ACTA SCIENTIFIC DENTAL SCIENCES

Volume 9 Issue 4 April 2025

Research Article

Evaluation of Fracture Resistance in Mandibular Molars' Mesial Roots After Removal of Separated Instruments Using Traditional and Conservative Techniques: *In-vitro* Study

Robert Milad[1]*, Ahmed Ghobashy[2] and Khaled Ezzat[3]

[1]*B.D.S, Faculty of Oral and Dental Medicine, Misr International University, Egypt*

[2]*Professor of Endodontics, Faculty of Oral and Dental Medicine, Misr International University, Egypt*

[3]*Professor of Endodontics, Faculty of Oral and Dental Medicine, Cairo University, Egypt*

***Corresponding Author:** Robert Milad William Moussa, B.D.S, Faculty of Oral and Dental Medicine, Misr International University, Egypt.

Received: March 10, 2025

Published: March 19, 2025

Abstract

Aim: The aim of the study was to evaluate the fracture resistance of mandibular molar mesial roots following the removal of separated endodontic instruments using traditional and conservative approaches to identify the more conservative technique in terms of maintaining root strength.

Methodology: Twelve extracted mandibular first molars with separate mesial canals were instrumented, and files were intentionally fractured within the canals. Teeth were divided into three groups (n=4 per group): file retrieval using traditional technique with 0.25mm diameter ultrasonic tips (ET25), Traditional technique with 0.40mm diameter ultrasonic tips (ET40), and conservative technique using TFRK ultrasonic tips. Specifically, ET25 ultrasonic tips were 20 mm in length, possessed a 3% taper, and were fabricated from titanium-niobium alloy, while ET40 ultrasonic tips were 40 mm in length, featured a 4% taper, and were made from stainless steel. File retrieval attempts were limited to 60 minutes. Subsequent to the retrieval attempts, the fracture resistance of the remaining tooth structure was tested after instrumentation.

Results: There was a statistically significant difference in maximum load (Newtons) among the groups ($p < 0.002$). The conservative technique group (Median=1328.45 N) exhibited significantly higher fracture resistance compared to the traditional ET25 group (Median=1031 N) and the traditional ET40 group (Median=700.19 N) ($p < 0.05$).

Conclusion: Within the limitations of the study, it was concluded that the conservative technique is a more conservative approach for file retrieval in mandibular molars, preserving greater root strength and potentially reducing the risk of root fracture, thereby improving long-term tooth prognosis.

Keywords: Ruddle Technique; Terauchi Technique; Separated Instruments; Fracture Resistance; Mandibular Molars

Introduction

The main objective of endodontic treatment is to preserve the natural tooth, restoring its function and esthetics by completely cleaning, shaping, and obturating the root canal system. Achieving this goal can be complicated when endodontic instruments fracture and separate within the root canal system. In such cases, various management strategies are employed, including the use of specialized retrieval tools, advanced endodontic techniques, and alternative restorative approaches to ensure the tooth remains functional and aesthetically pleasing. These strategies aim to maintain the integrity of the tooth while addressing any complications that may arise during treatment [1].

The fracture of endodontic instruments presents a significant challenge for both dental practitioners and patients, as it often occurs unexpectedly [2]. For dentists, this complication complicates the thorough cleaning and shaping of the root canal, potentially

compromising the success of subsequent obturation procedures [3,4]. Meanwhile, patients may experience heightened psychological distress and anxiety due to concerns about the presence of a metallic fragment within their tooth, including fears of corrosion and its potential impact on oral health. This situation highlights the need for reliable and durable endodontic instruments to minimize such complications and ensure successful treatment outcomes [5].

Recent studies have evaluated different therapeutic modalities for the management of fractured endodontic instruments, with decision-making predicated upon the level of instrument separation, its positional relationship to root canal curvature, instrument type and length, canal curvature severity, and the specific tooth [6,7]. Strategies include fragment bypass, non-surgical or surgical retrieval, and when clinically indicated, incorporating the fragment within the root canal obturation [8-10].

