# Evaluation of cleanliness of the pulp chamber and root canals after irrigant activation using different access cavity designs

A thesis submitted in partial fulfillment of the requirements for a master's degree in Endodontics


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وَقُل رَّبِّ زِدْنِي عِلْمًا

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# Dedication

To the soul of my father, who teach me to believe in God, myself, and my dreams.

To my mother and sisters, the pillars of my life for their endless support and help.

To my dear wife, for continuous assistance, encouragement and sacrifices throughout the completion of my studies.

To my lovely sons, Hamza and Yehia.

I dedicate this work……

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# List of abbreviations

| No. | Abbreviations | Meanings |
|---|---|---|
| 1. | CBCT | Cone beam computed tomography |
| 2. | DOM | Dental operating microscope |
| 3. | Ncm | Newton centimeter |
| 4. | Rpm | rotation per minute |
| 5. | ODT% | Opened dentinal tubules percentage |
| 6. | PCD | Peri-cervical dentin |
| 7. | CEJ | Cemento-enamel junction |
| 8. | µCT | Micro Computed Tomography |
| 9. | SEM | Scanning Electron Microscope |
| 10. | CT | computed tomography |
| 11. | NaOCl | sodium hypochlorite |
| 12. | EDTA | ethylenediaminetetraacetic acid |
| 13. | NiTi | Nickel Titanium |
| 14. | DICOM | Digital Imaging and Communication |
| 15. | STL | Surface tessellation language |
| 16. | TEC | Traditional endodontic access cavity |
| 17. | CEC | Conservative endodontic access cavity |
| 18. | TRAC | Truss access cavity |
| 19. | RPT | Remaining pulp tissue |
| 20. | NEC | ninja endodontic access cavity |
| 21. | GEC | Guided endodontic access cavity |
| 22. | 3D | Three dimensional |
| 23. | CI | Conventional irrigation |

# 1. Introduction

A successful endodontic treatment requires appropriate access cavity preparation, adequate cleaning and shaping and a complete three-dimensional obturation[(1)] . The endodontic access cavity is considered the foremost step in root canal treatment[(2)].

Preparing an adequate access cavity and identifying the canal orifice can be challenging and may create a massive loss of tooth structure that is associated with a higher risk of fracture and a high failure rate[(3)]. Several designs of endodontic access cavities have been proposed to minimize tooth structure loss, thus theoretically increase mechanical stability, and fracture resistance of root-filled teeth [(4)] .

One of these designs is a traditional endodontic access cavity design. It focuses on including all the pulp horns and deroofing the pulp chamber in order to achieve sufficient debridement of the coronal portion of the root canal system[(5)]. The extension of access cavity preparation may decrease strength of the tooth to fracture under functional load[(6)]. A new modification of access cavity design, which is conservative endodontic access that is a small conservative cavity allows the clinician to access all the canal orifices and minimizes the tooth structure removal through preserving some of the pulp chamber roof and the peri-cervical dentin(PCD) [(7)].

Another form of ultra conservative access cavity design is truss endodontic access. It is a direct access from the occlusal surface to expose the mesial and distal canal orifices while leaving the intervening dentin intact[(8)]. Factors such as maintenance of marginal ridge integrity and width of isthmus region may be important in reducing tooth fracture[(9)] .

The development of new radio diagnostic technologies like cone beam computed tomography(CBCT) has led to great advances in access cavity design based on the concept of guided endodontics[10 ,11].The combination of CBCT and construction of guide by surface scan aimed to gain a straight access cavity, avoid risk of root perforation and fracture of instruments during preparation [12,13].

In minimally invasive access cavity designs, the space available for irrigation solution flow is reduced due to the preservation of the pulp chamber roof. Therefore, activation of irrigation solutions is recommended to increase the contact area and enhance the irrigant efficiency [14]. Ideal irrigants should flush out debris, dissolve organic tissue, kill microbes, destroy microbial by- products, and remove the smear layer in order to accomplish these objectives, there must be an effective irrigation system[15,16].

Conventional irrigation system by side vented needle associated with apical positive pressure is the traditional method used in endodontic treatment[17].The main disadvantage of this system is that irrigant does not extend much beyond the tip of irrigation needle which affects debridement efficacy of the irrigant[18].To overcome the disadvantages of irrigant delivery by traditional methods in inaccessible areas, the apical negative pressure system is introduced to enhance the irrigant delivery to apical areas , irregularities of the root canal and obtain a good flow of the irrigating solutions [19,20]. Although the apical negative pressure is more safe than the apical positive pressure because it applies suction rather than forceful injection[21,22] .

Little researches were done to evaluate the cleanliness of the pulp chamber and root canals with different access cavity designs and irrigant activation.

# 2. Review of literature

**<u>Section outline:</u>**

**2.1 Different access cavity designs.**

**2.1.1 Traditional access cavity design.**

**2.1.2 Conservative access cavity design.**

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# Review of literature

## 2.1 Different access cavity designs

Endodontic treatment starts with an ideal access cavity preparation and further steps of root canal treatment are based on the accuracy of the access cavity preparation(1). An ideal access cavity allows localization, cleaning, shaping, irrigation, disinfection, and obturation of the root canal system(23).

### 2.1.1 Traditional access cavity design

Traditional endodontic access cavity design(TEC) aims to gain straight-line access to the root canal orifices with extension for visibility and accessibility(24). This design interfere with the mechanical and biological integrity of the endodontically treated teeth(25). Nowadays, minimal invasion is dominant in dentistry in preserving remaining tooth structure and survival(26).

### 2.1.2 Conservative access cavity design

Conservative endodontic access cavity designs(CEC) result in tooth structure conservation and increased fracture resistance (4). Minimally invasive preparations are advocated to maintain as much natural tooth structure as possible for optimal strength and longevity of the tooth. Many researches have discussed the relationship between access cavity designs and their outcome on endodontic treatment(27).

**Clark & Khademi** (28) in 2010 stated that they wanted to "coronally shift" the focus to the cervical area of the tooth, which would create "awareness for the endo restorative interface." Emphasis is placed on conserving soffit which is a small piece of roof of pulp chamber is retained around the pulp chamber and peri-cervical dentin (PCD) which is located 4 mm above the crestal bone and extending 4 mm apical to the crestal bone. It acts as the "neck" of the tooth. Three factors dictate why maintaining the PCD is important for ferrule, fracturing, and dentin tubule orifice proximity from inside to out. The long-term success and retention of the tooth and resistance to fracturing are correlated with the amount of remaining tooth structure.

**Rover et al.** [29] in 2017 compared the effect of contracted and traditional endodontic access cavities on root canal detection, instrumentation efficacy, debris accumulation, and fracture resistance on thirty maxillary molars using microcomputed tomographic scanning (μCT) and fracture resistance test. Root canal detection was performed in 3 stages: (1) with no magnification, (2) under dental operating microscope (DOM), and (3) under DOM and ultrasonic troughing. After root canal preparation, the non-instrumented canal area, hard tissue debris accumulation, canal transportation, and centering ratio were analyzed. After root canal filling and cavity restoration, the sample was submitted to the fracture resistance test. The result showed that locating more root canals in the TEC group in stages 1 and 2 was possible, whereas no differences were observed after stage 3. There was no significant difference between the two designs in the percentage of non-instrumented canal areas, percentage of accumulated hard tissue debris after preparation and fracture resistance. Canal transportation was significantly higher in CEC than in TEC. In conclusion, there is no significant difference between CEC and TEC in fracture resistance, canal instrumentation, and debris accumulation, but there is a significant difference in canal location.

In addition, **Plotino et al.** [30] 2017 assessed the fracture strength of root-filled and restored teeth with TEC,CEC and ninja access cavity (NEC) on maxillary and mandibular premolar and molars using fracture load test. The results stated that TEC showed lower fracture resistance. There was no significant difference between CEC and NEC. They concluded that ultraconservative design did not increase fracture resistance compared to conservative one.

**Saygili et al**.[31] in 2018 discussed the relationship between access cavity design and detecting the second mesiobuccal canal in the upper first molar. A pre-operative CBCT was done for all samples. Designs used were CEC, pointed, and TEC. They assessed weight before and after preparation. The results showed that the weight loss amount significantly differed between groups and MB2 detected from CBCT. They concluded that CEC was more reliable in MB2 detection and amount of preparation.

**Barbosa et al.** (32) in 2020 assessed the effect of CEC, TEC, and truss access cavities (TRAC) during root canal treatment of mandibular molars measuring the amount of microbial reduction in canals, cleaning of the pulp chamber, and the fracture resistance of the teeth using µCT and fracture resistance test. The specimens were accessed and root canals were contaminated with bacterial suspensions of Enterococcus faecalis for 21 days. The canals were prepared with Reciproc Blue R40 and finally irrigated with 2 mL of 0.5% sodium hypochlorite (NaOCl), 2 mL of 17% Ethelene diamine tetraacitic acid (EDTA) and another 2 mL of 0.5% NaOCl. The result illustrated that no difference was found regarding the percentage of dentine removed, transportation, microbial reduction, fracture resistance, centering ability, and filling voids between the groups. The difference between groups showed in the percentage of unprepared surface area and volume of remaining root-filling material within the pulp chamber. They concluded that contracted access cavities did not offer any advantages over traditional one and had larger percentages of unprepared canal surface area and larger volumes of remaining root-filling material within the pulp chamber.

**Vieira et al.** (33) in 2020 compared root canal disinfection and shaping in teeth with CEC and TEC after contamination with a pure culture of Enterococcus Faecalis for 30 days. Root canal preparation in both groups was performed using the XP-endo Shaper instrument and 2.5% NaOCl. Intracanal bacteriologic samples were taken before and after preparation, and DNA was extracted and subjected to a quantitative polymerase chain reaction. µCT scans taken before and after preparation were used for shaping evaluation. The result illustrated that all initial samples were positive for E. Faecalis. After preparation, the number of bacteria-positive samples was significantly higher in the contracted cavity group than in the conventional cavity group. The intergroup quantitative comparison showed that the reduction in bacterial counts was also significantly higher in conventional cavities. µCT data revealed no significant difference in the amount of unprepared areas between groups. They concluded that although mechanical preparation was similar between groups, disinfection was significantly compromised after root canal preparation of teeth with contracted endodontic cavities.

**Koonhnavard et al.**(34) in 2023 compared the shaping efficiency of the NiTi instrument systems, using µCT evaluation in different access cavity designs. Sixty mandibular molar teeth were randomly divided into two main groups; CEC and TEC then randomly divided into two subgroups according to the file system One Reci and ProTaper Ultimate. The results showed that no statistically significant differences in terms of volume change, surface area, or the thickness of the dentin in the danger zone area after root canal preparation. There was a significant difference between CEC and TEC in canal transportation at all distances from the apical region. The conclusion stated that the use of CEC can be recommended within the limitations of the study since this method of treating cavities protects the healthy dentin more.

**Patel et al.**(35) in 2023 compared TEC and CEC designs on fracture resistance and remaining thickness of PCD of maxillary central incisors using CBCT evaluation. The results showed that higher fracture resistance and remaining PCD after access cavity preparation was observed at CEC design. They concluded that preservation of PCD provided greater fracture resistance in CEC design.

### 2.1.3 Ultra-conservative access cavity design

Ultraconservative access cavity preparation focuses on maintaining the structural integrity of the tooth by minimizing the removal of healthy tooth structure. This approach aims to reduce the risk of tooth fracture and preserve the long-term prognosis[27]. One challenge of ultraconservative access cavity preparation is ensuring adequate access ,visibility to the root canals and cleanliness of the root canal system[36].

One of these ultra conservative designs is TRAC that aims to keep the dentinal bridge in place between two or more small cavities made to access the canal orifice in each multirooted tooth root. Separate cavities are formed in the mandibular molars to approach the mesial and distal canal systems while in maxillary molars, the mesio and distobuccal canals are accessed via one cavity, while the palatal canal is addressed through another[37].

**Neelakantan et al.**[38] in 2018 examined if orifice-directed dentin conservation access design debrides Pulp chamber and mesial root canal Systems of mandibular molars similar to a traditional access design. Specimens were processed for histologic evaluation, and the remaining pulp tissue (RPT) was measured from the pulp chamber, root canal, and isthmus at all root thirds. The result showed that RPT in the pulp chamber was significantly higher in orifice-directed dentin conservation access design than in TEC. When comparing the root thirds in each group, there was no significant difference in the RPT within the root canals or the isthmus. The RPT within the root canals and isthmus was not significantly different between the 2 access cavity designs at any root third. They concluded that debridement of the pulp chamber was significantly compromised in orifice-directed dentin conservation access design. The type of access cavity did not influence the amount of RPT in the root canals and isthmus.

**Abou-Elnaga et al**.[8] in 2019 evaluated the effects of traditional and TRAC in addition to artificial truss restoration on the fracture resistance of endodontically treated mandibular molars. Endodontic access cavities were performed in the experimental groups according to each treatment modality followed by instrumentation, irrigation, and obturation. After composite restoration, the teeth were subjected to a vertical occlusal force until a fracture occurred. The results showed TRAC group had statistically significantly higher mean values for fracture resistance than the traditional access group and the artificial truss restoration group. They concluded that the TRAC preparation improved the fracture resistance of endodontically treated teeth with mesio-occlusal-distal cavities, whereas the artificial truss restoration did not improve it.

**Silva et al.** (39) in 2020 evaluated the influence of ultraconservative endodontic cavities on canal shaping and filling ability, cleaning of the pulp chamber, time required to perform root canal treatment and fracture resistance of 2-rooted maxillary premolars in comparison with TEC in extracted teeth using µCT evaluation. The results showed that ultra conservative access cavity associated with high percentage of accumulated hard tissue debris after preparation, greater percentage of root filling remnants in the pulp chamber after cleaning procedures and longer time than TEC. There was no significant difference in percentage of untouched areas and fracture resistance between both designs. They concluded that there was no true benefit associated with ultraconservative access cavity compared to TEC.

**Gambarini et al.**(40) in 2020 compared the use of dynamic navigation and manual approach to perform ultraconservative access cavity design in crown weakening and shaping procedures using CBCT evaluation. The results showed that there was significant difference between dynamic navigation and manual approach. The conclusion stated that dynamic navigation system increased the benefits of ultraconservative access cavities, minimize risk of iatrogenic errors of critical portions of the crown and reducing negative influences to shaping procedures.

**Augusto et al.** [41] in 2020 evaluated the influence of ultraconservative access cavity design and the use of instruments with various tapers and tip diameters on the ability to shape canals in mandibular molars and their fracture resistance in comparison with TEC using µCT evaluation. The results stated that no significant difference was observed for the percentage of untouched canal area when comparing both designs and between the tapers with the same instrument tip size. No significant difference in the percentage of dentine removed was observed between the access cavities or the different tapers. No significant differences were observed in canal transportation, centering ability and fracture resistance in any of the tested groups. They concluded that ultraconservative endodontic access cavities did not offer any advantages in comparison with traditional endodontic access cavities on the ability to shape canals and the fracture resistance of mandibular molars. Apical preparation with larger instruments resulted in significantly less untouched canal area in all groups.

**Corsentino et al.** [42] in 2021 illustrated the effect of access cavity design on the fatigue resistance of Reciproc blue. The designs used were CEC and TRAC. After the mechanical preparation of each sample, all instruments were tested for cyclic fatigue. The result showed that there was a significant difference in cyclic fatigue resistance. The conclusion was, TRAC causes more fatigue of Reciproc blue than CEC.

**Memis et al.**[43] in 2021examined the effect of different endodontic access cavity designs on the amount of apically extruded debris. Grouping is done according to access cavity design, TEC, CEC, TRAC, and NEC groups. The weight of extruded debris was determined by subtracting the initial weights of the tubes from the final weights of the tubes containing the debris. The result showed that NEC had less debris extrusion than TEC and CEC. There was no significant difference in debris amount between the TRAC group and the CEC and TEC groups. They concluded that NEC and TREC had less debris extrusion than CEC and TEC.

**Patil et al.**[44] in 2021 compared the fracture resistance of TEC, CEC, TRAC, and NEC using mandibular first molar. Their results showed that |TRAC design showed the highest fracture resistance followed by NEC. The conclusion stated that ultraconservative designs enhanced fracture resistance than CEC and TEC.

### 2.1.4 Guided access cavity design

The exploration of CBCT techniques for dental treatment planning has allowed innovations in implantology and periodontics. It has enabled guided surgeries and three-dimensional (3D) prototypes of anatomical structures to be performed[45]. In endodontics, the new approach of digital planning using CBCT with 3D printing can aid in clinical situations that are more difficult to resolve[46]. Guided endodontics has already proved useful in cases requiring surgical and non-surgical treatment[47].

**Buchgreitz et al.** [48] in 2016 evaluated guided endodontic access cavity preparation(GEC) accuracy for teeth with pulp canal obliteration using a guide rail concept based on a CBCT scan merged with an optical surface scan. An apical canal preparation was created to simulate remnants of an apical root canal that acted as the target for a drill path. A pathway for the bur was created through a metal sleeve within the guide rail into the dentine. The result showed that the mean distance between the drill path and the target was significantly lower than 0.7 mm. They concluded that the combination of CBCT and surface scanning allow fabrication of guide rail with low risk and this technique has added value for the negotiation of partial or complete pulp canal obliteration.

In addition, **Connert et al.** [12] in 2017 discussed the accuracy of GEC for lower anterior teeth with pulp canal calcifications. Preoperative surface and CBCT scans were matched, designing the access cavity plan, and fabricating templates. After access cavity preparation, a post-operative CBCT was done and superimposed with the pre-operative CBCT to measure the deviation between both. The result showed no significant difference and the time required for preparation was 10 minutes for each tooth. They concluded that guided endodontics provides an accurate, fast, and operator-independent technique.

Furthermore, **Connert et al.** [49] in 2017 reported a clinical case with pulp canal calcification in mandibular lower central incisors. A CBCT and an intra-oral surface scan were done and aligned. The design was done for the access cavity up to the apical third of the root. A 3D-printed template guide and customized drill were used to reach the orifice of the root canal. After the negotiation of the root canals, conventional root canal treatment was performed. They concluded that guided endodontic access cavities had a favorable outcome in pulp canal calcification treatment.

In addition, **Tavares et al.**[50] in 2018 reported that guided endodontic access was an alternative solution for cases of partial and complete root canal obliteration. Fabrication of the endodontic guide was done by using CBCT and surface scanning. They concluded that access done using a guide was very reliable and did not obstruct the disinfection of root canals.

**Connert et al.**[10] in 2019 compared GEC and TEC cavities to detect root canals, substance loss, and duration of treatment in 3D printed incisors with simulated calcified root canals. A pre-operative surface scan and CBCT were done with clinical condition simulation. Access cavities were done and volumetrically assessed on postoperative CBCT scans. The results showed a significant difference between guided and traditional access cavities. They concluded that guided endodontic access allowed a more predictable outcome in the location and negotiation of calcified root canals with significantly less substance loss.

Moreover, **Jian et al.** [51] in 2020 compared dynamic navigated and free-hand access cavities in substance loss using 3D printed simulated teeth with pulp canal calcification. Post-operative CBCT determined the amount of loss. The results showed that dynamic navigation access cavity preparation showed lowered difference than free hand access cavity preparation in substance loss and canal location. They concluded that when calcified, dynamic navigation access cavity preparation had less substance loss and precise canal location.

**Wang et al.** [52] in 2021 discussed the impact of access cavity design on the amount of dentin removal and the effectiveness of canal instrumentation on maxillary molars using μCT evaluation. Samples were distributed to three groups: TEC, CEC and G3 GEC. The result showed that there was a great significant difference in the TEC group in the total volume of dentin removed in the crown, peri cervical dentine, and coronal third of the canal while there was no difference in CEC and GEC groups. The three groups had no difference in the middle and apical third of the canal. The three groups had no significant difference in the non-instrumented canal area, canal transportation, and centering ratio. They concluded that CEC and GEC preserved more tooth tissue in the crown, PCD, and coronal third of the canal compared with TEC after root canal preparation. The design of the endodontic access cavity did not affect canal instrumentation.

**Faus-Matoses et al.**[53] in 2022 compared the accuracy of guided and free-hand access cavities. The pre-and post-operative CBCT were used to compare the planned and performed designs in accuracy. The results showed that guided design reveals more accuracy than free hand. They concluded that guided access cavity design is more accurate and safer than free hand access cavity design.

Furthermore, **Haarmann et al.**[54] in 2023 determined the accuracy of template-based guided endodontics for access cavity preparation and root canal detection in posterior teeth. Deviations between planned and prepared access cavities were measured after superimposition of the pre-and postoperative CBCT scans. The results showed that all canals were detected. They demonstrated that guided endodontics is an accurate and predictable method for endodontic access cavity preparation in posterior teeth.

