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ORIGINAL ARTICLE

Morphological Changes of the Apical Foramen in Curved Root Canals After Use of Different Heat Treated NiTi Rotary Files: A Scanning Electron Microscopy Study

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ABSTRACT

Objective: The present study aimed to evaluate the effect of heat-treated nickel titanium (NiTi) files TruNatomy and XP- Endo Shaper on the major apical foramen deformation and enlargement in curved root canals using area, circularity, and Feret's diameter ratio.

Methods: Sixty mesio-buccal roots of maxillary and mandibular molars with Vertucci type II root canal were selected. The teeth were decoronated using a carborundum disc. The roots with a length of 13 mm were measured using a digital caliper. The preoperative scanning electron microscope images of apical roots were taken and then divided into 4 groups. Manual (K file, Mani Tochigi, Japan), ProTaper Universal (PTU, Dentsply Maillefer, Ballaigues, Switzerland), XP-Endo Shaper (XPS;FKG Dentaire SA, La Chaux-de-134 Fonds, Switzerland), and TruNatomy (TRN;Dentsply Sirona, Ballaigues, Switzerland) group. After instrumentation, the post-operative scanning electron microscope images were taken. Surface area, circularity, and Feret's diameter ratio was calculated before and after instrumentation using Image J software. For intergroup comparison of data, student's independent t-test was employed and for intra-group comparison of data, paired t-test was applied.

Results: The area after instrumentation increased in all groups but the K file and PTU show statistically significant differences compared to TRN and XPS ($p<0.001$). The circularity tends towards 0 in K file and PTU and canals became ellipticals after instrumentation. However, TRN and XPS showed no difference. There is no significant difference in the Feret's diameter ratio before and after instrumentation.

Conclusion: The enlargement of the major apical foramen occurs regardless of the type of file system used. The hand K files and PTU result in significant foramen deformation when instrumented up to the major apical foramen. However, TRN and XPS promote minor alterations at the foramen which are not statistically significant.

Keywords: Apical foramen deformation, apical transportation, Feret's diameter, heat treatment, K file, ProTaper universal, TruNatomy, XP-Endo Shaper

HIGHLIGHTS

- This study investigated the effect of newly heat-treated NiTi files TruNatomy (TRN, Dentsply Sirona, Ballaigues, Switzerland) and XP EndoShaper (XPS;FKG Dentaire SA, La Chaux-de-134 Fonds, Switzerland), predominantly martensite on the apical foramen deformation of curved root canals as compared to traditional stainless steel hand files (K file;Mani Tochigi, Japan), and conventional NiTi ProTaper Universal (PTU; Dentsply Maillefer, Ballaigues, Switzerland) by calculating surface area, circularity, and Feret's diameter ratio before and after shaping procedures using a scanning electron microscope.
- This study revealed that all the file systems show an increase in the area of apical foramen after shaping but the increase was more in the manual group and PTU group.
- The value of circularity was decreased in the manual group and PTU group and tends toward 0 after shaping, therefore foramen shape changes from round to elliptical with significant apical transportation.
- There was no gross difference in circularity after shaping with the XPS and TRN groups.
- Ferets' diameter ratio remained unchanged in all groups before and after shaping, However, the ratio slightly decreased in the manual and PTU groups.

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INTRODUCTION

An accurate working length is one of the most important criteria for achieving successful endodontic treatment. It indicates the apical extent of root canal preparation and filling (1). The endodontic or physiologic apex corresponds to the cement-dentinal junction, which usually (but not necessarily) presents the narrowest diameter of the canal lumen (2). The apical limit of root canal preparation is a controversial topic, and a lot of research has been done to find the accurate landmark for root canal preparation (3). The loss of working length, either long or short, especially in curved root canals, can compromise the outcome of root canal treatment because of inadequate debridement or incomplete apical seal respectively (4).