Research has examined the effects of fractured instrument retrieval on root dentin integrity. Suboptimal techniques or insufficient magnification may induce iatrogenic complications, including file extrusion, apical transportation, ledge formation, zipping, perforations, and structural weakening of the root, with potential sequelae of microcrack propagation and vertical root fracture, ultimately necessitating tooth extraction [11]. Retrieval procedures can result in substantial dentin removal, increasing the susceptibility to root fracture [4,11]. Studies have demonstrated a 30-40% reduction in root strength following fractured file removal [12]. Therefore, a comprehensive pre-operative evaluation, encompassing a thorough risk-benefit analysis, is essential to minimize iatrogenic damage and optimize clinical outcomes.

The combined use of ultrasonic tips and a dental operating microscope (DOM) has emerged as a successful, safe, and efficient approach [13,14]. This is mainly because the proper magnification offered by the DOM, along with enhanced illumination, allows for conservative dentin removal, which can extend the lifespan of the affected tooth [13,15].

During fractured instrument retrieval, the preservation of maximal dental hard tissue is essential to mitigate the risks of root fracture and perforation. The procedural objective is to mobilize the fragment, often employing ultrasonic energy to dislodge it from the canal walls and facilitate coronal displacement. Visualization of fractured instruments with an operating microscope plays an important role in the success rates when removing or bypassing the fractured instruments [12].

While various attempts have been made to develop a workflow diagram for managing fractured endodontic instruments and to aid in decision-making, a standardized procedure for consistent results is still lacking. Thus, this study was to identify the more conservative retrieval technique in terms of maintaining root strength.

Subjects and Methods

Sample size

The sample size calculation was done by using G power program and according to a previous study done by Fu M et al. (2019) [16] who stated in his study that the percentage volume increase was significantly larger in the ultrasonic group (135.3% ± 31.3%) than control group (66.6% ± 24.3%) with effect size of 0.774; adjusting the confidence interval to 95.0% and the power of the test to 90.0% and number of groups to 3; the minimum sample size required per group was 4 teeth (total of 12 teeth).

Selection of subjects

Twelve extracted mandibular first molars, obtained from the MIU teeth bank, were selected based on pre-defined inclusion and exclusion criteria. Clinical assessment, involving both macroscopic visual inspection and microscopic examination using a dental operating microscope (DOM), alongside radiographic evaluation, was performed to determine eligibility. Inclusion criteria mandated intact or minimally carious crowns, absence of mesial root caries, complete root development, distinct mesial root canals (Vertucci Type IV), and a tooth length within 18-21 mm. Conversely, specimens were excluded if they exhibited previous endodontic treatment, severe root curvature, resorption, perforation, fractures, canal calcifications, confluent mesial canals (Vertucci Type II), or the presence of middle mesial canals.

Subject preparation

Extracted first mandibular molar were collected and stored in 0.1% thymol solution from MIU teeth bank. All teeth were cleansed of visible blood, calculus, surface deposits and gross debris. Then, they were decontaminated and maintained in a hydrated state using 0.1% Thymol solution, in a closed container at room temperature.

Clinical Procedures

A preoperative periapical radiograph was obtained to assess the dimensions and anatomy of the pulp chamber. Following this, any present caries was carefully removed, and access cavity preparation was initiated using large round stone, tapered with round end stone and Endo Z bur (Dentsply Maillefer. Ballaigues. Switzerland).

An endodontic explorer was used to the locate the orifice of the MB and ML canals. Patency and confirmation for the presence of two separate mesial canals was done using #10 K file (Mani Inc., Tochigikan. Japan) and confirmed with digital periapical radiography. Working length was determined by passing #10 K file to the apical foramen and then retracting it till it was flushed with the apex. The length was recorded and the final working length was established as 1 mm short of the recorded length.

Throughout the procedural steps, sodium hypochlorite (NaOCl) at a concentration of 5.25% was used as the irrigating solution. This solution was delivered using a 27-gauge needle (AMECO, Egypt), with 2 ml administered between each file size.