**Hildebrand et al.**[55] in 2023 compared substance loss , time needed and number of radiographs needed after TEC and GEC preparations in anterior teeth with pulp canal calcification. CBCT evaluation was used to determine amount of substance loss. The results showed that there was no significant difference in substance loss and time needed for access preparation of both designs but additional radiographs were required with GEC than TEC. They concluded that both methods achieved similar success rate.

## 2.2 Different irrigation protocols

Contracted designs of access cavity preparation may hinder the cleanliness and the ability of irrigating solutions to reach inaccessible areas of the root canal system. Activation of irrigation had been claimed to be beneficial in enhancing the dynamic movements and potency of irrigating solutions thus improve the cleanliness of the root canal system[56]. Different activation systems were used such as sonic , ultrasonic, laser, and apical negative pressure activation systems[57, 58]. several studies had been done to compare the effect of different irrigation techniques on the outcome of endodontic treatment.

**Gade et al.** [59] in 2013 compared Endovac and conventional needle irrigation (CI) in debris removal from root canal walls using SEM evaluation. Twenty mandibular premolars were prepared up to rotary ProTaper F4 file and irrigated with 2.5%NaOCl and 17%EDTA and divided into two groups of activation. The results revealed that the Endovac group had a significant difference in the apical third than the CI group while no significant difference in the middle and coronal third. They concluded that Endovac showed less debris in the apical third with no difference in the coronal and middle third.

Furthermore, **Versiani et al.** [60] in 2015 evaluated the removal of accumulated hard tissue debris from the root canal system of mandibular molars by positive and negative pressure irrigation systems. Forty mandibular molars were selected and evaluated by µCT analysis. After preparation and irrigation 2.5 % NaOCl and 17% EDTA were then divided into two groups; CI and Endovac. The results revealed that there was no significant difference in root canal volume, surface area, and percentage of the non-instrumented canal wall. After preparation, accumulated hard tissue debris was not observed in the distal canal of both groups. However, in the mesial root canal system, the CI group was associated with a significantly higher median percentage of accumulated hard tissue debris than the Endovac group. They concluded that Endovac showed less accumulated hard tissue debris than CI.

**Karade et al.** [61] in 2017 compare different endodontic irrigation and activation systems for removal of the intracanal smear layer on mandibular premolars using SEM. Grouping done according to the root canal irrigation systems; CI, sonic irrigation, passive ultrasonic irrigation and Endovac irrigation system. All groups were prepared to #40 apical size with K-files. The results showed that no significant difference between all groups at coronal and middle part of the canal. Endovac showed significant difference at apical part of the canal. They concluded that Endovac system cleaned the apical part of the canal more efficiently than sonic, ultrasonic and CI.

**Jasrotia et al.** [62] in 2019 compared five different irrigation techniques for the removal of the smear layer at the apical third of the human mandibular first premolar using SEM evaluation. Fifty extracted teeth were mechanically prepared and irrigated with 3% NAOCL and 17% EDTA. After preparation samples were divided into 5 groups according to final irrigation protocol; CI, manual dynamic activation, passive ultrasonic irrigation, sonic irrigation, and negative apical pressure. The result showed that the high scores were at CI and manual dynamic activation followed by passive ultrasonic irrigation, sonic irrigation, and negative apical pressure. They concluded that sonic irrigation and negative apical pressure resulted in the better removal of the smear layer when compared to the other groups.

In addition**, Neelakantan et al.** [63] in 2019 evaluated the removal of the smear layer with different irrigation activation techniques on the human mandibular first premolar. Fifty extracted teeth were prepared and irrigated with 3%NAOCL and 17%EDTA then divided into five groups; CI (control group), sonic activation, passive ultrasonic irrigation, finishing file, ultrasonic activation and negative pressure irrigation with continuous warm activated irrigation and evacuation. Samples were scanned with SEM and analyzed by image J to evaluate Smear layer scores and ODT%. They stated that all groups showed higher ODT% than CI. The lowest smear score and highest ODT% were observed in the continuous warm activated irrigation group, which was significantly different from all other groups. Sonic activation group showed significantly higher smear scores and lower ODT% than finishing file and ultrasonic activation. They concluded that continuous warm activated irrigation showed superior removal of the smear layer in the middle and apical thirds of the root canal more than other irrigation techniques.

Furthermore, **Srivastava et al.** [64] in 2021 compared the effect of different irrigation techniques on debris removal from the apical third of mandibular premolars with TEC design. Forty teeth were prepared and irrigated with 5.25% NAOCL and 17% EDTA then divided into four equal groups according to irrigation technique, Endovac, Endo-irrigator plus, side-vented needle, and single-beveled needle. The samples were sectioned and scanned with SEM and then scored. The results showed that the efficacy of Endovac was more than the Endo-irrigator plus more than the side-vented needle and more than a single beveled needle. they concluded that Endovac had better cleaning efficacy in the apical areas of the root canal.

Moreover, **Tosco et al.** [65] in 2023 compared the efficacy of different irrigation techniques on smear layer removal of mandibular premolar teeth. Forty teeth were prepared and irrigated with 5.25% NAOCL. The groups were conventional irrigation, Irri Flex irrigation, ultrasonic irrigation system, and negative apical pressure irrigation. The samples were sectioned and scanned with SEM and then scored. The results stated a significant difference between negative apical pressure and CI while Irri- Flex irrigation and ultrasonic irrigation system showed favorable outcomes in coronal and middle thirds. They concluded that the greatest efficacy on smear layer removal was reached by negative apical pressure.

**Gunduz and Ozlek** [66] in 2023 evaluated the efficiency of laser and ultrasonic irrigation activation methods on smear layer and debris removal in TEC and CEC preparations on human mandibular molar teeth using scanning electron microscope (SEM). After the access cavity preparation, the mesiobuccal root canals were prepared to 35/0.4 and randomly divided into 3 subgroups according to the final irrigation activation protocol: Conventional needle irrigation, passive ultrasonic activation, and laser activation. The results showed that the relation between access cavity design, smear layer, and debris removal was not statistically significant. The significance was detected between irrigation activation and smear layer and debris removal. They concluded that access cavity design did not affect the smear layer and debris removal.

## 2.3 Methods of cleanliness evaluation

There are several methods used to evaluate cleanliness of canals. Optical microscopy such as stereomicroscope, digital microscope, dental loupes and an operating microscope that uses visible light and a system of lenses to magnify images to observe the debris(67). The tested samples are either sectioned or cleared to facilitate visibility of the canal contents. The limitations of using an optical microscopy that it can't observe details smaller than half of white light's wavelength, and the tested samples are destructed by sectioning or clearing techniques(68).

SEM is another method to evaluate cleanliness of canals that is used to magnify details too small for an optical microscopy but its main drawbacks that it is not possible to observe color, only black/white images in addition to destruction of the samples(69).

Furthermore, radiography is another method to evaluate cleanliness of canals without destruction the sample. It may be done using digital radiography in 2 dimensional images with its limitation of overlapping the root filling material remnant after retreatment. µCT can provide a qualitative data due to its dealing with the volume of the root filling material remnant(70,71). Unfortunately, µCT is an expensive equipment and not available in Egypt. Several studies have been established using these different methods.

**Ozyurek T. and Demiryurek O.**(72) in 2016 evaluated the efficacy of using the ProTaper Universal retreatment rotary system and Reciproc in removing gutta percha and sealer from canals of maxillary central incisors during retreatment using stereomicroscopic analysis at 8x and photographed using a digital camera. The samples were evaluated using the percentage of gutta percha and sealer remnants covering the canal walls in mm2. The results showed that the ProTaper Universal retreatment rotary system was more effective with a significant difference than Reciproc in removing of gutta percha and sealer from the canals.

Furthermore, **Ozyurek T. and Demiryurek O.**[73] in 2016, compared the effectiveness of the XP Finisher, Endo Activator, passive ultrasonic irrigation, Conventional needle irrigation in removing gutta percha and sealer remnants from the canals of mandibular canine during retreatment. The amount of gutta percha and sealer remnants was evaluated using the percentage of gutta percha and sealer remnants covering the canal walls in mm2 using stereomicroscopy with a digital camera at 8x. The results showed that there was significantly less gutta-percha and sealer remnants in the XP Finisher group than in the other groups.

Adversely, **Karamifar K et al.**[74] in 2017 evaluated cleanliness of canal walls of mandibular premolars following gutta percha and sealer removal with hand Files, Race and Race plus the XP Finisher by stereomicroscopic analysis at 6x and photographed using a digital camera. The samples were evaluated using the percentage of gutta percha and sealer remnants covering the canal walls in mm2. They found that cleanliness of canals in Race plus the XP Finisher group is better with statistically significant difference.

**Keles A et al.** [75] in 2014 evaluated the efficacy of SAF after using R Endo files in removing of smear layer and filling material remnants from oval canals of maxillary premolars using SEM at 2000x with scoring system. They found that SAF enhanced the cleanliness of canals significantly in middle third only when using after R Endo files while there was no significant difference in coronal and apical thirds with regard to removing of smear layer and filling material remnants from the canals.

Moreover, **Busanello F et al.**[76] in 2015 evaluated the efficacy of passive ultrasonic irrigation in removing calcium hydroxide paste from root canal of premolars when used for 1, 2 and 3 minutes using SEM at 500x with calculating the percentage of calcium hydroxide remaining in the canals in mm2. The results showed that there was no significant difference between different lengths of time of PUI in removing calcium hydroxide paste from the canals. They concluded that there was no benefit to extend the time duration of ultrasonic activation more than 1 minute when removing of calcium hydroxide paste from the canals.

**Turkaydin D et al.** (77) in 2017 compared the efficacy of XP Finisher, passive ultrasonic irrigation and needle irrigation in removing triple antibiotic paste from straight canals of immature teeth using SEM at 1500x with a scoring system. They found that XP Finisher cleaned the canals from triple antibiotic paste more effectively in significant difference than PUI and needle irrigation.

**Plotino et al.** (78) in 2018 evaluated the influence on root canal cleanliness in extracted mandibular molar teeth with a minimally invasive basic root canal preparation technique using SEM at various magnifications from 100 x to 1000 x with scoring system. Four different experimental groups depending on the subsequently root canal preparation technique: Group 1: a basic preparation was performed up to size 20, .04 taper; Group 2: a basic preparation was per- formed up to size 2, .06 taper; Group 3: a basic preparation was performed up to size 25, .04 taper; and Group 4: a basic preparation was performed up to size 25, .06 taper. The results stated that there was no difference between the groups in the middle and coronal thirds. There was significantly more residual debris and smear layer in the apical third. They concluded that apical size of 25 resulted in significantly cleaner canals walls compared to a size 20.

**Wigler et al.** (79) in 2023 compare the efficacy of different final irrigation protocols, including sonic- and ultrasonic-powered irrigant-activation systems, on debris and smear layer removal in the coronal, middle, and apical thirds of mandibular incisors using SEM at 200x for debris and 1000 x for smear layer with scoring system. Samples were prepared to size 40.04 and divided into four groups according to the final irrigation protocols: (a) Eddy sonic activation (b) endosonic passive ultrasonic irrigation, (c) Irrisafe passive ultrasonic irrigation and (d) CI which served as control. The results showed that CI group showed more debris and smear layer at the apical third of the canals. Activation of the final irrigant with each of the three devices significantly reduced the presence of debris and smear layer in the apical third. They concluded that removal of debris and smear layer from the apical part of the root canal by CI alone may be significantly improved by using activation method of the final irrigant. Endosonic activation was less effective in removal of smear layer from the apical part of the canals.

**Alves F et al.**(80) in 2016 compared the effectiveness of reciprocating single instrument system (Reciproc) and a rotary multi instrument system (Mtwo) followed by a supplementary approach with the XP Finisher instrument from canals of mesial roots of mandibular molars using μCT to evaluate the percentage of gutta percha and sealer remnants volume in the canals. They found that the Mtwo system was better than Reciproc in removing of gutta percha and sealer from the canals in significant difference and the XP Finisher enhanced the removal of gutta percha and sealer remnants from the canals.

**Silva E et al.** (81) in 2017 compared the efficacy of XP Finisher and XP Finisher R instruments in removing of gutta percha and sealer remnants from single oval canals using μCT. The samples were evaluated in percentage of volume and surface area of gutta percha and sealer remnants in the canals after retreatment. They found that both types of XP Finisher instruments were highly and similarly effective in removing of gutta percha and sealer remnants from the canals after retreatment.

**Peng et al.** (82) in 2022 evaluated the influence of a CEC and TEC on dentin preservation, biomechanical property, and instrumentation efficacy of first mandibular permanent molars using μCT evaluation. The results showed that CEC had a significantly lower volume and thickness reduction of coronal dentin and PCD above the alveolar crest compared with the TEC group. there was no difference was observed in PCD below the alveolar crest between the 2 groups. There was no difference regarding all instrumentation efficacy outcomes in the danger zone between the 2 groups. They concluded that CEC preserved more coronal dentin and PCD above the alveolar crest and thus reduced stress concentration on the occlusal surface and cervical region. The CEC had no significant adverse effects on the instrumentation efficacy compared with the TEC.

**Torres et al.** [(83)] in 2021 evaluate 3D accuracy and outcome of a dynamic navigation method for guided root canal treatment of severe pulp canal obliteration in 3D printed jaws using CBCT. Models were mounted on a phantom to mimic a real clinical situation. The results showed that the overall success of 93% without a difference between operator experience. They concluded that dynamic navigation was an accurate approach for root canal treatment in teeth with severely calcified canals.

**Kishan et al.** [(84)] in 2023 compared the effect of TEC and TRAC preparations on remaining dentin thickness, canal transportation, and centering ability in mandibular molars using CBCT. Postoperative CBCT scans were compared with preoperative CBCT scans to evaluate the remaining dentin thickness, canal transportation, and canal centering ability in mandibular molar with TEC and TRAC preparation. The results showed that remaining dentin thickness and canal centering ability were not show significant difference at all levels. Both groups showed a significant difference at 3 mm from the apex when comparing canal transportation. They concluded that TEC preparation is better than TRAC preparation to maintain original canal anatomy.

## 3. Aim of the study

This study was directed to evaluate the cleanliness of the pulp chamber and root canal using the following access cavity designs; conservative access cavity, truss access cavity, and guided conservative access cavity. In this study different irrigation protocols were used including; side vented irrigating needle and Endovac activation system. The null hypothesis stated that there will be no significant difference among the tested groups.

# 4. Materials and Methods

**4.1 Study design and ethical committee approval.**

**4.2 Sample size calculation.**

**4.3 Selection and preparation of the teeth.**

**4.4 Fabrication of the plastic molds.**

**4.5 Pre-intervention CBCT scanning of the molds.**

**4.6 Grouping of the samples.**

**4.7 Preparation of different access cavity designs.**

**4.8 Root canal chemo- mechanical preparation.**

**4.9 Irrigation and Activation Protocol.**

**4.10 Sectioning of the Specimens.**

**4.11 Scanning electron microscopic evaluation.**

**4.12 Statistical Analysis of the Data.**

# Materials and methods

## 4.1Study Design and Ethical Committee Approval

This in vitro study is an experimental, randomized, controlled, interventional prospective study. The ethical committee of The Faculty of Dental Medicine, Al Azhar University Cairo boys, accepted the study with the code number (469/2015).

## 4.2 Sample size calculation

The sample size was 20 in each group has an 80% power to detect a difference between means of 0.034 with a significance level (alpha) of 0.05 (two-tailed) and 95% confidence intervals. In 80% the power of those experiments, the P value will be less than 0.05 (two-tailed), so the results will be deemed "statistically significant." In the remaining 20% of the experiments, the difference between means will be deemed "not statistically significant"(85).

## 4.3 Selection and preparation of the teeth

A total of recently extracted 75 human mandibular first molar teeth were collected from the outpatient clinic (Department of Oral Surgery, Faculty of Dental Medicine, Al Azhar University). The teeth were extracted for medical reasons not related to the study.

The teeth were cleaned from calculus and remnants of soft tissues using an ultrasonic scaler (Guilin Woodpecker Medical Instrument Co., Guangxi, China). The teeth were disinfected using 5.25% NaOCl (Egyptian Company for household bleach, Cairo, Egypt) for 10 minutes and rinsed with distilled water, followed by scraping using a periodontal curette (Gracey curette, LM-Dental™, Finland) to disinfect and remove any soft tissue debris that attached on the root surface.

The teeth were evaluated under DOM (S2350, Zumax Medical Company, Jiangsu, China) at 8x magnification. Periapical radiographs were taken from buccolingual and mesiodistal directions using a digital sensor size 2 (Dabi-Atlanta, Brazil). Teeth were selected according to the following inclusion criteria;

- Teeth were extracted from patients with an age range from 18 to 40 years old.
- Teeth with completely sound tooth structure.
- Teeth with mature apices.
- Teeth with root canal curvature range from 15°to 30° according to Schneider's method of evaluation[86].
- Teeth with two roots and three root canals: 2 canals in the mesial root and one canal in the distal root.

Teeth that did not undergo the inclusion criteria were excluded from the study including;

- Teeth with external or internal surface defects.
- Teeth with immature apices.
- Teeth with calcified root canals with or without pulp stones.
- Teeth with coronal or root caries.
- Teeth with root fractures or cracks.

Out of 75 collected teeth,60 mandibular first molars were included in the study. The selected teeth were stored in normal 0.9% saline (Egypt Pharmaceutical Company, 10th of Ramadan City, Egypt) at room temperature till the time of use in the study.

### 4.4Fabrication of the molds

Six circular plastic molds were constructed (95 mm in width, 50 mm in length, and 12 mm in thickness) with ten rounded holes (12 mm in diameter and 12 mm in height), and each one contains ten samples. The sides of the molds were marked according to coronal and apical sides. A circular cavity filled with amalgam at the mold's coronal side at the proximal side of the samples was done and three circular cavities at the buccal side of the samples to easily identify the surfaces on the CBCT.

The roots of each sample were painted with two successive layers of colored nail polish (Yolo, Yolo Cosmetics, Cairo, Egypt). Each mold was placed on a glass slab (10 X 10 cm), and each hole in the mold was filled with softened wax (El-Kods Wax Company, El-Mansoura, Egypt). The wax was softened by an electric wax heater (Pro Wax 100, China). Softened wax was poured into each hole, and each sample was placed in softened wax till the level of cementoenamel junction (CEJ) at the level of the coronal side of the mold.

**Fig (1): A photograph showing a plastic mold**

## 4.5Pre-intervention CBCT scanning of the molds

A Preoperative CBCT (Ray scan, Korea) (voxel size = 0.150 mm with 90 kV,12 mA, and 15-second exposure time) was obtained for six molds with samples placed inside molds to evaluate the anatomy of roots, angle of curvature of roots, obtain outline form of the pulp chamber and root canals and for the planning of access cavity designs.

### 4.6 Grouping of the samples

According to access cavity design, samples were divided into three main groups (n=20).

**Group (1):** Conservative access cavity design.

**Group (2):** Truss access cavity design.

**Group (3):** Guided conservative access cavity design.

Each group would be divided into two sub-groups (n=10) according to the irrigation protocol.

**Group (A):** side vented irrigation needle protocol.

**Group (B):** Apical negative pressure irrigation system (ENDOVAC).

### 4.7Preparation of different access cavity designs

**Group (1):** Conservative access cavity design:

Access cavity was prepared for the samples using No.2 round diamond bur (Mani carbide bur, 001/012, Mani Inc., Taguchi, Japan) mounted on a high-speed handpiece with water coolant (NSK, Nakanishi, Japan). The access was prepared to start at the central fossa and extended till dropping into the pulp chamber. The CEJ acts as a reliable landmark for locating the pulp chamber. Partial removal of pulp chamber roof in all directions of the canals with smoothly convergent axial walls to the occlusal surface by Endo-Z bur (Dentsply Maillefer, Balaguer, Switzerland) mounted on high-speed handpiece with water coolant. Refining pulp chamber walls was done using ultrasonic tip E3D (Guilin Woodpecker Medical Instrument Company, Guangxi, China) connected to an ultrasonic scaler. The canal orifices were detected using size #10 K-file (Mani, Inc., Tochigi, Japan).

