COMPARISON OF FRACTURE RESISTANCE BETWEEN TRADITIONAL ENDODONTIC ACCESS AND MINIMAL ENDODONTIC ACCESS IN 3D-PRINTED MANDIBULAR FIRST MOLARS

A Thesis
Submitted to
Temple University Graduate Board

In Partial Fulfillment
of the Requirements for the Degree
MASTER OF SCIENCE

---

by
Pil Kwon
August 2024

Thesis Approvals:

Roni Nissan, Thesis Advisor, Endodontology
Santiago Orrego, Oral Health Science
Maobin Yang, Endodontology

ABSTRACT

Introduction*:* Many clinicians have employed the traditional endodontic access (TEA), which involves a straight-line access to root canals and a complete removal of the roof of the pulp chamber, whereas others advocate the minimal endodontic access (MEA) to minimize the removal of tooth structure. Several studies have compared the fracture resistance of TEA to that of MEA using human extracted teeth, but variability in size, morphology, and strength resistance has remained as uncontrolled variables.

Purpose: This study aims to compare the fracture resistance of teeth accessed using TEA to those accessed with MEA, using identical 3D-printed mandibular first molars to eliminate variables present in natural human molars.

Materials and Methods: 45 identical 3D-printed mandibular first molars were randomly assigned to three groups (n=15): TEA, MEA, and control. For the TEA group, the roof of the pulp chamber was completely removed, and a straight-line access was made to all three canals. For the MEA group, access was made at the central fossa without complete removal of the roof, just enough to access all three canals. For the control group, no access was made, and the crown was left intact. Each tooth in the TEA and MEA groups were instrumented, obturated, and restored with composite resin. The teeth were embedded in a self-curing epoxy resin to the cementoenamel junction (CEJ). All samples were mounted on the Instron Universal Testing Machine (Instron, Norwood, MA), and a continuous compressive force was loaded with a round end at the central fossa, 30˚ from the long axis at the speed of 0.5mm/min until fracture. The load at fracture (N) was recorded for each sample. One-way ANOVA and Tukey's honestly significant difference test were used for statistical analysis.

Results: The mean maximum load at fracture for the control, TEA, and MEA was 1171.37 ± 160.35, 697.95 ± 121.14, and 1047.08 ± 167.79, respectively. The control group and MEA showed significantly greater resistance to fracture than TEA group, and no significant difference was noted between the control group and MEA. The mean instrumentation time for TEA was 1 minute and 40 seconds (SD: 7 seconds). The mean instrumentation time for MEA was 2 minutes and 7 seconds (SD: 9 seconds). The mean instrumentation time of TEA was significantly lower than that of MEA, conveying better access to the canals.

Conclusion: Under the limitations of this study, it can be concluded that MEA showed significantly greater resistance to fracture compared to TEA yet with longer instrumentation time.

TABLE OF CONTENTS

Page

ABSTRACT……………………..…………………………………………….....……..ii

LIST OF FIGURES………………………..…………………..……………….…….v

LIST OF TABLES………………………………..…...……………………………..vi

CHAPTER

1. INTRODUCTION………………………………………...……………..1
2. MATERIALS AND METHOD……………………....……………………..4
3. RESULTS…………………………………………………………….......8
4. DISCUSSION……………………………………………………………. 10
5. CONCLUSIONS…………………………………………………………. 13

REFERENCES……………………………………………………………………..14

LIST OF FIGURES

Figure Page

1. (A) Traditional endodontic access and (B) Minimal endodontic access with blue dotted line showing the path of tooth structure removal during access ………………………………………………………………………..2

2. (A) Control, (B) TEA, and (C) MEA samples embedded in epoxy resin. (D) A sample embedded 30˚ off the long axis of the tooth ……………………5

