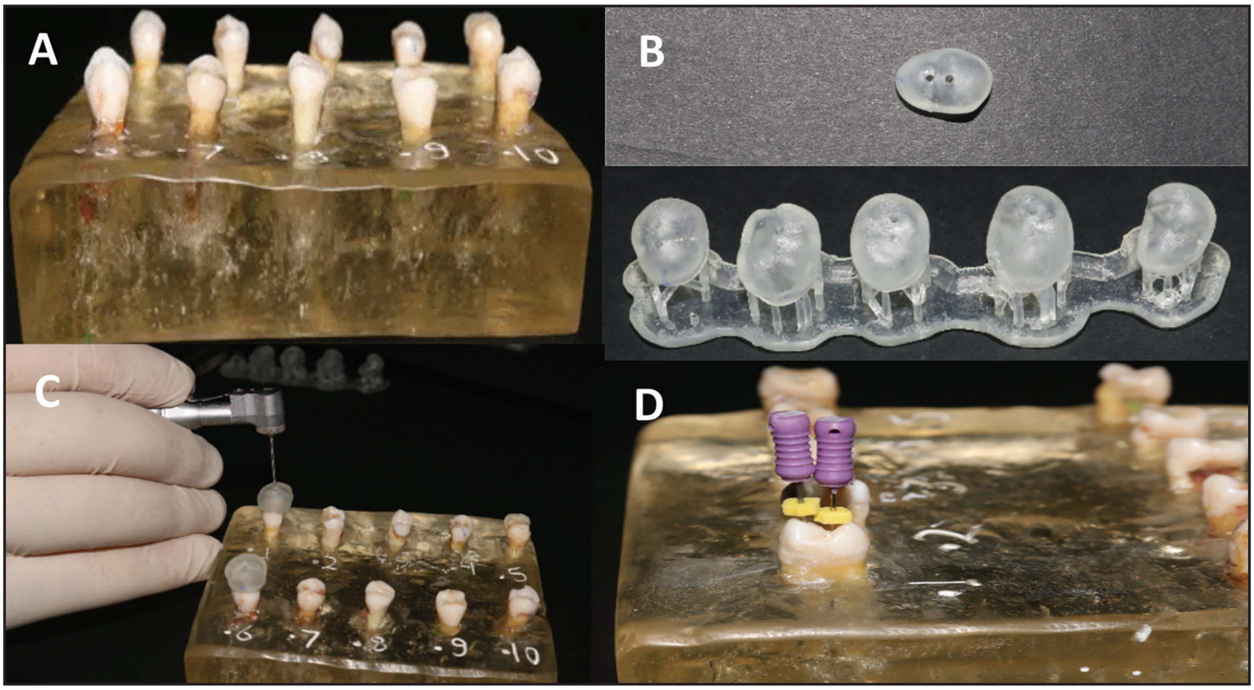

Fig. (1) Photographs showing: A) the mounting of teeth in a resin block, B) the fabricated endodontic guide, C) the preparation of conservative access cavity (CEC), and D) checking the patency of the canals.

