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Original Article

The influence of different root canal open access shapes on the use of rotary root canal enlargement

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KEYWORDS
Root canal enlargement;
Access cavity preparations;
Rotary instruments;
Centering ratio of canals;
Canal transportation

Abstract *Background/purpose:* The success of root canal treatments is influenced by the shape of the access opening and the outcomes of root canal enlargement. The aim of this study was to evaluate the impact of various rotary instruments on the maintenance of the root canal's central alignment post shaping, considering a range of access cavity designs.
Materials and methods: Using digital tooth simulation, 4 sets of 12 teeth underwent traditional (TradAC) or conservative (ConsAC) access cavity preparations. Root canals were enlarged with TruNatomy or ProTaper Ultimate rotary instruments. Canal transportation and centering ratio were separately measured. Statistical analysis was performed using JMP trial 17 software.
Results: The analysis revealed no significant difference in buccal and lingual canal transportation among different rotary instruments or canal enlargement designs ($P > 0.05$). TradAC yielded higher centering ratios in MB and ML canals, while ConsAC excelled in the distal canal for the TruNatomy group. Conversely, in the ProTaper Ultimate group, ConsAC demonstrated higher ML canal ratios ($P < 0.05$).
Conclusion: TruNatomy maintained superior canal centering with ConsAC, while ProTaper performed better with TradAC.

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Introduction

Access opening is an essential step before root canal cleaning and shaping to facilitate successful root canal treatment. To achieving straight-line access could by remove all interference from the crown to allow straight-line entry of root canal instruments to the first curvature point. Straight-line access is crucial in eras of limited visibility and insufficient instrument flexibility, often accompanied by the removal of healthy tooth structure. However, the amount of remaining crown structure is one of the important factors affecting long-term tooth preservation.[1]

In 2010, Clark and Khademi introduced a minimally invasive approach to accessing the pulp chamber for posterior teeth, aiming to preserve 4 mm of tooth structure around the cervix to enhance stress distribution and prevent fractures.[2] Different designs of access openings have been proposed based on this concept, categorized by their morphology. These include traditional access cavity design (TradAC), conservative access cavity (ConsAC), truss access cavity (TrussAC), caries-driven access cavity (CariesAC), and restorative-driven access cavity (RestoAC) (Fig. 1).[2—4]

Some studies have shown that specific minimally invasive access designs may result in difficulties in locating root canal openings,[5] increased unprepared areas inside the root canal,[6—9] excessive bending angle of instruments upon entering the root canal,[10] increased risk of canal transportation,[8,9,11] decreased cyclic fatigue resistance of instruments,[12] retention of unresected tissue in the pulp chamber,[13] difficulty in removing debris after root canal cleaning,[8] and inadequate disinfection of the root canal interior.[14]

Nickel-titanium (NiTi) rotary instruments were flexible tools used in endodontic treatment to clean and shape the root canal system. Their superelasticity allows for efficient canal negotiation and reduces the risk of procedural errors. NiTi rotary instruments were available in diverse designs tailored to specific clinical needs, encompassing various tapers, cross-sections, and tip geometries to address factors like curved canals and intricate anatomy.[15]

TruNatomy and ProTaper are NiTi rotary instruments used in endodontic treatment. TruNatomy, an advanced NiTi tool, was known for its innovative design with diverse tapers, cross-sections, and tip geometries, enabling precise shaping of curved canals and navigating complex root anatomy.[16] ProTaper instruments, widely employed in endodontics for years, come in various designs and were proficient at shaping root canals, especially in cases of moderate to severe curvature.[17]

The primary objective of substantial root canal enlargement was to maintain the original root canal shape while expanding it. Additionally, the efficacy of root canal enlargement could be affected by different access opening techniques. However, there is scarce research investigating how various designs of access openings impact shaping outcomes with different rotary instruments. Therefore, the aim of this study was to evaluate the impact of various rotary instruments on the maintenance of the root canal's central alignment post shaping, considering a range of access cavity designs.

Materials and methods

Sample preparation

This study was approved by the Institutional Review Board (IRB) of Chung Shan Medical University under protocol number CS2-22184, collected maxillary molars extracted for orthodontic reasons. Intact teeth with complete crowns and roots without prior root canal treatment were selected as standard samples for the research.

To create the ConsAC model for the experimental group, extracted teeth underwent initial extraction and X-ray examination. Subsequently, the pulp chamber was accessed using established procedures. A round bur initially enlarged the access opening, followed by further widening with a tungsten steel needle until the root canal probe reached the canal orifice. After confirmation with an #8 K-file and recording reference points and working lengths, Cone Beam Computed Tomography (CBCT, ProMax 3D, Planmeca, Finland) images were edited using 3D Slicer software to create STL files for printing, with the root portion printed separately.

For the experimental group's TradAC model, teeth initially prepared for the ConsAC model underwent additional modifications to precisely align the access opening with the root canal opening. The same CBCT imaging and editing procedure in 3D Slicer was followed. Crown and root STL files of both ConsAC and TradAC models were imported into Formlabs software (Formlabs, Somerville, MA, USA) for formatting and parameter adjustment. Subsequently, four sets of samples, each comprising 12 teeth, underwent 3D printing, followed by washing with isopropanol and post-curing.

Root canal enlargement by rotary instruments

TruNatomy rotary instrument (Dentsply Sirona, Charlotte, NC, USA) group

For both ConsAC and TradAC, four teeth each were utilized. Following the attachment of the root models to the crowns, each canal underwent initial negotiation using a stainless steel K-file to confirm the glide path and establish the working length. Subsequently, the TruNatomy Glider was employed to re-establish the glide path, followed by utilizing TruNatomy Prime as the final master apical file (MAF) for enlargement. Operational parameters, such as speed and torque, adhered to the manufacturer's recommendations, set at 500 rpm/1.5 Ncm. Canal shaping was executed in an in-and-out motion, progressing 2—5 mm with each iteration until reaching the working length (Fig. 2A).