In non-vital cases with or without apical periodontitis and even in the preapical lesions itself, the presence of microbes in the apical portion has supported the enlargement to apical foramen for the debridement of the root canal system (5–8). This approach helps to exchange irrigants effectively in the apical region to enhance the disinfection of the root canal and periapical repair (9–11). However, aggressive preparations usually result in excessive enlargement of apical foramen, weakening the root due to loss of apical dentine and cementum (12), resulting in apical transportation that will affect the periapical seal. This complication is more pronounced in curved root roots than in straight roots (13). Also, there are concerns that this procedure might promote postoperative pain, however, previous studies have found that enlargement of apical foramen does not show increased rates of postoperative pain (14, 15).

The instrument design and their metallurgy have been modified over time to make the biomechanical preparation minimally invasive. This minimally invasive procedure refers to situations with no endodontic biofilm accumulation (such as in pulpitis cases). In contrast, situations with long-standing contaminations, such as chronic lesions, acute lesions, and secondary retreatments, require systems that can effectively remove the endodontic smear layer and or previous filling material (16, 17). In contemporary endodontics, aggressive root canal preparations are no longer preferred for root canal preparation (18). New nickel titanium (NiTi) rotary file systems incorporating instruments with small tapered designs, enhanced flexibility, increased fatigue resistance, and canal centering ability for conservative root canal preparation have developed to prevent deformation of the apical foramen anatomy without compromising root canal disinfection (19). The need for minimally invasive treatments has led to the development of small tapered designs and modified tip design file systems to reduce root canal complications. These new and more flexible instruments work more efficiently and safely in curved root canals, thus preventing root canal straightening, apical foramen deformation, and transportation compared to their stainless-steel predecessors and conventional NiTi rotary files (20).

In the present study, two different heat-treated rotary file systems (XP-Endo Shaper and TruNatomy) were compared with conventional rotary files, i.e. ProTaper Universal (PTU) and stainless-steel hand files (K files). XP-Endo Shaper (FKG Dentaire, La Chauxde- Fonds, Switzerland) is manufactured from NiTi MaxWire alloy and combines both the austenite and martensite properties that are the function of temperature. The XPS at 20°C exists in the martensite phase and at 37°C as austenite. This phase transformation occurs during clinical use rendering the file extremely flexible. XPS has a guiding tip also called a booster tip that maintains the instrument's centric ability and avoids straightening of the root canal (21, 22). TruNatomy (Dentsply Sirona, Ballaigues, Switzerland) was developed as a novel type of special heat-treated NiTi instrument manufactured from 0.8 mm NiTi wire instead of 1.2 mm which is used to manufacture most generic files. TRN preserves radicular dentine and tooth integrity due to instrument geometry, regressive tapers, and slim design (23, 24).

The main purpose of this *ex vivo* study was to evaluate the effect of heat treatment, metallurgy, and instrument design of different file systems on the morphological changes of apical foramen in curved root canals after instrumentation using Feret's diameter, area, and circularity.

The tested null hypotheses were as follows: (1) None of the heat-treated NiTi rotary file systems cause morphological changes of major apical foramen (2) Root canal curvature does not influence the foramen deformation.

MATERIALS AND METHODS

The study was approved by institutional ethical committee (EC/NEW/INST/2021/1867), registered on ethical grounds (IEC/IGGDCJ/40/2023/03/06) and was conducted in accordance with Declaration of Helsinki.

Determination of Sample Size

Using G-Power software (version 3.0.1 0), it was estimated that the least number of samples required in each group with 80% power (1-β err prob =0.8) and 5% (α err prob=0.05) significance level is 15. This study aimed to compare four different file systems at moderate to severe curvature. Therefore, a total of 60 samples were included in this study.

Sample Selection

Non salvageable freshly extracted maxillary and mandibular molars were selected for the study. Preoperative digital radiograph in a mesio-distal and a bucco-lingual/palatal was taken to evaluate the root canal curvature following the method of Pruett et al. (25). The mesio-buccal roots of maxillary and mandibular molars with Vertucci type II root canal configuration, curvature 10° to 30°, closed apices, and apical patency were included in the study. Teeth with cracks, internal or external resorption, previous endodontic treatment, a calcified canal, straight roots, blocked or open apex and post restorations were excluded. The teeth were stored in 0.1% thymol solution at room temperature until they were used.