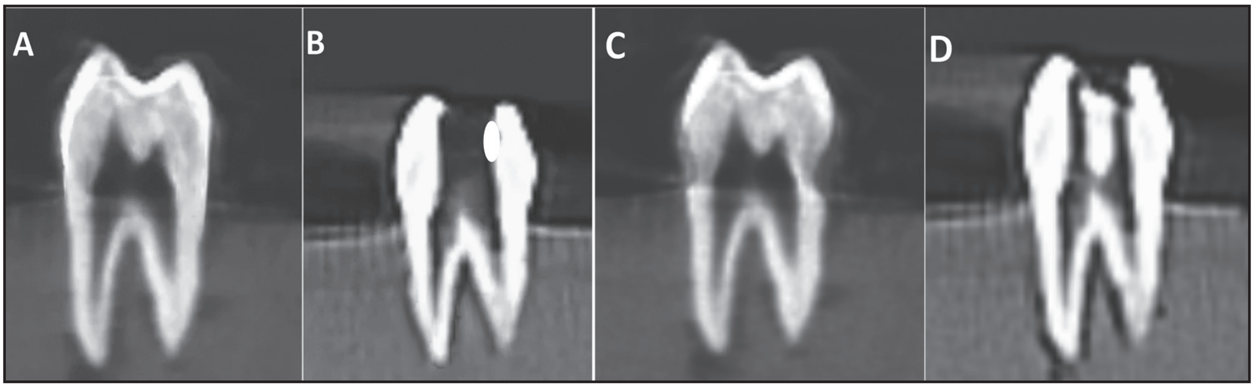

Fig. (2) CBCT photographers showing the volume of dentine removed (A and B) A tooth before and after traditional access cavity (TAC), (C and D) A tooth before and after conservative access cavity (CAC).

Obturation and restoration of the teeth:

The bioceramic sealer (Total Fill BC sealer; FKG Dentaire SA Switzerland) was used in a single cone procedure to fill the root canals (11). Ethylene alcohol was then used to clean the access cavity. After cleaning the access cavity, 37% phosphoric acid was used for 15 seconds to etch the enamel and dentin surfaces. An air/water syringe was used to dry the etched surfaces after they had been cleaned for 20 seconds. After applying a bonding agent (Solobond M; VOCO, Cuxhaven, Germany) with a micro brush, the surfaces were light-cured for 20 seconds. The pulp chamber floor and proximal boxes were covered with the flowable composite (Xtra base bulk-fill flowable composite, VOCO, Germany) in 4-mm increments until it was 1 mm below the dentin-enamel junction. The composite was then light-cured for 40 seconds. Composite resin (Polofil Nht, VOCO, Germany) was used to fill the residual cavity to the occlusal surface to maintain the occlusal architecture [5].

Fracture resistance test:

Instron®'s Bluehill Lite software was used to conduct these tests. Ten smaller blocks, each containing a single tooth, were cut from each block.

Each sample was mounted independently using a computer-controlled materials testing apparatus equipped with a 5 KN load cell, and the data was recorded using Instron® Bluehill Lite software. The samples were fastened to the lowest fixed compartment of the testing apparatus using tightened screws. The fracture test was carried out using a metallic rod with a spherical tip (3.8 mm diameter) fixed to the upper moveable compartment of the testing apparatus to achieve uniform stress distribution and reduce the transmission of local force peaks. With a sheet of tin foil between, the rod moved at a cross-head speed of 1 mm/min. The load at failure was detected by an audible fracture, which was confirmed by a severe decrease in the load-deflection curve recorded by computer software (Bluehill Lite Software Instron® Instruments). The load required to fracture was measured using Newton.

RESULTS

Comparison of VDR between groups

Table 1 compares the VDR of the groups and shows that there was a significant difference between them (Mann-Whitney test, $P<.001$). When compared to the conservative access group, the conventional access group's VDR was noticeably greater ($p<.001$).

Comparison of fracture resistance between groups

The groups' fracture resistance varied significantly (One Way ANOVA, $P=.038$). Table 2. The TAC group displayed the lowest fracture resistance, whereas the control group had the greatest, followed by the CAC group.

The TAC group differed from the control group in a major way. However, there was a significant difference between the TAC group and the CAC group (Bonferroni test, $p<.05$) but no significant difference between the control group and the CAC group in terms of fracture resistance.

Correlation between VDR and fracture resistance (FR)

Table 3 shows the relationship between VDR and fracture resistance (FR). VDR and FR had a significant negative association (Pearson correlation=-.319, $p=.045$), meaning that when VDR rose, FR substantially fell and vice versa.

