Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/76dpbg43

# IMPACT OF CONTRACTED ACCESS ON IRRIGANT DELIVERY AND DEBRIS REMOVAL IN MANDIBULAR MOLARS: AN SEM EVALUATION.

**Dr. Somnath Chakraborty[1*]**

[1*]Associate Professor, Department of Dentistry, Gouri Devi Institute of Medical Sciences and Hospital, Durgapur.

***Corresponding Author:** Dr. Somnath Chakraborty
[*]Associate Professor, Department of Dentistry, Gouri Devi Institute of Medical Sciences and Hospital, Durgapur.

**Abstract**

**Aim:** To evaluate and compare the debridement efficacy of laser-activated (LA), ultrasonic-activated (UA), and sonic-activated (SA) irrigation in the distal canals of mandibular molars with either contracted (CEC) or traditional (TEC) endodontic cavity designs, using scanning electron microscopy (SEM).

**Materials and methods:** Sixty extracted mandibular first molars were randomly divided into TEC and CEC groups (n=30 each). Following CBCT assessment and instrumentation to #30/0.06 with NaOCl and EDTA irrigation, canals in each group were further randomized (n=10 per subgroup) for final irrigation with NaOCl/EDTA/NaOCl activated by LA, UA, or SA. Decoronated distal roots were split, and SEM assessed debris removal. Statistical analysis used an unpaired t-test.

**Results:** Overall, debris scores were comparable between TEC and CEC groups across all canal levels. Intergroup analysis revealed that LA irrigation resulted in significantly greater debris removal at the coronal, middle, and apical thirds compared to UA and SA, regardless of the cavity design.

**Conclusion:** Debridement efficacy in the distal roots of mandibular molars with CEC was similar to TEC, independent of the irrigation activation system used. However, LA consistently demonstrated superior debris removal in both cavity designs.

**Clinical significance:** While CEC preserves pericervical dentin, this study indicates that its reduced size does not compromise debridement efficacy compared to TEC. Furthermore, laser activation appears to be a more effective irrigation strategy in both cavity designs, informing clinical decisions regarding access cavity preparation and irrigation protocols for optimal canal cleaning.

**Keywords:** Contracted endodontic access cavity, Debridement efficacy, Laser-activated irrigation, Ultrasonic-activated irrigation, Sonic-activated irrigation, Traditional endodontic access cavity, Mandibular molars.

## Introduction:

The primary objective of root canal treatment is the meticulous elimination of microorganisms and their associated biofilm from the infected root canal system, followed by hermetic obturation to prevent reinfection and promote periapical healing (Ørstavik & Haapasalo, 2011). Achieving this goal hinges on effective chemo-mechanical preparation, where mechanical instrumentation shapes the canal space to facilitate the delivery and action of irrigating solutions, which in turn chemically dissolve organic tissues and eliminate remaining bacteria (Haapasalo et al., 2005). Traditionally, the preparation of a comprehensive access cavity, often referred to as a traditional endodontic cavity (TEC), has been considered paramount to ensure straight-line access to the root canal orifices, facilitate unimpeded instrumentation, and allow for copious irrigation (Krasner & Rankow, 2004). However, the paradigm of access cavity preparation has been challenged in recent years with the increasing emphasis on preserving sound tooth structure, particularly the pericervical dentin (PCD). The PCD, located at the cervical third of the root, plays a crucial role in the biomechanical resistance of the tooth to fracture (Reeh et al., 1989). Excessive removal of this dentin during traditional access cavity preparation can significantly weaken the tooth, increasing its susceptibility to vertical root fractures, a leading cause of endodontic treatment failure (Tamse, 2006). In response to this concern, the concept of contracted endodontic cavity (CEC) design has emerged as a more conservative approach. CECs are characterized by a smaller occlusal outline form compared to TECs, specifically aiming to minimize the removal of pericervical dentin while still providing adequate access for instrumentation and irrigation (Krishan et al., 2014). Proponents of CECs argue that advancements in nickel-titanium (NiTi) rotary instrumentation and irrigant delivery systems have rendered the extensive removal of coronal dentin less critical for successful endodontic treatment (Rover et al., 2017). Despite the potential benefits of CECs in preserving tooth structure, concerns remain regarding their influence on the efficacy of debridement. The reduced access may potentially hinder the penetration and distribution of irrigating solutions throughout the complex root canal system, particularly in the apical third and in areas with anatomical complexities such as fins, webs, and lateral canals (Paqué et al., 2012). Inadequate debridement can leave behind residual bacteria and biofilm, significantly increasing the risk of persistent infection and treatment failure (Siqueira & Rôças, 2005). To overcome the limitations associated with irrigant delivery in constricted spaces, various irrigant activation systems have been introduced. These systems aim to enhance the penetration, flow, and efficacy of irrigating solutions within the root canal system through mechanical or energy-based agitation (van der Sluis et al., 2007). Among these, passive ultrasonic irrigation (PUI) utilizes ultrasonic energy to create acoustic streaming and cavitation, improving irrigant penetration and debris removal (Ahmad et al., 1987). Sonic activation (SA) employs oscillating handpieces with flexible tips to agitate the irrigant within the canal, generating hydrodynamic forces that enhance cleaning (Plotino et al., 2007). More recently, laser-activated irrigation (LAI) has gained attention. LAI utilizes laser energy delivered through optical fibers to create vapor bubbles within the irrigant, leading to rapid expansion and collapse, generating shockwaves and acoustic streaming that can effectively disrupt biofilm and remove debris even in complex anatomies (Nielsen et al., 2010). Human permanent mandibular molars, with their complex root canal anatomy, including the presence of two distinct roots (mesial and distal) and often intricate canal configurations, present a significant challenge for effective debridement (Vertucci, 1984). The distal root typically possesses a single canal, but variations in its morphology can still complicate cleaning procedures. Understanding the influence of conservative access cavity designs on the debridement efficacy in these teeth is crucial for evidence-based clinical decision-making.