**Fig (2): A photograph showing conservative access cavity**

**Group (2):** Truss access cavity design:

A pre-operative measuring of the pulp chamber dimensions of the samples was done for pre-operative planning of the access cavity design using the pre-intervention CBCT scanning. An access cavity was prepared for the samples using a No.2 round diamond bur mounted on a high-speed handpiece with water coolant. A perpendicular projection to the occlusal surface of their canal orifices directs the bur properly to the root canals. An oval-shaped access to the mesial root canal orifices in a buccolingual direction and a circular access cavity to the distal canal orifice. Detection of the canal orifices was done using size #10 K-file.

**Fig (3): A photograph showing the truss access cavity**

**Group (3):** Guided conservative access cavity design:

Designing and fabrication of the guide

The two molds were scanned with CBCT.CBCT images were stored as Digital Imaging and Communication (DICOM) files. The two molds were captured with a 3D intraoral scanner (Medit i500.Medit Corp. Seoul, South Korea) to create surface tessellation language files (STL). DICOM and STL files were imported into Mimics Medical Software 21 (Materialize, Leuven, Belgium). The registration of the surface scanning to the CBCT volume was first performed by using a 3-point registration method to approximate both structures. Subsequently, an automatic global registration was repeated for final registration until no further movement was possible. The correct registration was confirmed visually on the software.

Virtual planning of the access cavities was performed. A cylinder of 1 mm diameter was planned and emerged from each canal orifice. The three cylinders were connected to each other to designs the access cavity. One access cavity was planned per tooth. Then, a threshold was applied to segment all teeth, and a 3D model was created. The 3D models were exported as an STL file and imported, together with the virtual planning and the STL files of surface scanning, into 3-Matic Medical software 13 (materialize, Leuven, Belgium) for the guide design. A total of five tooth-supported guides, one guide per model, were designed and 3D printed with a liquid resin material (Norton, China) using a 3D printer (Halot-lite, Shenzhen, China).

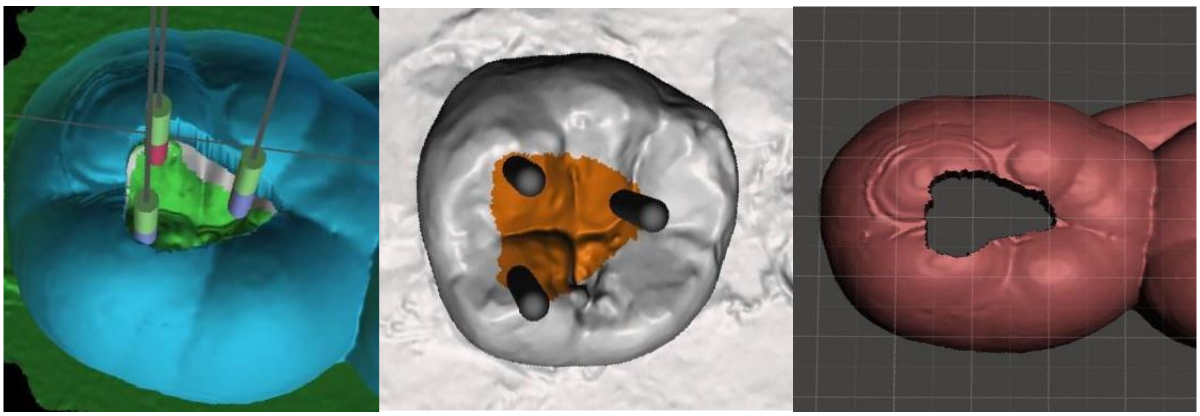


**Fig (4): A photograph showing the process of guided conservative access cavity design**

Access cavity preparation

The access cavity was prepared by attaching the guide to the teeth. Regions of access cavities were marked through holes in the guide using graphite. A long shank round diamond bur (Oko dent, Tautenhain, Germany) was mounted on a high-speed handpiece with water coolant to remove enamel in marked areas and expose dentin. Reattachment of the template to teeth and complete gaining access to root canals. Canal orifices were detected by size #10 K-file.

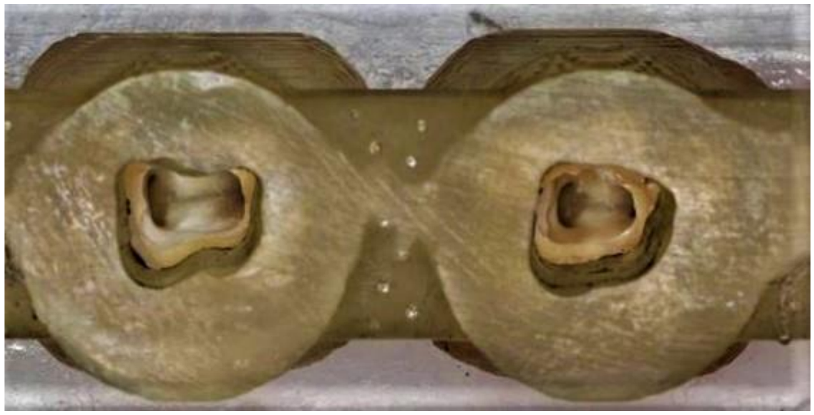


**Fig (5): A photograph showing guided conservative access cavity**

## 4.8 Root canal chemo-mechanical preparation:

Root canal preparation was carried out for all canals of all samples. Canal patency was maintained by inserting a size #10 and #15 K-file. Working length was detected by placing a size #10 k-file in each canal till the tip of the file was visible at the apical foramen of the root. The working length confirmation was done by subtracting 1mm from this length. Root canals were instrumented using the Endo Star E3 Azure rotary basic kit (Poldent, Warsaw, Poland). The cordless torque-limited electric motor (Motopex, Guilin Woodpecker Medical Instrument Co., Guangxi, China) was set to a rotation speed of 300 revolutions per minute (rpm) and the torque setting was set equivalent to 2 N cm according to the manufacturer's instructions.

File no. 1 (08/30) was connected with a rotary file handpiece powered by a cordless torque-limited electric motor to Shape the canal orifice until it reached a maximum of 1/2 of the total canal depth, then the file was removed from the canal. The next step was starting with file No. 2 (06/25) in up-and-down movements to Shape the canal up to 2/3 of the working length, then remove the file and reintroduce it to the full working length. Finally, file No. 3 (04/30) was used to widen the apical portion of the canal until the full working length was reached.

Between each file, root canals were irrigated with 3 ml of 5.25% NAOCL using a 30-gauge double-side vented irrigation needle (NaviTip needle, Ultradent Products Inc., South Jordan, UT, USA) mounted on Luer lock plastic syringe (Safe Way, Dehradun, Uttarakhand, India). A gutta percha cone size 30, 0.4 taper (Meta Biomed company, Korea) was placed to full working length inside each canal to confirm the completion of the instrumentation.

### 4.9 Irrigation and Activation Protocol

**Group (A):** Side-vented needle irrigation protocol

Irrigation was done for root canals using a 30-gauge double-sided vented irrigation needle mounted on a Luer lock plastic syringe. Before instrumentation, the samples' pulp chamber and root canals were irrigated with 3 ml of 5.25% NAOCL, and then instrumentation was done with 3 ml of 5.25% NAOCL between each rotary file up to the master apical file.

Finally, irrigation was done by rinsing canals with 3ml of 5.25% NAOCL followed by 3ml of 17% EDTA (MD-Cleanser™, Meta Bio-med, Chungcheong Buk-do, South Korea) followed by 3ml of 5.25 NAOCL. Finally, 3ml of distilled water as a final rinse.

**Group (B):** Apical negative pressure irrigation system (Endovac).

Irrigation was activated in the roots of this group using Endovac activation system. The system is composed of:

1. Multi-port adaptor and its rubber tube
2. Macrocannula with titanium handpiece and rubber tube
3. Microcannula with a metal finger piece
4. Master delivery tip with a disposable syringe and its rubber tube

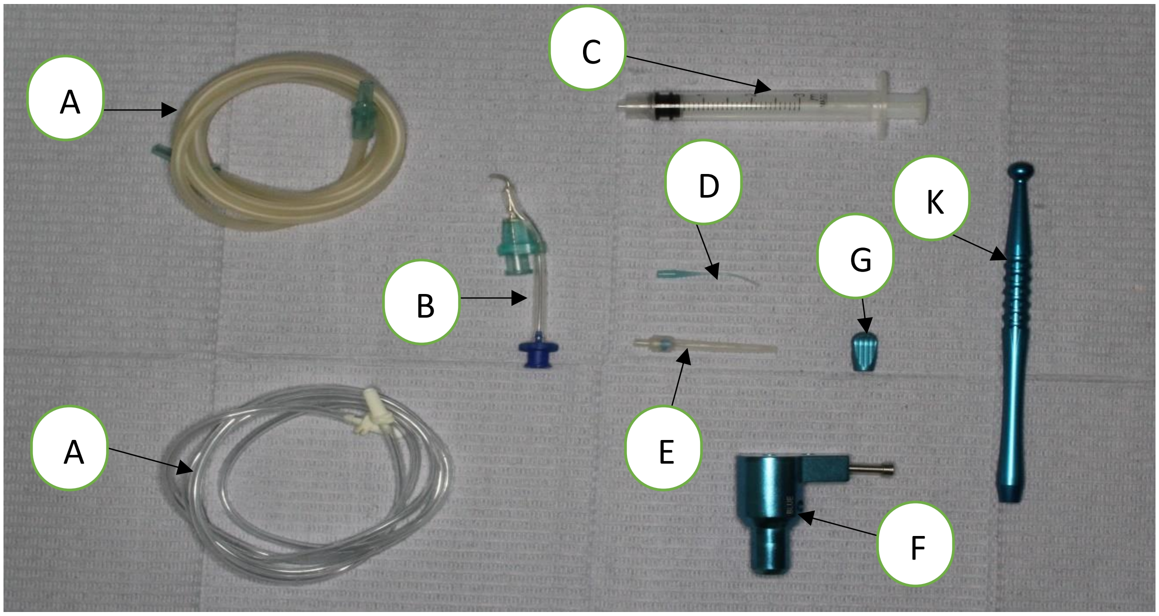



**Fig (6): A photograph showing the parts of Endovac activation system**

**A) Rubber tube B) Master delivery tip C) Plastic syringe**

**D) Macro cannula E) microcannula F) Multi-port adaptor**

**G) finger piece K) handpiece**

The multi-port adaptor was connected to the high suction port of the dental unit. Two rubber tubes: one was connected to the master delivery tip. In contrast, the other was connected to either the macro cannula's handpiece or the microcannula's finger piece. The master delivery tip was connected to a plastic syringe that delivered the irrigant to the pulp chamber. The master delivery tip delivers the irrigant and evacuates the excess irrigant simultaneously to prevent irrigant overflow. The Macrocannula was connected to the handpiece while microcannula was connected to finger piece.

The Endovac was connected, and its plastic syringe was filled with an irrigant solution. Irrigation activation was accomplished first using the Macrocannula. The Macrocannula is made of plastic and its diameter corresponds to a size 55, it was attached to a special titanium handpiece that was connected to a rubber tube which was connected to a multi-port adaptor. Macro cannula was introduced inside the root canal, then continuously moving up and down till the half-length of each root canal for 30 seconds.

The Macrocannula was replaced with the microcannula. The microcannula was attached to a metal finger piece connected to a multi-port adaptor by a rubber tube. The microcannula is a rounded closed-end metal needle 25 mm in length and its diameter corresponds to a size 32. The microcannula has 12 holes arranged in 4 raws, 3 holes each, the diameter of each hole is 0.1 mm, the distance from the first hole to the tip is 0.37 mm, and the distance between holes is 0.2 mm.

Final irrigation was done by using Endovac Micro cannula in three cycles. In the first cycle, 3ml of 5.25% NAOCL was delivered to each root canal by MDT and activated by micro-cannula till full working length for 20 seconds. The second cycle was performed with the same steps using 3ml of 17 % EDTA and finally the third cycle with 3ml of 5.25% NAOCL. A final rinse of the pulp chamber and root canals with 3ml of distilled water.

## 4.10 Sectioning of the Specimens

After preparation, all specimens were removed from molds using a hot water bath. The crowns of the samples were closed with sterile Teflon tape and then removed by grooving on the mesial and distal root with a diamond disc mounted on a low-speed handpiece (NSK, Nakanishi, Japan) powered by an electric motor (strong, China) then splitting using mallet and chisel. The placement of Teflon tape was checked then two longitudinal grooves were done on the mesial and distal walls of the crowns. The crowns were then longitudinally divided into buccal and lingual halves using a chisel placed in the grooves and mallet. Half of each specimen was randomly selected for imaging with SEM.

The mesial root canals were closed with sterile Teflon tape. Two shallow longitudinal grooves were made, one on the mesiobuccal roots and the other on the mesiolingual root without entering the root canal cavity, following the root slope. The roots were then longitudinally divided into mesial and distal halves using a chisel placed in the grooves and mallet ensuring that the root canal cavity was not touched. Half of each specimen was randomly selected for imaging with SEM.

## 4.11 Scanning electron microscopic evaluation (Fig 7, 8)

All slices were observed under an environmental SEM (Quanta FEG 250) (FEI Company, Hillsboro, Oregon-USA) at (EDRC, DRC, Cairo, EGYPT). Specimens were mounted on SEM stubs. Each slice was photographed at the pulp chamber and coronal, middle, and apical third of the mesiobuccal root. Imaging had been done at 500 x and 1500 x magnification in the same region in the specimen. 1500 x images were analyzed using the Image J software analysis program (National Institutes of Health, USA) to evaluate the opened dentinal tubules concerning the image area. The image analysis for SEM Images was processed using Image J software (version 1.53a National Institutes of Health, USA). The entire image area was automatically measured in $\mu m^2$, and then the total area of opened dentinal tubules was calculated as % of the total image area using the equation. The image analysis steps and measurement technique can be summarized in this equation.

$$\text{percentage of opened dentinal tubules }\% = \frac{Total\ area\ of\ opened\ dentinal\ tubules\ (\mu m)}{Total\ image\ area\ (\mu m)} x100$$

Furthermore, the 500 x images were scored to evaluate the amount of debris. The following scoring system by Hulsmann [87] was used to detect the amount of debris.

Debris:

| | |
|---|---|
| Score 1 | No debris |
| Score 2 | Clumps of debris covering <25% of the canal wall |
| Score 3 | Clumps of debris covering 25–50% of the canal wall |
| Score 4 | Clumps of debris covering more than 50–75%of the canal wall |
| Score 5 | More than 75% of the canal wall covered by debris |

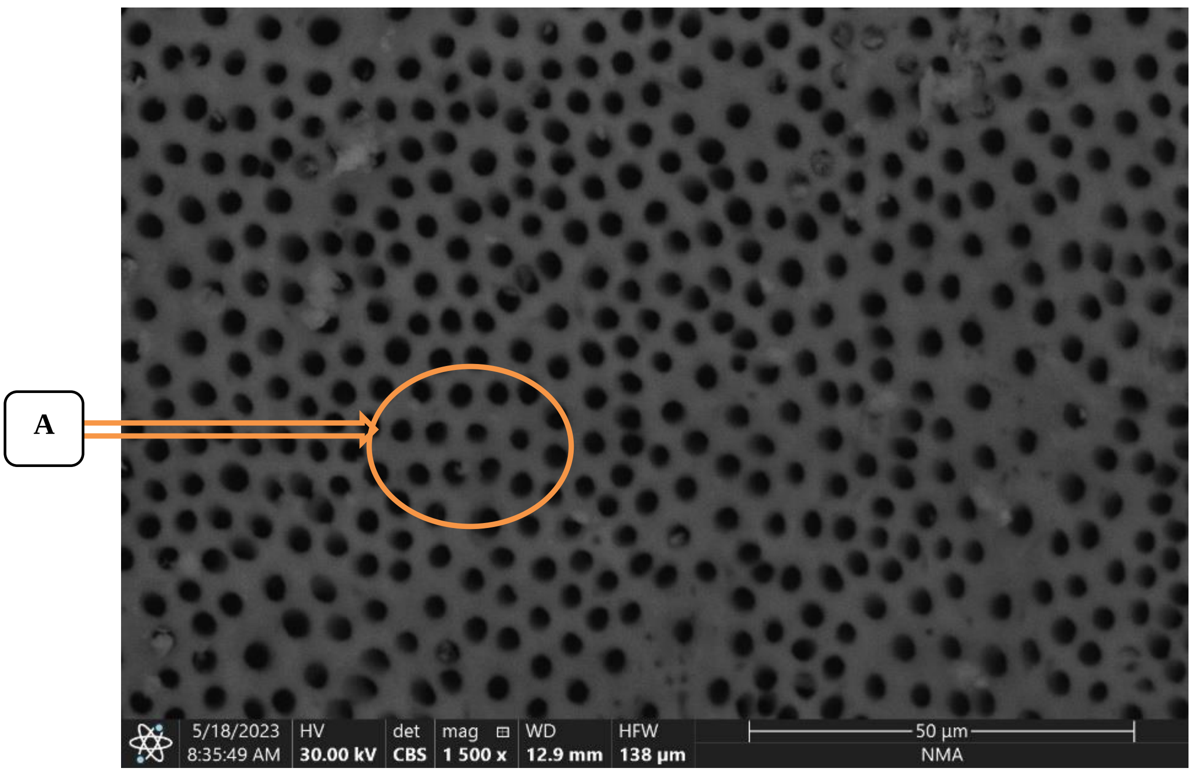



**Fig (7): A photomicrograph showing SEM image at 1500 X: A) Opened dentinal tubules**

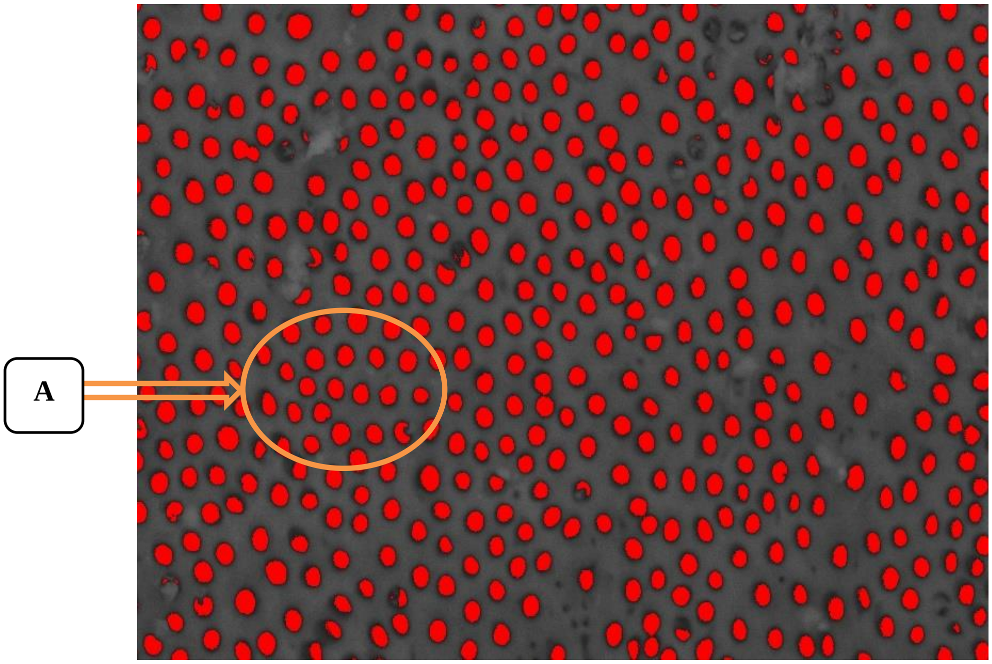



**Fig (8): A photomicrograph showing SEM image at 1500 X with image analysis for SEM Image: A) Red dots represent ODT% in image analysis**

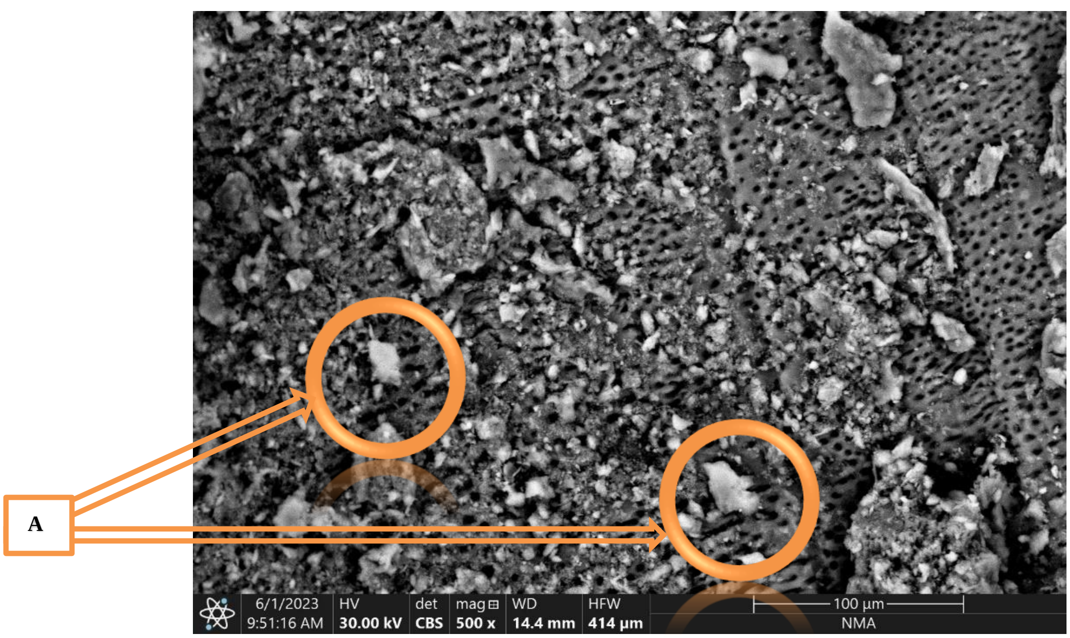



**Fig (9): A photomicrograph showing SEM image at 500 X**

**A) debris covering the wall**

## 4.12 Statistical Analysis of the Data.

Statistical evaluation was performed using SPSS statistical package (version 25, IBM Co. USA). Data would be statistically analyzed using One-way ANOVA test followed by Tukey Post Hoc test for parametric data. Further Kruskal-Wallis test followed by Mann-Whitney test would be used for non-parametric data.