Preoperative Analysis Using The Scanning Electron Microscope

The teeth were decoronated using carborundum discs and the root length of 13 mm were standardized using a digital caliper. For vacuum under SEM (ZEISS, Gemini SEM,500, IIT Jammu j&k, India), the samples were incubated in an oven at 37°C for 24 hours. Specimens were stabilized on the stubs with apex facing

TABLE 1. Comparability of canal's parameters before shaping procedure

Parameter	Group TRN		Group XPS		Group PTU		Group manual		p
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Angle of curvature (degree)	28.78	5.78	29.14	6.18	29.12	7.32	27.99	5.87	0.871
Radius of curvature (mm)	3.81	1.54	3.74	1.25	3.78	1.34	3.34	1.54	0.892
Foramen diameter (mm)	0.245	0.021	0.226	0.026	0.236	0.079	0.234	0.032	0.256

SD: Standard deviation

upwards and arranged in sequence A to H. A reference mark was made on both the tooth and stub to allow for repositioning of the tooth samples in the same position each time. The Gold-sputtering was done on the apical portion of root for SEM analysis at 75x and 100x and 15.00 kV. The present study included teeth with a diameter of 100 to 270 µm in the apical foramen (26).

Instrumentation of the Root Canals

Sixty mesio-buccal roots were selected and are randomly divided following alphabetical method on stubs of SEM into four groups (n=15) according to file system used: Manual (K file), ProTaper Universal (PTU), XP-Endo Shaper (XPS) and TRN following alphabetical method on SEM stubs. The acrylic jig was made for stability of specimens during instrumentation. The jig was open ended from both sides so that each specimen can be easily placed and removed during instrumentation. #10 K file was used to negotiate the root canal and was moved passively through the major apical foramen. The working length was measured up to major apical foramen using stereomicroscope at 10x magnification (27). For standardization of samples, the mean value and standard deviation of the degree of curvature (p=0.871), the radius of curvature (p=0.892), and apical foramen diameter (p=0.256) was statistically insignificant (p>0.05), among manual SS, PTU, XPS, and TRN before shaping (Table 1).

Manual Group (K- file) (n=15)

After initial working length determination, the coronal segment is flared using Gates Glidden (GG) drills sizes 2, 3 and 4; each drill was used sequentially shorter. The remaining canal was prepared using descending file sequence to the major apical foramen. The master apical file (MAF) was 40/0.02).

ProTaper Universal Group (PTU) (n=15)

The coronal preflaring was done using SX file, and the glide path was confirmed by 15 K file. The shaping files S1, S2 followed by finishing files F1, F2 using standardized technique (MAF 25/0.08).

XP-Endo Shaper Group (XPS) (n=15)

The glide path was confirmed with 15 K-file. The XPS was inserted in the canal by applying long gentle strokes (5–7 mm) to progress down to working length (WL), 800 RPM and 1 NCm torque. If WL is not reached in three strokes, stop, irrigate and recapitulate (MAF 30/0.04).

TruNatomy Group (TRN) (n=15)

A TRN Orifice Modifier (tip size 20/.08, variable taper) was used to shape the cervical third, and a TRN Glider (#17/.02) Small (#20/.04), and Prime (#26/.04) were used for the apical preparation. The shaping instruments were used with 2–3 gentle amplitude strokes with approximately a 2–5 mm in and out motion.

All the root canals were irrigated with 2 mL 2.5% sodium hypochlorite (NaOCl) using a 31 G side -vented needle between each instrument change. The final irrigation protocol, 5 mL of 5.25% NaOCl, Passive ultrasonic irrigation (PUI -Endo 3) with E73- smooth tip (25/3.1%) for 3 minutes followed by final rinse with a 5 mL distilled water for 1 min (28).

Postoperative SEM Analysis

The samples were dehydrated for 24 hours in oven at 37°C and the gold sputtering of samples was done again. The post instrumentation SEM images were obtained following the above-mentioned method.

