International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Impact of Conservative and Conventional Endodontic Access Designs on Pericervical Dentin Integrity in Single-Rooted Premolars: Insights from an In Vitro Micro-CT Investigation

Angela Gusiyska[1], Miryana Raykovska[2], Elvira Gyulbenkiyan[3]

[1]Department of Conservative Dentistry, Faculty of Dental Medicine, Medical University – Sofia, Bulgaria
Email: *gusiyska[at]yahoo.com*

[2] Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria
Email: *mirianaraykovska[at]gmail.com*

[3]Department of Conservative Dentistry, Faculty of Dental Medicine, Medical University – Sofia, Bulgaria
Email: *elvira.simon[at]gmail.com*

Abstract: ***Preservation of pericervical dentin (PCD) is critical for maintaining the biomechanical integrity and long-term success of endodontically treated teeth. This study evaluated the impact of conservative and conventional access cavity designs on PCD preservation in single-rooted premolars using micro–computed tomography (micro-CT). Thirty-five extracted human premolars were randomly allocated into two experimental groups - conventional (Group I) and conservative (Group II) endodontic access - and one control group (Group III). Within Groups I and II, canals were prepared using XP-endo Shaper, ProTaper Next, or a hybrid step-back technique (n = 5 per subgroup). Specimens underwent pre- and post-instrumentation scanning using high-resolution micro-CT system (voxel size 10 µm). Quantitative evaluation included the percentage reduction in PCD thickness, dentin removal (mm), and treated/untreated canal surface ratio. Compared to conventional access (26.08 ± 9.88%), conservative access cavities preserved more PCD (23.48 ± 9.77%).. Mean dentin removal was lower for conservative access (0.216 mm) than conventional (0.30 mm) (p < 0.05). XP-endo Shaper achieved the highest shaping efficiency with minimal dentin loss, whereas ProTaper Next exhibited the greatest dentin removal. The hybrid step-back technique showed the lowest efficiency. Coronal flaring with Gates-Glidden burs significantly increased dentin loss and risk of fissure formation in the PCD region. Micro-CT analysis confirmed that conservative, microscope-assisted access combined with adaptive NiTi systems optimises the balance between canal shaping and dentin preservation. Protecting the pericervical dentin is critical to prevent root weakening and to enhance long-term fracture resistance in endodontically treated premolars.***

Keywords: pericervical dentin preservation, conservative endodontic access, micro–computed tomography (micro-CT), nickel–titanium instrumentation, fracture resistance

1. Introduction

The enduring success of endodontic therapy hinges upon a delicate equilibrium between effective canal debridement and the preservation of crucial dentinal structures—particularly the pericervical dentin (PCD), which provides biomechanical stability and resistance to fracture [1][2][3][4]. Recent paradigms in minimally invasive endodontics (MIE) advocate for access cavity designs that limit unnecessary removal of coronal dentin while preserving stress-bearing regions such as the PCD [5][6][7][8][9]. While conventional access cavities (CACs) facilitate straight-line entry and improve instrumentation efficiency, they often compromise the integrity of the cervical dentin and reduce post-treatment tooth strength [2][10][11]. Conversely, conservative access designs (CACs) aim to preserve sound tooth structure and maintain the biomechanical continuity of the cervical zone, although restricted access may limit canal visibility and impede optimal debridement, potentially affecting disinfection efficacy [12][13][14][15].

Micro-computed tomography (*micro-CT*) has emerged as an indispensable non-destructive imaging modality that enables high-resolution, three-dimensional assessments of dentinal morphology, canal geometry, and procedural outcomes both pre- and post-instrumentation [16][17][18]. This technology provides precise volumetric data on dentin removal, canal transportation, and untouched canal surfaces, establishing itself as the methodological gold standard for evaluating endodontic shaping efficiency [19][20][21][22]. For instance, Khare et al. compared guided, conservative, and traditional access cavities in mandibular molars using micro-CT, demonstrating that traditional access yielded fewer untouched surfaces, although guided access achieved comparable shaping precision [16]. Similarly, Vorster et al.reported that conservative access designs combined with single-file systems such as WaveOne Gold and TruNatomy resulted in significantly greater preservation of pericervical dentin (*PCD*) and reduced dentin volume loss [2][23][24].

Moreover, minimal-invasive access cavities, including ultra-conservative or "ninja" approaches, have been investigated regarding dentinal microcrack formation and structural safety. Longitudinal micro-CT studies have confirmed that canal preparation with systems such as Reciproc or XP-endo Shaper, under both traditional and conservative access conditions, did not induce new dentinal microcracks, reinforcing the structural safety of conservative approaches [12][25][26]. Other micro-CT-based investigations have highlighted that instrument design, alloy metallurgy, taper configuration, and motion kinematics profoundly influence shaping efficacy and dentin conservation across varying access designs [27] [19] [20] [28] [29] [30]. Despite these advancements, the interplay between access cavity geometry and instrumentation technique remains insufficiently characterised—particularly in single-rooted premolars with Vertucci type I canal configuration, which provide an ideal model for controlled analysis of shaping behaviour and PCD integrity [31][32][33][34].