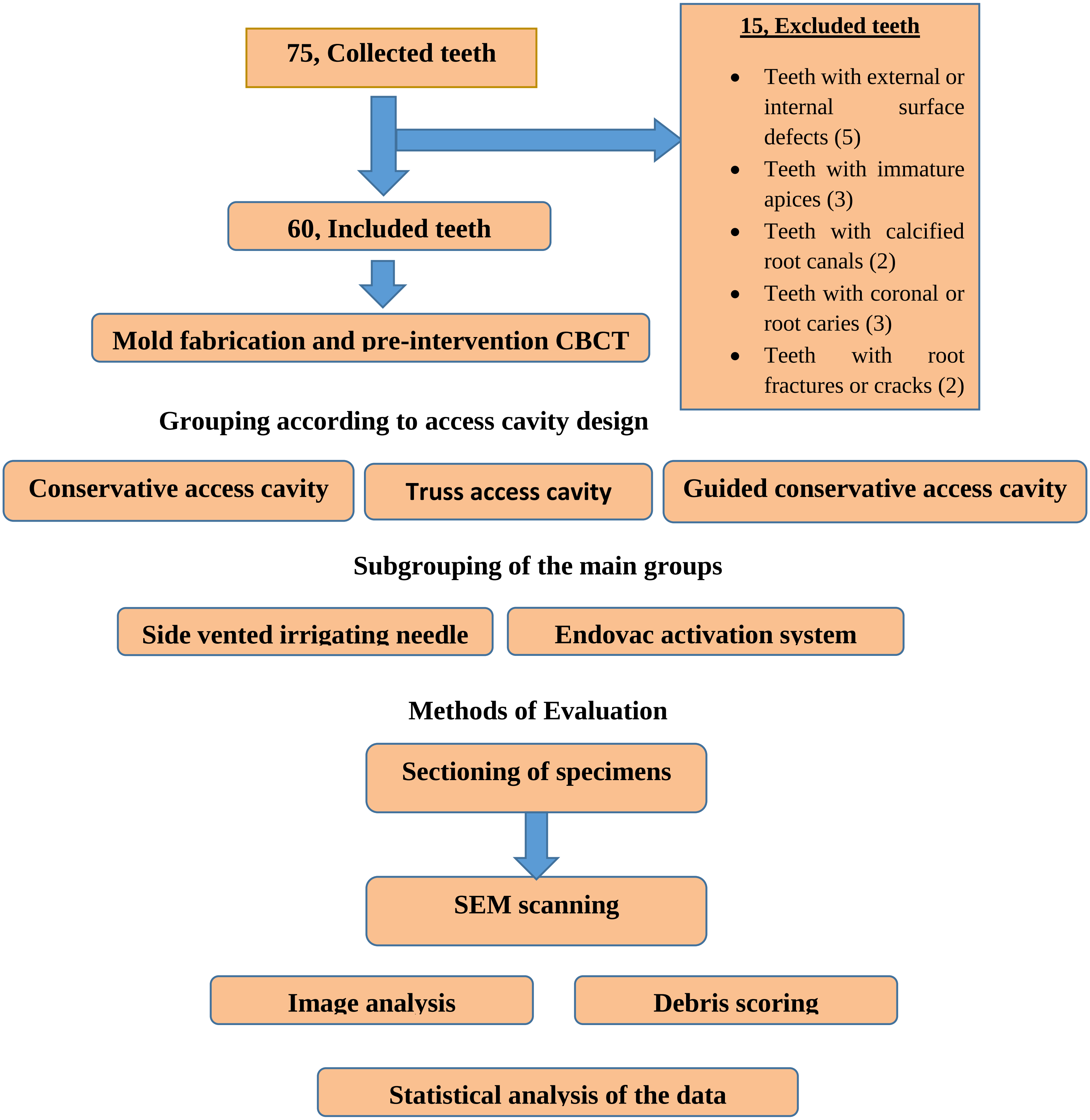



**Fig 10: A flow chart representing a review of materials and methods used in the study**

# 5. Results

## 5.1 Evaluation of the percentage of opened dentinal tubules at the pulp chamber and root canal thirds.

### 5.1.1 Comparison between different access cavity designs.

a. Using a side-vented irrigating needle.

b. Using Endovac activation system.

### 5.1.2 Comparison between irrigating systems.

a. Using conservative access cavity design.

b. Using truss access cavity design.

c. Using guided conservative access cavity design

## 5.2 Evaluation of debris covering the pulp chamber and root canal thirds.

### 5.2.1 Comparison between different access cavity designs.

a. Using a side-vented irrigating needle.

b. Using Endovac activation system.

### 5.2.2 Comparison between irrigating systems.

a. Using conservative access cavity design.

b. Using truss access cavity design.

c. Using guided conservative access cavity design.

## 5.1 Evaluation of the percentage of opened dentinal tubules at the pulp chamber and root canal thirds.

### 5.1.1 Comparison between different access cavity designs.

Data in this section were statistically analyzed using one-way ANOVA test. Further Tukey Post Hoc test was used to compare different four-thirds when there is a significant difference.

**a. Using a side-vented irrigating needle(A).**

- In the Pulp chamber region**,** the highest ODT% was recorded in guided conservative access cavity (21.78±2.18 %), followed by conservative access cavity (13.62±6.72 %). The lowest mean was in truss access cavity (3.06±3.82 %). There was a significant difference between the three groups (p-value=0.000).

- In the coronal third, the highest ODT% was recorded in guided conservative access cavity (17.96±5.68 %), followed by conservative access cavity (13.2±4.12 %). The lowest mean was recorded in truss access cavity (11.32±4.82 %). There was a significant difference between guided conservative access cavity and truss access cavity, while no significant difference between conservative access cavity and the two other groups (p-value=0.016).

- In the middle third, the highest ODT% was recorded in guided conservative access cavity (11.6±3.97 %), followed by conservative access cavity (8.38±3.7 %). The lowest mean was recorded in truss access cavity (6.69±3.79 %). There was a significant difference between guided conservative access cavity and truss access cavity, while no significant difference between conservative access cavity and the two other groups (p-value=0.007).

- In the apical third, the highest ODT% was recorded in guided conservative access cavity (4.47±2.62 %), followed by conservative access cavity (1.53±3.14 %). The lowest mean was recorded in truss access cavity (0.58±1.46 %). There was no significant difference between conservative and truss access cavity, while there was a significant difference between guided conservative access cavity and the two other groups (p-value=0.005).

Table (1): Mean values and standard deviations for comparison of the opened dentinal tubules percentage in different four-thirds under the side vented irrigating needle(A) for the three main groups

| | Conservative A | Truss A | Guided conservative A | P-value |
|---|---|---|---|---|
| **Pulp chamber** | 13.62±6.72 B | 3.06±3.82 C | 21.78±2.18 A | **0.000 S** |
| **Coronal** | 13.2±4.12 AB | 11.32±4.82 B | 17.96±5.68 A | **0.016 S** |
| **Middle** | 8.38±3.7 AB | 6.69±3.79 B | 11.6±3.97 A | **0.007 S** |
| **Apical** | 1.53±3.14 B | 0.58±1.46 B | 4.47±2.62 A | **0.005 S** |

-Capital letters for comparison (Tukey Post Hoc test) and the means with different superscripts are statistically significantly different at $P \le 0.05$.

- S= Statistically significant at $P \le 0.05$ - NS= Non-significant $P > 0.05$.

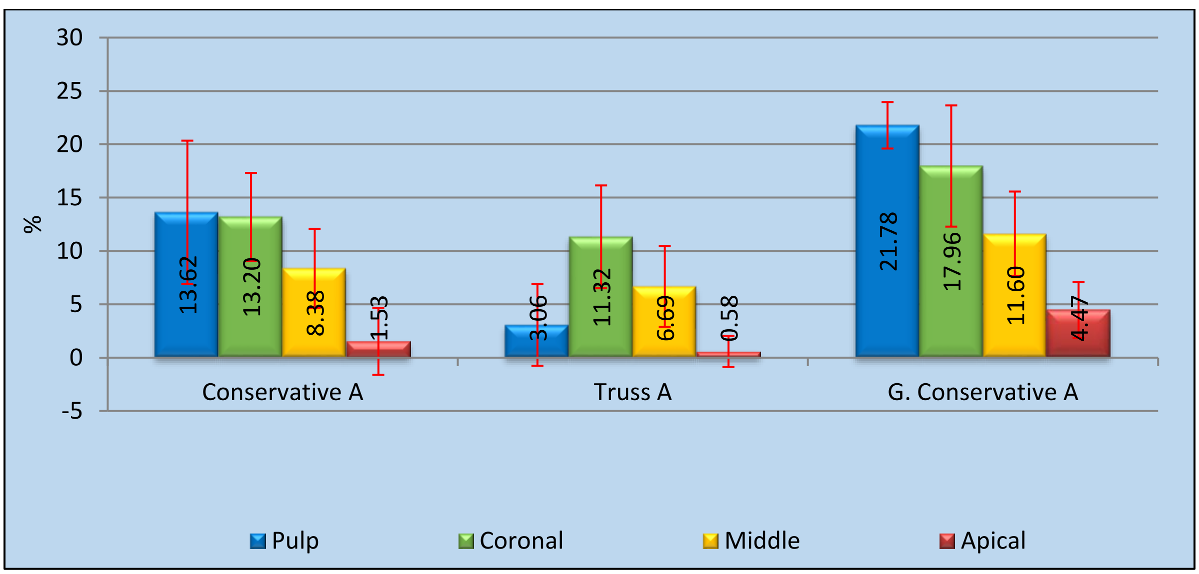



**Fig (11): A bar chart comparing the mean values and standard deviations of the opened dentinal tubules percentage in different four-thirds under a side-vented irrigating needle(A) for the three main groups**

## b. Using Endovac activation system(B)

- In the Pulp chamber region, the highest ODT% was recorded in guided conservative access cavity (23.58±3.41 %), followed by conservative access cavity (18.98±8.42 %). The lowest mean was recorded in truss access cavity (6.61±3.59%). There was no significant difference between guided conservative and conservative access cavity, while there was a significant difference between truss access cavity and the two other groups (p-value=0.000).

- In the coronal third, the highest ODT% was recorded in guided conservative access cavity (18.95±6.16 %), followed by conservative access cavity (17.46±5.85 %). The lowest mean was in truss access cavity (15.27±5.07 %). There was no significant difference between the three groups (p-value=0.363).

- In the middle third, the highest ODT% was recorded in guided conservative access cavity (14.06±5.58 %), followed by conservative access cavity (12.05±4.71 %). The lowest mean was in truss access cavity (11.01±6.19 %). There was no significant difference between the three groups (p-value=0.466).

- In the apical third, the highest ODT% was recorded in guided conservative access cavity (10.29±7.02 %), followed by conservative access cavity (5.27±4.5 %). The lowest mean was recorded in truss access cavity (4.74±5.38 %). There was no significant difference between conservative and truss access cavity, while there was a significant difference between guided conservative access cavity and the two other groups (p-value=0.035).

Table (2): Mean values and standard deviations for comparison of the opened dentinal tubules percentage in different four-thirds under Endovac activation system(B) for the three main groups

| | **Conservative B** | **Truss B** | **Guided conservative B** | **P-value** |
|---|---|---|---|---|
| **Pulp chamber** | 18.98±8.42 A | 6.61±3.59 B | 23.58±3.41 A | **0.000 S** |
| **Coronal** | 17.46±5.85 A | 15.27±5.07 A | 18.95±6.16 A | **0.363 NS** |
| **Middle** | 12.05±4.71 A | 11.01±6.19 A | 14.06±5.58 A | **0.466 NS** |
| **Apical** | 5.27±4.5 B | 4.74±5.38 B | 10.29±7.02 A | **0.035 S** |

-Capital letters for comparison (Tukey Post Hoc test) and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

- S= Statistically significant at $P \leq 0.05$ - NS= Non-significant $P > 0.05$.

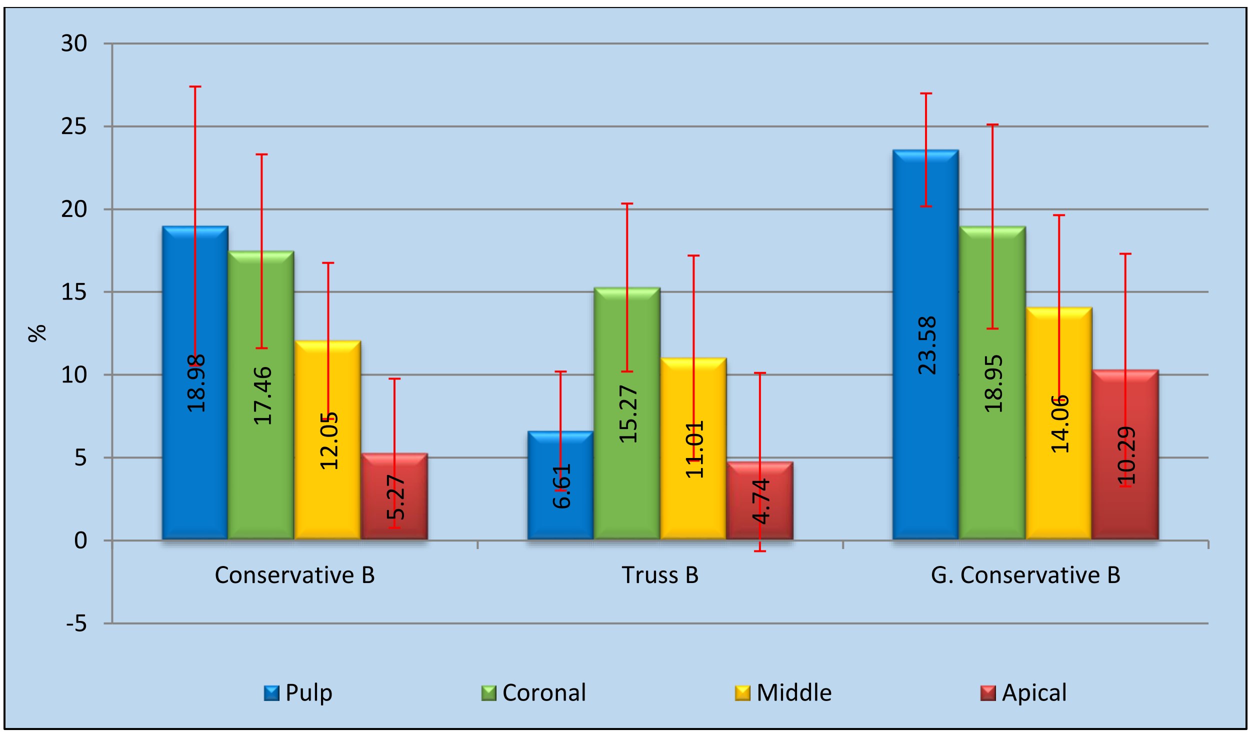



**Fig (12): A bar chart comparing the mean values and standard deviations of the opened dentinal tubules percentage in different four-thirds under Endovac activation system(B) for the three main groups**

### 5.1.2 Comparison between irrigating systems.

#### a. Using conservative access cavity design

When using a side-vented irrigating needle (A), the highest percentage of opened dentinal tubules (ODT%) was recorded at the pulp chamber (13.62±6.72 %) and at the coronal third (13.2±4.12 %) with no significant difference, followed by the middle third (8.38±3.7 %). The lowest percentage was at the apical third (1.53±3.14 %) with a significant difference between the middle and the apical thirds(p-value=0.000).

When using Endovac activation system (B), the highest ODT% was recorded at the pulp chamber (18.98±8.42 %), and at the coronal third (17.46±5.85 %) with no significant difference, followed by the middle third (12.05±4.71 %). The lowest percentage was at the apical third (5.27±4.5 %) with a significant difference between the middle and the apical thirds (p-value=0.000).

Table (3): Mean values and standard deviations for comparison of the opened dentinal tubules percentage in different four-thirds under the two irrigation protocols for the conservative access cavity group.

| | | Pulp chamber | Coronal | Middle | Apical | P-value |
|---|---|---|---|---|---|---|
| **Conservative** | **A** | 13.62±6.72$^{a}$ | 13.2±4.12$^{a}$ | 8.38±3.7$^{b}$ | 1.53±3.14$^{c}$ | **0.000$^{S}$** |
| | **B** | 18.98±8.42$^{a}$ | 17.46±5.85$^{a}$ | 12.05±4.71$^{b}$ | 5.27±4.5$^{c}$ | **0.000$^{S}$** |

- Small letters for comparison between different thirds (Tukey Post Hoc test) and the means with different superscripts are statistically significantly different at P ≤ 0.05.

- S= Statistically significant at P ≤ 0.05 - NS= Non-significant P > 0.05.

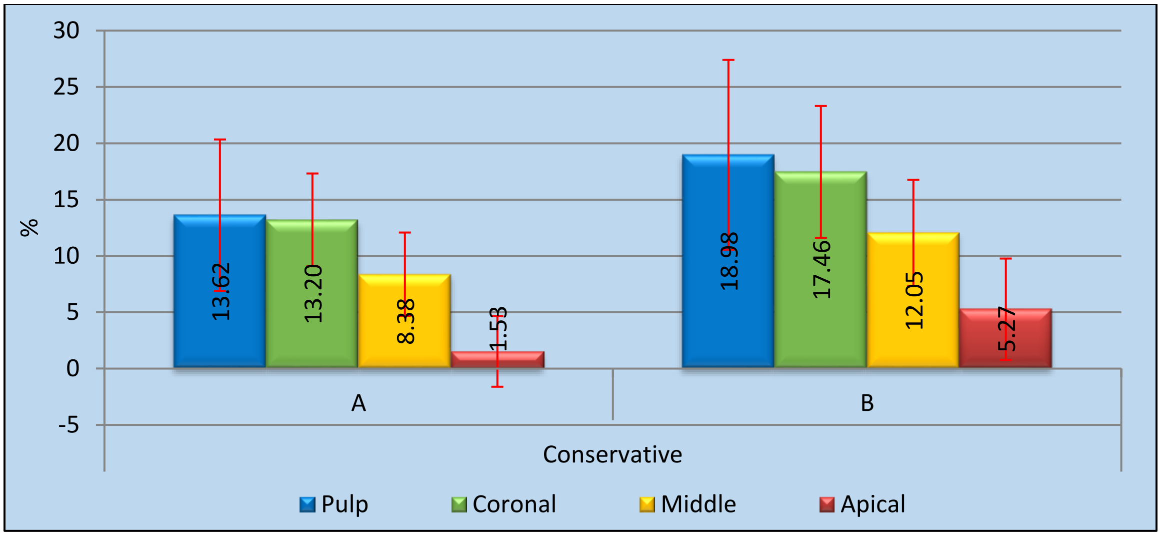



**Fig (13): A bar chart representing the mean values and standard deviations of the opened dentinal tubules percentage in different four-thirds under side-vented irrigating needle (A) and Endovac activation system (B) for conservative access cavity group.**

## b. Using truss access cavity design

When using a side-vented irrigating needle (A), the highest ODT% was at the coronal third (11.32±4.82 %), and the pulp chamber (3.06±3.82 %) with a significant difference, followed by the middle third (6.69±3.79 %). The lowest percentage was at the apical third (0.58±1.46 %) with a significant difference between the middle and the apical thirds (p-value=0.000).