Image Analysis

The experienced SEM operator who was blinded to the groups analyzed the pre and postoperative SEM images using the Image J software program (ZEISS, Gemini SEM,500, Indian Institute of Technology, IIT, J&K, India). The quantitative analysis was done by calculating area, circularity and ratio of Feret's diameter of the apical foramen before and after root canal shaping using draw function of Image J software. The circularity for a perfect circle tends towards 1.0 and for a straight line towards 0.0. Feret's diameter defines the longest distance between two parallel straight lines that are tangents to the shape of apical foramen. The ratio of the maximum and minimum Feret's diameter before and after shaping was calculated (26, 29).

Statistical Analysis

The recorded data was compiled and entered in a spreadsheet (Microsoft Excel) and then exported to data editor of SPSS Version 20.0 (SPSS Inc., Chicago, Illinois, USA). Continuous variables were expressed as Mean±SD. Graphically the data was presented by bar diagrams. For intergroup comparison of data, student's independent t-test was employed and for intra-group comparison of data, paired t-test was applied.

RESULTS

The values of mean and standard deviations of the surface area, circularity and Feret's diameter before and after the instrumentation at foramen are summarized in (Table 2). According to the results, there is significant increase in area in all the four groups after instrumentation. The area was increased by 0.055 mm^2 in manual group and 0.038 mm^2 in PTU group after instrumentation with significant difference

TABLE 2. Comparison of measurement between shaping systems

Parameter	Group	Before shaping		After shaping		Difference	p
		Mean	SD	Mean	SD		
Area	Manual	0.026	0.001	0.081	0.016	0.055	<0.001*
	PTU	0.027	0.004	0.065	0.128	0.038	<0.001*
	XPS	0.023	0.006	0.049	0.014	0.026	<0.001*
	TRN	0.025	0.008	0.044	0.012	0.019	<0.001*
Circularity	Manual	0.833	0.018	0.298	0.086	0.535	<0.001*
	PTU	0.787	0.047	0.412	0.091	0.375	0.012*
	XPS	0.765	0.032	0.704	0.031	0.061	0.012*
	TRN	0.816	0.052	0.779	0.027	0.017	<0.001*
Feret's diameter ratio	Manual	1.567	0.326	1.130	0.368	0.437	0.002*
	PTU	1.654	0.261	1.388	0.279	0.266	0.013*
	XPS	1.497	0.561	1.402	0.326	0.095	0.231
	TRN	1.587	0.125	1.513	0.463	0.074	<0.654

*: Statistically significant difference (p<0.05). SD: Standard deviation, PTU: ProTaper Universal, XPS: XP-Endo Shaper, TRN: TruNatomy

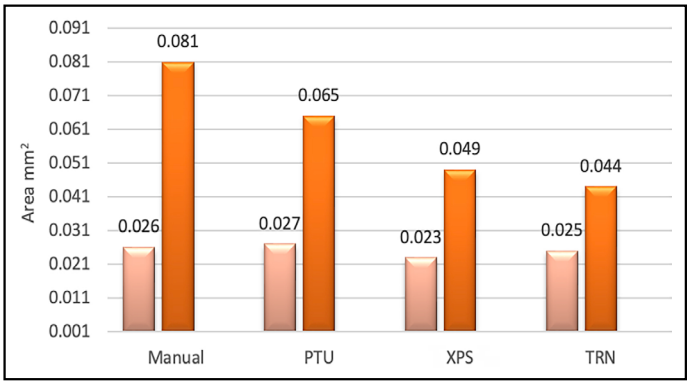

Figure 1. Area before and after shaping in four groups
PTU: ProTaper Universal, XPS: XP-Endo Shaper, TRN: TruNatomy

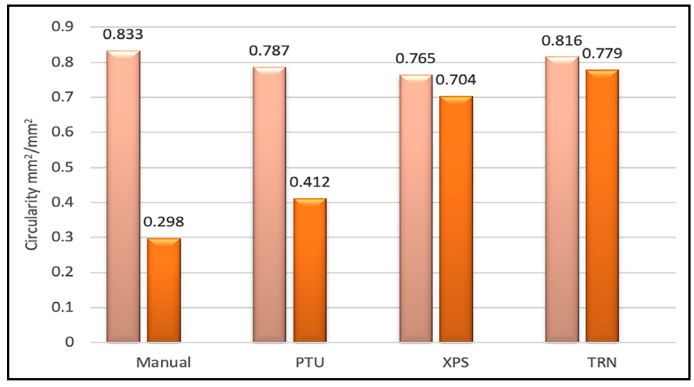

Figure 2. Circularity before and after shaping in four groups
PTU: ProTaper Universal, XPS: XP-Endo Shaper, TRN: TruNatomy

statistically. However, XPS and TRN shows increase of area by 0.026 mm^2 and 0.019 mm^2 respectively (Fig. 1).