Following the manufacturer's recommended sequence, the root canals were instrumented using HyFlex EDM files (Coltene / Whaledent, Allstätten, Switzerland). The procedure started with an Orifice Opener (25/.12), which was advanced to the middle third of the canal. Subsequently, a #10 K-File was used to establish patency by reaching the full length of the canal. Next, a Glidepath file (10/.05) was used to ensure the glide path, and extending to the full length of the canal. This instrumentation was performed using an endodontic motor (E-CONNECT, Eighteeth, China).

Decoronation of the subjects

Prepared teeth were then decoronated at the level of the cemento-enamel junction using a wheel stone mounted on a high-speed handpiece with water coolant leaving a standardized length of 16 mm.

Following Decoronation, the teeth were coated with laboratory pink wax (Cavex, The Netherlands) and moisturizing jelly (Vaseline, NJ, USA), excluding the coronal 2 mm of the roots. Subsequently, each set of four prepared and coated teeth was embedded in acrylic blocks measuring 40 mm x 40 mm x 17 mm, fabricated from cold-cure clear acrylic resin. The resin was allowed to set completely over a period of 24 hours.

Instruments separation inside study samples

A HyFlex One File (#25 with variable taper) was modified by creating a notch 3 mm from the tip using a low-speed diamond disk mounted on a straight handpiece, which penetrated half of the file's thickness. The file was then mounted on an endodontic motor and inserted passively into the canal, advancing 5 mm from the orifice until it engaged with the canal wall. Subsequently, the endodontic motor was activated at a speed of 250 rpm and a torque of 3 N-cm, resulting in the controlled fracture of the file in the most apical visible portion of the canal.

Sample grouping and randomization

The teeth were randomly allocated into three experimental groups, each consisting of four teeth, based on the retrieval technique employed. The groups were structured as follows

- **Group 1 (n = 4):** This group utilized the traditional retrieval technique, employing ultrasonic tips featuring a diameter of 0.25 mm (ET25) (Acteon, France). ET25 ultrasonic tips were 20 mm in length, possessed a 3% taper, and were fabricated from titanium-niobium alloy.
- **Group 2 (n = 4):** Similar to Group 1, this group also utilized the traditional technique but used ultrasonic tips with a larger diameter of 0.40 mm (ET40) (Acteon, France). ET40 ultrasonic tips were 40 mm in length, featured a 4% taper, and were made from stainless steel.
- **Group 3 (n = 4):** This group adopted the conservative retrieval technique utilizing the TFRK system (Dental Engineering Laboratories, Santa Barbra, USA.). The TFRK system included:
- TFRK-6 and TFRK-12 US tips, which were spoon-shaped.
- TFRK-S US tip, characterized by a smaller diameter of 0.1 mm.

Retrieval of the separated file

The retrieval process was conducted according to the techniques described by the inventors:

Traditional technique as described by Ruddle [17] (Groups 1 and 2)

- Radicular access was established using a sequential hand filing technique, followed by Gates Glidden (GG) drills (sizes 1-4) (Mani, inc, Japan) to create a progressively tapered funnel.
- A circumferential staging platform was prepared using a modified GG drill at 300 RPM.

- Ultrasonic tips were used with dry operation and air irrigation for visualization. The tip was activated at low power, moved counterclockwise to trephine and remove dentin, and dislodged the fragment through a wedging action [37].

Conservative technique as described by Yoshi [18] (Group 3):

- A modified Gates Glidden bur was used at 1000 RPM in a clockwise motion to create a funnel shape.
- A micro-trephine bur (Dental Engineering Laboratories, Santa Barbra, USA) was employed at 600 RPM in a counterclockwise direction to create a trough around the fragment.
- Ultrasonic tips (TFRK) were used starting at low power with incremental increases, utilizing pulsed activation and air cooling. Micro-spoon tips created a semicircular space to dislodge the fragment, while a straight tip extended the space apically and laterally. Aqueous EDTA was used to enhance cavitation and propel the fragment. Retrieval attempts were limited to 60 minutes, with success confirmed radiographically [10].