When using Endovac activation system (B), the highest ODT% was at the coronal third (15.27±5.07 %), and the pulp chamber (6.61±3.59 %) with a significant difference, followed by the middle third (11.01±6.19 %). The lowest percentage was at the apical third (4.74±5.38 %) with a significant difference between the middle and the apical thirds (p-value=0.001).

Table (4): Mean values and standard deviations for comparison of the opened dentinal tubules percentage in different four-thirds under the two irrigation protocols for the Truss access cavity group.

| | | Pulp chamber | Coronal | Middle | Apical | P-value |
|---|---|---|---|---|---|---|
| **Truss** | **A** | 3.06±3.82[bc] | 11.32±4.82[a] | 6.69±3.79[b] | 0.58±1.46[c] | **0.000**[S] |
| | **B** | 6.61±3.59[c] | 15.27±5.07[a] | 11.01±6.19[b] | 4.74±5.38[c] | **0.001**[S] |

- Small letters for comparison between different thirds (Tukey Post Hoc test) and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

- S= Statistically significant at $P \leq 0.05$ - NS= Non-significant $P > 0.05$.

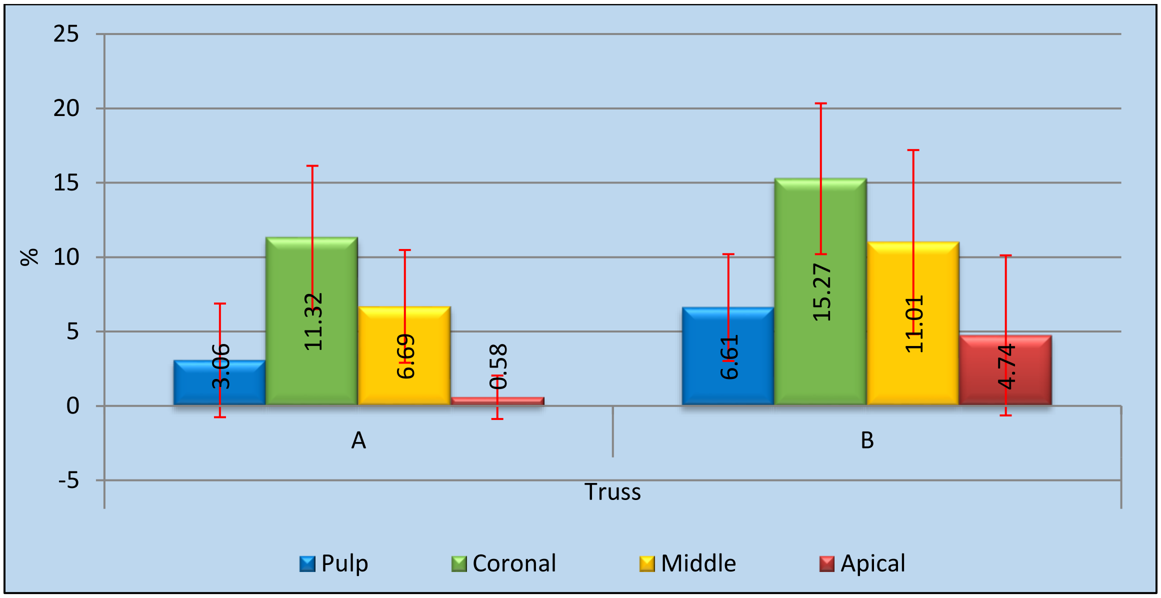



**Fig (14): A bar chart comparing the mean values and standard deviations of the opened dentinal tubules percentage in different four-thirds under side-vented irrigating needle (A) and Endovac activation system (B)for truss access cavity group.**

## c. Using the guided conservative access cavity design

When using a side-vented irrigating needle (A), the ODT% was the highest at the pulp chamber (21.78±2.18 %), and at the coronal third (17.96±5.68 %) with no significant difference, followed by the middle third (11.6±3.97 %). The lowest percentage was at the apical third (4.47±2.62 %) with a significant difference between the middle and the apical thirds (p-value=0.000).

When using Endovac activation system (B), the ODT% was highest at the pulp chamber (23.58±3.41 %), and at the coronal third (18.95±6.16 %) with no significant difference, followed by the middle third (14.06±5.58 %). The lowest percentage was at the apical third (10.29±7.02 %) with a significant difference between the middle and the apical thirds (p-value=0.000).

Table (5): Mean values and standard deviations for comparison of the opened dentinal tubules percentage in different four-thirds under the two irrigation protocols for the guided conservative access cavity group.

| | | Pulp chamber | Coronal | Middle | Apical | P-value |
|---|---|---|---|---|---|---|
| **Guided conservative** | **A** | 21.78±2.18[a] | 17.96±5.68[a] | 11.6±3.97[b] | 4.47±2.62[c] | **0.000[S]** |
| | **B** | 23.58±3.41[a] | 18.95±6.16[a] | 14.06±5.58[b] | 10.29±7.02[c] | **0.000[S]** |

- Small letters for comparison between different thirds (Tukey Post Hoc test) and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

- S= Statistically significant at $P \leq 0.05$ - NS= Non-significant $P > 0.05$.

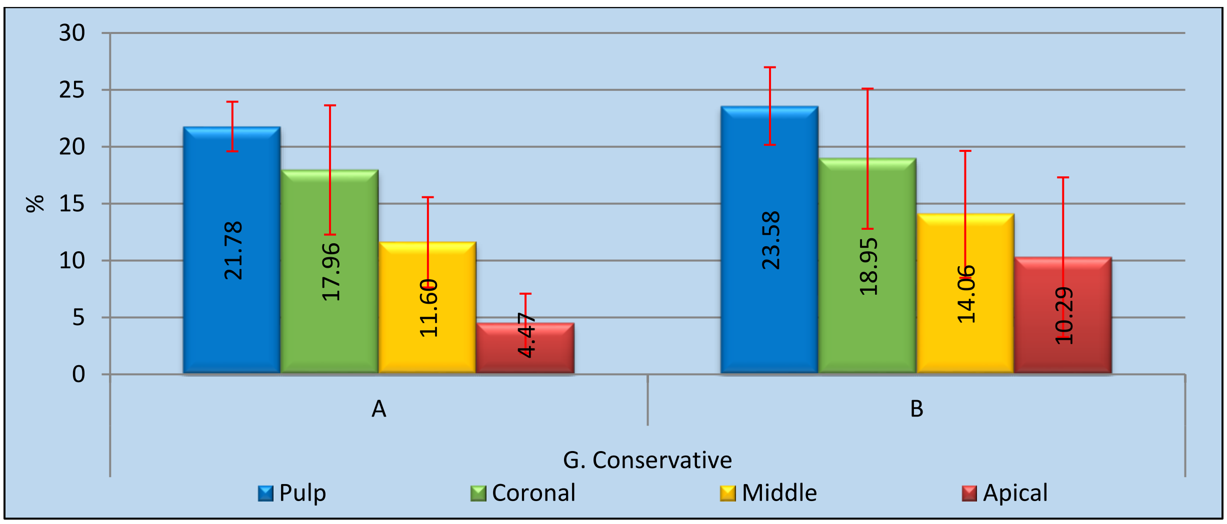



**Fig (15): A bar chart comparing the mean values and standard deviations of the opened dentinal tubules percentage in different four-thirds under side-vented irrigating needle (A) and Endovac activation system (B)for guided conservative access cavity group.**

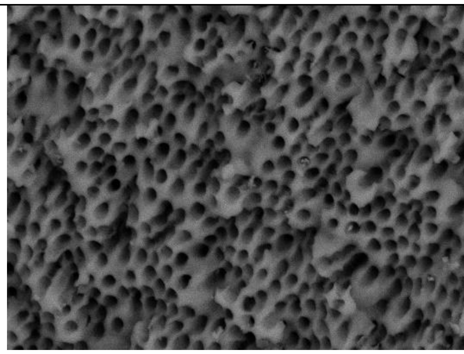
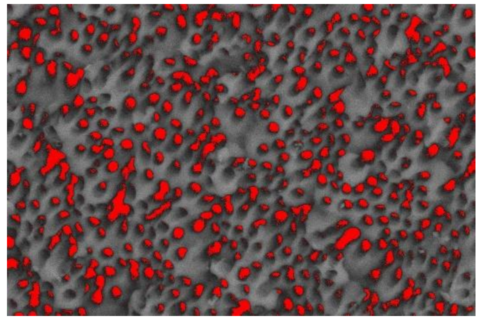
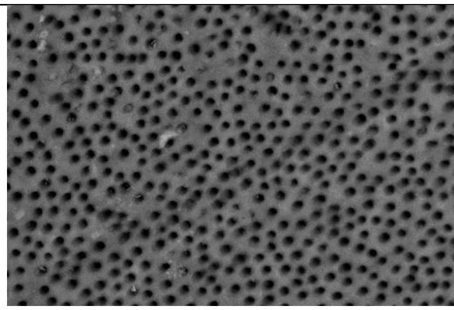
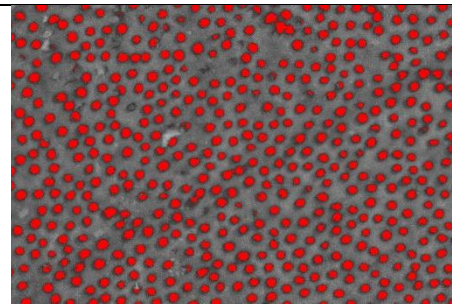
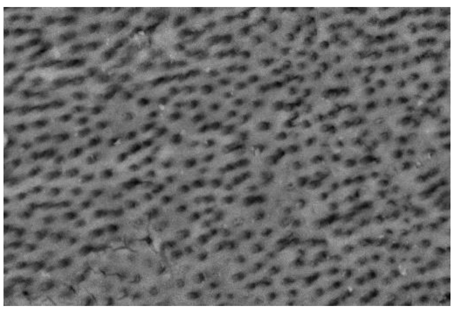
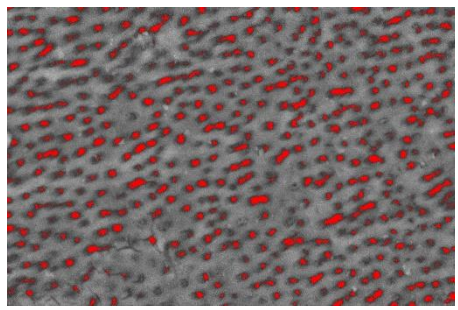
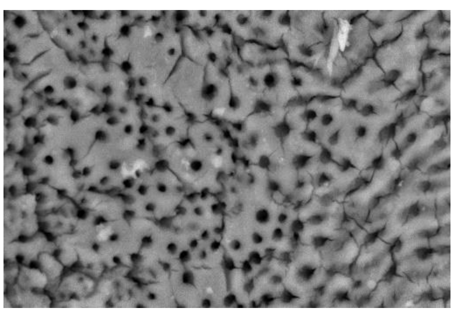
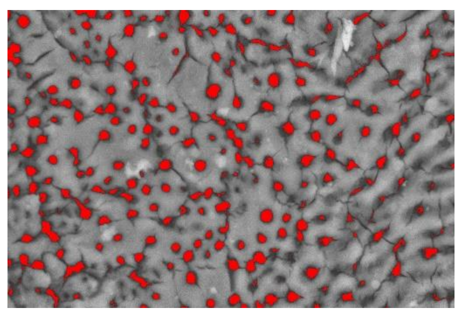
| | SEM image at 1500 x | Image analysis |
|---|---|---|
| **Pulp chamber** |  |  |
| **Coronal third** |  |  |
| **Middle third** |  |  |
| **Apical third** |  |  |

**Fig (16): a photomicrograph showing SEM images for different four-thirds and their image analysis when using conservative access cavity design with side-vented irrigating needle**

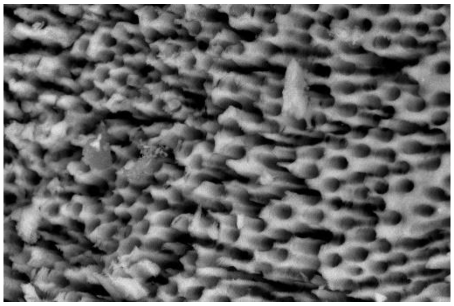
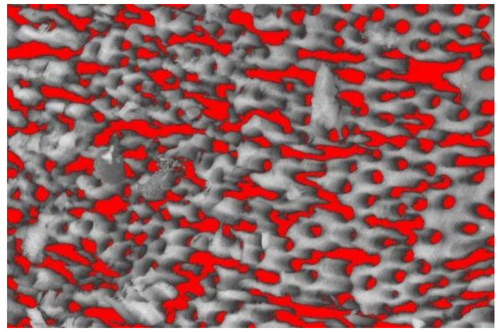
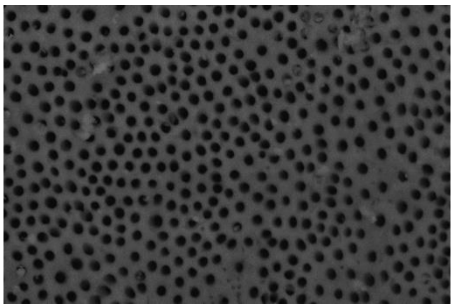
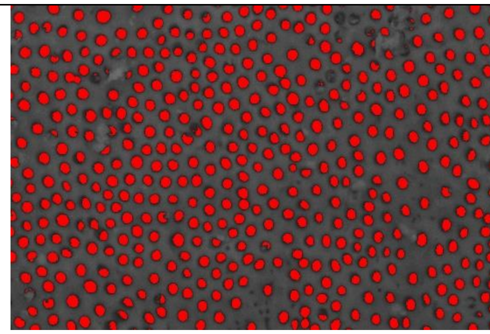
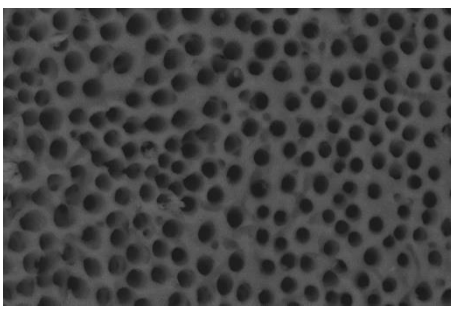
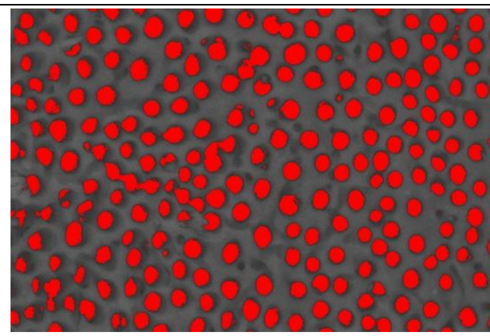
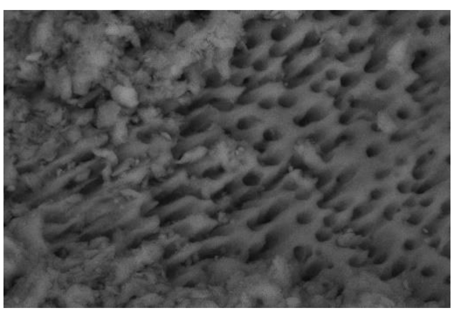
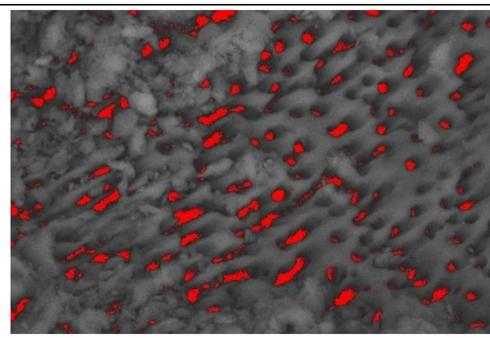
| | SEM image at 1500 x | Image analysis |
|---|---|---|
| **Pulp chamber** |  |  |
| **Coronal third** |  |  |
| **Middle third** |  |  |
| **Apical third** |  |  |

**Fig (17): a photomicrograph showing SEM images for different four-thirds and their image analysis when using conservative access cavity design with Endovac activation system**

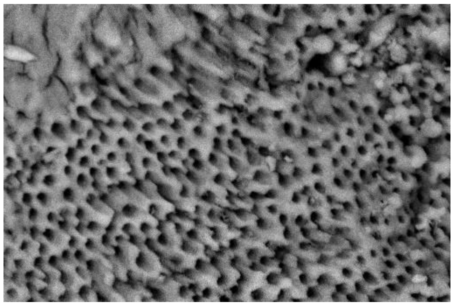
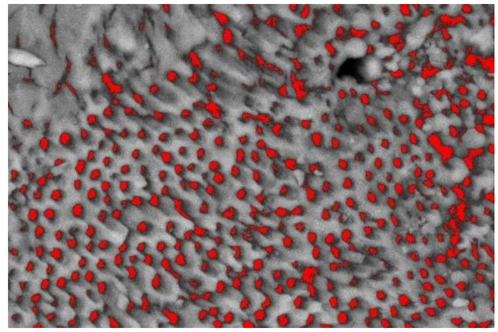
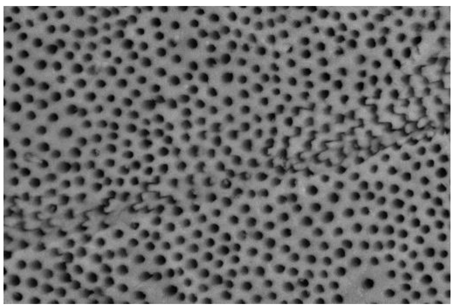
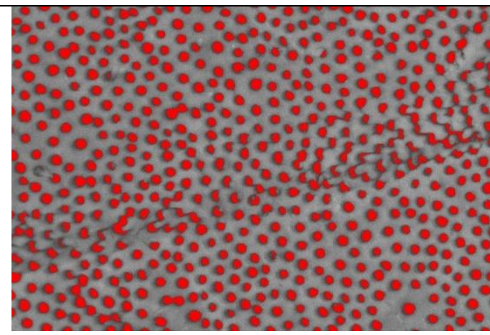
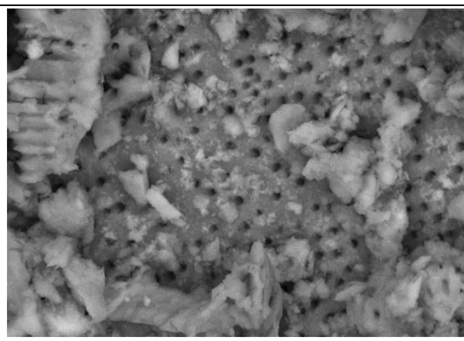
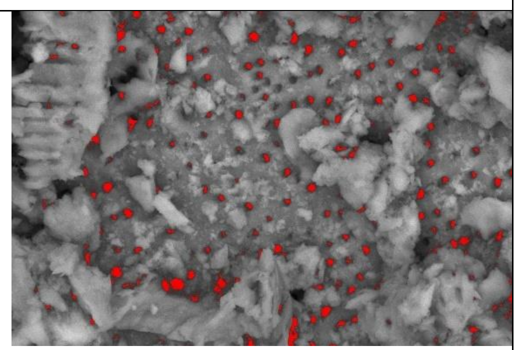
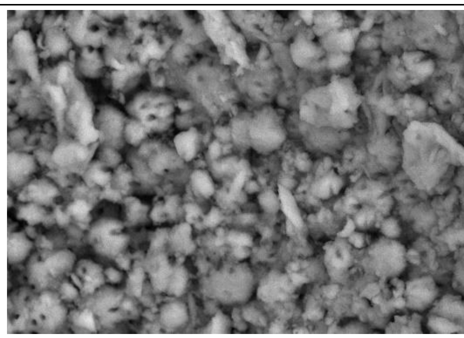
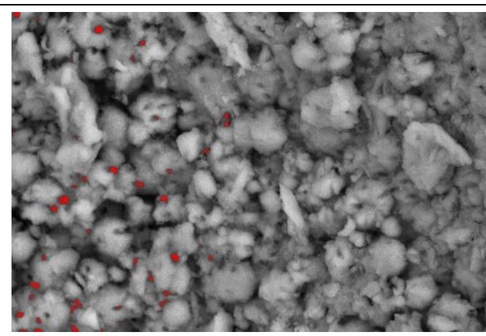
| | SEM image at 1500 x | Image analysis |
|---|---|---|
| **Pulp chamber** |  |  |
| **Coronal third** |  |  |
| **Middle third** |  |  |
| **Apical third** |  |  |