ProTaper Ultimate rotary instrument (Dentsply Sirona) group

Similarly, four teeth were used for both ConsAC and TradAC. Upon bonding the root models to the crowns, the working length of each canal was verified, and a glide path was established using a stainless steel K-file, followed by confirmation with a Slider. Subsequently, coronal enlargement of the canals was conducted using a shaper, followed

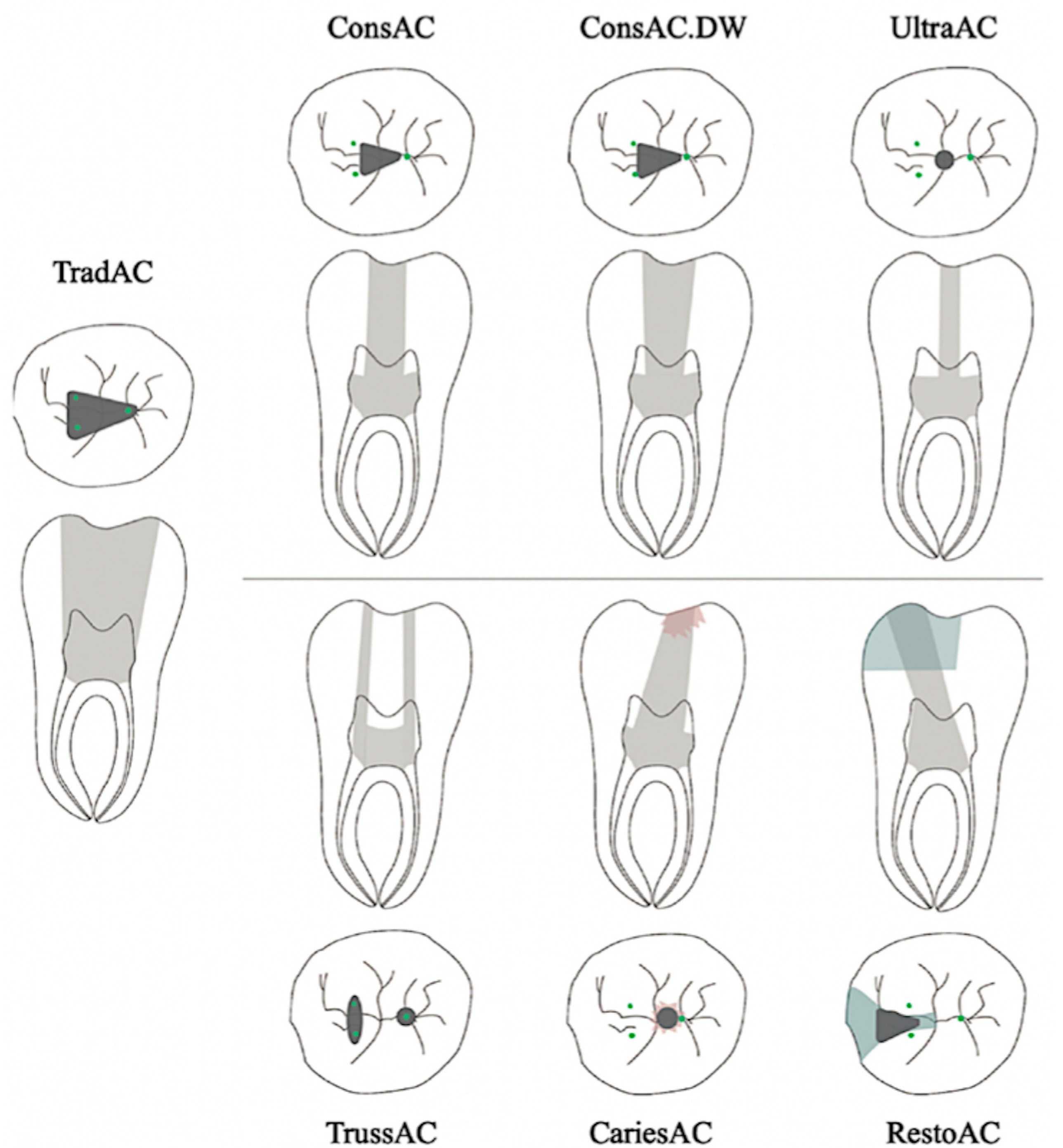

Figure 1 Different designs of access openings. Traditional access cavity (TradAC): represents the traditional straight-line access, completely removing the top of the pulp chamber to allow instruments to enter the root canal opening. Conservative access cavity (ConsAC): Only removes the pulp chamber until the instrument can touch the root canal opening, preserving some portion of the pulp chamber roof. The pulp chamber walls can also be slightly divergent (ConsAC/DW). Ultra-conservative access cavity (UltraAC/Ninja): Similar to the conservative approach but with even less outward extent, maximizing the preservation of the pulp chamber roof. Truss access cavity (TrussAC): designed for multi-canal teeth, preserving tooth structure between two or more canal openings. Caries-driven access cavity (CariesAC): creates a pulp chamber pathway by removing infected dentin. Restorative-driven access cavity (RestoAC): creates a pulp chamber pathway by removing existing fillings.

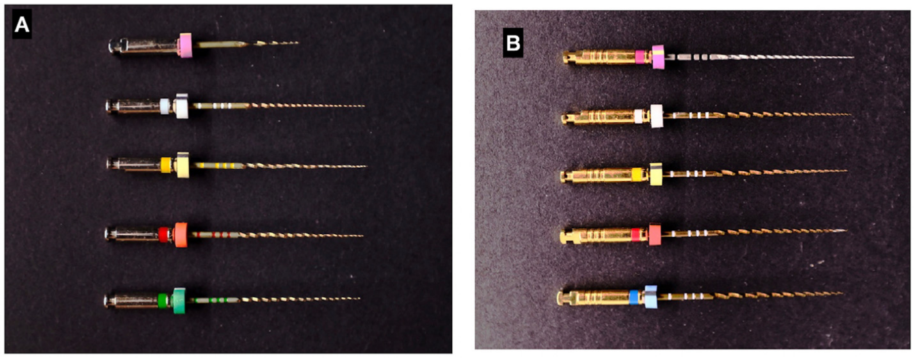

Figure 2 The rotary instrument used in this study is A. TruNatomy file. From top to bottom in the image, they are Orifice modifier, Glider, Small, Prime, and Medium. For B. Pro Taper Ultimate, from top to bottom, they are Slider, Shaper, F1, F2, and F3.

by sequential apical shaping with F1 and F2, where F2 acted as the final master apical file. Speed and torque settings adhered to the manufacturer's recommendations at 400 rpm/4 Ncm. Canal enlargement was passively carried out until reaching the working length (Fig. 2B).