These teeth, while anatomically simpler than multirooted molars, nonetheless demand meticulous preparation to achieve complete debridement while preserving the structural integrity of the surrounding dentin [32][33]. Variations in file kinematics—whether rotary, reciprocating, or adaptive—may differentially influence shaping efficacy, canal centring ability, and pericervical dentin preservation when applied under distinct access cavity designs [35][19][28]. Consequently, there is a compelling need to systematically evaluate how different instrumentation techniques perform within the framework of conservative versus conventional endodontic access. Such investigations should integrate comprehensive three-dimensional parameters, including shaping ability, the percentage of untouched canal surfaces, canal transportation, and dentin removal volume, with micro-computed tomography serving as the methodological gold standard for quantitative assessment [36][37].

The aim of this *in vitro* study was to evaluate the volume of remaining pericervical dentin in premolars with conventional and conservative endodontic access and three preparation techniques using micro-computed tomography (*micro-CT*).

2. Materials and Methods

2.1. Sample selection

A total of thirty-five (*n=35*) sound human permanent premolars (n = 35) extracted for periodontal or orthodontic reasons were selected. The teeth were mechanically cleaned with a periodontal curette to remove organic residues and subsequently polished with a brush and prophylactic paste. The specimens were stored at 4 °C in 0.1% thymol-containing isotonic saline solution (*pH=7*). The selection of suitable teeth was performed under a stereomicroscope at ×40 magnification (*Leica, Leica Microsystems, Wetzlar, Germany*) to exclude specimens with fractures, cracks, or apical resorption. Written informed consent has been obtained from the patient to use the tooth for this in vitro investigation and to publish the results in this paper.

2.2. Distribution of samples into groups

The 35 extracted human teeth (*n=35*) were numbered from 1 to 35 and, after that, randomly assigned to seven subgroups for the reliability of the study using the software Research Randomiser (Tabl.1)[38]. The six Subgroups were assembled into two main Groups (*n=15*) and one Control group according to the type of endodontic access:

Group I (***n=15***): Classical endodontic cavities:
Subgroup 1 (n=5) Preparation of the endodontic space with XP Shaper
Subgroup 2 (n=5) Preparation of the endodontic space with hybrid Step back technique
Subgroup 3 (n=5) Preparation of the endodontic space with ProTaper Next.

Group II (***n=15***): Conservative endodontic cavities:
Subgroup 1 (n=5) Preparation of the endodontic space with XP Shaper;
Subgroup 2 (n=5) Preparation of the endodontic space with hybrid Step back technique;
Subgroup 3 (n=5) Preparation of the endodontic space with ProTaper Next

Group III (***n=5***): Endodontic access and irrigation - control group.

Table 1: The presentation of randomized distribution of samples into groups and subgroups (*n=5*)

Group I	Group I	Group I	Group II	Group II	Group II	Group III
Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 1	Subgroup 2	Subgroup 3	
22	2	32	33	4	16	6
8	30	25	17	23	9	34
24	19	29	13	1	11	27
26	14	12	7	21	15	20
5	18	10	31	35	28	3

2.3 First micro-CT scanning - preoperative

During the initial preoperative micro-CT evaluation of the specimens, the anatomy of the intact endodontic space is evaluated and analysed. To capture 2,525 digital radiography projections, the specimen was scanned using a Nikon XT H 225 system (*Nikon Metrology, Tring, UK*). The exposure length was 700 ms, the voltage was 100 kV, the tube current was 110 µA, and the beam filtering was 1 mm Al. The resolution that is obtained is a cubic dimension that measures 10x10x10 µm. For the purpose of data collection, the scanning technique utilised Inspect-X, version XT 3.1.3 (*Nikon Metrology, Tring, United Kingdom*) as the source. X-AID v2023.11.1 (*MITOS, Garching, Germany*) was the reconstruction software that was employed. VGSTUDIO MAX 2023.4 (*Volume Graphics GmbH, Heidelberg, Germany*) was used to perform segmentation.