3. Instron Universal Testing Machine…………………………………………….6

4. Custom attachment installed on Instron Universal Testing Machine…………..6

5. A sample being tested on Instron Universal Testing Machine…………………7

6. A graph showing a sharp drop indicating fracture…………………….……..7

7. Comparison of the mean maximum load at fracture of the control, TEA, and MEA…………………………………………………………….…....…8

8. Comparison of the mean instrumentation time of control, TEA, and MEA…...9

LIST OF TABLES

Table Page

1. Maximum load at fracture (mean ± standard deviation) and instrumentation time (mean ± standard deviation)……………………………8

CHAPTER 1
INTRODUCTION

Access cavity preparation is the first important step in nonsurgical endodontic treatment, and for many years, clinicians have employed the traditional endodontic access (TEA), which involves a straight-line access to root canal orifices and a complete removal of the roof of the pulp chamber to prevent inadequate cleaning (Patel & Rhodes, 2007). Rankow & Krasner (1995) advocated that not only a complete removal of the roof of the pulp chamber but also a removal of obstructing dentin and enamel is crucial in order to ensure that there is no unfound root canal orifice. They pointed out that being too focused on minimizing tooth removal during access preparation may hinder identifying existing orifices, as they demonstrated that only 100% removal of the roof allowed them to fully visualize the orifices.

The association between unfound root canals during nonsurgical endodontic treatment and periapical pathology has been shown to be significantly high. When endodontically treated teeth were assessed, 82.6% of teeth with missed or unfound root canal was observed to have periapical lesion, supporting the statement that the outcome of a nonsurgical endodontic treatment must involve identifying all existing root canal orifices (Baruwa et al., 2020).

Advancements in technology have brought positive changes to endodontics as well, rendering root canal identification and morphology assessment less complicated than before. Compared to naked eye or magnifying loupes, the dental operating microscope enhances canal detection and negotiation with stronger magnification and illumination (de Carvalho & Zuolo, 2000; Karapinar-Kazandag et al., 2010). In addition to dental operating microscope, cone beam computerized tomography (CBCT) facilitates detection of root canals, enabling the clinician to locate canals even before accessing the tooth (Matherne et al., 2008).

With emergence of such modalities, some have pointed out that the large amount of tooth structure removal involved in the complete removal of the roof of pulp chamber may result in weakened tooth structure, increasing susceptibility to fractures (Tang et al., 2010). A study by Clark & Khademi (2010) presented minimal endodontic access (MEA) in effort to decrease the removal of tooth structure. They claimed that excessive removal of dentin of TEA is unnecessary and weakens the tooth structure by damaging the pericervical dentin, calling the complete removal of roof dangerous. It was argued that the angles of entry into root canals are mostly not perpendicular to the occlusal surface, therefore removing dentin on the pulp chamber wall in order to gain the straight-line access is not necessary but destructive (Clark & Khademi, 2010). Figure 1 illustrates the difference between TEA and MEA.

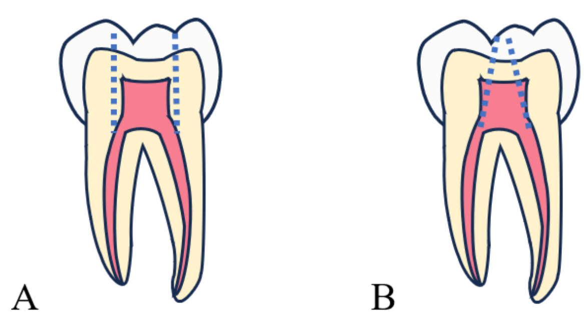

Figure 1. (A) Traditional endodontic access and (B) Minimal endodontic access with blue dotted line showing the path of tooth structure removal during access.

The proponents of MEA claim that it enables the clinician to preserve more pericervical dentin structure which contributes to better resistance to fracture of the remaining tooth structure unlike TEA where it involves removing pericervical dentin (Tang et al., 2010; Clark & Khademi, 2010). Since the concept of MEA has been suggested, many studies have evaluated and compared the fracture resistance of TEA and MEA. Most of these studies involved using human extracted teeth which are not identical in nature. In effort to reduce the variability in size and shape of the sample teeth, researchers have tried to group sample teeth according to their size and morphology (Plotino et al., 2017; Pereira et al., 2021; Silva et al., 2021). However, even in the same tooth from the same host, its fracture resistance may vary with age due to increase in hardness and mineral content in dentin (Arola & Reprogel, 2005; Montoya et al., 2015). Such variability in size, morphology, and density has remained as an uncontrolled variable in the previous studies investigating the relationship between the access cavity designs and the tooth fracture resistance.