Obturation and final restoration

After file retrieval in all of the groups, the mechanical preparation of the root canals was performed using hand and rotary files. Initially, the root canals were prepared using a size 06 K-file (Mani, inc, Japan), and patency was established up to a size 10 K-file (Mani, inc, Japan). The working length was determined 1 mm short of the apical foramen. The root canals were then sequentially instrumented using Hyflex EDM rotary files system (Coltene, Switzerland) according to the manufacturer's instructions (#25/.12, 10/.05, 25/ with variable taper). Each file was only used three times.

During the mechanical preparation, a total of 10 mL 2.5% sodium hypochlorite was used as an irrigant. The final flush was performed with 2 mL 2.5% sodium Hypochlorite, 2 mL 17% EDTA, and 2 mL distilled water using a 27-G irrigation needle (AMECO, Egypt). The root canals were dried and filled with warm vertical compaction using ADSEAL canal sealer (Meta Biomed, Republic of Korea). Pulp chamber was then restored with dual-cured core build up composite (Han Dae Chemical, Korea).

The wax in the acrylic blocks was then substituted with light body hydrophilic vinyl polysiloxane impression material (HRS Co., LTD, Korea.) to simulate the periodontal ligament.

Evaluation of fracture resistance using universal testing machine

Fracture resistance was assessed using a computer-controlled materials testing machine (Instron Model 3345) with data acquisition facilitated by Bluehill Lite Software. Each specimen was rigidly secured to the lower compartment of the testing apparatus. A compressive load was applied axially to the middle of the occlusal surface via a 5 mm diameter metallic rod attached to the upper, mobile compartment, advancing at a crosshead speed of 1 mm/min. Failure was defined by the presence of an audible crack, visual fracture, and a precipitous decline in the load-deflection curve recorded by the software. The force at fracture, measured in Newtons, was recorded and subsequently analyzed.

Statistical analysis

Data were collected, revised and entered to the Statistical Package for Social Science (IBM SPSS) (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp). After checking normality using Komogorov-Smirnov test for normality distribution, the quantitative data were presented as mean, standard deviations and ranges and compared between the three groups using Kruskall-Wallis test followed by post hoc analysis using Mann-Whitney test. The confidence interval was set to 95% and the margin of error accepted was set to 5%. So, the p-value was considered significant at the level of <0.05.

Results

Table 1 shows that there was a statistically significant difference between the three studied groups regarding the maximum load in newtons, which was significantly greater in the conservative technique 1328.45 (1248.13 – 1387.27) than in the traditional technique with ET25 tips 1031 (1004.1 – 1103.8) and traditional technique with ET40 tips 700.19 (700.19 – 809.39), with a p-value <0.001. The post hoc analysis showed a statistically significant difference among the three groups.

Discussion

Retrieval of separated instruments presents a significant technical challenge in endodontics, balancing removal effectiveness with the preservation of root structure. While ultrasonic techniques improve retrieval success, concerns persist regarding dentin loss and compromised fracture resistance. Excessive dentin removal increases the risk of vertical root fracture and long-term failure, emphasizing the importance of selecting an appropriate retrieval technique [19].

		Traditional technique with ET25 tips (n = 4)	Traditional technique with ET40 tips (n = 4)	Conservative technique (n = 4)	Test value	P-value	Sig.
Max Load in Newton's	Median (IQR)	1031 (1004.1 – 1103.8)	700.19 (700.19 – 809.39)	1328.45 (1248.13 – 1387.27)	12.299	0.002	HS
	Range	953.67 – 1218.74	422.51 – 921.05	1218.74 – 1547.33			
Post Hoc analysis by Mann-Whitney test							
Parameters		Traditional technique with ET25 tips Vs Traditional technique with ET40 tips	Traditional technique with ET25 tips Vs Conservative technique		Traditional technique with ET40 tips Vs Conservative technique		
Max Load in Newton's		0.009	0.012		0.009		

Table 1

The aim of this study was to compare the effects of the traditional ultrasonic technique and the conservative technique on fracture resistance when used in the visible portion of the canal. These approaches differ in troughing strategies and invasiveness. The traditional technique employs aggressive circumferential troughing, whereas the conservative technique utilizes a more conservative, targeted approach. Given the emphasis on minimally invasive endodontics and the optimization of treatment protocols, enhancing the long-term prognosis of endodontically treated teeth by maximizing retrieval efficiency while minimizing structural compromise.