Table (1) *Comparison of VDR between groups*

	Mean	Std. Deviation	Median	Minimum	Maximum
Traditional access group	130.78	41.53	110.25	75.00	231.00
Conservative access group	56.35	48.13	46.75	4.00	188.00
Mann-Whitney test (p-value)			<.001*		

**p-value is significant at 5% level.*

Table (2) *Comparison of fracture resistance (FR) between groups*

	Mean	Std. Deviation	Median	Minimum	Maximum
Control group	856.97 a	169.34	871.32	631.60	1126.10
Traditional access group	650.65 b	211.39	726.42	222.39	1286.40
Conservative access group	807.91 a	145.81	818.60	494.21	1042.00
One Way ANOVA test (p-value)			.038*		

**p-value is significant at 5% level. Different letters indicate a significant difference between means (Bonferroni test, p<.05). The same letters indicate a non-significant difference between means (Bonferroni test, p>.05).*

Table (3) *Correlation between VDR and fracture resistance (FR)*

		VDR	FR
VDR	Pearson Correlation	1	-.319*
	Sig. (2-tailed)		**.045***
FR	Pearson Correlation	-.319*	1
	Sig. (2-tailed)	**.045***	

** Correlation is significant at the 0.05 level (2-tailed).*

DISCUSSION

For decades, the traditional access cavity preparation was performed, which allows for the removal of more tooth structure, thus, leading to the weakening of the tooth, decreasing the fracture resistance, and eventually the extraction of the tooth[11, 12].

According to reports, the second biggest factor contributing to tooth structure loss is the endodontic access cavity's preparation using the TAC principles[1].

Thus, heading to minimally invasive techniques like conservative access cavity preparation was a main concern for the preservation of more tooth structure.

This study was performed because there were not enough studies comparing fracture resistance between TAC and CAC by micro-guided endodontics, there were several recommendations by other studies to do more in-vitro studies to assess if there is a significant difference in fracture resistance between TAC and CAC before clinical trials conduction [4].

Guided endodontics technique provides successful results in cases of pulp canal obliterations by Krastl et al. [13], van der Meer et al. [14], Connert et al. [15] in the treatment of dens invaginates by Macho et al. [16], and in the removal of fiber posts from maxillary molar [17].

Premolars were chosen for this investigation primarily based on their shape. Because of their cuspal inclination, premolars are more prone to cusp breakage when subjected to occlusal force. Numerous investigations have examined the frequency of dental fractures and demonstrated that premolars have a higher risk of fractures [18].

The present study didn't incorporate a metallic sleeve in the design of the guide. This was done before by Torres et al. [9], where there was no interference with the preparation procedure, instead, the guide had an internal cylindrical corridor to guide the drilling bur.

Clinically, in posterior teeth with short inter-occlusal distance, the metal sleeve may take more space, this could impair the treatment in limited space. Also, a sleeveless guide will eliminate the additional cost of the metal sleeve, resulting in a low-cost guide.

In contrast with other studies like Krastl et al.[13], van der Meer et al.[14]., and Connert et al.[6], they used a metal sleeve to guide the bur. However, placing it has to be considered in the future to protect the guide material from burning during drilling if there is enough inter-occlusal distance clinically [9].

Because the 3D printing material may exhibit a tiny dimensional change during polymerization during the printing process, a slight mismatch between the planning and execution may be expected when evaluating the accuracy of this 3D planning technique. The drilling bur may angulate slightly if the guide is not seated precisely as intended on the dentition, amplifying the discrepancies between the bur's initial and final angulations. In addition, the bur used to extract the dentin is extremely thin and may bend somewhat when compressed. A safety distance was created to account for the polymerization effect after these dimensional changes were considered[8,14].

The drill used was a Munce bur size 1, With a head diameter of 0.8 mm and a variable shaft diameter ranging from 0.7 to 1 mm, this round carbide bur has a total length of 34 mm. It was used before by Torres et al. [9] in endodontically treating maxillary lateral incisors. Munce bur is considered the better choice in drilling, the small diameter leads to a decreasing incidence of crack formation, and the heat generated during drilling may be harmful for surrounding periodontal structures, besides the decreasing of access opening size, to achieve a minimally invasive treatment which preserves more tooth structure [6, 10].

Torres et al.[9] used the expression "micro-guided endodontics" because they used a drilling bur with a small diameter, like Munce bur size 1, the same drill used in the present study; hence, the name "micro-guided endodontics."