Working time measurement

After establishing a glide path with a size 10 K-file for all root canals, the time taken for nickel-titanium rotary instruments to shape each canal was recorded in seconds. Each instrument shaped the canals to working length three times. The timer was paused during file changes and irrigation, and restarted when preparing to insert the instrument into the canal orifice. Finally, the time spent for each group of canals was totaled and organized.

Image measurement

After completing the root canal shaping, the samples are secured in rod-shaped wax for placement on the CT table for imaging. The stored DICOM files are measured using 3D Slicer, and various parameters were calculated using Excel.

The degree of canal transportation

Using the methodology outlined in previous studies, calculations are conducted.[18,19] Utilizing 3D Slicer, measurements are obtained at distances of 3, 5, and 7 mm from the root apex, then marked accordingly. Transitioning to the cross-sectional perspective, the distance between each canal and its surrounding wall is determined. A system of numerical and alphabetical identifiers is employed: 'm' denotes the shortest distance from the canal's nearest apical midpoint to the tooth's corresponding point (unit: mm); 'd' signifies the shortest distance from the canal's farthest apical midpoint to the tooth's equivalent point; 'l' indicates the shortest distance from the canal's lingual midpoint to the tooth's lingual midpoint; 'b' represents the shortest distance from the canal's buccal midpoint to the tooth's buccal midpoint. Additionally, numbers 1 and 2 differentiate between measurements taken before and after canal shaping, respectively (Fig. 3).

The formula is as follows:

Mesial distal direction: (m1-m2) − (d1-d2). Buccal lingual direction: (b1-b2)-(l1-l2)

Canal centering ratio

Canal centering ratio evaluates an instrument's capacity to maintain central alignment, akin to how canal transportation is assessed.[19] It is calculated by subtracting the smaller value from the larger one and using it as the denominator in the formula.

$$\text{Mesial distal direction}\ \frac{(m1-m2)}{(d1-d2).}\ \text{or}\ \frac{(d1-d2)}{(m1-m2)}$$

$$\text{Buccal lingual direction}\ \frac{(b1-b2)}{(l1-l2)}\ \text{or}\ \frac{(l1-l2)}{(b1-b2)}$$

The statistical analysis involved recording and organizing data in Microsoft Office Excel 2016, removing outliers, conducting analyses using JMP trial 17 (SAS Institute Inc., Madison, WI, USA), considering a P-value <0.05 as statistically significant, and performing normality tests with the Shapiro—Wilk test before employing statistical methods like ANOVA and Tukey HSD test for data analysis.

Results

Canal transportation measurement

The medial buccal, distal lingual and distal canal transportation measurement were shown in Table 1. Statistical analysis of the medial and distal canal transportation of different nickel-titanium rotary instruments under the same root canal shaping design were shown in Table 2. When considering displacement direction, and comparing

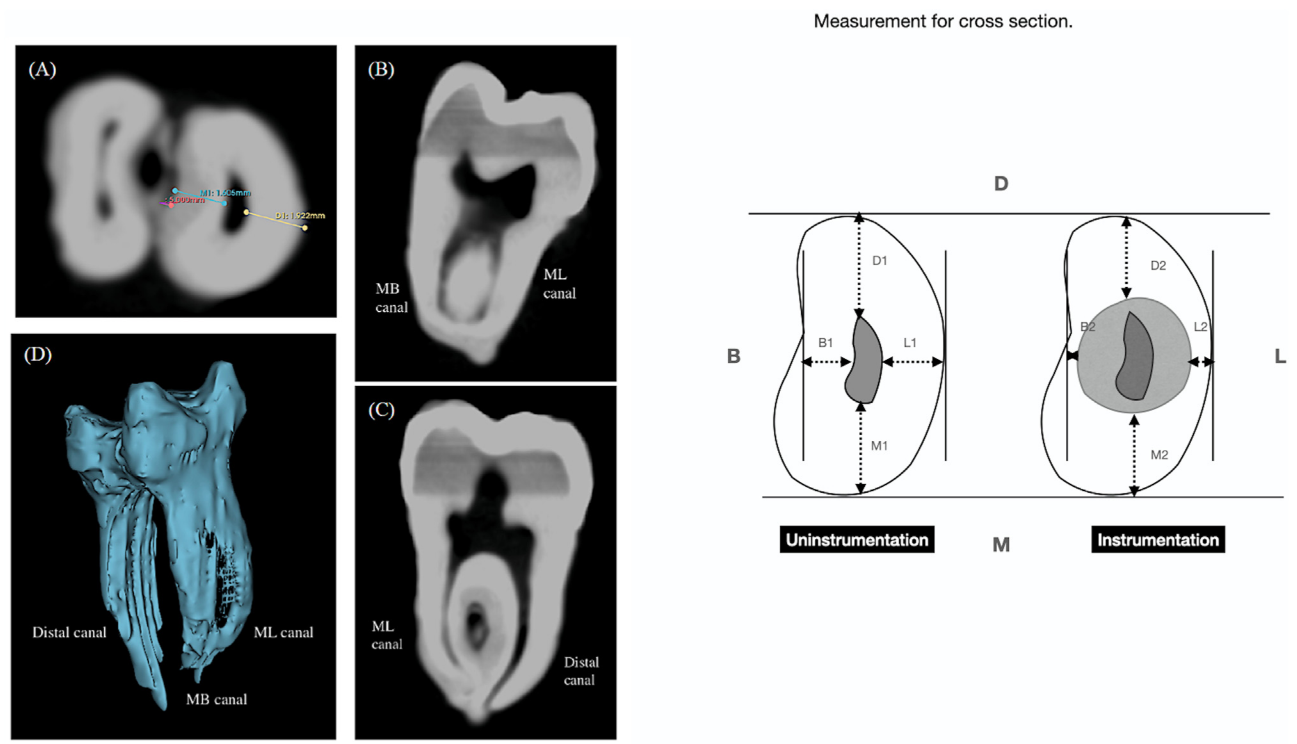

Figure 3 CT scanning assessed tooth cross-sections. (A): Cross section of roots view. (B): MB/ML view. (C):ML/Distal view. (D):Canal transportation extent and direction were determined by measuring the shortest distance from the uninstrumented canal edge to the tooth's edge in mesial and distal directions, comparing it with instrumented images. Original canal space was shaded dark, while post-instrumentation showed light shading. The transportation calculation is (B1 − B2) - (L1 - L2). B1 and L1 represented the shortest distances from the outside and inside of the curved root to the uninstrumented canal periphery, respectively. B2 and L2 represented the same for the instrumented canal periphery. A result of 0 indicates no canal transportation. M: Mesial, D: Distal, B: Buccal, L: Lingual.