The purpose of this study was to evaluate and compare the fracture resistance of the two endodontic access designs, TEA and MEA, using 3D-printed mandibular first molars identical in shape, size, and composition to eliminate such uncontrolled variables.

CHAPTER 2
MATERIALS AND METHODS

Forty-five 19-01 TrueTooth 3D-printed teeth (PlanB Dental, Goleta, CA) were randomly divided into three groups with 15 samples in each group: Control, TEA, and MEA.

For the TEA group, access was initially made at the central fossa of the tooth with a #4 round carbide bur (Integra, Princeton, NJ). Then the roof of the pulp chamber was completely removed using an Endo-Z Bur (Dentsply Sirona, Charlotte, NC), ensuring complete removal of pulp horns. Straight-line access to all three canals was established, perpendicular to the occlusal surface. The dimension of the access for the TEA group was 4 mm mesiodistally and 4 mm buccolingually.

For the MEA group, access was made at the central fossa of the tooth also with a #4 round carbide bur, but the roof of the pulp chamber was not completely removed. The access was extended only to have the dimension of 2 mm by 2mm. Access to all three canals was confirmed by using the endodontic explorer.

The samples of TEA and MEA were then instrumented using K-files and ProTaper Gold rotary file system (Dentsply Sirona, Charlotte, NC). All canals were initially negotiated with #10 K-file 0.5 mm short of the apex, which was determined as the working length. #15 K-file was then used, followed by the ProTaper Gold Sx rotary file to flare the coronal third of the canals. The following ProTaper Gold rotary files were used in order to shape and finish the mesiobuccal (MB) and mesiolingual (ML) canals: S1, S2, F1, and F2. The distal (D) canal was instrumented in the following sequence: S1, S2, F1, F2, F3, and F4. The canals were irrigated and recapitulated intermittently. The total time of instrumentation was recorded in seconds (s) from initial file to final file.

After instrumentation, the canals were dried with paper points. All canals were then obturated with ProTaper Gold Conform Fit Gutta-Percha (Dentsply Sirona, Charlotte, NC) and EndoSequence BC Sealer (Brasseler USA, Savannah, GA) to the orifice level. The pulp chambers were cleaned with cotton pellets soaked in alcohol and were air dried. G-Premio BOND (GC America, Alsip, IL) was then applied on the floor and walls of pulp chamber, was lightly air dried, and was light-cured for 20 seconds. Spectra STLV composite (Dentsply Sirona, Charlotte, NC) was placed in the chamber in 2 mm increments to the occlusal level, light-cured 20 seconds per increment.

For the control group, the samples were left intact without access or instrumentation.

The roots of all 45 samples of the three groups were then embedded in aluminum casing filled with self-curing epoxy resin (Polymer Composites Inc., Ontario, CA) to the level of the cementoenamel junction (CEJ), 30˚ off the long axis as shown in Figure 2 (Moore et al., 2016).

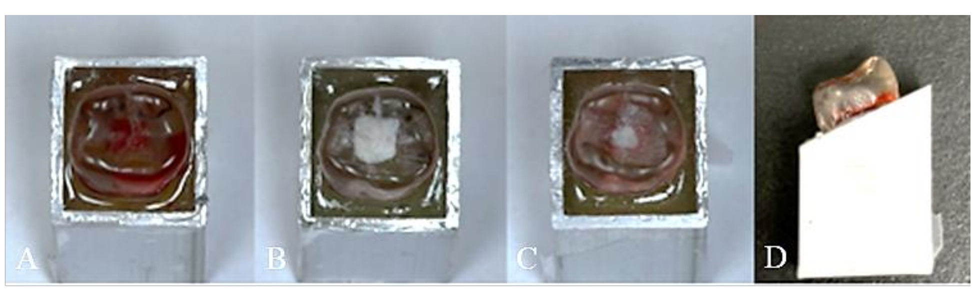

Figure 2. (A) Control, (B) TEA, and (C) MEA samples embedded in epoxy resin. (D) A sample embedded 30˚ off the long axis of the tooth.