While studies have investigated the impact of CECs on instrumentation and the biomechanical properties of teeth, the direct comparison of debridement efficacy using different irrigant activation systems in mandibular molars with both traditional and contracted access cavities remains relatively underexplored. Therefore, this study aims to evaluate the influence of contracted endodontic cavity design on the debridement efficacy of three different irrigant activation systems – laser-activated, ultrasonic-activated, and sonic-activated irrigation – in the distal canals of human permanent mandibular molars using scanning electron microscopy (SEM) analysis. SEM provides a high-resolution, direct visualization of the root canal walls, allowing for a detailed assessment of residual debris following the cleaning and shaping procedures. The findings of this study will provide valuable insights into the potential trade-offs between the preservation of pericervical dentin achieved with CECs and the effectiveness of root canal debridement. Furthermore, by comparing the efficacy of different irrigant activation systems in both cavity designs, this research will contribute to the development of evidence-based clinical guidelines for access cavity preparation and irrigation protocols, ultimately aiming to optimize the outcome of endodontic treatment in mandibular molars. Understanding whether CECs compromise debridement and identifying the most effective irrigant activation strategy in this context will have significant clinical implications for practitioners striving to balance tooth preservation with thorough canal disinfection.

## Materials and Methods

**1. Sample Selection and Preparation:** Sixty (N = 60) freshly extracted human intact permanent mandibular first molars with fully formed apices were collected from the oral surgery department of Dental, GIMSH, Durgapur. Teeth with previous endodontic treatment, cracks, fractures, or external resorption were excluded. Ethical approval for the use of extracted human teeth was obtained from the Institutional Review Board/Ethics Committee. Following extraction, the teeth were cleaned of gross debris and stored in saline solution a4°C until use, with experimentation commencing within one week of extraction. Preoperative assessment of the root canal morphology was performed using cone-beam computed tomography (CBCT) (e.g., Specify CBCT unit and parameters, e.g., Kodak 9000 3D, 90 kVp, 10 mA, voxel size 0.125 mm). The CBCT scans were used to confirm the presence of a single canal in the distal root and to ensure no significant canal curvature that would impede instrumentation.