**Fig (18): a photomicrograph showing SEM images for different four-thirds and their image analysis when using truss access cavity design with side-vented irrigating needle**

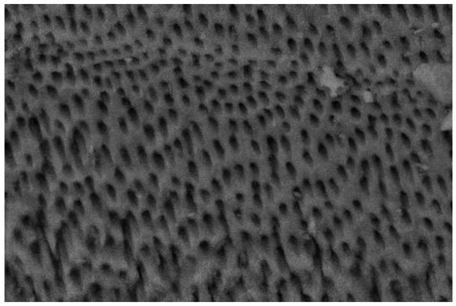
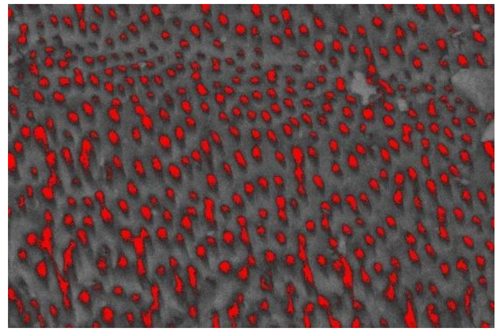
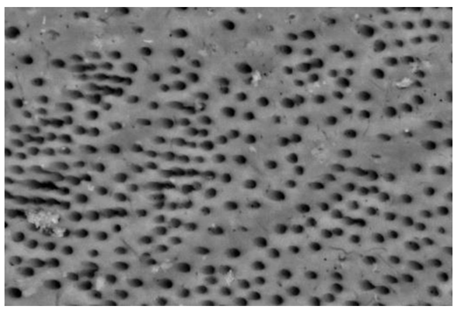
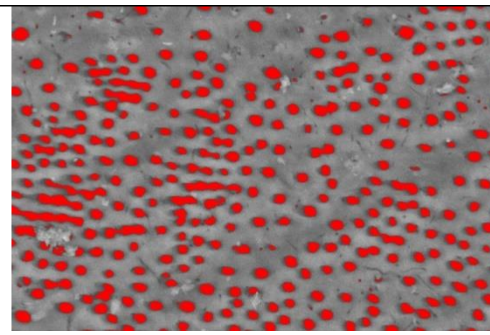
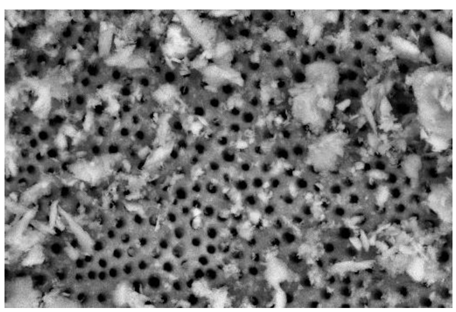
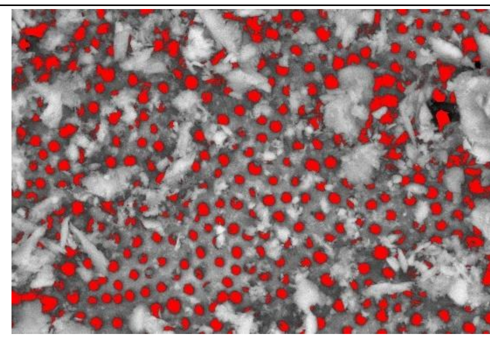
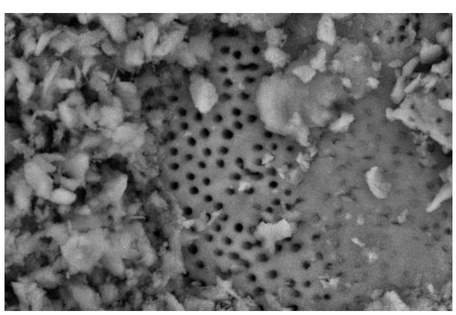
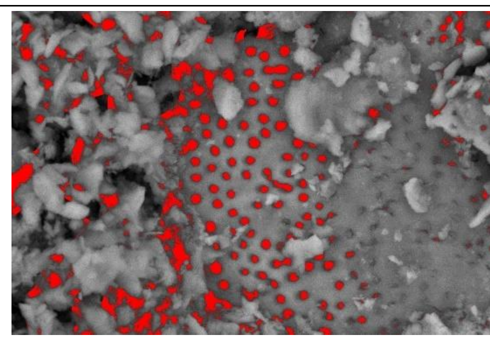
| | SEM image at 1500 x | Image analysis |
|---|---|---|
| **Pulp chamber** |  |  |
| **Coronal third** |  |  |
| **Middle third** |  |  |
| **Apical third** |  |  |

**Fig (19): a photomicrograph showing SEM images for different four-thirds and their image analysis when using truss access cavity design with Endovac activation system**

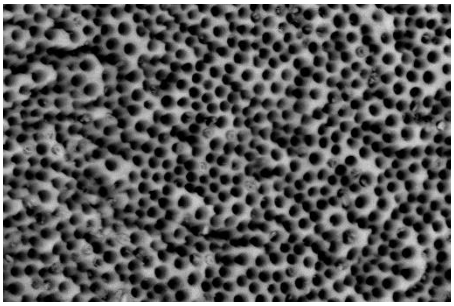
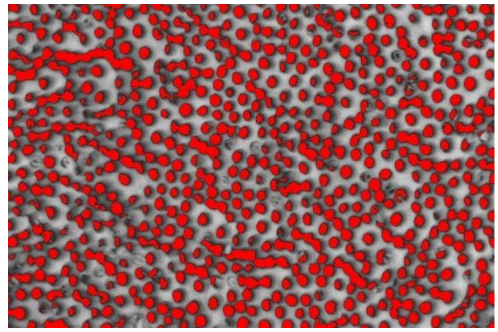
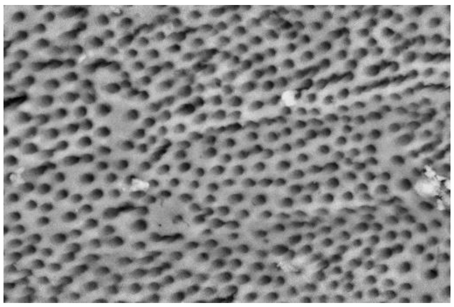
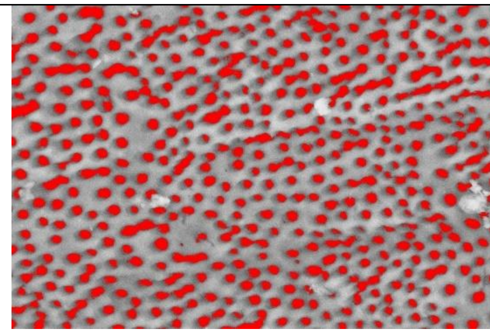
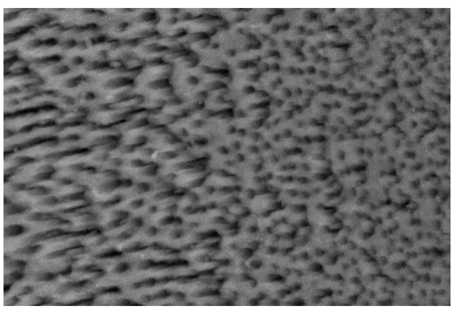
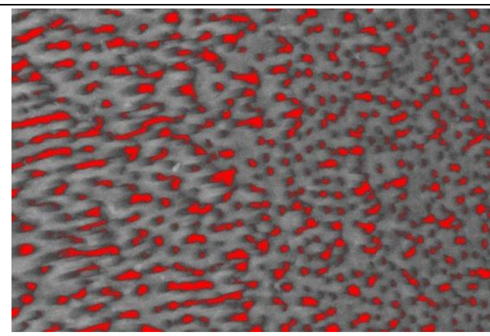
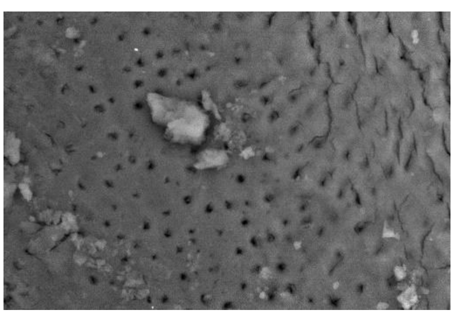
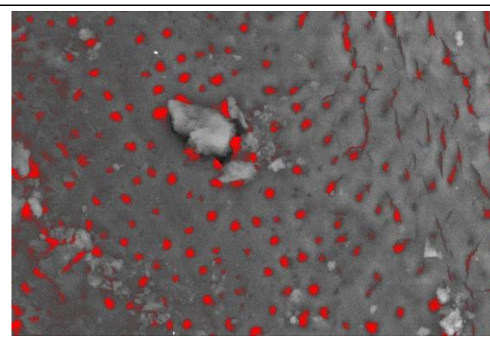
| | SEM image at 1500 x | Image analysis |
|---|---|---|
| **Pulp chamber** |  |  |
| **Coronal third** |  |  |
| **Middle third** |  |  |
| **Apical third** |  |  |

**Fig (20): a photomicrograph showing SEM images for different four-thirds and their image analysis when using guided conservative access cavity design with side-vented irrigating needle**

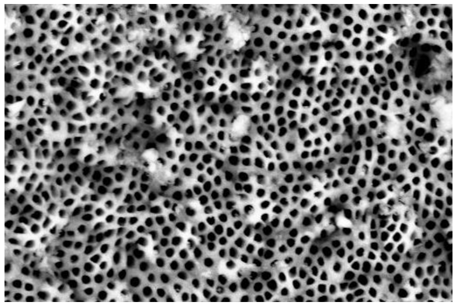
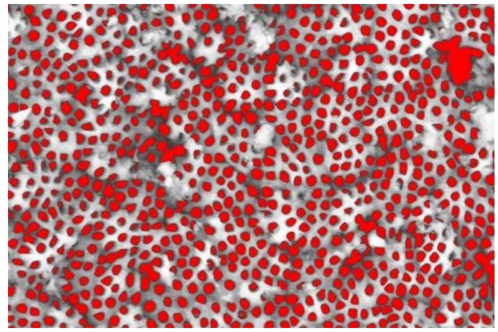
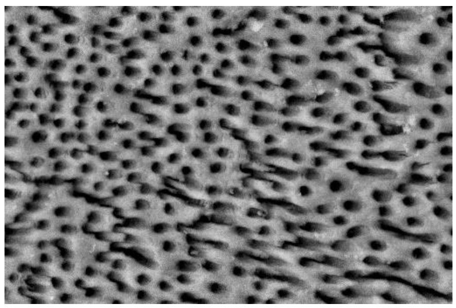
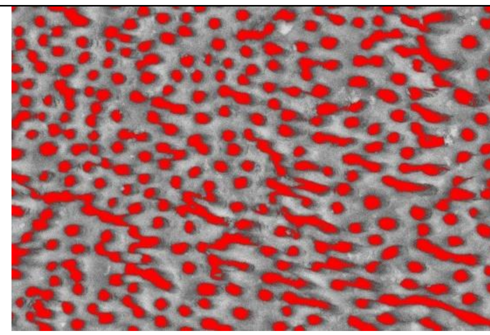
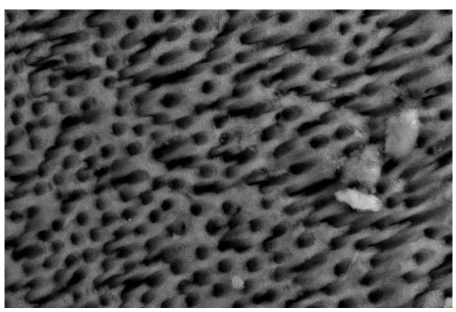
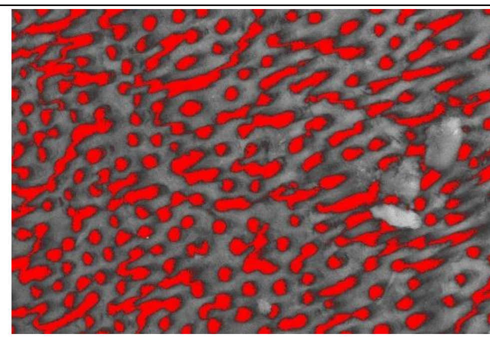
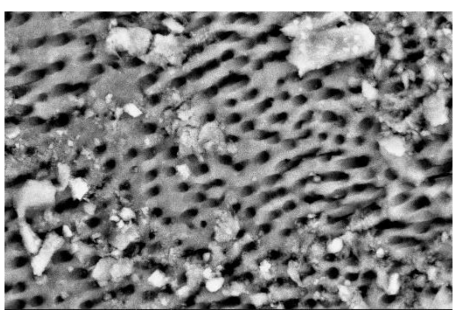
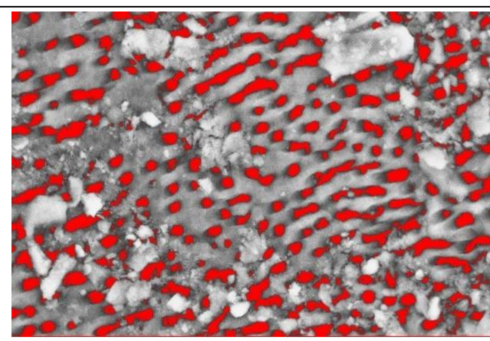
| | SEM image at 1500 x | Image analysis |
|---|---|---|
| **Pulp chamber** |  |  |
| **Coronal third** |  |  |
| **Middle third** |  |  |
| **Apical third** |  |  |

**Fig (21): a photomicrograph showing SEM images for different four-thirds and their image analysis when using guided conservative access cavity design with Endovac activation system**

### 5.2 Evaluation of debris covering the pulp chamber and root canal thirds

#### 5.2.1 Comparison between different access cavity designs.

Data in this section were statistically analyzed using Kruskal-Wallis test. Further Mann-Whitney test was used to compare the four different thirds when there is a significant difference between them.

**a. Using a side-vented irrigating needle(A).**

- In the pulp chamber, the mean at truss access cavity (1.22±0.67), conservative access cavity (1.25±0.46), and at guided conservative access cavity (1.11±0.33). There was no significant difference between the three groups (p-value=0.392).

- In the coronal third, the mean was recorded in truss access cavity (1.11±0.33), conservative access cavity (1.5±0.85), and was recorded in guided conservative access cavity (1.4±0.52). There was no significant difference between the three groups (p-value=0.724).

- In the middle third, the highest mean of debris scores was recorded in truss access cavity (2.9±1.79), followed by conservative access cavity (1.7±0.67). The lowest mean was recorded in guided conservative access cavity (1.67±0.71). There was no significant difference between guided conservative and conservative access cavity, while there was a significant difference between truss access cavity and the two other groups (p-value=0.036).

- In the apical third, the highest mean of debris scores was recorded in truss access cavity (4.38±0.92), followed by conservative access cavity (3±2.11). The lowest mean was recorded in guided conservative access cavity (2.89±1.63). There was no significant difference between guided conservative and conservative access cavity, while there was a significant difference between truss access cavity and the two other groups (p-value=0.041).

Table (6): Mean values and standard deviations for comparison of the mean of debris scores in different four-thirds under the side vented irrigating needle(A) for the three main groups

| | Conservative A | Truss A | Guided conservative A | P-value |
|---|---|---|---|---|
| **Pulp chamber** | 1.25±0.46$^{A}$ | 1.22±0.67$^{A}$ | 1.11±0.33$^{A}$ | **0.392**$^{NS}$ |
| **Coronal** | 1.5±0.85$^{A}$ | 1.11±0.33$^{A}$ | 1.4±0.52$^{A}$ | **0.724**$^{NS}$ |
| **Middle** | 1.7±0.67$^{B}$ | 2.9±1.79$^{A}$ | 1.67±0.71$^{B}$ | **0.036**$^{S}$ |
| **Apical** | 3±2.11$^{B}$ | 4.38±0.92$^{A}$ | 2.89±1.63$^{B}$ | **0.041**$^{S}$ |

-Capital letters for comparison (Mann-Whitney test) and the means with different superscripts are statistically significantly different at P ≤ 0.05.

- S= Statistically significant at P ≤ 0.05 - NS= Non-significant P > 0.05.

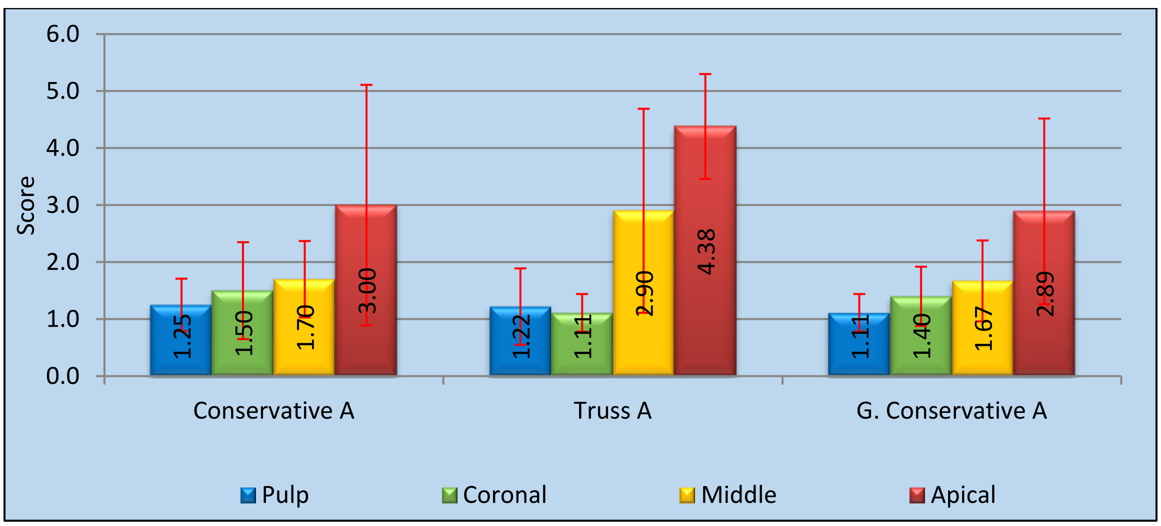



**Fig (22): A bar chart comparing the mean values and standard deviations of the mean of debris scores in different four-thirds under the side vented irrigating needle(A) for the three main groups.**

## b. Using Endovac activation system(B).

- In the pulp chamber, the mean at truss access cavity (1.6±0.84), conservative access cavity (1.1±0.32), and was recorded in guided conservative access cavity (1.3±0.48). There was no significant difference between the three groups (p-value=0.771).

- In the coronal third, the mean was recorded in truss access cavity (1.12±0.30), conservative access cavity (1.44±0.73), and was recorded in guided conservative access cavity (1.38±0.50). There was no significant difference between the three groups (p-value=0.570).

- In the middle third, the highest mean of debris scores was recorded in truss access cavity (2.5±1.27), followed by conservative access cavity (1.59±0.78). The lowest mean was recorded in guided conservative access cavity (1.4±0.54). There was a significant difference between guided conservative and truss access cavity, while there was no significant difference between conservative access cavity and the two other groups (p-value=0.050).

- In the apical third, the highest mean of debris scores was recorded in truss access cavity (3.2±1.93), followed by conservative access cavity (2±1.29). The lowest mean was recorded in guided conservative access cavity (1.63±0.74). There was no significant difference between guided conservative and conservative access cavity, while there was a significant difference between truss access cavity and the two other groups (p-value=0.023).

Table (7): Mean values and standard deviations for comparison of the mean of debris scores in different four-thirds under Endovac activation system(B)for the three main groups

| | Conservative B | Truss B | Guided conservative B | P-value |
|---|---|---|---|---|
| **Pulp chamber** | $1.1\pm0.32^{A}$ | $1.6\pm0.84^{A}$ | $1.3\pm0.48^{A}$ | **$0.771^{S}$** |
| **Coronal** | $1.44\pm0.73^{A}$ | $1.12\pm0.30^{A}$ | $1.38\pm0.50^{A}$ | **$0.570^{NS}$** |
| **Middle** | $1.59\pm0.78^{AB}$ | $2.5\pm1.27^{A}$ | $1.4\pm0.54^{B}$ | **$0.050^{S}$** |
| **Apical** | $2\pm1.29^{B}$ | $3.2\pm1.93^{A}$ | $1.63\pm0.74^{B}$ | **$0.023^{S}$** |

-Capital letters for comparison (Tukey Post Hoc test) and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

- S= Statistically significant at $P \leq 0.05$ - NS= Non-significant $P > 0.05$.