The fracture resistance was measured by using Instron Universal Testing Machine (Instron, Norwood, MA), as shown in Figure 3. An attachment with 20 mm shank and 5 mm diameter round end was fabricated and was installed on Instron Universal Testing Machine (Figure 4). A continuous compressive force was loaded with the round end on the central fossa of the sample at the speed of 0.5 mm/min until fracture (Figure 5). Load at fracture (N) was recorded for each sample, which was defined as a sharp drop of the line graph drawn simultaneously by Instron Universal Testing Machine, indicating a sharp decrease in compressive load (Figure 6).

Figure 3. Instron Universal Testing Machine.

Figure 4. Custom attachment installed on Instron Universal Testing Machine.

Figure 5. A sample being tested on Instron Universal Testing Machine.

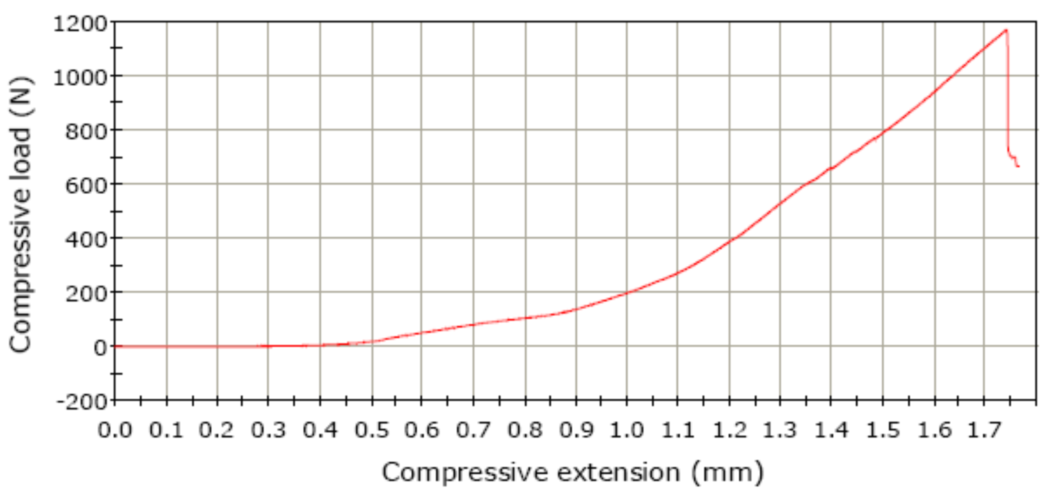

Figure 6. A graph showing a sharp drop indicating fracture.

The mean maximum load at fracture of each group was statistically analyzed using One-way ANOVA and Tukey's honestly significant difference test. The statistical significance was set as $P < 0.05$. The mean instrumentation time was statistically analyzed using unpaired t-test. The statistical significance was set as $P < 0.05$.

CHAPTER 3
RESULTS

The mean maximum load at fracture for the control was 1171.37 ± 160.35 N (Table 1). For TEA and MEA, the average maximum load at fracture was 697.95 ± 121.14 N and 1047.08 ± 167.79 N, respectively. Statistical analysis showed a significant difference between the control group and TEA (Figure 7). A significant difference was also observed between TEA and MEA, but no significant difference was noted between the control group and MEA.

Group	Mean maximum load at fracture (N) ± standard deviation	Mean instrumentation time (s) ± standard deviation
Control	1171.37 ± 160.35*	
TEA	697.95 ± 121.14	100.07 ± 6.99
MEA	1047.08 ± 167.79*	127.47 ± 8.67*

Table 1. Maximum load at fracture (mean ± standard deviation) and instrumentation time (mean ± standard deviation). The asterisk (*) indicates statistically significant difference.