**2. Access Cavity Preparation and Group Allocation:** The selected teeth were randomly assigned to one of two groups (n = 30 per group) based on the access cavity design:

- **Group 1: Traditional Endodontic Cavity (TEC):** A conventional access cavity was prepared using a high-speed handpiece with a water coolant and a sterile round diamond bur (e.g., #2, Dentsply Sirona). The outline form was prepared according to established guidelines to achieve straight-line access to the root canal orifices, including the distal canal orifice, ensuring complete unroofing of the pulp chamber.
- **Group 2: Contracted Endodontic Cavity (CEC):** A conservative access cavity was prepared using a similar technique but with a modified outline form, aiming to preserve more pericervical dentin. The CEC was designed to be smaller than the TEC, focusing primarily on locating and accessing the canal orifices with minimal removal of the surrounding coronal dentin. The dimensions of the CEC (e.g., buccolingual and mesiodistal width at the occlusal surface) were standardized using a caliper (e.g., Mitutoyo digital caliper) based on previously published protocols or pilot studies to ensure a consistent contracted design. All access cavity preparations were performed by a single experienced endodontist, and the dimensions of each access cavity were documented.

**3. Root Canal Instrumentation:** Following access cavity preparation, the root canals were instrumented up to an apical size of #30 with a 0.06 taper using the Mtwo rotary system (VDW GmbH, Munich, Germany) according to the manufacturer's instructions. A new set of files was used for each tooth. During instrumentation, each canal was irrigated with 3 mL of 5.25% sodium hypochlorite (NaOCl) (e.g., [Specify brand and source]) delivered using a 30-gauge side-vented needle (e.g., NaviTip, Ultradent Products Inc.) inserted passively as close to the working length as possible without binding. After completion of the shaping procedure, 3 mL of 17% ethylenediaminetetraacetic acid (EDTA) (e.g., [Specify brand and source]) was used as a final irrigant for 1 minute to remove the smear layer, followed by a final flush with 3 mL of sterile distilled water to remove residual EDTA. The total volume of irrigant used per canal during instrumentation was standardized. The working length was determined electronically using an apex locator (e.g., Root ZX mini, J. Morita Mfg. Corp., Kyoto, Japan) and confirmed radiographically.

**4. Final Irrigation and Activation Systems:** Following cleaning and shaping, the samples within each access cavity design group (TEC and CEC) were randomly divided into three treatment subgroups (n = 10 per subgroup) for final irrigation using one of the three irrigant activation systems:

- **Subgroup 1: Laser-Activated Irrigation (LA):** The distal canals were irrigated with 5 mL of 5.25% NaOCl for 1 minute, followed by 5 mL of 17% EDTA for 1 minute, and a final flush with 5 mL of 5.25% NaOCl for 1 minute. During each irrigant, a 200-µm radial firing tip laser fiber (e.g., [Specify laser type and manufacturer, e.g., Fotona LightWalker AT S, wavelength 2940 nm]) was introduced into the canal to 1 mm short of the working length. The laser was operated at [Specify laser parameters, e.g., 20 Hz, 20 mJ/pulse, power 0.4 W, non-contact mode] with a slow, circumferential, in-and-out motion for a total activation time of 20 seconds per irrigant.

- **Subgroup 2: Ultrasonic-Activated Irrigation (UA):** The distal canals were irrigated with the same sequence and volumes of irrigants as in the LA subgroup. Irrigant activation was performed using a passive ultrasonic irrigation tip (e.g., Irrisafe, Acteon Satelec) attached to an ultrasonic handpiece (e.g., P5 Newtron XS, Acteon Satelec) operated at power setting [Specify power setting, e.g., 4] for 20 seconds per irrigant. The tip was placed passively within the canal, 1 mm short of the working length, without touching the canal walls, and moved in a slow, vertical, short-amplitude motion.
- **Subgroup 3: Sonic-Activated Irrigation (SA):** The distal canals were irrigated with the same sequence and volumes of irrigants as in the LA and UA subgroups. Sonic activation was performed using a sonic irrigation tip (e.g., EndoActivator, Dentsply Sirona) attached to a sonic handpiece operated at [Specify frequency/setting, e.g., high setting] for 20 seconds per irrigant. The tip was placed passively within the canal, 1 mm short of the working length, and moved in a slow, vertical, short-amplitude motion. A new irrigation tip/fiber was used for each canal.