2.4 Preparation of endodontic cavities and root canal instrumentation

The samples were prepared under conditions of microscope-assisted technique (*x10-x16 Opmi pico, Zeiss, Oberkochen, Germany*). The endodontic cavities were prepared with cylindrical diamond bur (*S6882.314 Komet, Lemgo, Germany*) with continuous water cooling. After determining the working length using K-file No.10, the root canals were instrumented with XP Shaper (*FKG, Le Crêt-du-Locle, Switzerland*) for Subgroups 1 of Groups I and II. The Hybrid step-back technique was used for Subgroups 2 of Group I and II, and ProTaper Next was used for Subgroups 3 of Group I and II, and Group III. In the protocol of irrigation Sodium hypochlorite 5,25%, EDTA 17% and saline solution were used. After the preparation, the root canals were dried to create the conditions for accurate micro-CT scanning.

2.5 Second micro-CT scanning - postoperative

After root canal preparation, the Nikon XT H 225 system (*Nikon Metrology, UK*) was used to perform micro-CT scanning of 35 specimens (extracted permanent human premolars). The same parameters used for the initial scanning are used in this re-scanning stage. The reconstructed pictures produced an isotropic voxel size of 10×10×10 µm, the same as the original scan. Getting the exact post-preparation geometry for every single endodontic access and root canal geometry required this second scan.

2.6 Statistical analysis used

Statistical analyses were performed using SPSS Statistics 25 (2017, IBM Corporation, USA). The mean values across groups were compared using Tukey's post hoc test, the Student's t-test, and ANOVA; $p < 0.05$ was deemed statistically significant.

The study included 35 human premolars (n=35) that had been eliminated for orthodontic or periodontal reasons. Informed agreement that the removed teeth will be utilised for scientific research was obtained by each patient. A periodontal curette was used to mechanically remove organic debris from the teeth, and a brush and paste were used to polish them. The premolars were kept in a pH=7, 0.1% saline solution containing thymol at 4°C. As a result, all teeth having apical zone resorption, fissures, or fractures were excluded. Two-dimensional radiographs were used to standardise the one-rooted, one-canal, intact permanent removed premolars, and three-dimensional micro-CT examination was used as a secondary method of confirmation.

1. Results

Each instrumentation system demonstrated the ability to effectively shape complex root canal anatomy; however, Protease Next achieved the greatest dentin removal, while XP-endo Shaper exhibited the highest shaping efficiency. From a clinical perspective, the findings emphasise that the choice of instrumentation should achieve an optimal balance between effective canal shaping and preservation of sound dentin structure. Minimising unprepared canal areas while maintaining the integrity of the pericervical dentin is essential to enhance disinfection efficacy and reduce the likelihood of root fractures, thereby contributing to the long-term success of endodontic therapy. The hybrid step-back technique showed the lowest overall efficiency among the evaluated methods.

The average percentage reduction in pericervical dentin thickness in the studied specimens was 26.08 +/- 9.88% for Group I, 23.48 +/- 9.77% for Group II and 22.20 +/- 6.24% for Group III (Fig.1). The ratio of treated/untreated surface in the pericervical dentin area was established and analyzed by micro-CT study in both types of endodontic access - conventional and conservative. The average value of dentin removal for the specimens with conventional endodontic access from Group I is 0.30, and for Group II, it is 0.216. Statistical analysis revealed a minimal statistically significant difference ($p<0.05$). In Group II Subgroups 1 and 2, the hard dental tissues are maximally preserved in the coronal and radicular zones of the pericervical dentin ($p>0.05$) (Fig.2).

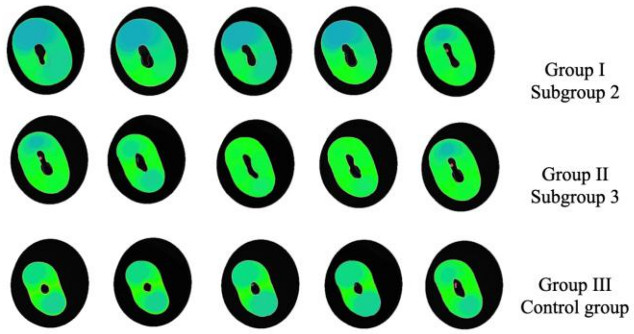

Figure 1: Transverse digital modelling of the pericervical zone in premolars from the presented groups.

Specimens No. 4, 17, 30, 35, and 6 exhibited the lowest average dentin removal (0.02-0.11mm). The treatment of the coronal section of the pericervical dentin with Gates Glidden led to increased dentin removal when employing the hybrid Step back approach, in contrast to the other two techniques examined.

Conservative endodontic access and preparation techniques with the XP endo Shaper would minimise excessive dentin removal in the coronal and pericervical areas, but would reduce the efficiency of endodontic space preparation. Instrumenting the coronal region of the root canal with Gates-Glidden machine instruments would remove extra dentin, perhaps causing fissures and fracture lines in the pericervical dentin area.

The average values of E and F in the area of interest in the coronal section of the pericervical zone are higher in Group I samples (EI=0.42; FI=0.39) than in Group II (EII=0.37; FII=0.31).