The circularity after instrumentation in manual group and PTU group was decreased to 0.298 mm^2 /mm^2 and 0.412 mm^2 /mm^2 respectively, therefore tends towards 0 and hence depicts significant foramen deformation. However, there is no significant difference in circularity after instrumentation in case of XPS and TRN (Fig. 2).

There is no significant difference before and after values of Feret's diameter ratio within and between the rotary instruments (XPS and TRN) p>0.05. However, this ratio shows slight decrease in manual and PTU group (Fig. 3).

Morphologic changes of apical foramen before and after instrumentation using scanning electron microscopic image analysis are depicted in (Fig. 4).

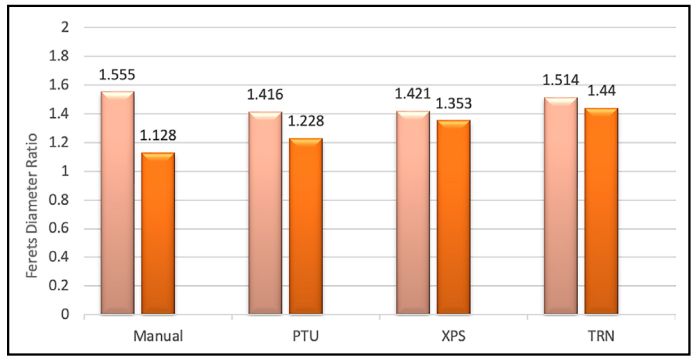

Figure 3. Ferets' diameter ratio before and after shaping in four group
PTU: ProTaper Universal, XPS: XP-Endo Shaper, TRN: TruNatomy

DISCUSSION

In literature, the apical termination of instrumentation is a controversial topic, suggesting data depicts that canal obturation must stop at the cement-dentinal junction, corresponding to the minor apical constriction (30). However, the site of the cement-dentinal junction is so variable that attempting to use it as a landmark is of little help to the endodontist (31). However, the apical limit of canal instrumentation and obturation should not be cement-dentinal junction nor 0.5–1mm from the radiographic apex, but rather the apical constriction (3). The loss of working length and over-instrumentation during endodontic procedures are common, resulting in procedural errors such as transportation, zipping, elbow, thinning of dentine walls, and ledge formation at the apical third of the root canal (32). Furthermore, the NiTi rotary files lack tactile control and protrude

