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Original Article

Cone Beam Computed Tomographic Evaluation of Effect of Different Taper and Technique of Biomechanical Preparation on Root Dentin Thickness: An *in Vitro* Study

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Abstract

Objective: The aim of the present study was to evaluate the remaining dentin thickness (RDT) after instrumentation with different endodontic file systems through CBCT.

Materials and Methods: In the present study, 40 extracted, untreated human mandibular Premolars, with curvature less than 20° were divided into four groups (n=10, each group). Biomechanical preparation was done according to the group where, Group 1 included SS Hand K files, Group 2 included Hand ProTaper files, Group 3 included ProFile rotary files, and Group 4 included ProTaper Gold rotary files. CBCT images of Pre and Post instrumented canals were taken, and RDT was measured at 3 mm, 5 mm, and 7 mm from the radiographic root apex.

Results: Results of the present study showed that Group 2 removed the maximum amount of root dentin compared to other groups, Group 3 and 4 instrumentation techniques removed almost equal amounts of dentin while Group 1 removed the least amount of root dentin.

Conclusion: It can be concluded that engine driven Ni-Ti instruments better maintain the anatomy of the root canal during instrumentation with lesser removal of root dentin as compared to hand instruments.

Keywords: CBCT, root dentin thickness, Hand ProTaper, ProFile, ProTaper Gold

Introduction

The objective of root canal preparation is to form a continuously tapered shape with the smallest diameter at the apical foramen and the largest at the orifice to allow effective irrigation and filling.[1] Cleaning and shaping procedure invariably leads to loss of root dentin regardless of the instrumentation techniques but flaring the canals excessively decreases the dentin thickness resulting, thus increasing the possibility of vertical root fracture.[2,3] So, the remaining root dentin thickness (RDT) is directly related to the fracture resistance of the tooth.

Hand instruments have been in clinical use for almost a hundred years, and they still are an integral part of clean-

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ing and shaping procedures.[4] Traditional stainless-steel (SS) instruments, when used in severely curved canals, often fail to achieve the tapered root canal shapes needed for adequate cleaning and filling.[2] It is time consuming as well as there is more chance of getting canal aberrations such as zips, elbows, ledges, and perforations.[5]

With the evolution of the endodontic instrument, flexible Nickel–titanium (Ni-Ti) instruments have been developed with new design features such as varying tapers, non-cutting safety tips, with varying lengths of cutting blades, and a combination of metallurgical properties of Ni-Ti alloy.[6] The increased flexibility of hand instruments made out of Ni-Ti has been shown to produce improved preparation shapes compared to stainless steel.[7-9] Root canal preparation with rotary nickel-titanium (Ni-Ti) instruments became popular as it facilitates the difficult and time-consuming process of shaping and improves the final quality of root canal preparation. It has been demonstrated that rotary Ni-Ti instruments are able to maintain canal shape even in severely curved canals.[1]

Recently, a new type of rotary Ni-Ti instrument, ProTaper Gold, has been introduced, which has the same geometry as that of ProTaper Universal but offers increased flexibility. These instruments have resistance to cyclic fatigue and better canal centering ability, especially when preparing curved canals.[10]

Several approaches have been used to assess the shaping ability of different Ni-Ti rotary systems, but recently a non-destructive technology has been advocated for pre-and post-instrumentation evaluation of root canals. Cone-beam computed tomography (CBCT) can render cross-sectional and three-dimensional images that are highly accurate and quantifiable.[11] Comparisons using CBCT provided repeatable results and also have allowed non-invasive experimentation at various aspects of endodontic instrumentation at any level the root dentin thickness can be viewed without loss of specimen.[11,12]

Different rotary file systems have been compared to see biomechanical canal preparation and their effect on remaining dentin thickness, but studies comparing hand and rotary files of different tapers and metallurgy are less. Therefore, the purpose of the present study was to evaluate the effect of preparation by differently tapered hand and rotary instruments on root dentin thickness through CBCT.

Materials and Methods

In the study 40 permanent mandibular premolar teeth indicated only for orthodontic extraction were collected. After cleaning, all the teeth were stored in 10% formalin till the start of the procedure.

Inclusion criteria

Teeth with

1. Root curvature <20°
2. Devoid of developmental defects

Exclusion criteria

Teeth with

1. Calcified canals.
2. Root canals with double or more curvatures.
3. Curvature more than 20 degree.
4. Double canals.

Materials and product details of various endodontic files used for the study are shown in Table 1.

Selection of teeth

40 Mandibular Premolars with less than 20° root canal curvature were selected after taking a digital radiograph using Schneider's method.

Preparation of samples (Fig. 1)

The teeth selected were divided into four groups depending upon the taper of the instrument. The teeth were marked on the buccal aspect using round and straight fissure bur and filling indentations with amalgam, i.e., Group I (making dots), Group II (numerical value1-10), Group III (roman value I-X), Group IV (alphabets A-I).