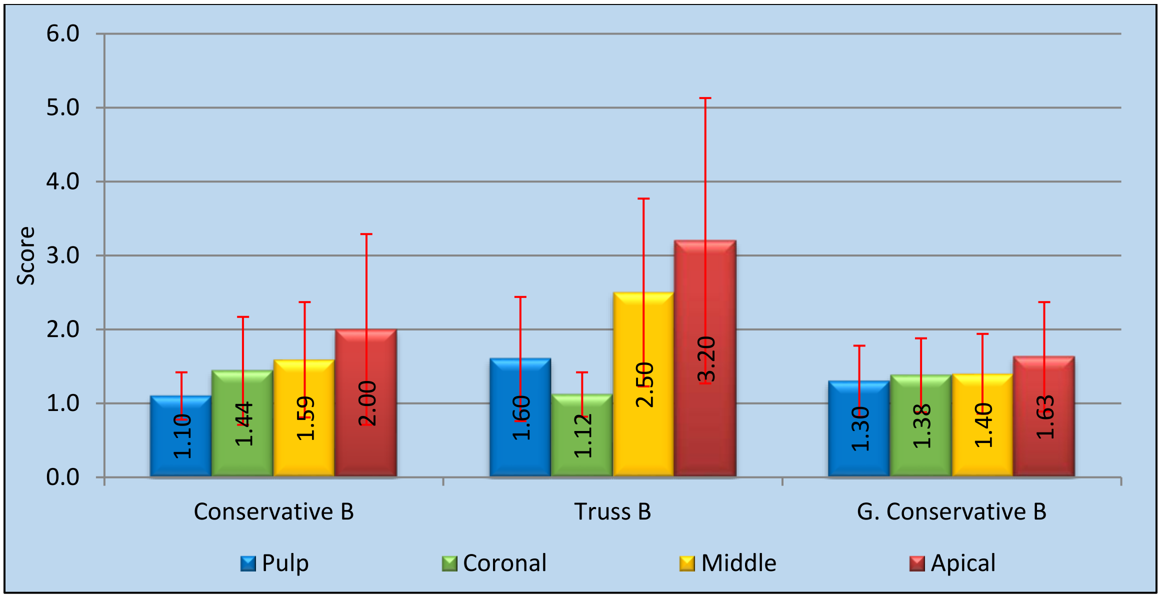



**Fig (23): A bar chart comparing the mean values and standard deviations of the mean of debris scores in different four-thirds under Endovac activation system(B)for the three main groups.**

## 5.2.2 Comparison between irrigating systems.

### a. Using conservative access cavity design.

When using a side-vented irrigating needle(A), the mean of debris scores was (1.25±0.46) at the pulp chamber, (1.5±0.85) at the Coronal third, and (1.7±0.67) at the middle third with no significant difference. The highest mean was at the apical third (3±2.11) with a significant difference between the apical and the other three-thirds (p-value=0.027).

When using Endovac activation system(B), the mean of debris scores was (1.1±0.32) at the pulp chamber, (1.44±0.73) at the coronal third, and (1.59±0.52) at the middle third with no significant difference. The highest mean was at the apical third (2±1.29) with a significant difference between the apical and the other three-thirds (p-value=0.041).

Table (8): Mean values and standard deviations for comparison of debris scores in different four-thirds under the two irrigation protocols for the conservative access cavity group.

| | | Pulp chamber | Coronal | Middle | Apical | P-value |
|---|---|---|---|---|---|---|
| **Conservative** | **A** | 1.25±0.46[b] | 1.5±0.85[b] | 1.7±0.67[b] | 3±2.11[a] | **0.027[S]** |
| | **B** | 1.1±0.32[b] | 1.44±0.73[ab] | 1.59±0.52[ab] | 2±1.29[a] | **0.041[S]** |

- Small letters for comparison between different thirds (Mann-Whitney test) and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

- S= Statistically significant at $P \leq 0.05$ - NS= Non-significant $P > 0.05$.

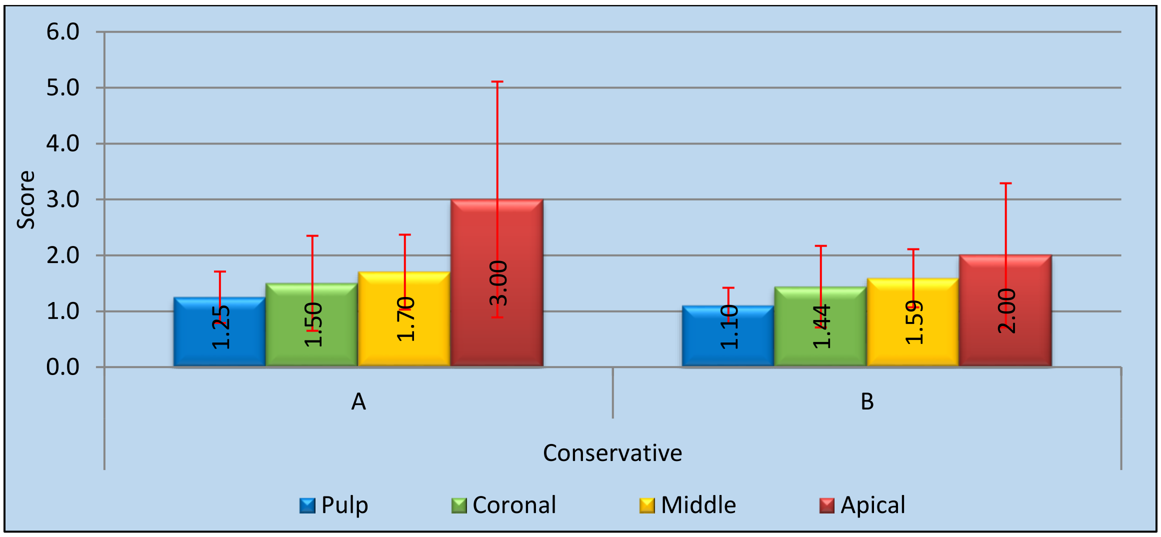



**Fig (24): A bar chart representing the mean values and standard deviations of debris scores in different four-thirds under side-vented irrigating needle (A) and Endovac activation system (B)for conservative access cavity group.**

## b. Using truss access cavity design.

When using a side-vented irrigating needle (A), the mean of debris scores was (1.22±0.67) at the pulp chamber, (1.11±0.33) at the coronal third with no significant difference, followed by (2.9±1.79) at the middle third. The highest mean was at the apical third (4.38±0.92) with a significant difference between the middle and the apical thirds (p-value=0.000).

When using Endovac activation system (B), the mean of debris scores was (1.6±0.84) at the pulp chamber, (1.12±0.30) at the Coronal third with no significant difference, followed by (2.5±1.27) at the middle third. The highest mean was at the apical third (3.2±1.93) with no significant difference between the middle and the apical thirds (p-value=0.033).

Table (9): Mean values and standard deviations for comparison of debris scores in different thirds under the two irrigation protocols for the Truss access cavity group.

| | | Pulp chamber | Coronal | Middle | Apical | P-value |
|---|---|---|---|---|---|---|
| **Truss** | **A** | 1.22±0.67[c] | 1.11±0.33[c] | 2.9±1.79[b] | 4.38±0.92[a] | **0.000[S]** |
| | **B** | 1.6±0.84[c] | 1.12±0.30[c] | 2.5±1.27[a] | 3.2±1.93[a] | **0.033[S]** |

- Small letters for comparison between different thirds (Mann-Whitney test) and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

- S= Statistically significant at $P \leq 0.05$ - NS= Non-significant $P > 0.05$.

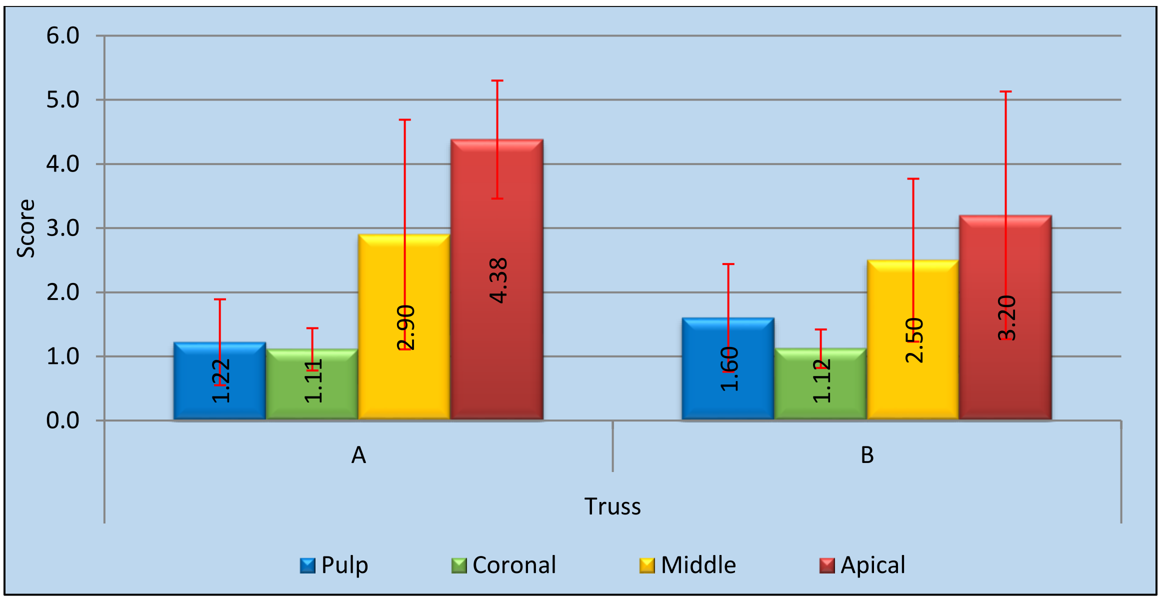



**Fig (25): A bar chart comparing the mean values and standard deviations of the mean of debris scores in different four-thirds under side-vented irrigating needle (A) and Endovac activation system (B)for truss access cavity group.**

## c. Using guided conservative access cavity design.

When using a side-vented irrigating needle (A), the mean of debris scores was (1.11±0.33) at the pulp chamber, (1.4±0.52) at the coronal third, and (1.67±0.71) at the middle third with no significant difference. The highest mean was at the apical third (2.89±1.63) with a significant difference between the apical and the other three-thirds (p-value=0.005).

When using Endovac activation system (B), the mean of debris scores was (1.3±0.48) at the pulp chamber, (1.38±0.52) at the coronal third, (1.4±0.52) in the middle third, and the highest mean was at the apical third (1.63±0.74). there was no significant difference between the four-thirds (p-value=0.381).

Table (10): Mean values and standard deviations for comparison of debris scores in different four-thirds under the two irrigation protocols for the guided conservative access cavity group.

| | | Pulp chamber | Coronal | Middle | Apical | P-value |
|---|---|---|---|---|---|---|
| Guided conservative | A | 1.11±0.33[b] | 1.4±0.52[b] | 1.67±0.71[b] | 2.89±1.63[a] | 0.005[S] |
| | B | 1.3±0.48[a] | 1.38±0.50[a] | 1.4±0.54[a] | 1.63±0.74[a] | 0.381[NS] |

- Small letters for comparison between different thirds (Mann-Whitney test) and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

- S= Statistically significant at $P \leq 0.05$ - NS= Non-significant $P > 0.05$.

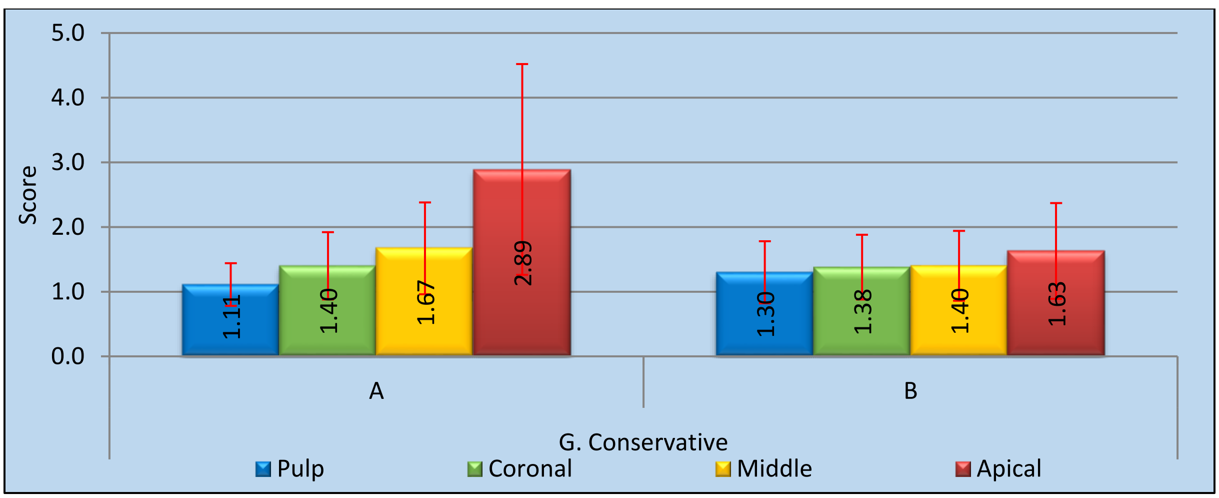



**Fig (26): A bar chart comparing the mean values and standard deviations of debris scores in different four-thirds under side-vented irrigating needle (A) and Endovac activation system (B)protocols for guided conservative access cavity group.**

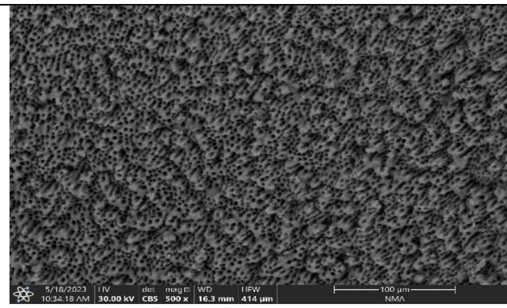
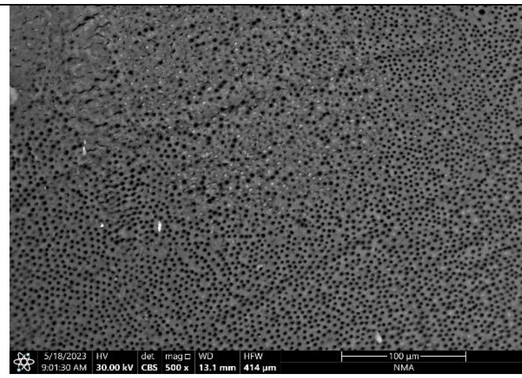
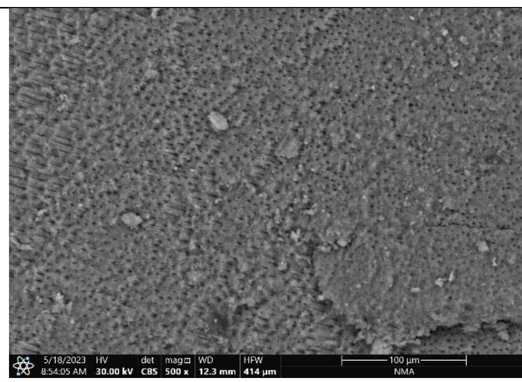
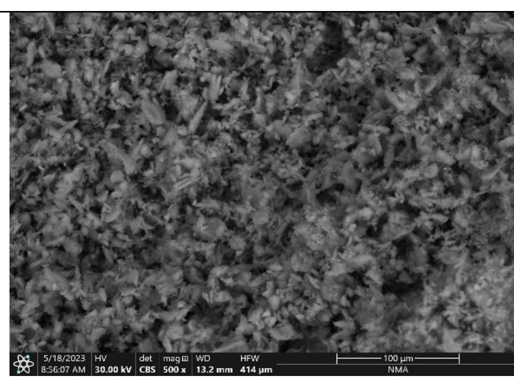
| | SEM image at 500 x |
|---|---|
| **Pulp chamber** |  |
| **Coronal third** |  |
| **Middle third** |  |
| **Apical third** |  |

**Fig (27): A photomicrograph showing SEM image at 500 x s for different four-thirds to show amount of debris covering after using conservative access cavity design with side-vented irrigating needle**

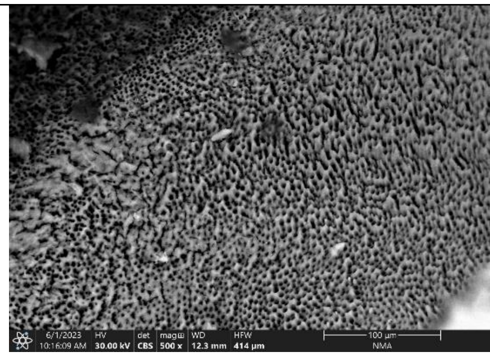
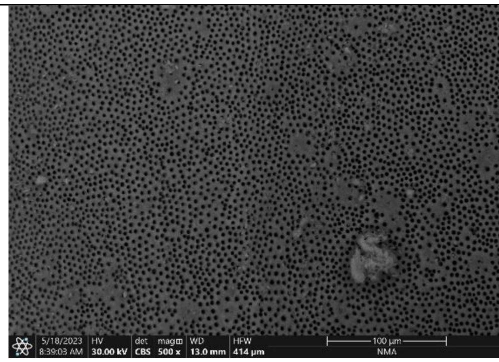
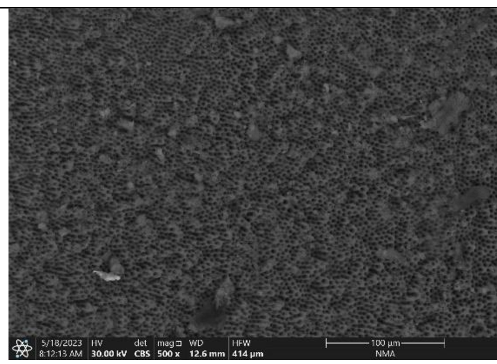
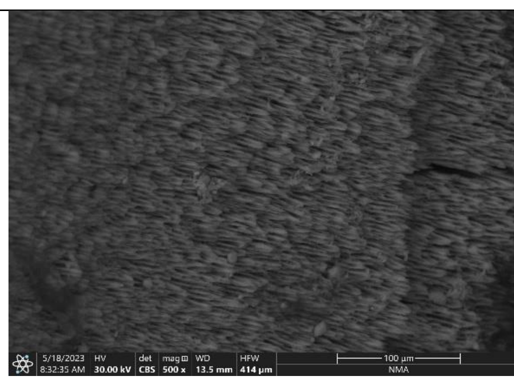
| | SEM image at 500 x |
|---|---|
| **Pulp chamber** |  |
| **Coronal third** |  |
| **Middle third** |  |
| **Apical third** |  |

**Fig (28): A photomicrograph showing SEM image at 500 x s for different four-thirds to show amount of debris covering after using conservative access cavity design with Endovac activation system**

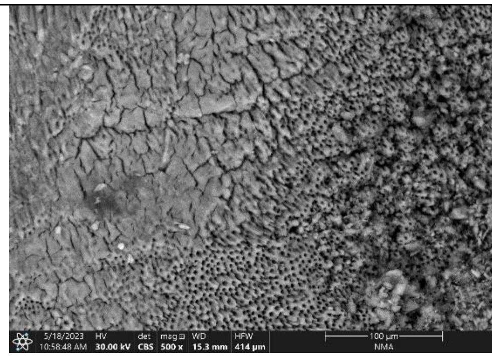
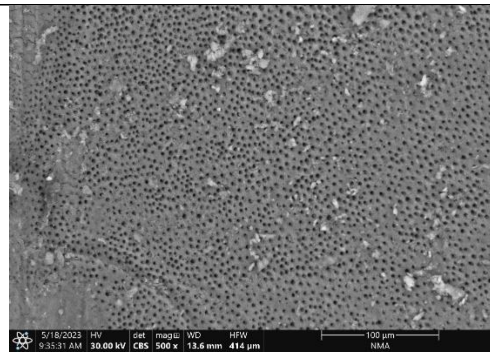
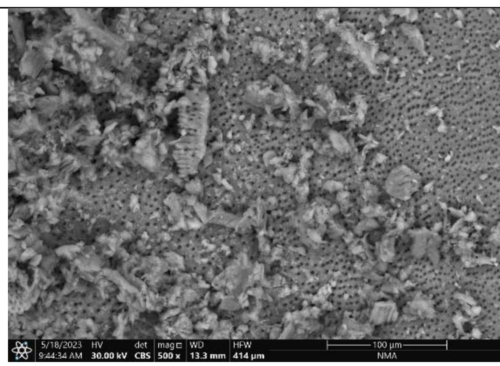
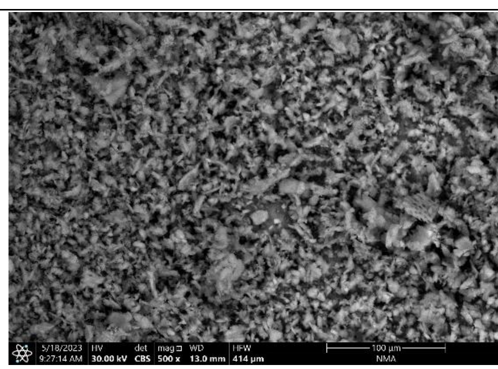
| | SEM image at 500 x |
|---|---|
| **Pulp chamber** |  |
| **Coronal third** |  |
| **Middle third** |  |
| **Apical third** |  |