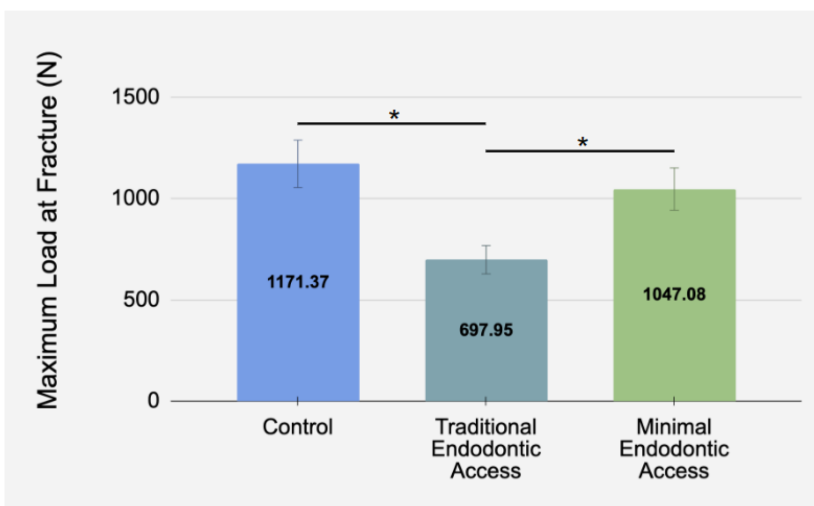

Figure 7. Comparison of the mean maximum load at fracture of the control, TEA, and MEA. The asterisk (*) indicates statistically significant difference.

The mean instrumentation time for TEA was 1 minute and 40 seconds ± 7 seconds, whereas the mean instrumentation time for MEA was 2 minutes and 7 seconds ± 9 seconds. The mean instrumentation time of TEA was significantly lower than that of MEA (Figure 8).

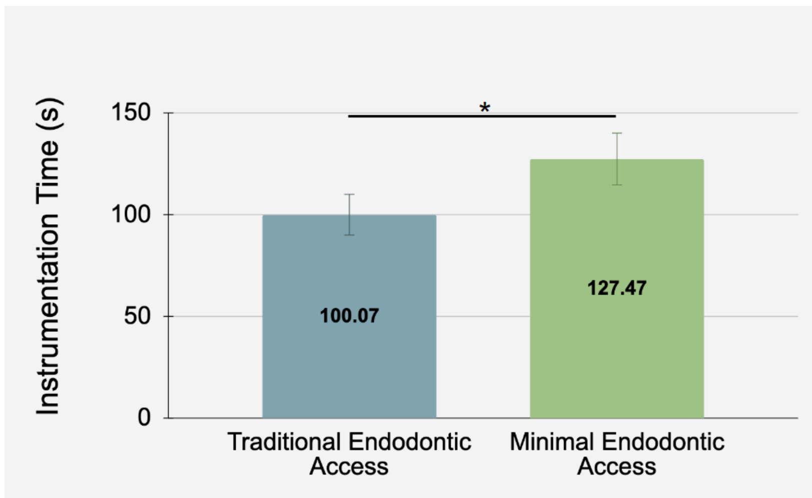

Figure 8. Comparison of the mean instrumentation time of control, TEA, and MEA. The asterisk (*) indicates statistically significant difference.

CHAPTER 4
DISCUSSION

When making an endodontic access, any unnecessary removal of tooth structure should be avoided as less amount of remaining tooth structure is associated with higher risk of fracture (Tang et al., 2010; Nagasiri & Chitmongkolsuk, 2004; Kishen, 2006). The concept of minimal endodontic access was suggested stating that the traditional endodontic access involves unnecessary removal of tooth structure (Clark & Khademi, 2010). To see if such size difference in endodontic access plays a crucial role in affecting the fracture resistance of endodontically treated teeth, many studies were conducted using human extracted teeth. As human teeth differ in size, morphology, and even in density, efforts to minimize such variables were made including but not limited to using the same kind of tooth and matching the size and shape (Arola & Reprogel, 2005; Montoya et al., 2015; Plotino et al., 2017; Pereira et al., 2021; Silva et al., 2021). In this study, to completely eliminate such variables, identical 3D-printed mandibular molars were used.