Table 1 The medial buccal, distal lingual and distal canal transportation measurement (μm, Mean ± SD) at 3 mm, 5 mm and 7 mm root cross section.

Open method	Rotary machine	Number	Position	Apical distance		(Mean ± SD)
				3 mm	5 mm	7 mm
TradAC	TruNatomy	12	MB	–	−332.60 ± 143.02	−299.54 ± 132.57
			ML	–	182.73 ± 170.16	−322.25 ± 225.81
			Distal	−288.95 ± 459.22	498.66 ± 192.13	302.75 ± 366.32
	ProTaper Ultimate	12	MB	–	−297.81 ± 126.32	−276.87 ± 186.85
			ML	–	287.30 ± 214.42	−449.25 ± 181.944
			Distal	−332.16 ± 389.15	551.10 ± 192.42	232.91 ± 370.84
ConsAC	TruNatomy	12	MB	–	−331.15 ± 116.84	−413.075 ± 146.40
			ML	–	213.35 ± 257.06	−343.42 ± 209.28
			Distal	−404.97 ± 361.26	676.70 ± 176.74	79.37 ± 243.73
	ProTaper Ultimate	12	MB	–	−435.03 ± 205.90	−334.69 ± 244.26
			ML	–	131.69 ± 107.43	−254.92 ± 126.15
			Distal	−163.78 ± 329.65	590.78 ± 133.92	240.45 ± 212.02

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.
MB: Mesial buccal.
ML: Mesial lingual.

Table 2 Statistical analysis of the medial and distal canal transportation of different nickel-titanium rotary instruments under the same root canal shaping design.

Open type	Rotary machine	Number	Mean transportation (μm) Mean ± SD	*P*-value
TradAC	TruNatomy	12	362.20 ± 105.74	$P > 0.05$
	ProTaper Ultimate	12	382.09 ± 99.72	
ConsAC	TruNatomy	12	396.18 ± 153.46	$P > 0.05$
	Proaper Ultimate	12	345.13 ± 140.74	

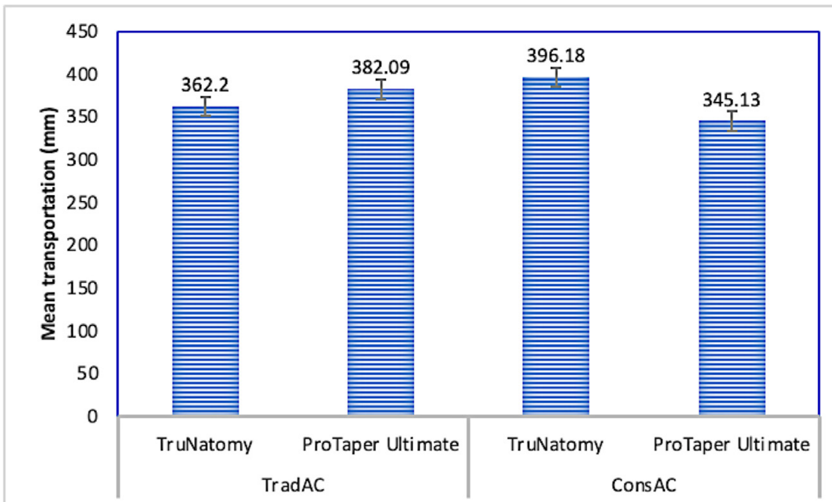

Figure 4 Statistical analysis of the apical and coronal deviation distances of different nickel-titanium rotary instruments under the same root canal shaping design. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

the average absolute values of displacement across all groups, the findings indicate that irrespective of the instrument type utilized, there is no statistically significant difference ($P > 0.05$) in the average displacement for all groups (Fig. 4).

Examining the medial and distal canal transportation across various canal enlargement designs using the same nickel-titanium rotary instrument, as depicted in Table 3, the findings reveal that there is no significant difference ($P > 0.05$) among all groups, irrespective of the instrument type employed, as illustrated in Fig. 5.

The measurements for medial buccal, mesial lingual, and distal canal transportation are presented in Table 4. In Table 5 and Fig. 6, the statistical analysis indicates that there is no significant difference ($P > 0.05$) in the buccal and lingual canal transportation distances among different nickel-titanium rotary instruments used under the same root canal shaping design. Similarly, Table 6 and Fig. 7 demonstrate that there is no significant difference ($P > 0.05$) in the buccal and lingual canal transportation when analyzing various canal enlargement designs using the same nickel-titanium rotary instrument.

Table 3 Analyzing the medial and distal canal transportation of different canal enlargement designs under the same nickel-titanium rotary instrument.

Rotary type	Open type	Number	Mean transportation (μm) Mean ± SD	P-value
TruNatomy	TradAC	12	362.20 ± 105.74	$P > 0.05$
	ConsAC	12	396.18 ± 153.46	
ProTaper Ultimate	TradAC	12	382.09 ± 99.72	$P > 0.05$
	ConsAC	12	345.13 ± 140.74	

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.