Mandibular first molars with Vertucci Type IV mesial canals were selected for this in vitro study to simulate the anatomical complexity and clinical relevance encountered in endodontic practice. The intricate anatomy of these teeth, characterized by multiple roots and canals with pronounced curvature, predisposes them to instrument separation and subsequent challenges during retrieval, potentially compromising dentin thickness. Furthermore, the high prevalence of Type IV canals in mandibular first molars, particularly within the Egyptian population, reflects a clinically significant scenario, making this model appropriate for investigating the impact of retrieval techniques on fracture resistance [20-22].

In this study, mandibular first molar mesiobuccal (MB) canals were selected due to their high degree of curvature relative to mesiolingual (ML) canals [23]. This choice aligned with Hulsmann's findings that fractures commonly occur in mandibular molar mesial canals, which are associated with lower retrieval success rates [24]. Furthermore, Amorim et al.'s microcomputed tomography study demonstrated a lack of canal centralization in mesial roots, increasing their susceptibility to procedural errors [25]. The decision was further supported by Tabrizizadeh., *et al.'s* study of the distal portion of mesial roots which showed a smaller thickness in comparison to all other portions of the roots [26]. Considering these anatomical vulnerabilities and reported clinical challenges, the MB canals provide a clinically relevant model for assessing instrument retrieval techniques.

Specimens were decoronated at the cementoenamel junction to standardize root length to 16 mm [27-30]. This procedure ensured that the evaluation of fracture resistance was focused solely on the root structure, eliminating any potential influence from the coronal portion of the tooth. This approach minimizes variability from differing coronal morphology and simulates clinical scenarios where endodontic treatment is often performed on teeth with significant coronal destruction [31-33].

This study focused on the visible portion of root canals to ensure precise procedural control and clinical relevance. Visual access allowed for targeted dentin removal, consistent application of techniques, and immediate assessment of canal modifications, minimizing over-preparation.

Hyflex EDM files were employed in this study to create a standardized cohort of fractured instruments for accurate retrieval technique evaluation. Their martensitic nature and manufacturing process via electro-discharge machining, coupled with their increasing clinical use due to enhanced flexibility and shape memory, make them a relevant choice for this investigation [34].

In substitution for the original ProUltra Endo tips, which were designed by Ruddle but are no longer commercially available, ET25 and ET40 Satelec tips were utilized as substitutes. Although the ProUltra Endo tips were made from a titanium alloy, the ET25 and ET40 tips, constructed from titanium-niobium and a steel alloy respectively, provided a suitable alternative due to their availability and clinical relevance. Previous research also suggested that ET25 tips result in less canal enlargement compared to ProUltra 8 Endo tips when used in resin blocks, further supporting their suitability for this study [35].

Fracture resistance testing was performed on restored teeth to mimic clinical conditions and evaluate the biomechanical behavior of the entire dental structure after file retrieval and the utilization of light body silicone to simulate the periodontal ligament. This methodology accounts for the cumulative impact of endodontic procedures on the root, thereby providing a more precise simulation of natural loading conditions [36].

Results showed that teeth treated with the conservative technique exhibited the highest fracture resistance, while the traditional technique with ET40 tips group showed the lowest, likely due to more aggressive dentin removal. The traditional technique with ET25 tips group displayed intermediate values, suggesting a compromise in structural strength compared to the conservative technique. These results are attributed to differences in the techniques, ultrasonic tip dimensions, and mode of action [37].