Access cavity and working length (Fig. 2)

An endodontic access was prepared using an air rotor handpiece, #2 round bur and tapered fissured bur. A patency K-file size #10 was passively entered into the

Table 1. Metallurgy and product details of various endodontic files

Metallurgy	Type of file used	Manufacturer	Length used (25 mm)	Sizes used	Taper (%)
SS	K-file	Mani Inc, Japan	25	15, 20, 25, 30	2
Ni-Ti	Hand ProTaper	Dentsply Maillefer	25	Sx, S1, S2, F1, F2, F3	Progressive
Ni-Ti	Rotary ProFile	Dentsply Maillefer	25	20, 25, 30	4
Ni-Ti	ProTaper Gold	Dentsply Maillefer	25	Sx, S1, S2, F1, F2, F3	Progressive

Ni-Ti: Nickel-titanium, SS: Stainless steel

Figure 1. Grouping of the samples (1-4) as used in the study

canal until it become visible from apical foramen, and the working length was established at 1 mm short of this point. The pulp was removed with the help of barbed broach no.15. The canal was irrigated with 2.5% sodium hypochlorite to remove any pulpal remnants and then irrigated with saline.

Pre-instrumentation CBCT (Figs. 3, 4)

Occlusal rims were prepared with modeling wax with the size equivalent to the bite plane of CBCT. Five teeth were inserted in each occlusal rim, so each group consisted of two occlusal rims. Also, to keep the measurement area constant in pre-and post-instrumentation images grooving along the root length on the buccal, lingual, mesial, and the distal surface was done with disc bur.

A pre-instrumentation CBCT was taken for each group, and root dentin thickness was measured at four different surfaces (buccal, lingual, mesial, and distal) on each slice at different levels, i.e., 3, 5, 7 mm from the radiographic root apex. The CT scans were done at 75 KV and 2.5 m A, 0.1 mm thick sections.

Biomechanical preparation of root canals (Fig. 2)

Samples were divided into 4 groups based on the metallurgy, technique and taper of different endodontic files used for instrumentation, as shown in Table 2. The same operator did biomechanical preparation of the canals with various file systems and manufacturer instructions.

Post-instrumentation CBCT (Fig. 4)

Post instrumentation CBCT was taken, and root dentin thickness was measured at the levels corresponding to the Pre-instrumentation levels, i.e., 3, 5, 7 mm maintaining the same position, and the readings were compared with pre instrumentation readings.

Same values of brightness and contrast were fixed in pre-and post-images to keep umbra and penumbra constant.