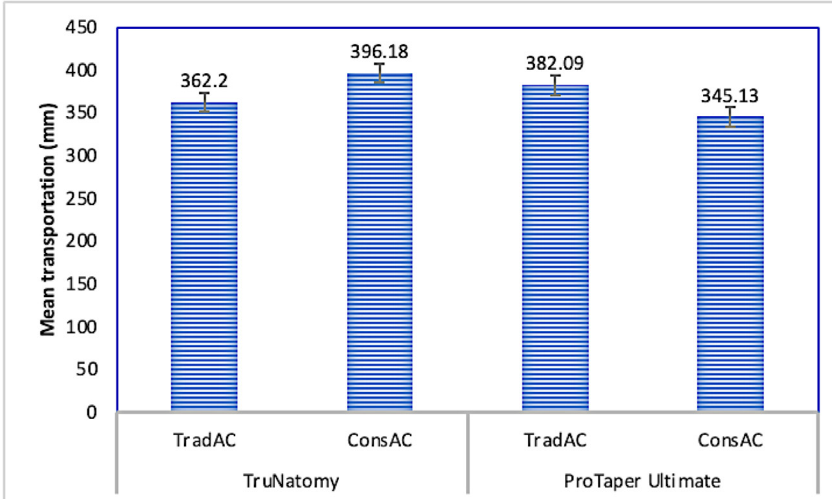

Figure 5 Analyzing the medial and distal canal transportation of different canal enlargement designs under the same nickel-titanium rotary instrument. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

Table 4 The medial buccal, distal lingual and distal canal transportation measurement (μm, mean ± SD) at 3 mm, 5 mm and 7 mm root cross section.

Open chamfer	Rotary machine	Position	Number	Apical distance		(Mean ± SD)
				3 mm	5 mm	7 mm
TradAC	TruNatomy	MB	12	–	310.91 ± 318.62	489.79 ± 306.93
		ML	12	–	556.97 ± 188.74	322.89 ± 263.80
		Distal	12	170.71 ± 173.65	152.94 ± 170.38	69.78 ± 2 27.67
	ProTaper Ultimate	MB	12	–	443.08 ± 274.80	460.86 ± 183.79
		ML	12	–	401.83 ± 231.65	62.17 ± 114.44
		Distal	12	−150.33 ± 303.68	286.77 ± 133.5	350.14 ± 223.43
ConsAC	TruNatomy	MB	12	–	590.8 ± 334.85	383.17 ± 259.23
		ML	12	–	651.58 ± 423.99	63.34 ± 331.30
		Distal	12	−182.32 ± 295.42	223.09 ± 228.31	4.98 ± 205.23
	ProTaper Ultimate	MB	12	–	459.50 ± 314.94	495.83 ± 187.17
		ML	12	–	541.48 ± 231.00	102.27 ± 356.71
		Distal	12	−61.36 ± 347.51	340.06 ± 276.04	65.91 ± 193.64

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.
MB: Mesial buccal.
ML: Mesial lingual.

Centering ratio of canals

The analysis in Table 7 revealed the mean centering ratio of canals in the medial and distal directions. In the TruNatomy group, the TradAC group exhibited higher centering ratio values in the MB and ML canals, while the ConsAC group had higher values in the distal canal, showing statistical significance ($P < 0.05$). However, in the ProTaper Ultimate group, there were no statistical differences in the MB and distal canals, but in the ML canal, the ConsAC group showed higher values ($P < 0.05$) (Fig. 8).

Table 8 presented the statistical analysis results of the mean centering ratio in the buccal and lingual directions. In the TruNatomy group, the ConsAC group had a higher ratio in the medial-buccal canal, while the TradAC group had higher values in the distal canal. In the ProTaper Ultimate group, the ConsAC group showed higher ratios in the MB canal but lower ratios in the ML and distal canals, all with statistical significance ($P < 0.05$) (Fig. 9).

Table 9 demonstrated a statistically significant difference ($P < 0.05$) in the average canal centering ratio under the same root canal instrument and within the same root canal. Notably, in the MB and distal groups under both TruNatomy and ProTaper Ultimate treatments, ConsAC values surpassed TradAC. However, in the ML group under TruNatomy treatment, ConsAC values were higher, whereas

Table 5 Statistical analysis of the buccal and lingual canal transportation distances of different nickel-titanium rotary instruments under the same root canal shaping design.

Open type	Rotary machine	Number	Mean transportation distance (μm) Mean ± SD	*P*-value
TradAC	TruNatomy	12	335.47 ± 165.05	$P > 0.05$
	ProTaper Ultimate	12	324.00 ± 136.22	
ConsAC	TruNatomy	12	372.02 ± 189.17	$P > 0.05$
	ProTaper Ultimate	12	381.35 ± 132.85	

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.

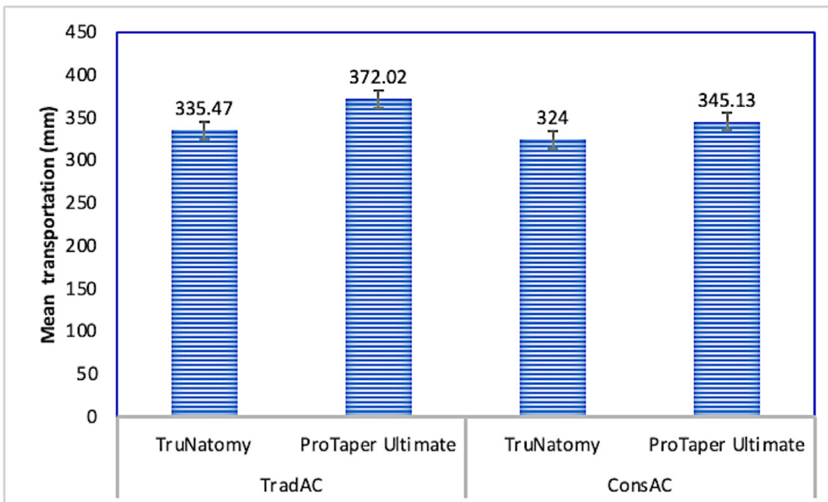

Figure 6 Statistical analysis of the buccal and lingual canal transportation distances of different nickel-titanium rotary instruments under the same root canal shaping design. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

Table 6 Analyzing the buccal and lingual canal transportation of different canal enlargement designs under the same nickel-titanium rotary instrument.

Rotary type	Open chamber	Number	Mean transportation distance (μm) Mean ± SD	*P*-value
TruNatomy	TradAC	12	335.47 ± 165.05	$P > 0.05$
	ConsAC	12	372.02 ± 189.17	
ProTaper Ultimate	TradAC	12	324.00 ± 136.22	$P > 0.05$
	ConsAC	12	345.13 ± 140.74	

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.

under ProTaper Ultimate treatment, TradAC values were higher (Fig. 10).