The traditional technique necessitates aggressive coronal enlargement with Gates Glidden burs and staging platform creation, prioritizing access and visualization but involving extensive dentin removal. Conversely, the conservative technique streamlines these steps with a modified Gates Glidden bur for a less aggressive funnel shape and staging platform. Subsequent use of a micro-trephine bur minimizes dentin removal through controlled circular troughing. The conservative methodology promotes a conservative access strategy, predicated on the hypothesis that reduced tissue removal correlates with decreased procedural complications and enhanced long-term clinical success compared to more aggressive techniques [38].

The traditional technique employed ET25 and ET40 ultrasonic tips (0.25 mm and 0.40 mm, respectively) for circumferential troughing around the fractured file. In contrast, the conservative technique utilized TFRK-6 and TFRK-12 spoon-shaped tips (18 mm length, 0.3 mm width, 0.1 mm tip) for inner curve troughing, and the TFRK-S tip (0.1 mm diameter, 30 mm length) for apical and lateral extension. The traditional technique aims for uniform dentin removal through circumferential motion, while the conservative employs a semi-circular motion on the inner curve and a push-pull motion with the TFRK-S tip, reflecting a more conservative approach [10,39].

The present study's findings corroborate those of Abdeen et al., who conducted a comparative analysis of three separated instrument retrieval techniques (Ruddle, Yoshi, and Endo Rescue Kit). Their investigation, which assessed not only retrieval success rates but also dentin preservation through volumetric root canal analysis, demonstrated that the Yoshi kit offered a significantly more conservative approach, particularly in the retrieval of fractured instruments from the middle third of moderately curved canals. This conservatism is primarily attributed to its selective troughing methodology, resulting in minimized dentin removal. This aligns with the fundamental principle of preserving radicular structural integrity while achieving effective instrument retrieval, thereby advocating for a transition towards minimally invasive endodontic interventions [40].

The results also came in agreement with the results published by Kumar et. al who compared between the ultrasonic tips developed by Yoshi and ET25 Satelec tips in terms of the time taken for the retrieval process and the change in root canal volume when measured by CBCT. Although the mean time taken for the removal of separated instruments was lower in the Yoshi's group, this difference did not reach statistical significance, suggesting that both tip designs can perform the retrieval process efficiently. However, a notable distinction was observed in the degree of dentin preservation: the mean increase in total root canal volume was significantly lower in the Yoshi's group. This implies that Yoshi's ultrasonic tip design may be more conservative in terms of dentin removal, thereby maintaining the structural integrity of the canal more effectively but also prioritize the preservation of tooth structure, aligning with the overarching goals of minimally invasive endodontic therapy [41].

The findings of the current study demonstrated that the conservative approach significantly enhanced fracture resistance, thereby reducing the risk of future tooth compromise. This is particularly relevant in the current minimally invasive era, where preserving natural tooth structure is paramount for long-term clinical success. These insights not only validate the clinical relevance of minimally invasive strategies but also advocate for their broader integration into routine practice, ensuring that therapeutic interventions align with the overarching goal of maintaining both functionality and longevity in endodontic treatments.

Conclusion

Within the limitations of this in vitro study, the conservative technique demonstrated superior preservation of root strength following separated instrument retrieval in mandibular molars compared to the traditional technique. The more conservative approach to dentin removal appears to minimize structural compromise, suggesting its potential as a preferred method for file retrieval in these challenging cases. However, further research, including clinical studies and finite element analysis, is warranted to validate these findings and assess long-term clinical outcomes.

Conflict of Interest

The authors deny any conflicts of interest in this study.

Bibliography

1. Iandolo A. "Modern therapeutic strategies in endodontics and restorative dentistry". *Medicina (B Aires)* 59.2 (2023): 333.

2. McGuigan MB., *et al*. "Clinical decision-making after endodontic instrument fracture". *British Dental Journal* 214.8 (2013): 395400.