Compared to TEA, MEA showed significantly greater fracture resistance in this study, which is in agreement with human extracted molar studies by Krishan et al. (2014), Plotino et al. (2017), and Santosh et al. (2021). Similarly, recent studies using finite element analysis to investigate fracture resistance of molars with different endodontic access designs have also shown that more conservative endodontic access increases the fracture resistance (Zhang et al., 2019; Wang et al., 2020; Rahmatian et al., 2023).

In this study, there was no significant difference in fracture resistance when MEA was compared to the control group. This further supports that minimizing the size of endodontic access will enhance fracture resistance, close to that of a nontreated tooth. However, as there are studies showing decreased stiffness of endodontically treated teeth, this result may need further investigation as artificial 3-D printed molars were used in this study (Reeh et al., 1989; Langan et al., 2004).

In a very recent study of extracted human mandibular molars with simulated mastication showed there was no significant difference between the traditional and minimal endodontic accesses (Selvakumar et al., 2023). This finding is similar to those of many previous studies (Corsentino et al., 2018; Ozyurek et al., 2018; Pereira et al., 2021; Silva et al., 2021). A study by Rover et al. (2017) on human extracted maxillary first molars also revealed that there was no difference between traditional endodontic access and minimal endodontic access. Rover et al. (2017) also found that traditional endodontic access was more advantageous in locating root canals when no ultrasonic troughing was used. Literature reviews by Kapetanaki et al. (2021) and Shabbir et al. (2021), as well as the systematic review of Saeed et al. (2021), say that MEA is not necessarily more advantageous than TEA in terms of fracture resistance yet may have more risks than benefits such as inadequate disinfection, fill, and restoration. The findings of the previous studies are for sure conflicting, and further investigations are required to reach a consensus.

In terms of the instrumentation time, TEA took significantly less time compared to MEA, indicating easier access to the canals. A similar finding was observed in Vorster et al.'s study in 2022, where the instrumentation times for TEA and MEA were 38.2 ± 4.57 seconds and 55.6 ± 6.91 seconds, respectively.

In future studies, designing 3-D printed teeth with premade access opening may help with the consistency. Also, natural human teeth are comprised of enamel, dentin, and pulp which vary in stiffness, whereas 3-D printed teeth may not have the relative difference in stiffness of each layer. Some studies employed using finite element analysis to overcome this problem, but it is yet unclear how well the simulated test results will be reflected clinically. Also, embedding the sample teeth in epoxy resin contained in the aluminum casing was another challenge of this study. Due to limited materials and funds, the placement of sample teeth could have had minor discrepancies, which might have also affected its position on Instron Universal Testing Machine. Lastly, increasing the sample size would help in increasing reliability of the outcome.

CHAPTER 5
CONCLUSIONS

This study aimed to compare the traditional endodontic access and the minimal endodontic access in terms of fracture resistance. Furthermore, instrumentation times of the two groups were compared. The following conclusions were drawn:

1. Compared to the traditional endodontic access (TEA), the minimal endodontic access (MEA) showed greater fracture resistance.
2. Compared to TEA, MEA took longer time to instrument the canals, conveying that the smaller access has made more difficult access to the root canal orifices.

In future studies, a larger sample size and using 3-D printed teeth with premade access opening may help with eliminating more variables. This study may serve as a preliminary study, further investigations are encouraged to confirm the findings from this study.

REFERENCES

Arola, D., & Reprogel, R. K. (2005). Effects of aging on the mechanical behavior of human dentin. Biomaterials, 26(18), 4051–4061.