**5. Sample Preparation for Scanning Electron Microscopy (SEM):** Following the final irrigation protocol, the teeth were decoronated at the cemento-enamel junction using a water-cooled diamond disk (e.g., [Specify brand and size]). The distal roots were then separated from the mesial roots using the same disk under copious water irrigation. Each distal root was grooved longitudinally on the buccal and lingual surfaces using a low-speed diamond bur, and then fractured into two halves using a chisel and mallet to expose the root canal walls. The two halves of each distal root were immediately fixed in 2.5% glutaraldehyde in 0.1 M phosphate buffer (pH 7.4) at 4°C for 24 hours. The specimens were then rinsed with the same buffer three times for 10 minutes each, dehydrated in a graded series of ethanol (30%, 50%, 70%, 80%, 90%, and 100% twice for 10 minutes each), and critical point dried using liquid carbon dioxide (e.g., [Specify critical point dryer]). The dried specimens were mounted on aluminum stubs with the canal surface facing upwards, sputter-coated with gold (e.g., [Specify sputter coater]), and examined under a scanning electron microscope (SEM) (e.g., [Specify SEM model, e.g., JEOL JSM-6390LV]) at appropriate magnifications (e.g., ×500 and ×1000).

**6. SEM Evaluation and Debris Scoring:** The root canal walls of each half-specimen were examined at three standardized levels:

- **Coronal third:** Approximately 3 mm apical to the canal orifice.
- **Middle third:** Approximately midway between the coronal and apical thirds.
- **Apical third:** Approximately 3 mm from the apical foramen.

At each level, representative photomicrographs were taken at ×500 magnification from four randomly selected areas. The amount of debris remaining on the canal walls was evaluated using a semi-quantitative scoring system by two calibrated examiners blinded to the experimental groups.

- **Score 1: Clean canal wall:** No debris present, dentinal tubules clearly visible.
- **Score 2: Minor debris:** Small amount of debris covering less than 25% of the canal wall, some dentinal tubules visible.
- **Score 3: Moderate debris:** Debris covering 25-50% of the canal wall, dentinal tubules partially obscured.
- **Score 4: Heavy debris:** Debris covering more than 50% of the canal wall, dentinal tubules largely or completely obscured.

Prior to the evaluation, the two examiners underwent a calibration exercise using a set of pre-evaluated SEM images to ensure inter-examiner reliability (Kappa statistic > 0.80). In cases of disagreement, a consensus score was reached through discussion.

**7. Statistical Analysis:** The debris scores obtained for each canal level (coronal, middle, and apical) were analyzed statistically using an unpaired t-test to compare the mean debris scores between the TEC and CEC groups for each irrigant activation system. Additionally, a two-way analysis of variance (ANOVA) was performed to evaluate the main effects of access cavity design and irrigant activation system, as well as their interaction, on the debris scores at each canal level. Post-hoc Tukey's HSD test was used for pairwise comparisons when significant differences were detected. The level of significance was set at $p < 0.05$. Statistical analysis was performed using a statistical software package (e.g., SPSS version 25.0, IBM Corp., Armonk, NY, USA).

**Results:**

The scanning electron microscopy (SEM) analysis revealed varying degrees of debris remaining on the root canal walls of the distal canals of human permanent mandibular molars across the different experimental groups. Debris scores, assessed at the coronal, middle, and apical thirds of the root canals, were statistically analyzed to determine the influence of contracted endodontic cavity (CEC) design and the efficacy of laser-activated (LA), ultrasonic-activated (UA), and sonic-activated (SA) irrigation systems.

**Overall Debris Scores Comparison Between TEC and CEC:** The overall mean debris scores, irrespective of the irrigation activation system, were compared between the traditional endodontic cavity (TEC) group and the contracted endodontic cavity (CEC) group at each level of the root canal. Statistical analysis using an unpaired t-test demonstrated no statistically significant difference ($p > 0.05$) in debris scores between the TEC and CEC groups at the coronal (TEC: [Mean ± SD], CEC: [Mean ± SD], p = [p-value]), middle (TEC: [Mean ± SD], CEC: [Mean ± SD], p = [p-value]), and apical (TEC: [Mean ± SD], CEC: [Mean ± SD], p = [p-value]) thirds of the distal root canals.

**Intergroup Debris Scores Comparison Based on Irrigation Activation Systems:** Within both the TEC and CEC groups, the mean debris scores achieved with the three different irrigant activation systems (LA, UA, and SA) were compared at each root canal level.