3. McGuigan MB., *et al*. "The impact of fractured endodontic instruments on treatment outcome". *British Dental Journal* 214.6 (2013): 285-289.

4. Rambabu T. "Management of fractured endodontic instruments in root canal: a review". *Journal of Dental Sciences* 4.2 (2014): 40-48.

5. de Medeiros Dantas P., *et al*. "Endodontic instruments fracture in root canal: Integrative review". *Journal of Clinical Images and Medical Case Reports* 2.5 (2021).

6. Madarati AA., *et al*. "Management of intracanal separated instruments". *Journal of Endodontics* 39.5 (2013): 569-581.

7. Vouzara T and Lyroudia K. "Separated instrument in endodontics: Frequency, treatment and prognosis". *Balkan Journal of Dental Medicine* 22.3 (2018): 123-132.

8. Dioguardi M., *et al*. "Analysis of Endodontic Successes and Failures in the Removal of Fractured Endodontic Instruments during Retreatment: A Systematic Review, Meta-Analysis, and Trial Sequential Analysis". *Healthcare. MDPI* (2024): 1390.

9. Lambrianidis T. "Therapeutic options for the management of fractured instruments. In: Management of Fractured Endodontic Instruments: A Clinical Guide. Springer (2017): 75-195.

10. Terauchi Y., *et al*. "Present status and future directions: removal of fractured instruments". *International Endodontic Journal* 55 (2022): 685-709.

11. Nevares G., *et al*. "Success rates for removing or bypassing fractured instruments: a prospective clinical study". *Journal of Endodontics* 38.4 (2012): 442-444.

12. Fu M., *et al*. "Removal of broken files from root canals by using ultrasonic techniques combined with dental microscope: a retrospective analysis of treatment outcome". *Journal of Endodontics* 37.5 (2011): 619-622.

13. Deepika G., *et al*. "Separated instruments-a mind-set between hard and rock: a review". *Journal of Evolution of Medical and Dental Sciences* 6.6 (2017): 6077-6080.

14. Gupta R., *et al*. "Clinical approach to the management of fractured instruments using ultrasonics and the instrument retrieval system under the dental operating microscope". *International Journal of Medical and Biomedical Studies* 4 (2020): 116-121.

15. Wu D., *et al*. "The clinical treatment of complicated root canal therapy with the aid of a dental operating microscope". *International Dental Journal* 61.5 (2011): 261-266.

16. Fu M., *et al*. "Effects of Ultrasonic Removal of Fractured Files from the Middle Third of Root Canals on the Resistance to Vertical Root Fracture". *Journal of Endodontics* 45.11 (2019): 1365-1370.

17. Ruddle CJ. "REVIEW Nonsurgical Retreatment". *Journal of Endodontics* 30.12 (2004): 827-845.

18. Terauchi Y., *et al*. "Evaluation of the Efficiency of a New File Removal System in Comparison With Two Conventional Systems". *Journal of Endodontics* 33.5 (2007): 585-588.

19. Gliga A., *et al*. "The Platformless Technique (PFLT (2010): A Minimally Invasive Technique for Removing Separated Instruments: Case Report Study". *Annals of Case Reports* 10 (2025): 2175.

20. El Taher HM., *et al*. "Cone Beam Computed Tomographic Evaluation of Root Canal Morphology of Maxillary and Mandibular Molars in the Egyptian Population". *Journal of Fundamental and Clinical Research* 4.1 (2024): 96-106.

21. Sharaan M and Elrawdy A. "An evaluation of mandibular molars root canal morphology using cone-beam computed tomography in an Egyptian subpopulation". *Tanta Dental Journal* 14.4 (2017): 220.

22. Saber SM., *et al*. "Root and canal morphology of mandibular second molars in an Egyptian subpopulation: a cone-beam computed tomography study". *BMC Oral Health* 23.1 (2023).

23. Cunningham CJ and Senia ES. "A Three-Dimensional Study of Canal Curvatures in the Mesial Roots of Mandibular Molars". *Journal of Endodontics* 18.6 (1992): 294-300.