Baruwa, A. O., Martins, J. N. R., Meirinhos, J., Pereira, B., Gouveia, J., Quaresma, S. A., Monroe, A., & Ginjeira, A. (2020). The Influence of Missed Canals on the Prevalence of Periapical Lesions in Endodontically Treated Teeth: A Cross-sectional Study. Journal of Endodontics, 46(1), 34-39.e1.

Clark, D., & Khademi, J. (2010). Modern Molar Endodontic Access and Directed Dentin Conservation. Dental Clinics of North America, 54(2), 249–273.

Corsentino, G., Pedullà, E., Castelli, L., Liguori, M., Spicciarelli, V., Martignoni, M., Ferrari, M., & Grandini, S. (2018). Influence of Access Cavity Preparation and Remaining Tooth Substance on Fracture Strength of Endodontically Treated Teeth. Journal of Endodontics, 44(9), 1416–1421.

de Carvalho, M., & Zuolo, M. (2000). Orifice Locating with a Microscope. Journal of Endodontics, 26(9), 532–534.

Kapetanaki, I., Dimopoulos, F., & Gogos, C. (2021). Traditional and minimally invasive access cavities in endodontics: A literature review. *Restorative Dentistry & Endodontics*, *46*(3), e46.

Karapinar-Kazandag, M., Basrani, B. R., & Friedman, S. (2010). The Operating Microscope Enhances Detection and Negotiation of Accessory Mesial Canals in Mandibular Molars. Journal of Endodontics, 36(8), 1289–1294.

Kishen, A. (2006). Mechanisms and risk factors for fracture predilection in endodontically treated teeth. Endodontic Topics, 13(1), 57–83.

Krishan, R., Paqué, F., Ossareh, A., Kishen, A., Dao, T., & Friedman, S. (2014). Impacts of Conservative Endodontic Cavity on Root Canal Instrumentation Efficacy and Resistance to Fracture Assessed in Incisors, Premolars, and Molars. Journal of Endodontics, 40(8), 1160–1166.

Langan, S. J., Liewehr, F. R., Patton, W. R., McPherson, J. C., & Runner, R. R. (2004). Effect of Intracanal Restorative Material on the Stiffness of Endodontically Treated Teeth. Military Medicine, 169(12), 948–951.

Matherne, R. P., Angelopoulos, C., Kulild, J. C., & Tira, D. (2008). Use of Cone-Beam Computed Tomography to Identify Root Canal Systems In Vitro. Journal of Endodontics, 34(1), 87–89.

Montoya, C., Arango-Santander, S., Peláez-Vargas, A., Arola, D., & Ossa, E. A. (2015). Effect of aging on the microstructure, hardness and chemical composition of dentin. Archives of Oral Biology, 60(12), 1811–1820.

Moore, B., Verdelis, K., Kishen, A., Dao, T., & Friedman, S. (2016). Impacts of Contracted Endodontic Cavities on Instrumentation Efficacy and Biomechanical Responses in Maxillary Molars. Journal of Endodontics, 42(12), 1779–1783.

Nagasiri, R., & Chitmongkolsuk, S. (2005). Long-term survival of endodontically treated molars without crown coverage: A retrospective cohort study. THE JOURNAL OF PROSTHETIC DENTISTRY, 93(2).

Özyürek, T., Ülker, Ö., Demiryürek, E. Ö., & Yılmaz, F. (2018). The Effects of Endodontic Access Cavity Preparation Design on the Fracture Strength of Endodontically Treated Teeth: Traditional Versus Conservative Preparation. Journal of Endodontics, 44(5), 800–805.

Patel, S., & Rhodes, J. (2007). A practical guide to endodontic access cavity preparation in molar teeth. British Dental Journal, 203(3), 133–140.

Pereira, R. D., Leoni, G. B., Silva-Sousa, Y. T., Gomes, E. A., Dias, T. R., Brito-Júnior, M., & Sousa-Neto, M. D. (2021). Impact of Conservative Endodontic Cavities on Root Canal Preparation and Biomechanical Behavior of Upper Premolars Restored with Different Materials. Journal of Endodontics, 47(6), 989–999.