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

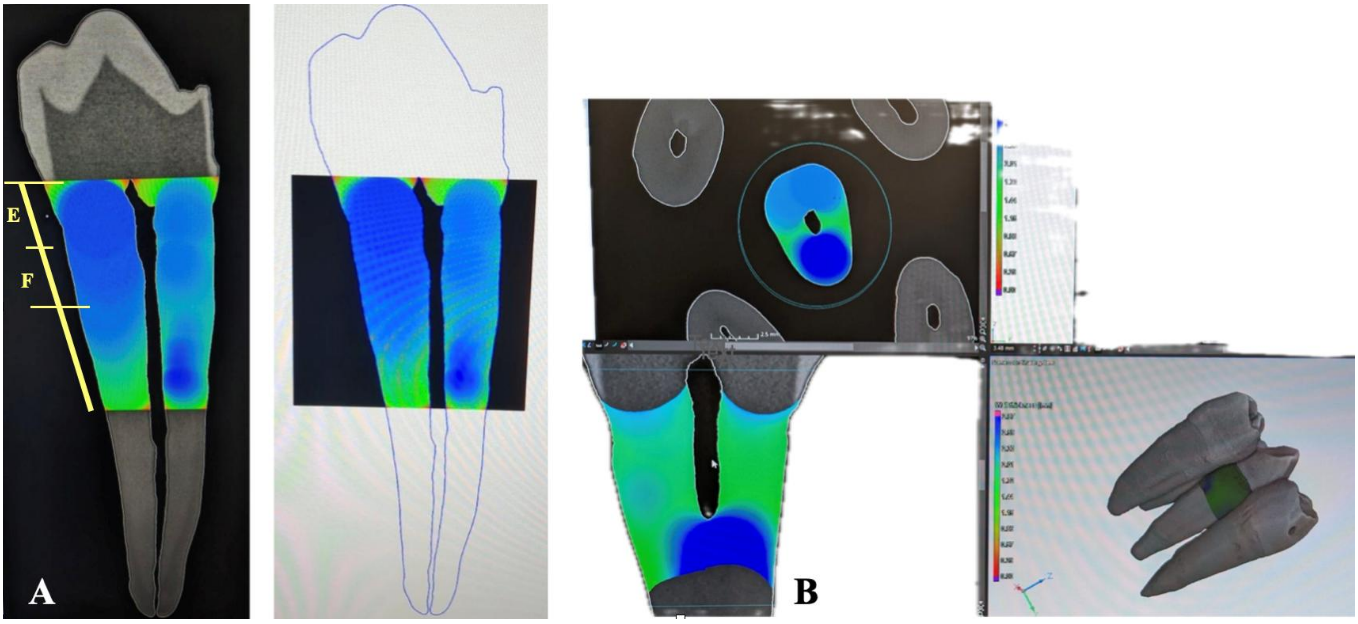

Figure 2: (A) Axial digital modelling of the pericervical zone in a premolar (Group II, Subgroup 3); **(B)** The prepared samples from Subgroup 3, Group II.

2. Discussion

The present micro-CT investigation evaluated the influence of conservative and conventional access cavity designs on pericervical dentin (PCD) integrity and dentin removal patterns in single-rooted premolars prepared with different instrumentation systems. Both access designs achieved adequate canal shaping; however, conservative access produced lower mean dentin removal (0.216 mm) and smaller reductions in PCD thickness (23.48 ± 9.77%) than conventional access (0.30 mm; 26.08 ± 9.88%). These findings indicate that minimally invasive cavity design, when performed under magnification, can significantly enhance dentin preservation without compromising canal instrumentation quality [1][2][10][11]. From a biomechanical standpoint, PCD preservation is essential for maintaining post-endodontic tooth strength and long-term functional stability. The pericervical zone acts as a biomechanical hub, distributing occlusal and lateral forces between coronal and radicular structures [1][2][3][15][40]. Excessive dentin removal in this region weakens the cervical cross-section and increases susceptibility to vertical root fracture under masticatory or restorative loading [2][10][11][40]. The present results confirm that conservative access protects this critical area by reducing unnecessary coronal flaring and maintaining dentinal bulk. Vorster et al. similarly showed that restricted-access cavities combined with single-file systems such as WaveOne Gold and TruNatomy yielded superior PCD preservation and reduced dentin loss without compromising canal cleanliness [23].

The XP-endo Shaper demonstrated the highest shaping efficiency while preserving more dentin than ProTaper Next, underscoring the importance of instrument metallurgy and kinematic behaviour. The XP-endo's martensitic–austenitic phase transformation at body temperature enables adaptive expansion to canal morphology while exerting minimal wall pressure, thus reducing dentin removal [19][28]. This thermomechanical responsiveness supports previous reports showing that heat-treated or adaptive NiTi instruments provide superior canal-centring ability and dentin preservation [20][21][30][41][42]. In contrast, ProTaper Next's active cutting design and progressive taper promote aggressive dentin removal, corroborating earlier micro-CT findings that instrument geometry and motion dynamics directly affect shaping efficiency and dentin loss regardless of access type [20][36][43][44][45].