**Fig (29): A photomicrograph showing SEM image at 500 x s for different four-thirds to show amount of debris covering after using truss access cavity design with side-vented irrigating needle**

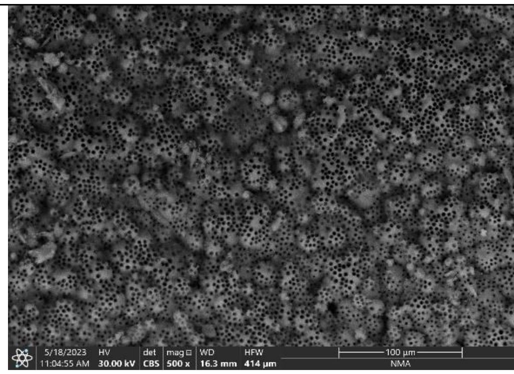
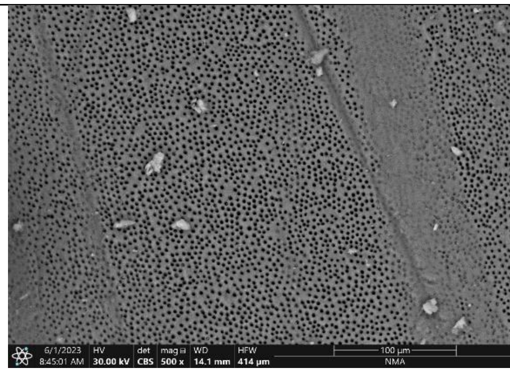
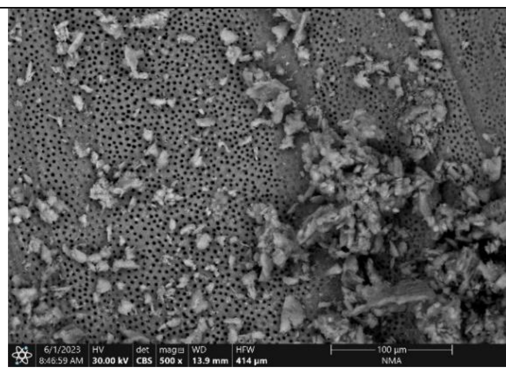
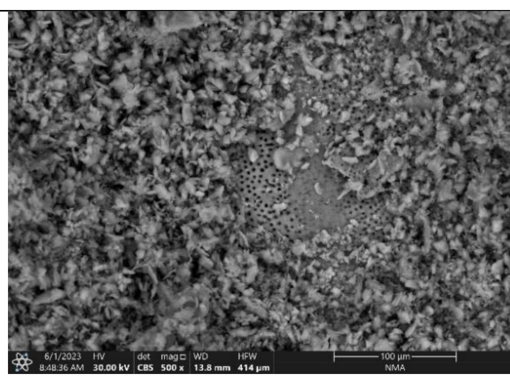
| | SEM image at 500 x |
|---|---|
| **Pulp chamber** |  |
| **Coronal third** |  |
| **Middle third** |  |
| **Apical third** |  |

**Fig (30): A photomicrograph showing SEM image at 500 x s for different four-thirds to show amount of debris covering after using truss access cavity design with Endovac activation system**

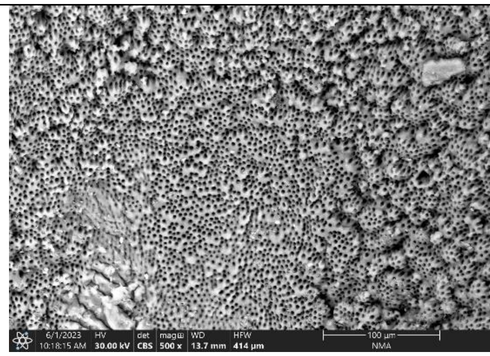
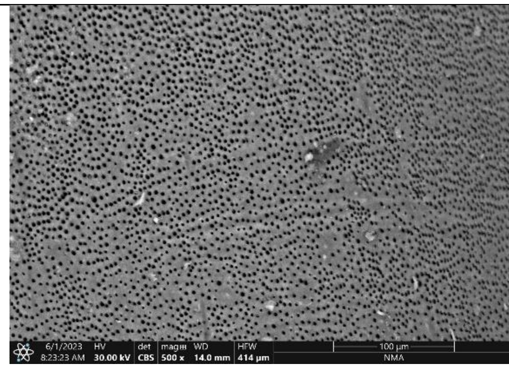
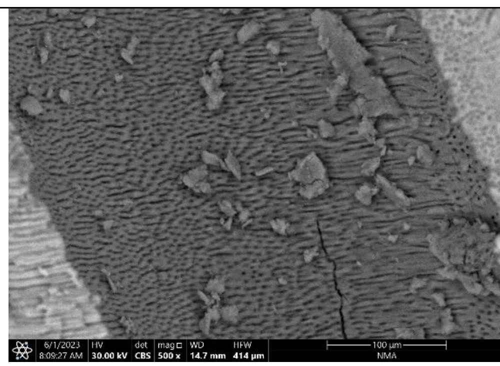
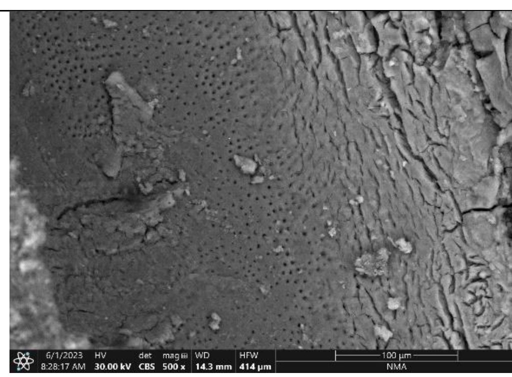
| | SEM image at 500 x |
|---|---|
| **Pulp chamber** |  |
| **Coronal third** |  |
| **Middle third** |  |
| **Apical third** |  |

**Fig (31): A photomicrograph showing SEM image at 500 x s for different four-thirds to show amount of debris covering after using guided conservative access cavity design with side-vented irrigating needle**

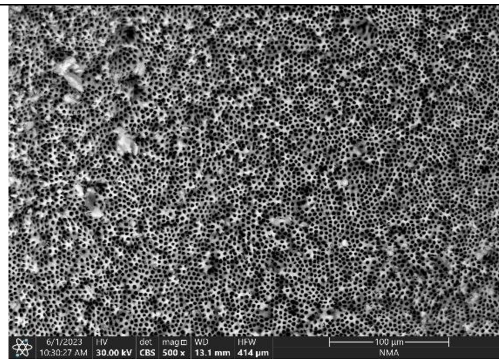
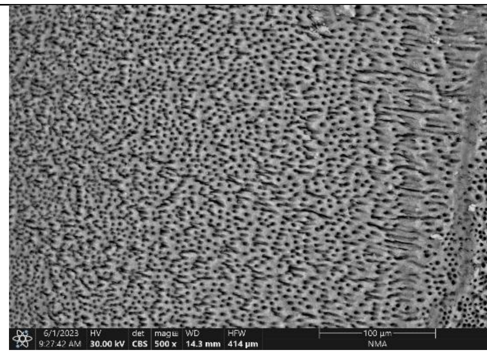
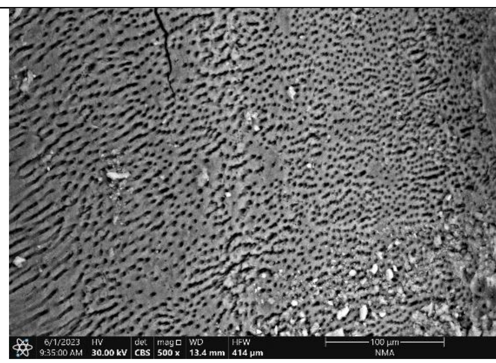
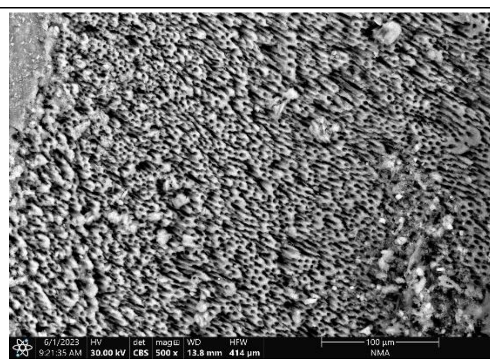
| | SEM image at 500 x |
|---|---|
| **Pulp chamber** |  |
| **Coronal third** |  |
| **Middle third** |  |
| **Apical third** |  |

**Fig (32): A photomicrograph showing SEM image at 500 x s for different four-thirds to show amount of debris covering after using guided conservative access cavity design with Endovac activation system**

# 6. Discussion

Successful root canal treatment greatly depends on the cleanliness of the pulp chamber and root canals(15). Among the variables that may affect the cleanliness of the root canal system are the irrigating solutions and techniques used in relation to the access cavity designs(88,89). This experimental, randomized, controlled, interventional prospective in-vitro study aimed to evaluate the cleanliness of the pulp chamber and root canals after irrigant activation using different access cavity designs.

Out of 75 recently extracted mandibular first molars, 60 teeth were used in the study Fifteen teeth were excluded for the following reasons; teeth with external or internal surface defects (5), teeth with immature apices (3), teeth with calcified root canals (2), teeth with coronal or root caries (3), and teeth with root fractures or cracks (2).

Mandibular first molars were used as; they are the most common teeth that undergo root canal treatment due to their early eruption in addition to their curved mesial roots are considered a challenge during cleaning and shaping(90,91). Teeth were collected from patients aged between 18 and 40 years old to minimize variations in dentin nature(92,93). The teeth with two roots and three root canals; the mesial root is type III Vertucci classification and the distal root is type I Vertucci classification to standardize the outline form of the access cavity(94).

A Preoperative CBCT was obtained to evaluate the anatomy of roots, the angle of curvature of roots, obtain an outline form of the pulp chamber and root canals, and for the planning of access cavity designs(83,95,96). The roots of each tooth were painted with nail polish to prevent blockage of the root openings with future embedding in pink wax that was done to secure the teeth during CBCT scanning and access cavity preparation inside the prefabricated plastic molds.

The access cavity designs were conservative access cavity, truss access cavity, and guided conservative access cavity. The conservative access cavity preparation allows removal of the pulp tissue and aims to preserve the soffit and peri-cervical dentin[97 ,98]. The truss access cavity preparation aimed to reinforce the coronal tooth structure by leaving intervening dentin intact [8,99,100,101,102]. The guided conservative access cavity preparation conserves the coronal tooth structure through preoperative designing and planning of the access cavity to locate canal orifices[103,104].

The mechanical preparation was done using Endo Star E3 Azure rotary file system. It is heat-treated, highly flexible, and can easily fit in strongly curved canals[105,106]. The samples were prepared up to 30,0.4 taper to decrease the percentage of unprepared areas and improve the flow of the irrigation till the apical third of the root[107,108].

The root canals were irrigated using NAOCL 5.25 %, EDTA 17 %, and distilled water as a final rinse. NAOCL 5.25 % was a well-established irrigant for cleaning root canals because of both its antimicrobial activity and organic tissue dissolution capability[109,110].EDTA 17 % was able to dissolve inorganic contents of the root canals[111,112]. Distilled water was used as a final rinse as it was an isotonic solution[113].

Irrigation activation was done using Endovac activation system. It is a negative-pressure irrigating system that promotes rapid circulation and continuous renewal of the irrigating solution inside the root canals[20,59,85]. The Endovac system avoids the vapor lock phenomenon, which appears in the apical third of the root canals[114,115]. It reduces the risk of extrusion of irrigants beyond the apex, which can cause damage to the surrounding tissues[62,116].

A longitudinal sectioning method of the samples through the pulp chamber and mesial root was chosen for cleanliness evaluation because it enables a direct examination of the root canal space and it is also cheap and available[117]. Teflon tape was used to close the access cavity and mesial root to prevent accumulation of the cutting debris into the pulp chamber and root canals[118].

The specimens were evaluated for cleanliness under SEM as it is the most common technique used to assess the removal of debris and smear layer[119,120,121]. Debris evaluation was at a magnification of 500 X, to show a wide area for a larger field of vision[64]. On the other hand, a magnification of 1500 x for image analysis narrows the field of vision and focuses on the dentinal tubules and their openings[61,63]. ImageJ software was used to determine the percentage area of open dentinal tubules in relation to the image area ODT%[122,123].

When comparing different access cavity designs, the highest percentage of the opened dentinal tubules was achieved in guided conservative access cavity design than conservative and truss access cavity designs at all regions. This may be attributed to deeper penetration of the irrigating solutions as it explores all canal orifices with minimal coronal interferences and minimal loss of the remaining tooth structure. This is in agreement with Moore et al. [124] in 2016 and Viera et al. [125] in 2020 who concluded that the smaller the access cavity, the greater the danger and probability of missing canal orifices with sequent increase in the liability of having debris and necrotic tissues.

While conservative and truss access cavity designs showed lowered opened dentinal tubules. In conservative access cavity design, it may be attributed to the presence of coronal interferences after access cavity preparation which creates an inclination for the instruments and an irregular distribution of force. This interference may be due to the preservation of the soffit and peri-cervical dentin as it is not a straight-line access. This is in agreement with Eaton et al. [126] in 2015 and Alovisi et al. [127] in 2018 who demonstrated that greater canal transportation is present in conservative access cavity design than traditional access cavity design in mandibular molars and this may be due to coronal interference.

While in truss access cavity design, the lowered opened dentinal tubules may be attributed to the design which leave a dentin bridge intact that may lead to a decreased amount of delivered irrigant, difficulty of cleaning the pulp chamber and it is less visible and accessible. This is in agreement with Barbosa et al. (32)in 2020 and Lima et al. (108) in 2021. Their studies revealed that ultraconservative access cavity design have greater percentage of unprepared areas on canal walls and chamber. This confirmed that the narrowness of this design affects the cleanliness of the root canals and pulp chamber.

Regarding the results of debris scores covering the pulp chamber and root canal thirds, the highest percentage of debris was achieved in truss access cavity design than conservative and guided conservative access cavity designs at all regions. This may be attributed to the design of the truss access itself which has more coronal interferences during root canal preparation that prevent adequate irrigation to reach under the remained dentin bridge. These coronal interferences might cause the inadequate cleanliness mainly at the pulp chamber region as it belongs to ultraconservative access cavity design. This is in agreement with Neelakantan et al. (38)in 2018 who stated that the debridement of the pulp chamber in truss access cavity design was compromised than traditional access cavity design on mandibular molars and Silva et al. (39) in 2019 who stated that ultraconservative cavities resulted in accumulation of hard tissue dentin inside the root canal, difficult cleaning of the pulp chamber and required more time for root canal treatment on maxillary premolars.

The present study had revealed that Endovac activation system achieved the highest ODT% and lowest debris scores than side side-vented irrigating needle. There is a significant difference at apical third while no significant difference at the pulp chamber, coronal, and the middle thirds. This difference at the apical third may be attributed to the smaller apical size compared to the other thirds in addition to the depth of penetration of the irrigating solutions and the anatomical complexity owe a bigger barrier to clean the apical third as the irrigation did in other thirds. The higher mechanical flushing action created by the Endovac system, more irrigants can be delivered through the delivery/evacuation tip in addition to negative pressure to apical third. The volume of irrigant delivered to the canal apically by the Endovac system was significantly higher than the volume delivered by conventional syringe needle irrigation during the same period. This is in agreement with Nielsen and Baumgartner [20] in 2007, Gade et al. [59] in 2013 , Srivastava et al. [64] in 2021 and Mancini et al. [128] in 2013 who cocnluded that Endovac activation system showed better removal of debris and smearlayer at the apical third. Based on the results of this study, the null hypothesis was rejected as the guided conservative access cavity design achieved the highest mean of ODT% and lowest mean of debris.

# 7. Conclusions

Within the limitations of this study, the following conclusion were drawn:

1. Activation of irrigation enhances the cleanliness of the root canal system in all tested groups.
2. Conventional irrigation with side-vented needle is insufficient to achieve the cleanliness of root canal system especially in the apical third.
3. Removal of the soffit and peri-cervical dentin using guided access cavity design improve the cleanliness of the root canal system and vice versa.
4. Leaving dentin bridge in truss access cavity design is considered as obstacle to remove debris and smear layer from the root canal system with conventional irrigation.
5. The conjunction between CBC|T and guided endodontics improve the cleanliness of the root canal system with minimal destruction of the tooth structure.

# 6. Recommendations

1. Further research should be done using new technologies or combination methods to improve the conventional irrigation with ultraconservative access cavity designs.
2. Further research should be done to evaluate the postoperative pain in relation to different access cavity designs used in the study.

# 9. Summary

Successful endodontic treatment starts with adequate access cavity preparation. Access cavity preparation is a crucial step of endodontic treatment. There are several designs of access cavity aimed to conservation of hard tooth structure.

This study was directed to evaluate to the efficiency of smear layer and debris removal using different irrigation methods in different access cavity designs. In this study, A total of 60 mandibular first molars were selected according to inclusion criteria. Pre-intervention CBCT was done for all teeth. The teeth were grouped into three main groups according to access cavity design. Group 1 conservative access cavity design, group 2 truss access cavity design, and group 3 guided conservative access cavity design. Each group would be sub-divided into two groups according to irrigation protocol used; group A side-vented irrigating needle and group B apical negative pressure activation system.

The result showed that the guided conservative access cavity design group achieved the highest mean of opened dentinal tubules percentage and lowest mean of accumulated debris. The truss access cavity design group achieved the lowest mean of opened dentinal tubules percentage and the highest mean of accumulated debris.

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## ١١. الملخص العربي

تبدأ المعالجة اللبية الناجحة بإعداد تجويف الوصول المناسب. يعد تحضير تجويف الوصول خطوة حاسمة في المعالجة اللبية. هناك العديد من تصميمات تجويف الوصول التي تهدف إلى الحفاظ على بنية الأسنان الصلبة .

تم توجيه هذه الدراسة لتقييم كفاءة إزالة طبقة اللطاخة والحطام باستخدام طرق الري المختلفة في تصاميم تجويف الوصول المختلفة. في هذه الدراسة ، تم اختيار مجموعه من ٦٠ من أضراس الفك السفلي الأولى طبقا لمعايير الاشتمال. تم إجراء تصوير مقطعي بالاشعاع المخروطي قبل التدخل لجميع الأسنان. تم تجميع الأسنان في ثلاث مجموعات رئيسية وفقا لتصميم تجويف الوصول. تصميم تجويف الوصول المحافظ من المجموعة ١ ، وتصميم تجويف الوصول التراص من المجموعة ٢ ، وتصميم تجويف الوصول المحافظ الموجه من المجموعة ٣. سيتم تقسيم كل مجموعة إلى مجموعتين وفقا لبروتوكول الري المستخدم. إبرة الري ذات التهوية الجانبية من المجموعة أ ونظام تنشيط الضغط السلبي القمي من المجموعة ب.

أظهرت النتائج أن مجموعة تصميم تجويف الوصول المحافظ الموجه حققت أعلى متوسط لنسبة الأنابيب العاجية المفتوحة وأقل متوسط للحطام المتراكم. حققت مجموعة تصميم تجويف الوصول إلى الجمالون أدنى متوسط لنسبة الأنابيب العاجية المفتوحة وأعلى متوسط للحطام المتراكم.

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# تقييم نظافة حجرة اللب وقنوات الجذور بعد الغسول المَنشط بإستخدام تصاميم مختلفة لمدخل حجرة اللب

رسالة مقدمة كجزء من مقومات الحصول على درجة الماجستير في علاج الجذور


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طبيب أسنان بمركز رعاية طفل الظاهر



٢٠٢٣م – ١٤٤٥هـ