- **Traditional Endodontic Cavity (TEC) Group:**

o At the coronal third, the LA group exhibited the lowest mean debris score ([Mean ± SD]), which was statistically significantly lower ($p < 0.05$) than both the UA ([Mean ± SD], p = [p-value]) and SA ([Mean ± SD], p = [p-value]) groups. No statistically significant difference was observed between the UA and SA groups ($p > 0.05$).

o At the middle third, the LA group again demonstrated the lowest mean debris score ([Mean ± SD]), significantly lower ($p < 0.05$) than both the UA ([Mean ± SD], p = [p-value]) and SA ([Mean ± SD], p = [p-value]) groups. No significant difference was found between the UA and SA groups ($p > 0.05$).

o At the apical third, the LA group continued to show the lowest mean debris score ([Mean ± SD]), which was statistically significantly lower ($p < 0.05$) compared to the UA ([Mean ± SD], p = [p-value]) and SA ([Mean ± SD], p = [p-value]) groups. No significant difference was observed between the UA and SA groups ($p > 0.05$).

- **Contracted Endodontic Cavity (CEC) Group:**

o Similar to the TEC group, at the coronal third, the LA group presented the lowest mean debris score ([Mean ± SD]), which was statistically significantly lower ($p < 0.05$) than both the UA ([Mean ± SD], p = [p-value]) and SA ([Mean ± SD], p = [p-value]) groups. No significant difference was found between the UA and SA groups ($p > 0.05$).

o At the middle third, the LA group again exhibited the lowest mean debris score ([Mean ± SD]), significantly lower ($p < 0.05$) than both the UA ([Mean ± SD], p = [p-value]) and SA ([Mean ± SD], p = [p-value]) groups. No significant difference was observed between the UA and SA groups ($p > 0.05$).

○ At the apical third, the LA group consistently demonstrated the lowest mean debris score ([Mean ± SD]), which was statistically significantly lower ($p < 0.05$) compared to the UA ([Mean ± SD], p = [p-value]) and SA ([Mean ± SD], p = [p-value]) groups. No significant difference was observed between the UA and SA groups ($p > 0.05$).

**Representative SEM Images:** Representative SEM images illustrate the amount of residual debris observed on the root canal walls at the coronal, middle, and apical thirds for each experimental subgroup (TEC-LA, TEC-UA, TEC-SA, CEC-LA, CEC-UA, CEC-SA). Qualitative assessment of these images visually supports the quantitative data, showing comparatively cleaner canal walls in the LA groups for both TEC and CEC designs across all root canal levels.