Canal instrumentation time

The mean canal instrumentation time (second) on different reference groups were shown in Table 10. Among all groups, it was found that the longest time consumption occurred in the ML canal, and the group with the longest total instrumentation time for all canals was the one using the ProTaper Ultimate instrument set (Fig. 11).

Discussion

The crown-down technique in root canal preparation offers biological benefits, such as the rapid removal of contaminated tissue from the root canal system. The key steps in coronal-to-apical root canal cleaning and shaping include:

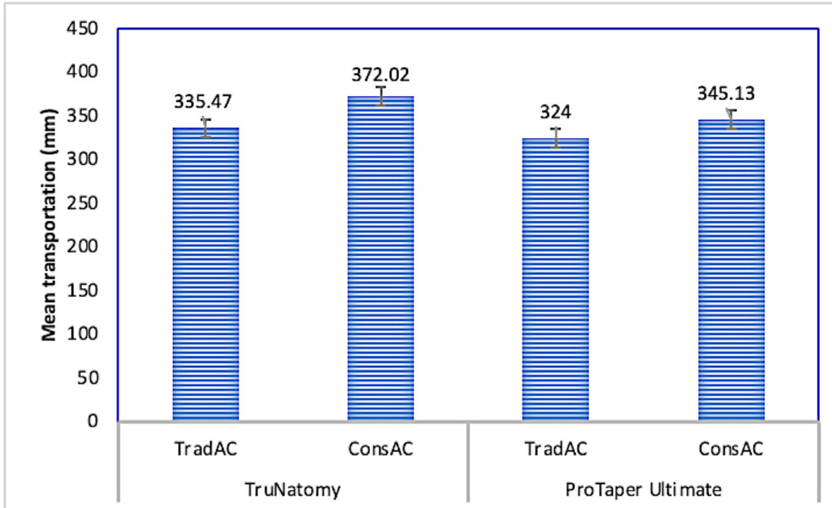

Figure 7 Analyzing the buccal and lingual canal transportation of different canal enlargement designs under the same nickel-titanium rotary instrument. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

Table 7 The analysis of mean centering ratio of canals on medial and distal direction.

Rotary machine	Position	Open method	Number	Mean centering ratio Mean ± SD	*P*-value
TruNatomy	MB	TradAC	12	0.45 ± 0.01	$P < 0.05$
		ConsAC	12	0.37 ± 0.10	
	ML	TradAC	12	0.53 ± 0.01	$P < 0.05$
		ConsAC	12	0.46 ± 0.13	
	Distal	TradAC	12	0.33 ± 0.01	$P < 0.05$
		ConsAC	12	0.47 ± 0.05	
ProTaper Ultimate	MB	TradAC	12	0.40 ± 0.16	$P > 0.05$
		ConsAC	12	0.41 ± 0.14	
	ML	TradAC	12	0.43 ± 0.06	$P < 0.05$
		ConsAC	12	0.50 ± 0.19	
	Distal	TradAC	12	0.46 ± 0.08	$P > 0.05$
		ConsAC	12	0.49 ± 0.02	

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.
MB: Mesial buccal.
ML: Mesial lingual.

creating straight-line access from the occlusal or lingual surface, eliminating overhanging ledges and cervical bulges, forming divergent walls from the cavosurface to the chamber floor, and shaping a funnel with the narrowest part at the apex.[20]

Based on the data in Table 1, comparing the ConsAC group with the TradAC group under the same open access shape condition, the results showed no significant difference in canal deviation distance (Fig. 4). Under the same nickel-titanium rotary instruments, different root canal enlargement designs for mesial and distal root canal displacement were examined. The results indicated no significant difference in canal deviation distance between the two sets of instruments (Fig. 5). This suggested that the two types of instruments exhibit similar levels of displacement during root canal enlargement.

ProTaper instruments excel in shaping root canals, especially in moderate to severe curvature, while TruNatomy effectively shapes curved canals and navigates intricate root canal anatomy. ProTaper utilizes various head sizes and file shapes for sequential enlargement, allowing rapid treatment of diverse canal shapes and potentially inducing some enlargement. TruNatomy, with its unique design, simplifies enlargement using fewer files, reducing changes and treatment time, while accurately maintaining root canal shape compared to traditional instruments. These instruments differ in approach: ProTaper addresses various canal shapes quickly, whereas TruNatomy

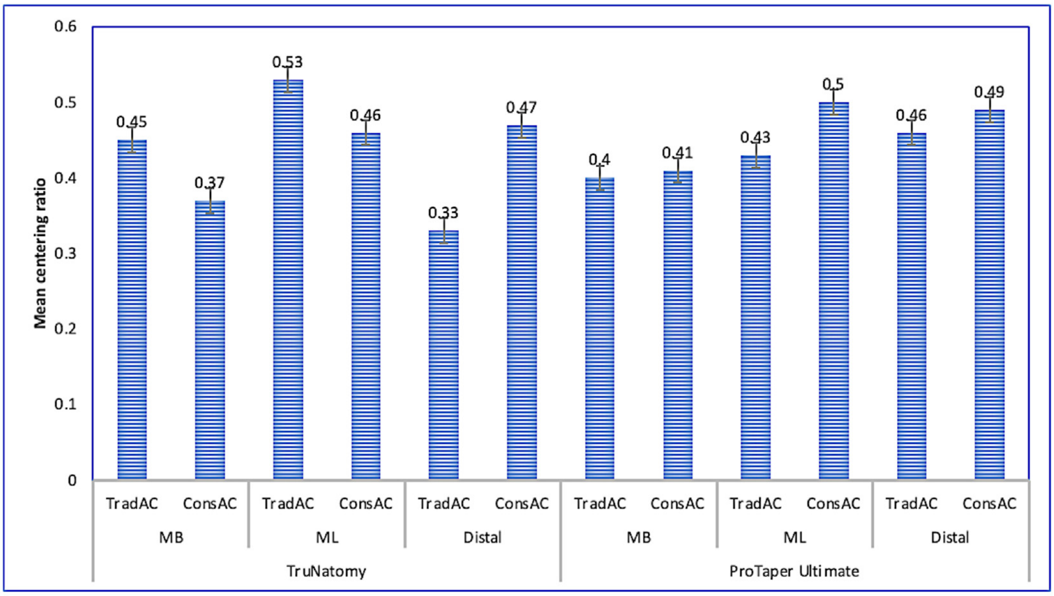

Figure 8 The analysis of mean centering ratio of canals on medial and distal direction. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

Table 8 The statistical analysis results of the mean centering ratio of canals in the buccal and lingual directions.