In contrast to other files, such as ProTaper and WaveOne Gold uses the reciprocating motion principle, which allows root canals to be completely shaped and cleaned with a single, single-use tool[19,20]. The engagement zone is constrained by the reverse helix, offset parallelogram-shaped cross-section, and semi-active and modified guiding tip. Reciprocating movement improves the canal's centering ability, decreases the instrument's lock within the canal, and lessens torsional and flexural strains. Therefore, WaveOne Gold reported a superior centering ratio with less canal transit and a relatively less aggressive volume of removed dentin[20].

A graphical user interface is offered by the software program ITK-SNAP for both manual and user-guided semi-automatic segmentation of 3D medical imaging datasets. To tackle image segmentation issues for which completely automated techniques are currently unavailable, ITK-SNAP was developed [21].

This software was previously used to segment structures in 3D pictures that allowed the user to manually explore and choose anatomical regions of interest and execute automatic image segmentation. It was used to forecast age based on the pulp cavity/chamber volume of 13 different types of teeth [22, 23].

Evaluation of VDR was done before by Krishan et al. [24]., as teeth were scanned before and after treatment with micro-CT imaging, Then, using a software-controlled iterative superimposition process, pre-and post-treatment images were accurately placed.

Although the present study used a static load until fracture occurs, which does not simulate the loads in the oral cavity which is dynamic, static compressive loading by Instron universal testing machine was used because of its ease of availability and low costs, this is the most frequently used method to evaluate tooth resistance to fracture as it was used by Mohammad Sabeti et al. [2].in maxillary molars, and by Abou-Elnaga et al. [5]. in mandibular molars. To ensure sufficient contact with the cuspal inclines during testing, the compressive force was applied occlusal using a metallic rod with a spherical tip (3.8 mm diameter) [2, 5].

The results of the present investigation showed that the fracture resistance values of the control group were significantly greater than those of the TAC and CAC groups. The removal of the pulp chamber ceiling during access cavity preparation, which reduces the teeth's resistance to fracture, explains this [5].

Because the dentin bridge in the CAC group remained intact, the fracture resistance was better than in the TAC group, which may account for the lack of a significant difference in fracture resistance between the two groups. Nonetheless, it was shown that TAC and CAC differed significantly in terms of fracture resistance. According to a prior study by Plotino et al. [1], there was a significant difference in the fracture resistance of maxillary and mandibular premolars and molars between CAC and TAC. Similarly, Krishan et al. [24] demonstrated that CAC increased the fracture resistance of molars that had undergone endodontic treatment when compared to TAC [2, 25].

In contrast, Chlup et al. [26] registered no significant difference between fracture resistance of maxillary premolar teeth when treated by TAC and CAC, this does not agree with the present study results, this may be due to CAC being performed without applying guided endodontics technique, besides that minor sample size used, which was 10 premolars only.

Additionally, the results of the current study differ from those of Sabeti et al. [2], who found no significant difference between CAC and TAC in maxillary molars, while both showed significant differences when compared to intact teeth. This could be because the conservative approach was not carried out using guided endodontics, and the study's results were obtained on different teeth.

Even though CAC increases fracture resistance more than TAC, as previously noted, it may also raise the possibility of ineffective canal instrumentation and procedural mistakes.

These risks originate from accessing canals through restrictive access. However, recent studies showed that CAC in maxillary incisors, mandibular second premolars, and maxillary teeth did not seem to affect the effectiveness of the instrumentation, especially when using WaveOne instruments, which were used in the present study, as they have high fatigue resistance [1, 24].

This rejects the null hypothesis that there is no difference in fracture resistance between TAC and CAC.

CONCLUSION

When compared to TAC, the CAC via micro-guided endodontics approach increased the fracture resistance of endodontically treated teeth, according to the study's limitations. Where an increase in VDR led to a considerable decrease in fracture resistance. More studies investigating the ability of guided endodontics to be performed on molars, especially for detecting the location of extra canals. To test the possibility of leaving the teeth accessed by guided endodontics without extra coronal coverage.