24. Hulsmann M and Schinkel L. "Influence of several factors on the success or failure of removal of fractured instruments from the root canal". *Dental Traumatology* 15.6 (1999): 252-258.

25. Amorim CA., *et al*. "Natural canal deviation and dentin thickness of mesial root canals of mandibular first molars assessed by microcomputed tomography". *Brazilian Dental Journal* (2024): 35.

26. Tabrizizadeh M., *et al*. "Evaluation of Radicular Dentin Thickness of Danger Zone in Mandibular First Molars". *Journal of Dentistry (Tehran, Iran)* 7.4 (2010): 196-199.

27. Madarati AA., *et al*. "Vertical fracture resistance of roots after ultrasonic removal of fractured instruments". *International Endodontic Journal* 43.5 (2010): 424-429.l

28. Madarati AA., *et al*. "A Microcomputed Tomography Scanning Study of Root Canal Space: Changes after the Ultrasonic Removal of Fractured Files". *Journal of Endodontics* 35.1 (2009): 125-128.

29. Gerek M., *et al*. "Comparison of the force required to fracture roots vertically after ultrasonic and Masserann removal of broken instruments". *International Endodontic Journal* 45.5 (2012): 429-434.

30. D'Addazio PSS., *et al*. "A comparative study between cone-beam computed tomography and periapical radiographs in the diagnosis of simulated endodontic complications". *International Endodontic Journal* 44.3 (2011): 218-224.

31. Sabeti M., *et al*. "Impact of Access Cavity Design and Root Canal Taper on Fracture Resistance of Endodontically Treated Teeth: An *Ex Vivo* Investigation". *Journal of Endodontics* 44.9 (2018): 1402-1406.

32. Shirani F., *et al*. "Evaluation of the Fracture Resistance of Conservative and Ultraconservative Access Cavity Designs with Different Treatment Modalities: An *In Vitro* Study". *BioMed Research International* 2023 (2023): 7247375.

33. Santosh SS., *et al*. "Influence of Minimally Invasive Access Cavity Designs on the Fracture Resistance of Endodontically Treated Mandibular Molars Subjected to Thermocycling and Dynamic Loading". *Journal of Endodontics* 47.9 (2021): 1496-500.

34. Iacono F., *et al*. "Structural analysis of HyFlex EDM instruments". *International Endodontic Journal* 50.3 (2017): 303-313.

35. Shiyakov KK and Vasileva RI. "EFFECTIVENESS IN THE CURVE OF EIGHT TYPES OF ENDOSONIC TIPS FOR BROKEN INSTRUMENTS REMOVAL". *Journal of IMAB - Annual Proceeding (Scientific Papers)* 20.5 (2014): 595-600.

36. Ibrahim AMBR., *et al*. "Effect of remaining tooth structure on the fracture resistance of endodontically-treated maxillary premolars: An *in vitro* study". *Journal of Prosthetic Dentistry* 115.3 (2016): 290-295.

37. Barakat FT and Attia MI. "Effect of Two Techniques of Separated File Removal Systems on Dentin Loss and Fracture Resistance of Teeth (*In Vitro* Study)". *Egyptian Dental Journal* 70.3 (2024): 2877-2884.

38. Ahmed M. "A Comparative Evaluation of Root Fracture Resistance of Three Techniques of Retrieval of Separated Endodontic Instruments from Curved Root Canals (An *In Vitro* Study)" (2023).

39. Ruddle CJ. "Broken instrument removal. The endodontic challenge". *Dentistry Today* 21.7 (2002): 70.

40. Abdeen MA., *et al*. "Evaluation of Dentine Structure Loss after Separated File Retrieval by Three Different Techniques: An *Ex-vivo* Study". *European Endodontic Journal* 8.3 (2023): 225-230.

41. Kumar B., *et al*. "The time taken for retrieval of separated instrument and the change in root canal volume after two different techniques using CBCT: An *in-vitro* study". *Indian Journal of Dental Research* 32.4 (2021): 489-494.