Rotary machine	Position	Open method	Number	Mean centering ratio Mean ± SD	*P*-value
TruNatomy	MB	TradAC	12	0.44 ± 0.08	$P < 0.05$
		ConsAC	12	0.58 ± 0.11	
	ML	TradAC	12	0.29 ± 0.10	$P < 0.05$
		ConsAC	12	0.52 ± 0.19	
	Distal	TradAC	12	0.58 ± 0.08	$P < 0.05$
		ConsAC	12	0.44 ± 0.09	
ProTaper Ultimate	MB	TradAC	12	0.45 ± 0.21	$P < 0.05$
		ConsAC	12	0.57 ± 0.01	
	ML	TradAC	12	0.48 ± 0.02	$P < 0.05$
		ConsAC	12	0.26 ± 0.06	
	Distal	TradAC	12	0.45 ± 0.07	$P < 0.05$
		ConsAC	12	0.05 ± 0.01	

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.
MB: Mesial buccal.
ML: Mesial lingual.

prioritizes preserving the natural canal shape.[16,17] Since there was no difference in the comparison results, it can be inferred that it may be related to the root canal shape of the teeth selected in this study. Further investigation could be conducted in the future.。

Maintaining centering during root canal treatment was crucial because it ensured the natural anatomy of the root canal was preserved, minimizing distortion during treatment.[21] Additionally, proper centering facilitates thorough cleaning of the root canal, which reduced the presence of bacterial residue and debris, promoting better disinfection.[22] Furthermore, it played a key role in minimizing complications such as ledge formation and perforation, thereby enhancing treatment outcomes and reducing the likelihood of treatment failure.[20] Ultimately, by contributing to effective shaping, cleaning, and filling of the root canal, maintaining centering enhances the overall success rates of root canal treatments.

In the study, TruNatomy and ProTaper groups demonstrated superior centering ability for the ConsAC shape in the mesial buccal root (MB) and mesial lingual root (ML), respectively. Conversely, ProTaper showed better centering

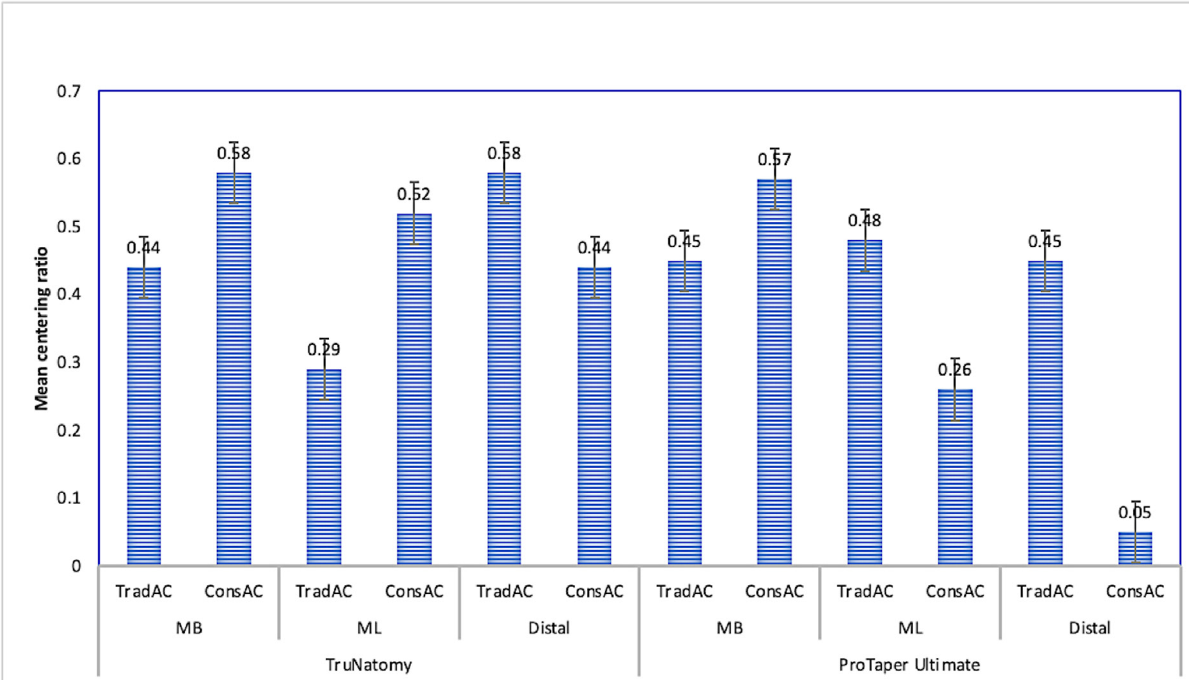

Figure 9 The statistical analysis results of the mean centering ratio of canals in the buccal and lingual directions. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

Table 9 Statistical analysis results of the average canal centering ratio measurement comparison under the same root canal instrument and within the same root canal.

Rotary machine	Position	Open method	Number	Mean centering ratio Mean ± SD	*P*-value
TruNatomy	MB	TradAC	12	0.44 ± 0.08	$P < 0.05$
		ConsAC	12	0.58 ± 0.11	
ProTaper Ultimate	MB	TradAC	12	0.45 ± 0.21	$P < 0.05$
		ConsAC	12	0.57 ± 0.01	
TruNatomy	ML	TradAC	12	0.29 ± 0.10	$P < 0.05$
		ConsAC	12	0.52 ± 0.19	
ProTaper Ultimate	ML	TradAC	12	0.48 ± 0.02	$P < 0.05$
		ConsAC	12	0.26 ± 0.06	
TruNatomy	Distal	TradAC	12	0.58 ± 0.08	$P < 0.05$
		ConsAC	12	0.44 ± 0.09	
ProTaper Ultimate	Distal	TradAC	12	0.45 ± 0.07	$P < 0.05$
		ConsAC	12	0.05 ± 0.01	

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.
MB: Mesial buccal.
ML: Mesial lingual.

ability for the TradAC shape in the MB canal. Additionally, TruNatomy and ProTaper groups exhibited better centering ability for the TradAC shape in the distal root. Expanding the ConsAC shape required more time compared to the TradAC shape, irrespective of using TruNatomy or ProTaper instruments. Although ConsAC preserves more tooth structure, it demands additional time for canal expansion.