Clinically, these findings highlight the importance of balancing shaping efficiency with structural preservation. The hybrid step-back technique showed the lowest shaping efficiency and greatest reduction in PCD thickness due to the use of Gates-Glidden burs for coronal flaring. The present data (E = 0.42 mm; F = 0.39 mm versus E = 0.37 mm; F = 0.31 mm in conservative access) confirm that this approach removes additional dentin in the cervical third. Although Gates-Glidden instruments improve straight-line access and irrigation, their aggressive cutting can induce stress concentrations and microcrack formation within the pericervical region [2][10][15][46]. These results align with micro-CT studies showing that extensive coronal enlargement compromises cervical dentin thickness and reduces fracture resistance [11][15][40][47]. Conventional access facilitates direct entry and predictable file navigation but sacrifices greater amounts of PCD, a key determinant of post-treatment resilience [2][6][11][39]. Conservative access maintains cervical integrity and lowers the risk of crack propagation or vertical fracture but requires enhanced operator skill, magnification, and precision to avoid procedural errors such as ledging or incomplete debridement [7][8][39]. When performed under microscopic control and combined with adaptive or heat-treated NiTi systems, conservative access can achieve efficient cleaning without structural compromise [19][20][21]. Microscope-assisted conservative preparations also enable selective dentin removal, preserving resistance zones and ensuring continuity between coronal and radicular structures [6][7][8][15][40]. These results reinforce the paradigm shift toward biologically oriented, minimally invasive strategies that safeguard PCD to extend tooth longevity [39][47][48]. Micro-CT evaluation provided quantitative insight into the trade-off between access design and dentin preservation. Three-dimensional reconstructions (Figs 1–2) showed distinct dentin-loss patterns: Group I specimens exhibited circumferential reduction, whereas Group II demonstrated localised and uniform changes confined to the access outline. These models allowed precise volumetric assessment of PCD alterations and identification of over-instrumented or unprepared canal areas [17][18][22]. Specimens 4, 6, 17, 30, and 35 showed minimal dentin removal (0.02–0.11 mm), reflecting the benefits of conservative entry with adaptive metallurgy and controlled kinematics [19][20][26][28]. Uninstrumented regions were slightly more frequent in conservative cavities but were confined mainly to the coronal third, without affecting canal patency. This finding aligns with prior studies showing that minimally invasive cavities, when combined with thermally treated or reciprocating systems, maintain effective canal cleaning while preserving PCD [19][20][21][29][35][49].

The present results strengthen the consensus that minimally invasive endodontics provides both biological and biomechanical advantages [3][5][11][13][46]. Previous micro-CT research demonstrated that maintaining ≥ 1 mm of cervical dentin significantly enhances fracture resistance after root canal therapy [2][10][11][40]. Plotino et al. and Silva et al. confirmed that greater residual PCD thickness correlates with improved load-bearing capacity and reduced fracture incidence [11][15]. In this study, both access designs maintained post-instrumentation PCD thickness losses below 25%, remaining within biomechanically safe limits, with conservative access yielding superior preservation. By maintaining continuous cervical structure, conservative access preserves the tooth’s natural stress-dissipation pathway and the ferrule effect, reducing the risk of catastrophic failure [40][50]. These principles align with Clark and Khademi’s concept of “directed dentin conservation” [51]. Accordingly, integrating minimally invasive access into restorative protocols represents a key step toward preserving tooth biomechanics and extending functional longevity [5][6][40][46][47].

The findings also reaffirm the methodological value of micro-CT as the gold standard for three-dimensional, non-destructive assessment of root canal morphology and dentin volume changes [9][17][18][36]. Unlike two-dimensional radiography, micro-CT enables precise superimposition of pre- and post-instrumentation scans for reproducible analysis of canal geometry and PCD variation [18][21][22]. Its high resolution allows detection of uninstrumented surfaces, microcracks, and morphological irregularities undetectable by other modalities [9][17][26]. This precision ensures consistent quantification of dentin loss at cervical, 2 mm, and 4 mm apical levels, validating its use for evaluating canal centring, transportation, and untouched areas in various NiTi systems [19][20][21][29][30]. Moreover, the standardisation potential of micro-CT facilitates comparative data across studies and supports meta-analytic synthesis [13][17][22]. Despite its strengths, this study has limitations, notably the lack of biomechanical simulation and a small sample size, as well as the absence of cyclic fatigue, masticatory loading, and periodontal ligament simulation [52][53]. Hence, extrapolating PCD alterations to clinical fracture resistance should be approached cautiously. The small sample size per subgroup (n = 5) may restrict statistical power, though randomisation and consistent protocols minimised bias [38]. Furthermore, the focus on single-rooted premolars with Vertucci Type I configuration allowed methodological control but limited anatomical generalisability compared with multirooted or C-shaped canals [31][33][34][49]. Future research should expand to molars with complex canal systems and integrate finite element analysis and fatigue testing to relate dentin-loss patterns to cervical stress distribution and fracture thresholds [15][40][53].