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REFERENCES

1. Plotino G, Grande NM, Isufi A, Ioppolo P, Pedulla E, Bedini R, Gambarini G, Testarelli L. Fracture Strength of Endodontically Treated Teeth with Different Access Cavity Designs. J Endod. 2017; 43:995-1000 https://doi.org/10.1016/j.joen.2017.01.022
2. Sabeti M, Kazem M, Dianat O, Bahrololumi N, Beglou A, Rahimipour K, and Dehnavi F. Impact of Access Cavity Design and Root Canal Taper on Fracture Resistance of Endodontically Treated Teeth: An ExVivo investigation. J Endod. 2018; 44:1402–6 https://doi.org/10.1016/j.joen.2018.05.006
3. Kapetanaki I, Dimopoulos F, Gogos C. Traditional and minimally invasive access cavities in endodontics: a literature review. Restor Dent Endod. 2021;46(3): e46. https://doi.org/10.5395/rde.2021.46.e46
4. Silva E, Rover G, Belladonna F G, De-Deus G, Teixeira C, Fidalgo T. Impact of contracted endodontic cavities on fracture resistance of endodontically treated teeth: a systematic review of in vitro studies. Clin Oral Invest 2018; 22:109–118. https://doi.org/10.1007/s00784-017-2268-y
5. Abou-Elnaga M, Alkhawas M, Kim H, Refai AS: Effect of Truss Access and Artificial Truss Restoration on the Fracture Resistance of Endodontically Treated Mandibular First Molars. J Endod. 2019;45(6):813-7 https://doi.org/10.1016/j.joen.2019.02.007
6. Connert T, Zehnder M, Amato M, Weiger R, Kuhl S, Krastl G. Microguided Endodontics: a method to achieve minimally invasive access cavity preparation and root canal location in mandibular incisors using a novel computer-guided technique. Int Endod J. 2018; 51:247–55 https://doi.org/10.1111/iej.12809
7. Ali A and Arslan H. Guided endodontics: a case report of maxillary lateral incisors with multiple dens invaginatus. Restor Dent Endod. 2019; 44(4):38 https://doi.org/10.5395/rde.2019.44.e38
8. Shah P, and Chong B S. 3D imaging, 3D printing and 3D virtual planning in endodontics. Clin Oral Invest 2018; 22:641–54 https://doi.org/10.1007/s00784-018-2338-9
9. Torres A, Shaheen E, Lambrechts P, Politis C, Jacobs R. Micro-guided Endodontics: a case report of a maxillary lateral incisor with pulp canal obliteration and apical periodontitis. Int Endod J. 2018; 52:540-9 https://doi.org/10.1111/iej.13031
10. Connert T, Krug R, Eggmann F, Emsermann I, ElAyouti A, Weiger R, Kuhl S, Krastl G. Guided Endodontics versus Conventional Access Cavity Preparation: A Comparative Study on Substance Loss Using 3-dimensional–printed Teeth. J Endod. 2019;45(3):327-31 https://doi.org/10.1016/j.joen.2018.11.006
11. Elshinawy M, Abdelaziz K, Khawshhalc A, Alqisic A, Al-Sharic H, and Alsalhi I. Sealing ability of two adhesive sealers in root canals prepared with different rotary file systems. Tanta dent. J.2019; 16:21-4 http://dx.doi.org/10.4103/tdj.tdj_24_18
12. Alovisi M, Pasqualini D, Musso E, Bobbio E, Giuliano C, Mancino D, Scotti N, and Berutti E. Influence of Contracted Endodontic Access on Root Canal Geometry: An in Vitro Study. J Endod. 2018; 44:614-20 https://doi.org/10.1016/j.joen.2017.11.010

13. krastl G, Zehnder M S, Connert T, Weiger R, Kuhl S. Guided Endodontics: a novel treatment approach for teeth with pulp canal calcification and apical pathology. Dent Traumatol. 2016; 32:240–6 https://doi.org/10.1111/edt.12235