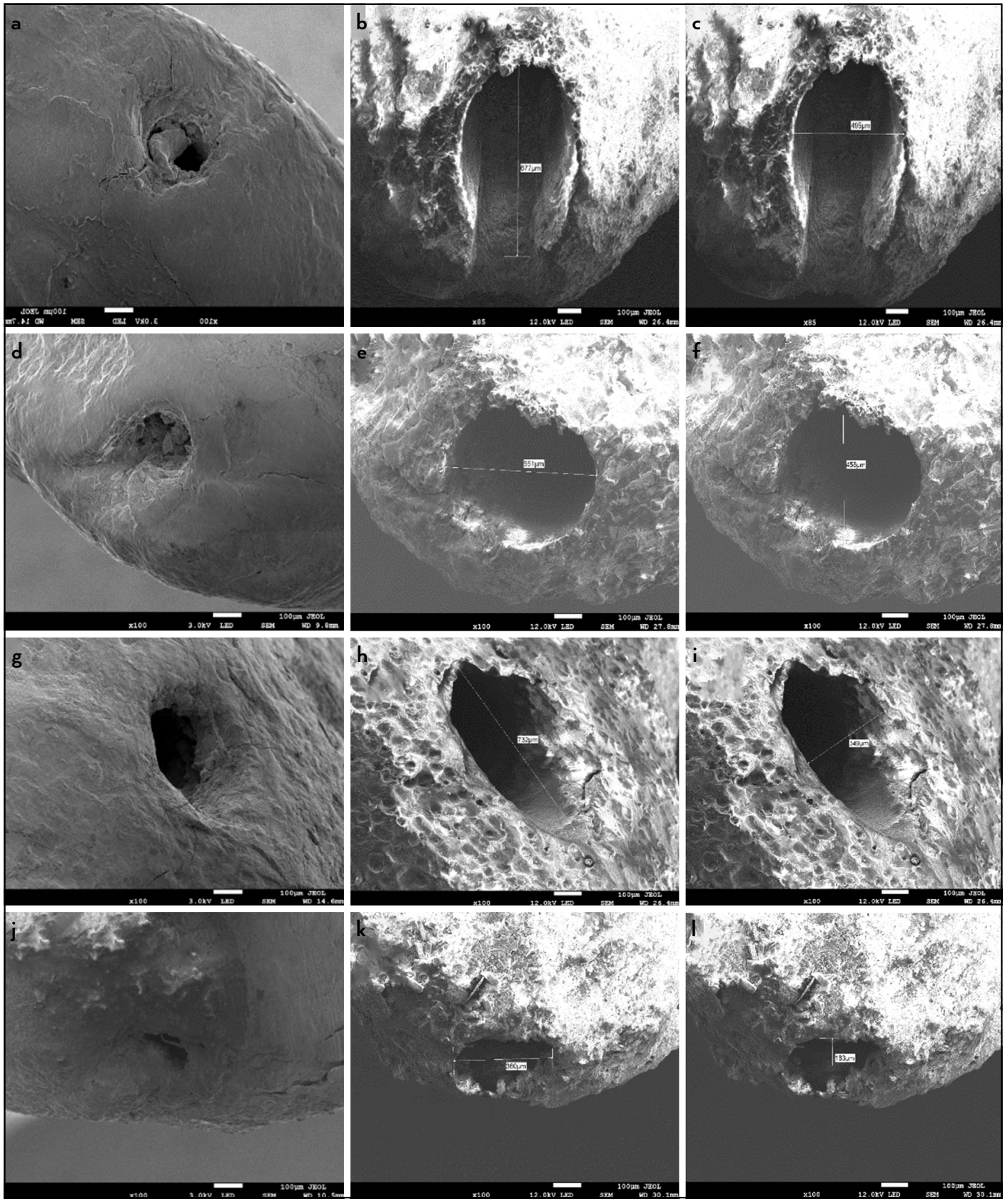

Figure 4. (a-l) Morphologic changes after major apical foramen enlargement (SEM analysis) Pre and Post FeSEM images of the major apical foramen. (a) The major apical foramen before shaping with K file (b, c) Major apical foramen became elliptical and apical transportation with thinning and loss of dentine after shaping with K file (d) Major apical foramen before shaping with PTU (e, f) foramen deformation and thinning dentine walls (g) Major apical foramen before shaping with XPS (h, i) foramen enlargement with no apical deformation after shaping with XPS (j) Major apical foramen before shaping with TRN (k, l) Major apical foramen enlargement without deformation after shaping with TRN

SEM: Scanning electron microscope, PTU: ProTaper Universal, XPS: XP-Endo Shaper, TRN: TruNatomy

beyond the apical foramen during instrumentation. This effect of rotary files led to changes in the working length, foramen enlargement, postoperative pain, unnecessary dentine removal, and extrusion of infected debris (33). Conversely, Paredes-Vieyra and Enriquez (34) stated that instrumentation up to or beyond apical foramen could lead to better healing in cases of apical periodontitis. There is no correlation between foramen enlargement and increased incidence of postoperative pain.