From these findings, during root canal treatment, the use of different canal instruments significantly affects treatment outcomes. According to current research, TruNatomy excels in maintaining canal centrality, particularly in ConsAC. This may be due to its design, which optimizes navigation in narrow or curved canals. Conversely, ProTaper shows better performance in TradAC, likely due to its

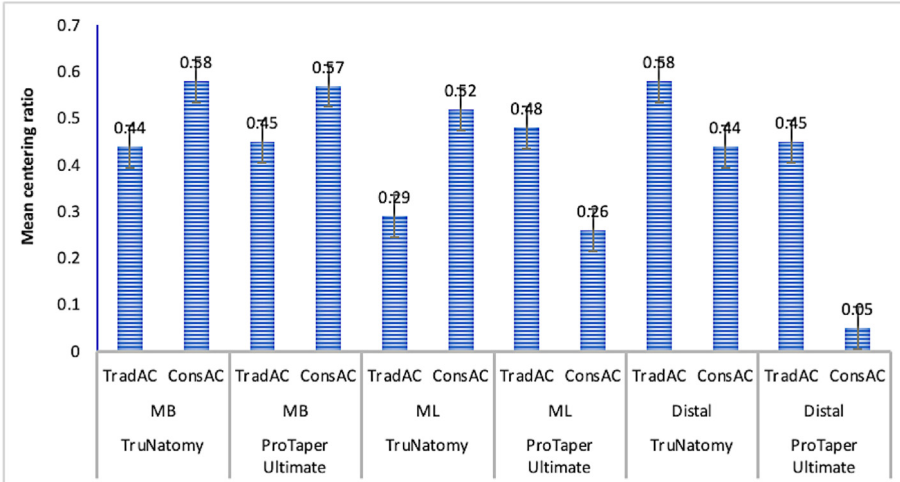

Figure 10 Statistical analysis results of the average canal centering ratio measurement comparison under the same root canal instrument and within the same root canal. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

Table 10 The mean canal instrumentation time (second) on different reference groups.

Open chamfer	Rotary machine	Position	Number	Time (second) Mean	SD
TradAC	TruNatomy	MB	12	106.25	43.71
		ML	12	279.92	49.67
		Distal	12	127.33	15.86
		Total	12	513.50	70.76
	ProTaper Ultimate	MB	12	163.42	28.96
		ML	12	299.42	40.88
		Distal	12	136.42	24.53
		Total	12	599.25	59.95
ConsAC	TruNatomy	MB	12	193.33	42.25
		ML	12	396.00	64.18
		Distal	12	165.17	44.34
		Total	12	754.50	100.73
	ProTaper Ultimate	MB	12	315.92	128.78
		ML	12	461.92	215.55
		Distal	12	169.92	35.49
		Total	12	947.75	252.17

TradAC: Traditional access cavity.
ConsAC: Conservative access cavity.
MB: Mesial buccal.
ML: Mesial lingual.

suitability for wider or straighter canals. These findings indicate that choosing the appropriate canal instruments depends not only on the dentist's preference but also on the specific characteristics of the patient's canals. In practical application, this means that selecting the most suitable instrument for different canal situations can enhance the efficiency and safety of the treatment.

It's important to recognize that this study's limitation is based in its in vitro methodology, which, despite replicating dental conditions, cannot fully capture the complexities of actual clinical environments. Variations in the mouth, such as individual differences in tool positioning and maneuvering angles, could significantly influence the outcomes.

In summary, TruNatomy excelled in maintaining superior canal centering ability under the ConsAC shape, while ProTaper demonstrated better performance under the TradAC shape.

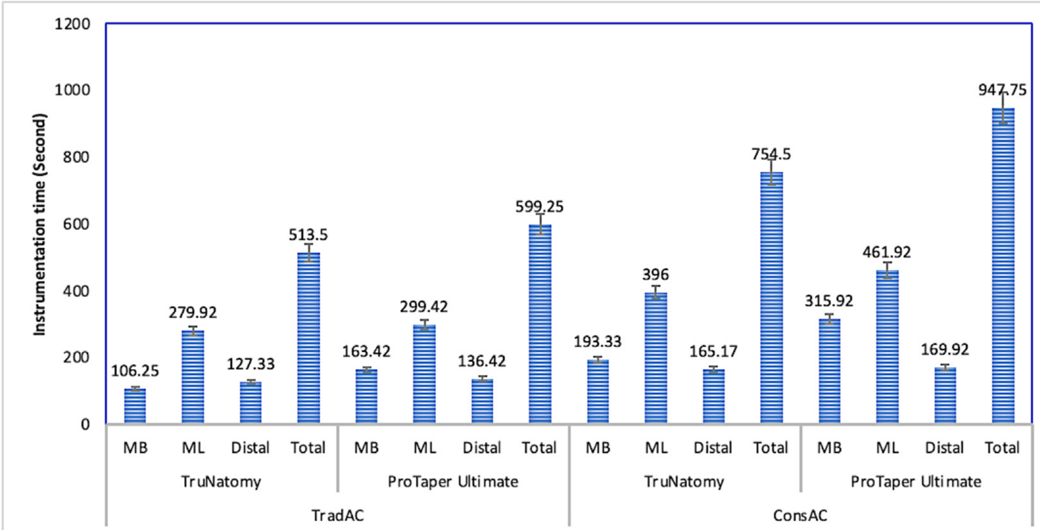

Figure 11 The mean canal instrumentation time (second) on different reference groups. TradAC: Traditional access cavity, ConsAC: Conservative access cavity.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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