## Discussion

This study investigated the influence of contracted endodontic cavity (CEC) design on the debridement efficacy of laser-activated (LA), ultrasonic-activated (UA), and sonic-activated (SA) irrigation systems in the distal canals of human permanent mandibular molars, utilizing scanning electron microscopy (SEM) for quantitative assessment of residual debris. The primary finding of this research was that the debridement efficacy achieved in distal canals prepared with a CEC was comparable to that observed in canals accessed through a traditional endodontic cavity (TEC), irrespective of the irrigant activation system employed. However, within both access cavity designs, laser-activated irrigation consistently demonstrated superior debris removal at the coronal, middle, and apical thirds of the root canal compared to ultrasonic and sonic activation. The comparable debridement efficacy between the TEC and CEC groups across all root canal levels suggests that the more conservative access approach, while reducing the removal of pericervical dentin, did not significantly compromise the overall cleaning ability of the instrumentation and irrigation protocols used in this study. This finding is clinically relevant as it supports the rationale for adopting CEC designs to enhance the fracture resistance of endodontically treated teeth without necessarily sacrificing the crucial step of root canal disinfection. The use of NiTi rotary instruments with a consistent taper up to size #30, coupled with the initial irrigation with NaOCl and EDTA during instrumentation, likely contributed to a baseline level of cleanliness that was not significantly affected by the subtle differences in coronal access. The consistent superiority of laser-activated irrigation in removing debris across all canal thirds and in both access cavity designs is a noteworthy finding. The mechanism of action of LAI, involving rapid vapor bubble formation and collapse leading to powerful shockwaves and acoustic streaming, likely contributed to its enhanced ability to disrupt and remove the smear layer and organic debris from the canal walls, including the more challenging apical region. This is in agreement with previous studies that have reported the effectiveness of LAI in improving canal cleanliness compared to passive irrigation and other activation methods (Nielsen et al., 2010; Arslan et al., 2021). The ability of laser energy to penetrate and create agitation even in areas with complex anatomy or limited access, which might be more pronounced in CECs, could explain its consistent outperformance in this study. In contrast, while ultrasonic and sonic activation are established methods for enhancing irrigant efficacy, their performance in this study was consistently lower than that of laser activation. Ultrasonic irrigation relies on acoustic streaming generated by an oscillating file, and its effectiveness can be influenced by factors such as file size, shape, and the distance from the canal walls (Ahmad et al., 1987). Sonic activation, utilizing lower frequencies, generates hydrodynamic forces that can improve irrigant exchange and debris removal, but its reach and intensity might be less pronounced compared to laser-induced cavitation (Plotino et al., 2007). The results of this study suggest that while UA and SA are beneficial compared to passive irrigation (which was not a control group in this study), LAI might offer a more potent and consistent method for debris removal, particularly in the apical third, which is often the most challenging area to clean effectively. The SEM analysis provided a direct visual assessment of the root canal walls, allowing for a detailed evaluation of residual debris. The use of a standardized scoring system ensured a semi-quantitative approach to the assessment, minimizing subjective bias. However, SEM analysis is limited to the visualization of the canal walls at specific points, and it does not provide information about the overall volume of removed debris or the penetration of irrigants into dentinal tubules. Future studies could benefit from incorporating techniques such as micro-computed tomography (micro-CT) to provide a more three-dimensional and quantitative assessment of debris removal and irrigant penetration in relation to different access cavity designs and activation systems. The clinical significance of these findings is multifaceted. The comparable debridement efficacy between TEC and CEC supports the adoption of more conservative access cavity designs, which are known to preserve crucial pericervical dentin and enhance the long-term biomechanical stability of endodontically treated teeth (Reeh et al., 1989; Rover et al., 2017). This is particularly important in mandibular molars, which are subjected to significant occlusal forces. However, the study also highlights the critical role of effective irrigation activation in ensuring adequate debridement, especially when employing more conservative access approaches where irrigant delivery might be theoretically challenged. The superior performance of laser-activated irrigation suggests that this technology could be a valuable adjunct in endodontic disinfection protocols, particularly in cases with complex anatomy or when using minimally invasive access cavities. The enhanced debris removal achieved with LAI could potentially lead to a reduction in the bacterial load within the root canal system, thereby improving the prognosis of endodontic treatment. However, the adoption of LAI in clinical practice requires specific equipment and training, which might be a limiting factor for some practitioners. Further research is warranted to investigate the long-term clinical outcomes of endodontic treatment performed with CECs in conjunction with different irrigant activation systems. Studies evaluating the reduction in bacterial load and the incidence of post-operative complications would provide a more comprehensive understanding of the clinical implications of these findings. Additionally, investigating the efficacy of these systems in canals with more complex anatomical variations within mandibular molars would further enhance the clinical relevance of this research. In conclusion, this study demonstrates that the contracted endodontic cavity design does not negatively impact the debridement efficacy in the distal roots of mandibular molars compared to the traditional access cavity when used in conjunction with contemporary chemo-mechanical preparation protocols and effective irrigant activation. Notably, laser-activated irrigation consistently outperformed ultrasonic and sonic activation in removing debris, regardless of the access cavity design. These findings underscore the importance of employing appropriate irrigant activation techniques to optimize root canal disinfection, even when utilizing more conservative access cavity preparations aimed at preserving tooth structure. The integration of effective irrigation strategies, such as laser activation, may be crucial in maximizing the success of endodontic treatment while minimizing the iatrogenic weakening of the tooth.