Plotino, G., Grande, N. M., Isufi, A., Ioppolo, P., Pedullà, E., Bedini, R., Gambarini, G., & Testarelli, L. (2017). Fracture Strength of Endodontically Treated Teeth with Different Access Cavity Designs. Journal of Endodontics, 43(6), 995–1000.

Rahmatian, M., Jafari, Z., Moghaddam, K. N., Dianat, O., & Kazemi, A. (2023). Finite Element Analysis of Fracture Resistance of Mandibular Molars with Different Access Cavity Designs. Journal of Endodontics, 49(12), 1690–1697.

Rankow, H. J., & Krasner, P. R. (1995). The access box: An Ah-Ha phenomenon. Journal of Endodontics, 21(4), 212–214.

Reeh, E. S., Messer, H. H., & Douglas, W. H. (1989). Reduction in tooth stiffness as a result of endodontic and restorative procedures. Journal of Endodontics, 15(11), 512–516.

Rover, G., Belladonna, F. G., Bortoluzzi, E. A., De-Deus, G., Silva, E. J. N. L., & Teixeira, C. S. (2017). Influence of Access Cavity Design on Root Canal Detection, Instrumentation Efficacy, and Fracture Resistance Assessed in Maxillary Molars. Journal of Endodontics, 43(10), 1657–1662.

Saeed, M., Al-Obadi, M., Salim, A., Alsawaf, A. Y., & Hadi, K. (2021). Impact of Access Cavity Design on Fracture Resistance of Endodontically Treated Molars: A Systematic Review. *Clinical, Cosmetic and Investigational Dentistry*, *Volume 13*, 1–10.

Santosh, S. S., Ballal, S., & Natanasabapathy, V. (2021). Influence of Minimally Invasive Access Cavity Designs on the Fracture Resistance of Endodontically Treated Mandibular Molars Subjected to Thermocycling and Dynamic Loading. Journal of Endodontics, 47(9), 1496–1500.

Selvakumar, R. J., Surendran, S., Sundar, S., Arul, B., & Natanasabapathy, V. (2023). Impact of Contracted Endodontic Access Cavities on the Fracture Resistance of Endodontically Treated Teeth After Mechanical Aging by Simulated Chewing Forces. Journal of Endodontics, 49(9), 1176–1182.

Shabbir, J., Zehra, T., Najmi, N., Hasan, A., Naz, M., Piasecki, L., & Azim, A. A. (2021). Access Cavity Preparations: Classification and Literature Review of Traditional and Minimally Invasive Endodontic Access Cavity Designs. *Journal of Endodontics*, *47*(8), 1229–1244.

Silva, E. J. N. L., Lima, C. O., Barbosa, A. F. A., Augusto, C. M., Souza, E. M., Lopes, R. T., De-Deus, G., & Versiani, M. A. (2021). Preserving dentine in minimally invasive access cavities does not strengthen the fracture resistance of restored mandibular molars. International Endodontic Journal, 54(6), 966–974.

Tang, W., Wu, Y., & Smales, R. J. (2010). Identifying and Reducing Risks for Potential Fractures in Endodontically Treated Teeth. Journal of Endodontics, 36(4), 609–617.

Vorster, M., Van Der Vyver, P. J., & Markou, G. (2022). The Effect of Different Molar Access Cavity Designs on Root Canal Shaping Times Using Rotation and Reciprocation Instruments in Mandibular First Molars. Journal of Endodontics, 48(7), 887–892.

Wang, Q., Liu, Y., Wang, Z., Yang, T., Liang, Y., Gao, Z., Fang, C., & Zhang, Y. (2020). Effect of Access Cavities and Canal Enlargement on Biomechanics of Endodontically Treated Teeth: A Finite Element Analysis. Journal of Endodontics, 46(10), 1501–1507.

Zhang, Y., Liu, Y., She, Y., Liang, Y., Xu, F., & Fang, C. (2019). The Effect of Endodontic Access Cavities on Fracture Resistance of First Maxillary Molar Using the Extended Finite Element Method. Journal of Endodontics, 45(3), 316–321.