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Dentin loss and fracture resistance after ultrasonic retrieval of separated NiTi instruments

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Abstract:

Retrieval of separated nickel-titanium instruments may preserve endodontic treatment options, but excessive dentin removal can weaken the root and reduce fracture resistance. This *in vitro* study used micro-computed tomography and universal testing machine analysis to compare dentin loss and fracture resistance after retrieval with different ultrasonic retrieval systems. Eighty extracted single-rooted mandibular premolars with standardized root dimensions were allocated to conventional ultrasonic tip, micro-ultrasonic tip, and loop-assisted ultrasonic retrieval and control groups. Retrieval success was highest with loop-assisted ultrasonic retrieval (90.0%), while dentin volume loss was lowest with micro-ultrasonic tips ($3.8 \pm 1.1 \text{ mm}^3$) and fracture resistance was significantly reduced after conventional ultrasonic retrieval compared with controls ($412.6 \pm 84.7 \text{ N}$ vs $586.4 \pm 92.3 \text{ N}$; $p < 0.001$). Thus, ultrasonic retrieval systems differed significantly in dentin preservation and post-retrieval fracture resistance, supporting the need for conservative retrieval protocols guided by three-dimensional assessment.

Keywords: Micro-CT, separated instrument, ultrasonic retrieval, nickel-titanium file, dentin loss, fracture resistance, endodontics

Background:

Separation of nickel-titanium instruments inside the root canal complicates endodontic treatment because the fragment may restrict apical cleaning, irrigation, shaping and obturation [1]. The decision to remove, bypass, or retain a separated file depends on fragment location, canal curvature, remaining dentin thickness, periapical status and operator skill [2, 3]. Ultrasonic retrieval under magnification is commonly used because it allows controlled troughing around the coronal portion of the fragment, but dentin removal during this process can weaken the root [4]. Different retrieval systems may differ in cutting efficiency, vibration transfer, heat generation and amount of circumferential dentin sacrificed before the fragment becomes mobile [5]. Micro-computed tomography provides a non-destructive method to quantify dentin volume before and after retrieval, while universal testing can measure the mechanical consequence of the removed tooth structure [6]. Clinical reports have described success rates for separated instrument removal, but fewer studies directly connect retrieval technique, dentin loss, retrieval time and fracture resistance in a standardized model. The present *in vitro* study aimed to compare dentin loss and fracture resistance after retrieval of separated nickel-titanium instruments using different ultrasonic retrieval systems assessed by micro-CT and universal testing machine analysis [7, 8]. Retrieval decisions become more difficult when the fragment lies beyond a canal curvature or when the root has a narrow mesiodistal diameter. In such situations, the attempt to remove the fragment may create a greater structural risk than the fragment itself. A combined assessment of volume loss and mechanical resistance is therefore

necessary. Dentin preservation is meaningful only if it translates into a stronger remaining root and fracture testing helps establish whether measured volume differences have practical consequences. The challenge in separated file management is that the operator must work inside a narrow root while preserving the same dentin that gives the tooth its long-term strength. This creates a conflict between visibility and conservation. Laboratory evaluation is useful because clinical retrieval cases vary widely in fragment type, location, curvature and pre-operative infection. A standardized model allows retrieval systems to be compared under controlled conditions before their clinical use is generalized. Because root fracture is often non-restorable, the amount of dentin removed during retrieval has long-term significance. A recent evidence-based review emphasized that microscope-guided ultrasonics, microtubes and loop devices can improve retrieval predictability while limiting dentin sacrifice, although outcomes remain strongly operator-dependent [19]. Therefore, it is of interest to compare the dentin loss and fracture resistance after retrieval of separated nickel-titanium instruments using different ultrasonic retrieval systems.

Materials and Methods:**Study design and setting:**

This *in vitro* comparative study was performed on extracted single-rooted mandibular premolars with mature apices and similar root dimensions. Teeth were cleaned, disinfected and stored in distilled water until use.

Sample size and grouping:

Eighty teeth were prepared. Separated instrument fragments were created in 60 canals and allocated into three retrieval groups of 20 each: conventional ultrasonic tip, micro-ultrasonic tip and loop-assisted ultrasonic retrieval. Twenty additional prepared canals served as controls without retrieval.

Specimen preparation:

Working length was established 1 mm short of the apex. Canals were prepared using rotary nickel-titanium files and a standardized 4-mm fragment was intentionally separated in the middle third of the canal using controlled cyclic fatigue.

Retrieval protocol:

All retrieval procedures were performed under dental operating microscope magnification by the same experienced operator. Ultrasonic activation was applied intermittently with coolant. Retrieval time and procedural complications were recorded.

Micro-CT analysis:

Teeth were scanned before fragment placement, after fragment placement and after retrieval. Dentin volume loss, canal transportation and minimum remaining dentin thickness were calculated using three-dimensional reconstruction software.

Fracture resistance testing:

After retrieval and obturation simulation, roots were embedded in acrylic resin with periodontal ligament analog. A universal testing machine applied compressive load along the long axis until fracture. Failure mode was classified as favorable or unfavorable.