The introduction of newer technologies has led the manufacturers to make a continuous effort to improve the composition, metallurgy, design, durability, cyclic fatigue resistance, and other processes like heat treatment, electric discharge machining, CM wire technology, MAX wire, R-phase, and electropolishing. Instruments with greater flexibility, increased cyclic fatigue resistance, prebendability, and canal tracking ability with guiding tips may avoid undesirable outcomes in maintaining the shape of curved canals (35). In the present study, K files and conventional austenite NiTi instruments were compared with martensite files. The 10 K file was used as a patency file and passed passively through the major apical foramen. The file was pushed 1mm apical to the foramen to discourage debris accumulation (27). At D1 the 10 No. file has a 0.12 mm diameter and by moving 0.02 tapered 10 No. file 1 mm apically will decrease the percentage change at D0 between the 10 and 15 No. Files from 50% to 25% (36).

In contemporary endodontic practice, the strategies that are employed for cleaning and shaping are minimally invasive which can be achieved by conservative radicular preparations and activation of irrigant. The apical preparation in the present study was #25–40 with respective tapers depending on the file system used. This is the minimum instrumentation size that is needed to allow the exchange of irrigants in the apical third. The irrigating solution was activated by ultrasonic activation to increase irrigant efficacy, adequate disinfection, and smear layer removal (37, 38).

Area, circularity, and Feret's diameter ratio were used to access the foramen deformation by quantitative analysis that was first adopted by Hu et al. (39) using SEM and Image J software. The result of the present study shows that there is significant foramen deformation and transportation in root canals prepared with stainless steel hand files and ProTaper universal. Following instrumentation to the foramen, a drastic change from circular to oval shape was observed in the manual group and PTU group. The area increases significantly after instrumentation in both groups resulting in thinning of dentine walls at apical foramen. The reason is the high modulus of elasticity of stainless-steel files, which lack flexibility and prebendability, thus resulting in significant deformation. Therefore, the first null hypothesis is rejected. Schafer and Florek (40) reported that NiTi instruments are superior to stainless steel ones in canal shaping and found little incidence of procedural errors and dentine removal of 0.15 mm in NiTi while stainless steel files remove up to 0.69 mm. PTU led to greater apical deviation at apical foramen and the results are in agreement with previous studies, and concluded that PTU is austinite with a high modulus of elasticity and operated at high torque value (41).

The TRN and XPS show an enlargement of apical foramen without its deformation and transportation. Both file systems are heat-treated with different thermomechanical processing, which makes them extremely flexible and bendable. Also, TruNatomy has a regressive tapper and parallelogram cross-section which enhances its centric ability. The XPS has a serpentine shape and guiding tip which helps to clean and shape the canal without any iatrogenic error. The findings of the present study are satisfactory as both file systems are advanced in terms of design and thermomechanical treatment and are in agreement with studies done by Daou et al. (26), Arican and Uysal (42) and Frota et al. (43) observed that ProDesign R (25/.06) shows less foramen deformation as compared to Reciproc (25/.08), Wave One (25/.08). The performance of ProDesign R system was attributed to its shape - memory technology and less instrument taper and Size. In the study of Vieira et al. (44), morphological changes occur when instrumented beyond working length however there was no significant difference in foramen deformation in straight and curved roots using Reciproc Blue. Therefore, the second null hypothesis is accepted as it is concluded that NiTi instruments manufactured from advanced technology and improved design don't promote foramen deformation in curved canals due to their less taper and flexibility.

The objective of a minimally invasive endodontic procedure is to advocate smaller apical preparations and continuous taper with a three-dimensional hermetic seal. It is important for the clinician to decide which is the appropriate file system to be used in curved root canals without compromising root canal disinfection and the long-term success of root canal treatment (45).

CONCLUSION

Within the limitation of the present study foramen enlargement occurs regardless of the type of file system used. The hand stainless steel files and PTU result in significant foramen deformation when instrumented up to apical foramen. However, TRN and XPS promote minor alterations at the foramen which are not statistically significant. The large apical preparation has been advocated in apical periodontitis cases to achieve better healing and disinfection, but this will affect the apical seal because large preparation leads to foramina deformation. In minimal invasive endodontics, the use of thermomechanical treated martensite files provides adequate cleaning and shaping without foramen deformation.

Disclosures

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Ethics Committee Approval: The study was approved by the Institutional Ethics Committee of Indira Gandhi Govt Dental College Jammu (no: EC/NEW/INST/2021/1867-IGGDCJ/40/2023/03/06, date: 06/03/2023).

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