In practical terms, microscope-assisted conservative access, especially when paired with adaptive or heat-treated NiTi systems, achieves an optimal balance between shaping efficiency and dentin preservation [19][20][21][28]. This supports the minimally invasive philosophy, where selective tissue removal maintains biomechanical continuity while ensuring disinfection [7][8][40]. Although the hybrid step-back technique remains clinically reliable, its greater dentin removal and potential to initiate microcracks make it less suitable for modern conservative protocols [25][40]. In contrast, adaptive systems such as XP-endo Shaper demonstrated efficient shaping with minimal PCD reduction, confirming that preservation of the pericervical dentin is a critical determinant of long-term tooth survival and biomechanical stability [1][2][3][40][47].

Clinical significance

Within the limitations of this in vitro study, conservative endodontic access designs demonstrated significantly greater preservation of pericervical dentin compared with conventional cavities, without a clinically relevant loss in shaping efficiency. The use of adaptive instrumentation systems, particularly the XP-endo Shaper, minimised unnecessary dentin removal while maintaining adequate canal patency. Clinically, adopting conservative, microscope-guided access may enhance the fracture resistance and longevity of endodontically treated teeth by maintaining the integrity of the cervical structure and reducing the risk of vertical root fracture [18, 35, 38]. Future in vivo trials and finite element analyses are warranted to validate these outcomes under functional loading conditions and to establish evidence-based guidelines for conservative access preparation in modern endodontic practice.

3. Conclusion

Within the limitations of this *in vitro* micro–computed tomography study, both conventional and conservative endodontic access designs demonstrated satisfactory canal shaping capability; however, the conservative approach proved significantly superior in preserving pericervical dentin integrity. Quantitative analysis revealed a mean reduction in PCD thickness of 26.08 ± 9.88% for conventional access and 23.48 ± 9.77% for conservative cavities, with the control group showing 22.20 ± 6.24%. Mean dentin removal values were notably lower in conservative access specimens (0.216 mm) than in conventional ones (0.30 mm). Among the tested systems, XP-endo Shaper provided the most efficient shaping with minimal dentin loss, while the Hybrid step-back technique resulted in the greatest PCD reduction, particularly in the coronal third.

Overall, the findings confirm that conservative, microscope-assisted endodontic access, when combined with advanced adaptive instrumentation, maintains an optimal balance between cleaning efficacy and structural preservation. Clinically, this approach may enhance long-term fracture resistance and tooth longevity by limiting unnecessary removal of pericervical dentin - a region crucial for biomechanical stability.

References

[1] Shyma P, Mathew J, George L, Vineet RV, Paul S, Joy A. Comparative evaluation of pericervical dentin preservation and fracture resistance of root canal–treated teeth with rotary endodontic file systems of different taper types. J Conserv Dent. 2023;26:429-33.

[2] Özyürek T, Ülker Ö, Demiryürek EÖ, Yılmaz F. The effects of endodontic access cavity preparation design on the fracture strength of endodontically treated teeth: traditional versus conservative preparation. *J Endod*. 2018;44(5):800–805.

[3] Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. *J Endod*. 2010; 36: 609–17.

[4] Haridoss S, Rajendran M, Swaminathan K, et al. Impact of pericervical dentin on fracture resistance of endodontically treated posterior permanent teeth: A systematic review and meta-analysis. J Contemp Dent Pract. 2024;25(4):372-85.

[5] Gluskin AH, Peters CI, Peters OA. Minimally invasive endodontics: challenging prevailing paradigms. *Br Dent J*. 2014; 216: 347-53.

[6] Clark D, Khademi J, Herbranson E. The new science of strong endo teeth. *Dent Today*. 2013; 32: 112, 114, 116–7.

[7] Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. *Dent Clin North Am*. 2010; 54: 249–73.

[8] Clark D, Khademi JA. Case studies in modern molar endodontic access and directed dentin conservation. *Dent Clin North Am*. 2010; 54: 275–89.

[9] Xu T, et al. Micro–Computed Tomography Assessment of Apical Accessory Canal Morphologies. *J Endod.* 2016 May;42(5):798-802.