Statistical analysis:

Mean dentin loss and fracture resistance were compared using one-way ANOVA and Tukey post-hoc tests. Retrieval success and failure mode distribution were compared using chi-square analysis. Pearson correlation evaluated the association between dentin loss and fracture resistance. Significance was set at $p<0.05$. Teeth were decoronated to a standardized length before embedding. A silicone-based periodontal ligament analog was applied around the root surface to reduce unrealistic direct contact between root dentin and acrylic resin during fracture testing. Micro-CT reconstruction was performed using the same thresholding settings for all specimens. The region of interest extended from 2 mm coronal to 2 mm apical to the separated fragment, allowing focused measurement of dentin loss caused by the retrieval procedure. The operator was allowed a maximum retrieval time for each specimen to avoid excessive

dentin sacrifice in unsuccessful cases. If the fragment was not retrieved within that time, the attempt was stopped and the canal was scanned for dentin loss. After fracture testing, roots were examined under magnification to classify the fracture line. Fractures coronals to the simulated bone level were considered favorable, while vertical or deep root fractures extending apically were classified as unfavorable. Retrieval attempts were video recorded through the microscope for later review of activation time and procedural sequence. These recordings were not used for outcome scoring but helped verify that the assigned technique was followed consistently. The universal testing machine applied load at a constant crosshead speed until a sudden drop in force was detected. The peak load before failure was recorded as fracture resistance.

Results:

Retrieval was successful in 17 of 20 conventional ultrasonic specimens, 18 of 20 micro-ultrasonic specimens and 18 of 20 loop-assisted ultrasonic specimens. Retrieval time was shorter in the loop-assisted group than in the conventional ultrasonic group. Micro-CT analysis showed significantly greater dentin loss after conventional ultrasonic retrieval than after micro-ultrasonic retrieval. Minimum remaining dentin thickness was lowest in the conventional ultrasonic group. Fracture resistance differed significantly among groups. The control group showed the highest fracture resistance, while conventional ultrasonic retrieval produced the lowest value. Dentin volume loss showed a moderate negative correlation with fracture resistance. Retrieval success was high in both micro-ultrasonic and loop-assisted groups. Conventional ultrasonic retrieval required longer activation time and produced greater reduction in minimum remaining dentin thickness. Fracture resistance was inversely related to dentin volume loss. Specimens retaining more dentin after retrieval showed a greater proportion of favorable fracture patterns, whereas severe thinning was associated with non-restorable root fracture. Micro-ultrasonic retrieval showed the best balance between dentin preservation and post-retrieval fracture load. Loop-assisted retrieval was efficient, but its success depended on creating enough space to engage the separated segment without over-enlarging the canal. Procedural complications were uncommon, but ledge formation was observed more frequently in conventional ultrasonic specimens. No perforation occurred in the micro-ultrasonic or control groups. Baseline specimen characteristics, retrieval and micro-CT outcomes and post-retrieval fracture resistance are presented in **Tables 1, 2 and 3** respectively.

Table 1: Baseline specimen characteristics before retrieval

Variable	Conventional US	Micro-US	Loop-assisted US	Control	p value
Root length (mm)	19.6 ± 1.2	19.4 ± 1.1	19.5 ± 1.3	19.7 ± 1.2	0.874
Canal curvature (degrees)	28.4 ± 4.1	27.9 ± 4.3	28.2 ± 4.0	28.0 ± 4.2	0.951
Baseline canal volume (mm ³)	12.8 ± 2.1	12.5 ± 2.0	12.7 ± 2.2	12.6 ± 2.1	0.936
Fragment length (mm)	4.0 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	NA	0.998

Table 2: Retrieval efficiency and micro-CT dentin loss outcomes

Outcome	Conventional US	Micro-US	Loop-assisted US	p value
Retrieval success, n (%)	17 (85.0)	18 (90.0)	18 (90.0)	0.861

Retrieval time (min)	41.8 ± 8.6	36.2 ± 7.4	31.5 ± 6.8	0.002
Dentin volume loss (mm³)	6.4 ± 1.7	3.8 ± 1.1	4.6 ± 1.3	<0.001
Minimum dentin thickness (mm)	0.72 ± 0.16	0.98 ± 0.18	0.89 ± 0.17	<0.001

Table 3: Fracture resistance and failure pattern after retrieval

Group	Fracture resistance (N)	Favorable fracture n (%)	Unfavorable fracture n (%)	p value
Conventional US	412.6 ± 84.7	7 (35.0)	13 (65.0)	<0.001
Micro-US	498.3 ± 88.5	11 (55.0)	9 (45.0)	
Loop-assisted US	471.9 ± 91.2	10 (50.0)	10 (50.0)	
Control	586.4 ± 92.3	15 (75.0)	5 (25.0)	

Discussion:

The present study showed that retrieval technique significantly influenced dentin loss and fracture resistance. Micro-ultrasonic retrieval preserved dentin more effectively; while conventional ultrasonic retrieval produced the greatest dentin sacrifice and lowest fracture load [9]. The relationship between dentin loss and fracture resistance is clinically important. Circumferential troughing around a fragment may be necessary for visibility and loosening, but excessive removal thins the root wall and creates a stress concentration zone [10]. Loop-assisted ultrasonic retrieval reduced operative time and achieved favorable success, probably because once the fragment was exposed, mechanical engagement helped dislodge it with less prolonged ultrasonic contact. However, adequate coronal access remains necessary [11]. Micro-CT analysis strengthened the study by measuring true volumetric dentin loss rather than relying on two-dimensional radiographs. This is relevant because small circumferential changes may be missed radiographically while still affecting mechanical resistance [12]. The lower fracture resistance after conventional ultrasonic retrieval supports a cautious approach to aggressive staging. A successful retrieval is not necessarily a successful biological outcome if the remaining root is structurally compromised [13]. The limitations include the use of extracted straight premolars, standardized fragment length and one experienced operator. Curved canals, narrow roots and less favorable fragment positions may produce different results. Thermal effects were not measured directly. Future work should evaluate curved canals, heat generation, finite element stress distribution and long-term fatigue loading. Clinically, the decision to retrieve should continue to balance access, infection control, strategic value of the tooth and the amount of dentin likely to be sacrificed [14]. The study emphasizes that the endpoint of retrieval should not be fragment removal alone. A canal may be cleared successfully, but the tooth may become less restorable if the root wall has been excessively thinned during the procedure. Loop-assisted retrieval appears useful when a fragment can be sufficiently exposed for engagement. Its advantage is not that it eliminates troughing, but that it may reduce the duration of ultrasonic contact after the fragment is accessible. Three-dimensional imaging is especially valuable for separated instrument research because dentin loss is not uniform around the canal. A two-dimensional view can underestimate a thin danger zone on one root surface, while micro-CT can identify the minimum remaining wall thickness. The strong inverse association between dentin loss and fracture resistance supports a conservative retrieval philosophy. Removing more dentin may

increase visibility, but the mechanical penalty becomes clinically relevant when the remaining root wall is thin. The findings do not imply that every separated instrument should be removed. In some cases, bypassing or retaining the fragment may be safer when the fragment is apical, the canal is sharply curved, or adequate disinfection has already been achieved. Future retrieval guidelines should incorporate a structural risk estimate. Combining preoperative CBCT, root thickness measurements and expected troughing depth could help clinicians decide whether retrieval is likely to preserve or compromise the long-term prognosis. The occurrence of ledge formation in the conventional group may reflect less controlled dentin removal around the fragment. Even when perforation is avoided, irregular canal modification can complicate subsequent cleaning and obturation. Micro-ultrasonic tips provide more precise cutting under magnification, but they require operator training. The advantage observed in this study should not be separated from the controlled microscope-guided environment in which the procedure was performed. The clinical message is conservative decision-making. Retrieval should be pursued when it improves disinfection and prognosis, but the operator should stop when the structural cost becomes greater than the expected benefit. The control group retained the highest fracture resistance, which confirms that any retrieval attempt carries some structural cost. The clinical goal should therefore be to minimize necessary dentin removal rather than to assume that successful file removal is mechanically neutral. The study has practical implications for microscope-based endodontics. Magnification improves visibility, but it does not remove the need for conservative dentin management. The operator must constantly judge whether continued troughing is justified. Micro-CT findings can also inform training. By showing the actual three-dimensional dentin removed during retrieval, trainees can better understand how small visual changes inside the canal may translate into substantial structural loss. The favorable fracture pattern in some specimens indicates that retrieval-related weakening is not unavoidable. When a technique preserves radicular walls and limits troughing depth, the tooth may retain a more restorable failure pattern. Nevertheless, the control group demonstrates the baseline cost of intervention. Every attempt should be planned with a clear endpoint and prolonged retrieval should be avoided when the prognosis becomes structurally unfavorable. Combining retrieval success, remaining dentin thickness and fracture resistance gives a more balanced outcome than reporting retrieval rate alone. Future studies should adopt similar combined endpoints to reflect real clinical decision-making.

Recent studies support this conservative interpretation. Shajahan *et al.* and Natanasabapathy *et al.* reported differences in retrieval efficiency and dentin loss among contemporary retrieval systems [15, 16], while Yassa *et al.* found that ultrasonic management preserved more fracture resistance and produced less volumetric dentin change than a static-navigation degradation approach [17]. Lobo *et al.* similarly showed technique-dependent differences in vertical root fracture resistance after separated-instrument removal [18]. The 2026 review by AlQahtani and the comparative study by Mohamed *et al.* further emphasize minimally invasive access, careful staging and the structural cost of prolonged ultrasonic retrieval [19, 20].

Conclusion:

Micro-ultrasonic retrieval caused the least dentin loss and high fracture resistance among retrieval groups. Loop-assisted retrieval reduced procedure time while maintaining high retrieval success. Conventional ultrasonic retrieval removed more dentin and resulted in the lowest post-retrieval fracture resistance.

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