14. Van Der Meer WJ, Vissink A, Ng YL, Gulabivala K. 3D computer-aided treatment planning in endodontics. J Dent. 2016; 45:67-72. https://doi.org/10.1016/j.jdent.2015.11.007

15. Lara-Mendes O, Barbosa C, Machado V, Santa-Rosa C. A new Approach for Minimally Invasive Access to Severely Calcified Anterior Teeth Using the Guided Endodontics Technique. J Endod. 2018; 44:1578-82 https://doi.org/10.1016/j.joen.2018.07.006

16. Macho A, Ferreiroa A, Rico-Romano C, Alonso-Ezpeleta L, Mena-Álvarez J. Diagnosis and endodontic treatment of type II dens invaginatus by using cone-beam computed tomography and splint guides for access cavity. J Am Dent Assoc.S 2015; 146:266-70 https://doi.org/10.1016/j.adaj.2014.11.021

17. Perez C, Finelle G, and Couvrechel C. Optimization of a guided endodontics protocol for removal of fiber-reinforced posts. Aust Endod J 2020; 46:107–14. https://doi.org/10.1111/aej.12379

18. Mincik J, Urban D, Timkova S, Urban R. Fracture Resistance of Endodontically Treated Maxillary Premolars Restored by Various Direct Filling Materials: An in Vitro Study. Int J Biomater. 2016; 2016:9138945 https://doi.org/10.1155/2016/9138945

19. Matus D, and Betancourt P. Mechanical root canal preparation using the WaveOne gold® system. Case series. Biomed Res J. 2018; 29 (13): 2686-9. https://doi.org/10.4066/biomedicalresearch.29-17-3587

20. Singh S, Abdul M, Sharma U, Sainudeen S, Jain C, Kalliath T. An in vitro Comparative Evaluation of Volume of Removed Dentin, Canal Transportation, and Centering Ratio of 2Shape, WaveOne Gold, and ProTaper Gold Files Using Cone-Beam Computed Tomography. J Int Soc Prev Community Dent. 2019; 9(5): 481–5. https://doi.org/10.4103/jispcd.jispcd_444_18

21. Yushkevich P, Pashchinskiy A, Oguz1 I, Mohan S, Schmitt J, Stein J et al. User-Guided Segmentation of Multi-Modality Medical Imaging Datasets with ITK-SNAP. Neuroinformatics. 2019; 17:83–102 https://link.springer.com/article/10.1007/s12021-018-9385-x

22. Shaikh S Y, and Shaikh S: Direct Linear Measurement of Root Dentin Thickness and Dentin Volume Changes with Post Space Preparation: A Cone-Beam Computed Tomography Study. Contemp Clin Dent. 2018; 9(1): 77–82. https://doi.org/10.4103/ccd.ccd_785_17

23. Ge1 Z, Yang P, Li1 G, Zhang J, Ma X. Age estimation based on pulp cavity/chamber volume of 13 types of teeth from cone beam computed tomography images. Int J Legal Med. 2016; 130:1159–1167 https://doi.org/10.1007/s00414-016-1384-6

24. Krishan R, Paque F, Ossareh A, Kishen A, Dao T, Friedman S. Impacts of Conservative Endodontic Cavity on Root Canal Instrumentation Efficacy and Resistance to Fracture Assessed in Incisors, Premolars, and Molars. J Endod. 2014;40 (8):1160-6. https://doi.org/10.1016/j.joen.2013.12.012

25. Lin C, Lin D, He W. Impacts of 3 Different Endodontic Access Cavity Designs on Dentin Removal and Point of Entry in 3-dimensional Digital Models. J Endod. 2020;46(4):524-530 https://doi.org/10.1016/j.joen.2020.01.002

26. Chlup Z, Zizka R, Kania J, Pribyl M. Fracture behavior of teeth with conventional and mini-invasive access cavity designs. J Eur Ceram Soc.2017; 37:4423-9. http://dx.doi.org/10.1016/j.jeurceramsoc.2017.03.025