[10] Sabeti M, Kazem M, Dianat O, et al. Impact of access cavity design and root canal taper on fracture resistance of endodontically treated teeth: An ex vivo investigation. *J Endod*. 2018; 44: 1402–6.

[11] Plotino G, Grande NM, Isufi A, Ioppolo P, Pedullà E, Bedini R, et al. Fracture strength of endodontically treated teeth with different access cavity designs. *J Endod*. 2017; 43: 995- 1000.

[12] Krishan R, Paqué F, Ossareh A, Kishen A, Dao T, Friedman S, et al. Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars. *J Endod*. 2014; 40: 1160–6.

[13] Ballester B, Giraud T, et al. Current strategies for conservative endodontic access cavity preparation techniques- systematic review, meta-analysis, and decision-making protocol. *Clin Oral Invest*. 2021;25(11):6027-6044.

[14] Krishan R, Paqué F, Ossareh A, Kishen A, Dao T, Friedman S, et al. Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars. *J Endod*. 2014; 40: 1160–6.

[15] da Silva P, et al. Influence of cervical preflaring and root canal preparation on the fracture resistance of endodontically treated teeth. BMC Oral Health. 2020;20(1).

[16] Leoni GB, Versiani MA, Pécora JD, Sousa-Neto MD. Micro-computed tomographic analysis of the root canal morphology of mandibular incisors. *J Endod*. 2014;40(5):710-6.

[17] Singhal A, Grande JC, Zhou Z. Micro/Nano CT for visualization of internal structures. *Microscopy Today.* 2013;21(02):16-22.

[18] Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P. A methodology for quantitative evaluation of root canal instrumentation using microcomputed tomography. *Int Endod J.* 2001; 34: 390–98.

[19] Versiani MA, Carvalho KKT, Mazzi-Chaves JF, Sousa-Neto MD. Micro-computed Tomographic Evaluation of the Shaping Ability of XP-endo Shaper, iRaCe, and EdgeFile Systems in Long Oval-shaped Canals. *J Endod*. 2018 Mar;44(3):489-495.

[20] Zuolo ML, Zaia AA, Belladonna FG, et al. Micro-CT assessment of the shaping ability of four root canal instrumentation systems in oval-shaped canals. *Int Endod J.* 2018; 51: 564–71.

[21] Alovisi M, Cemenasco A, Mancini L, et al. Micro-CT evaluation of several glide path techniques and ProTaper Next shaping outcomes in maxillary first molar curved canals. *Int Endod J.* 2017; 50: 387–97.

[22] Neves AA, Silva EJ, Roter JM, et al. Exploiting the potential of free software to evaluate root canal biomechanical preparation outcomes through micro-CT images. *Int Endod J.* 2015; 48: 1033–42.

[23] Vorster M, van der Vyver PJ, Paleker F. Effect of traditional and conservative endodontic access cavities on instrumentation efficacy of two different Ni-Ti systems: A micro-CT study. Appl Sci. 2023;13(9):5803.

[24] Vorster M, van der Vyver PJ, Paleker F. The influence of access cavity design on pericervical dentine preservation and shaping outcomes. Int Endod J. 2022;55(11):1234-1245.

[25] Tsenova-Ilieva I, Vassileva R, Karova E. A micro-CT assessment of dentinal damage after shaping of oval-shaped root canals. *J of IMAB*. 2020 Jul-Sep;26(3):3288-3292.

[26] Peters OA, et al. A Micro-Computed Tomographic Assessment of Root Canal Preparation with a Novel Instrument, Trushape, in Mesial Roots of Mandibular Molars. *J Endod.* 2015 Sep;41(9):1545-1550.

[27] Karobari MI, Parveen A, Mirza MB, Makandar SD, Nik Abdul Ghani NR, Noorani TY, Marya A. Root and Root Canal Morphology Classification Systems. Int J Dent. 2021 Feb 19; 2021: 6682189.

[28] Shen Y, Zhou HM, Zheng YF, Peng B, Haapasalo M. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. *J Endod*. 2013,39(2):163–172.