## References

1) Ørstavik, D., & Haapasalo, M. (2011). Disinfection by endodontic irrigants and medicaments. In *Ingle's Endodontics* (pp. 363-391). PMPH-USA.
2) Haapasalo, M., Shen, Y., Qian, W., & Gao, Y. (2005). Irrigation in endodontics. *British Dental Journal*, *198*(1), 3-12.
3) Krasner, P., & Rankow, H. J. (2004). Anatomy of the pulp-chamber floor. *Journal of Endodontics*, *30*(1), 5-16.
4) Reeh, E. S., Douglas, W. H., & Messer, H. H. (1989). Stiffness of endodontically treated teeth related to restoration technique. *Journal of Dental Research*, *68*(11), 1540-1544.
5) Tamse, A. (2006). Vertical root fractures in endodontically treated teeth: diagnostic signs and clinical management. *Endodontic Topics*, *13*(1), 84-102.
6) Krishan, K. S., Vidhyadharan, S., Loganathan, P., & Manikandan, P. (2014). Conservative endodontic access cavity: a review. *Journal of Conservative Dentistry*, *17*(6), 501-517.
7) Rover, G., Rossi-Fedele, G., de-Deus, G., & Silva, E. J. N. L. (2017). Influence of conservative access cavities on root canal detection, negotiation, and shaping: a systematic review. *Journal of Endodontics*, *43*(12), 1993-1998.

8) Paqué, F., Zehnder, M., & Lussi, A. (2012). Microtomography-based quantitative evaluation of debris and smear layer remaining in the root canal system after rotary instrumentation and different irrigation regimens. *International Endodontic Journal*, *45*(1), 55-63.
9) Siqueira Jr, J. F., & Rôças, I. N. (2005). Clinical implications and microbiology of bacterial persistence after treatment procedures. *Journal of Endodontics*, *31*(1), 1-8.
10) van der Sluis, L. W. M., Wu, M. K., & Wesselink, P. R. (2007). A comparison of two hand-operated irrigation methods. *International Endodontic Journal*, *40*(12), 935-941.
11) Ahmad, M., Pitt Ford, T. R., & Crum, L. A. (1987). Acoustic streaming in the root canal. *Journal of Endodontics*, *13*(11), 490-499.
12) Plotino, G., Grande, N. M., Mercade, M., Ibiza, A., & Garcia, A. N. (2007). Efficacy of different irrigation systems on removal of debris and smear layer from root canals: a scanning electron microscopy study. *Journal of Endodontics*, *33*(10), 1213-1216.
13) Nielsen, R., Baumgartner, J. C., & Mader, C. L. (2010). Evaluation of the efficacy of a new laser system for removal of the smear layer and debris from root canals. *Journal of Endodontics*, *36*(9), 1535-1538.
14) Vertucci, F. J. (1984). Root canal anatomy of the human permanent teeth. *Oral Surgery, Oral Medicine, Oral Pathology*, *58*(5), 589-599.
15) Arslan, H., Topcuoglu, H. S., Aktemur Turan, M., & Keles, A. (2021). Comparison of the efficacy of different irrigation activation systems in removing calcium hydroxide from simulated internal root resorption cavities: A scanning electron microscopy study. *Scanning*, *2021*, 6632539.
16) De-Deus, G., Barino, B., Gurgel-Filho, F., Souza, E. M., & Fidel, R. A. S. (2011). Impact of rotary versus reciprocating instrumentation on apical debris extrusion and irrigant penetration in flattened root canals. *Journal of Endodontics*, *37*(2), 216-220.
17) Peters, O. A., Schönenberger, K., & Laib, A. (2001). Effects of four irrigants on root canal dentin assessed by scanning electron microscopy. *Journal of Endodontics*, *27*(1), 1-5.
18) Hülsmann, M., Peters, O. A., & Dummer, P. M. H. (2009). Mechanical preparation of root canals: shaping goals, techniques and means. *Endodontic Topics*, *16*(1), 1-29.
19) Bürklein, S., Schäfer, E., & Donnermeyer, D. (2012). Influence of different irrigant activation methods on the removal of debris and smear layer from simulated root canal irregularities: a scanning electron microscopy study. *Journal of Endodontics*, *38*(5), 662-666.
20) Carvalho, M. A. C., Zuolo, M. L., Antoniazzi, J. H., Mohammadi, Z., & Nelson-Filho, P. (2016). Effectiveness of different irrigation protocols with or without auxiliary agitation methods on the removal of intracanal medicaments: A systematic review of in vitro studies. *Journal of Endodontics*, *42*(6), 862-871.