[29] Pasqualini D, Alovisi M, Cemenasco A, et al. Micro-computed tomography evaluation of protaper next and biorace shaping outcomes in maxillary first molar curved canals. *J Endod.* 2015; 41: 1706–10.
[30] Silva EJNL, Pacheco PT, Pires F, et al. Microcomputed tomographic evaluation of canal transportation and centring ability of ProTaper Next and Twisted File Adaptive systems. *Int Endod J.* 2017; 50: 694–99.
[31] Fan B, et al. Three-Dimensional Morphological Analysis of C-Shaped Canals in Mandibular First Premolars in a Chinese Population. *Int Endod J.* 2012 Nov; 45(11):1035-1041.
[32] Versiani MA, Pécora JD, Sousa-Neto MD. Microcomputed tomography analysis of the root canal morphology of single-rooted mandibular canines. *Int Endod J.* 2013; 46: 800–7.
[33] Liu N, Li X, Liu N, et al. A micro-computed tomography study of the root canal morphology of the mandibular first premolar in a population from southwestern China. *Clin Oral Investig*. 2013;17(3):999-1007.
[34] Sierra-Cristancho A, González-Osuna L, Poblete D, et al. Micro-tomographic characterization of the root and canal system morphology of mandibular first premolars in a Chilean population. *Sci Rep.* 2021;11.
[35] Marceliano-Alves MFV, et al. Shaping Ability of Single-File Reciprocating and Heat-Treated Multifile Rotary Systems: A Micro-Ct Study. *Int Endod J.* 2015 Dec; 48(12):1129-1136.
[36] Khare M, Singh V, Tikku AP, et al. A comparison of guided, conservative, and traditional endodontic access cavity designs in mandibular molars using micro-computed tomography: An in vitro study. J Endod. 2024;50(6):745-752.
[37] Koohnavard M, Celikten B, Buyuksungur A, Orhan K. Effect of Traditional and Conservative Endodontic Access Cavities on Instrumentation Efficacy of Two Different Ni–Ti Systems: A Micro-CT Study. *Applied Sciences*. 2023; 13(9):5803.
[38] Urbaniak G, Plous S. "Research randomizer. 2013." *URL: https://www. randomizer. org/[accessed 2018-04-23]* (2013).
[39] Gluskin AH, Peters CI, Peters OA. Minimally invasive endodontics: challenging prevailing paradigms. *Br Dent J*. 2014; 216: 347-53.
[40] Haridoss S, Rajendran M, Swaminathan K, et al. Impact of pericervical dentin on fracture resistance of endodontically treated posterior permanent teeth: A systematic review and meta-analysis. J Contemp Dent Pract. 2024;25(4):372-85.
[41] Saberi N, Patel S, Mannocci F. Comparison of centring ability and transportation between four nickel titanium instrumentation techniques by micro-computed tomography. *Int Endod J.* 2017; 50: 595–603.
[42] Pinheiro SR, Alcalde MP, Vivacqua-Gomes N, et al. Evaluation of apical transportation and centring ability of five thermally treated NiTi rotary systems. *Int Endod J.* 2018; 51: 705–31.
[43] Brasil SC, Marceliano-Alves MF, Marques ML *et al.* (2017) Canal transportation, unprepared areas, and dentin removal after preparation with BT-RaCe and ProTaper Next systems. *Journal of Endodontics* **43**, 1683–7.
[44] Peters OA, Schonenberger K, Laib A. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. *Int Endod J.* 2001; 34: 221–30.
[45] Peters OA, Peters CI, Schonenberger K, Barbakow F. ProTaper rotary root canal preparation: Effects of canal anatomy on final shape analysed by micro CT. *Int Endod J.* 2003;36:86–92.
[46] Sanfelice CM, da Costa FB, Reis Só MV, Vier-Pelisser F, Souza Bier CAGF. Effects of four instruments on coronal pre-enlargement by using cone beam computed tomography. *J Endod*. 2010; 36: 858–61.
[47] Tyagi S, Choudhary E, Kabra P, Chauhan R. An *in vitro* comparative evaluation of fracture strength of roots instrumented with self-adjusting file and reciproc reciprocating file, with and without obturation. *Int J Clin Dent Res.* 2017; 1:20–5.
[48] Gutmann J. Minimally invasive dentistry (Endodontics). *J Conserv Dent*. 2013;16(4):282–283.
[49] Guimarães LS, Gomes CC, Marceliano-Alves MF, Cunha RS, Provenzano JC, Siqueira JF Jr. Preparation of oval-shaped canals with TRUShape and reciproc systems: a micro-computed tomography study using contralateral premolars. *J Endod*. 2017;43(6):1018-22.
[50] Lenchner NH. Considering the "Ferrule effect" Pract Proced Aesthet Dent. 2001; 13: 102.
[51] Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. *Dent Clin North Am*. 2010;54(2):249-273.
[52] Soares CJ, Pizi ECG, Fonseca RB, Martins LRM. Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. *Braz Oral Res*. 2005;19(1):11–16.
[53] Naumann M, Metzdorf G, Fokkinga W, Watzke R, Sterzenbach G, Bayne S, et al. Influence of test parameters on in vitro fracture resistance of post-endodontic restorations: a structured review. *J Oral Rehabil*. 2009;36(4):299–312.
[54] Fan B, Yang J, Gutmann JL, Fan M. Root canal systems in mandibular first premolars with C-shaped root configurations, Part I: Microcomputed tomography mapping of the radicular groove and associated root canal cross-sections. *J Endod.* 2008; 34: 1337–41.