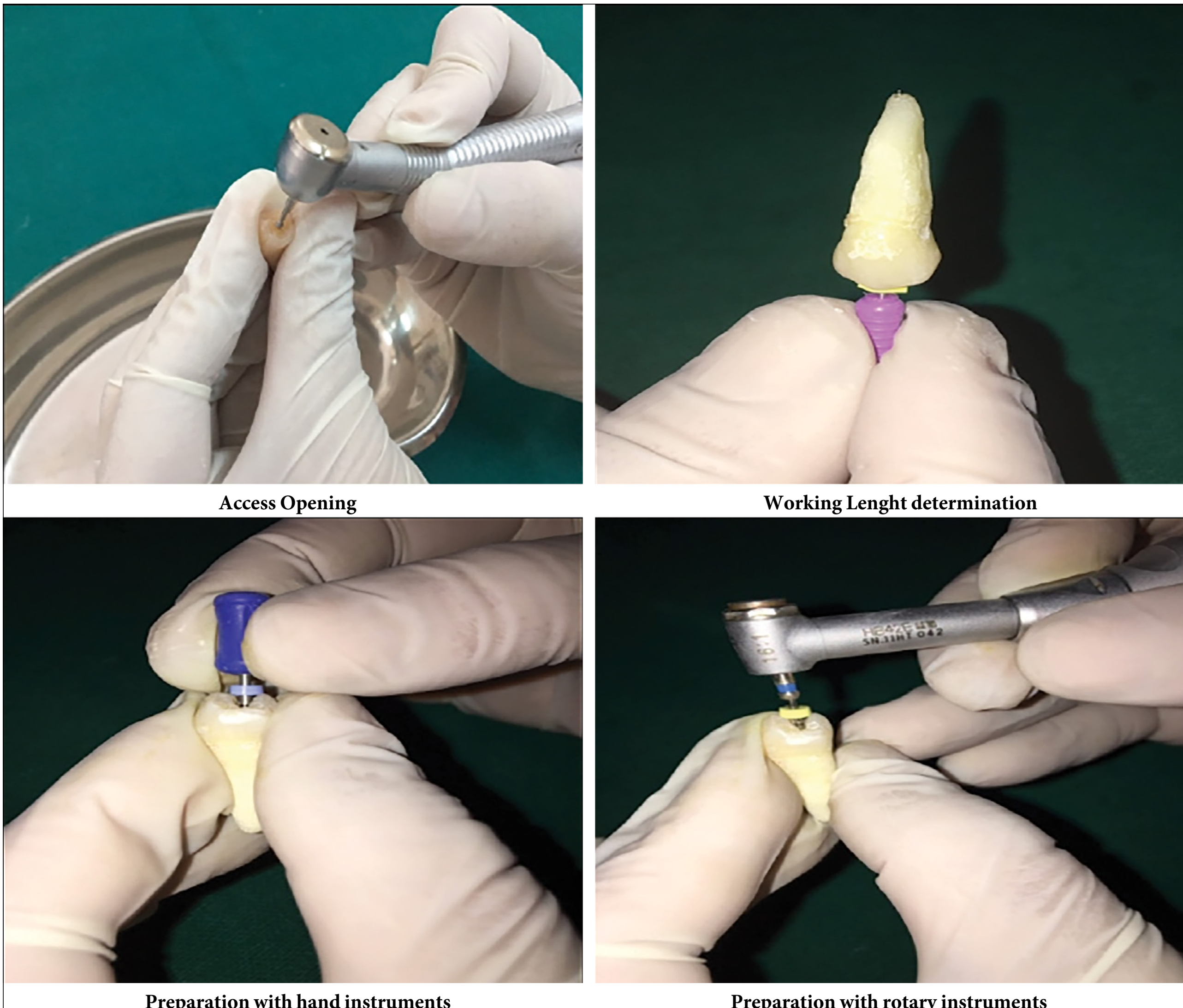
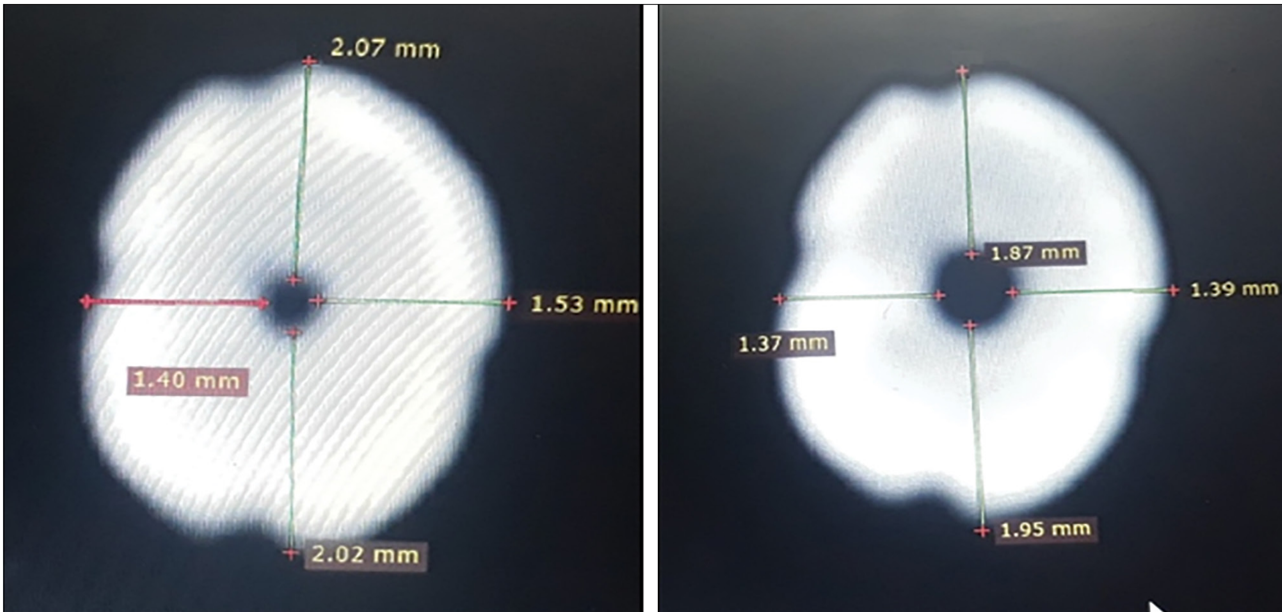


Figure 2. Various procedural steps followed in the study

Figure 3. Photograph showing bite plane (a, b)

CBCT: Cone-beam computed tomography



Pre-instrumentation CBCT **Post-instrumentation CBCT**

Figure 4. Images of pre-and-post instrumentation CBCT before and after cutting showing the difference in dentin thickness

CBCT: Cone-beam computed tomography

The scanned images were stored on a computer hard disk for further comparison between pre-and post- instrumentation data by using Di Com software.

The data analysis was done using SPSS version 16 (IBM SPSS, Armonk, NY: IBM Corp, USA). Kruskal Wallis test was applied for multiple group comparison, and the Man-Whitney U test was conducted to compare the median/mean rank of cutting scores between the groups. The level of significance was $p \leq 0.05$.

Results

Pre and Post instrumentation comparison of RDT in CBCT at 3 mm (Table 3, 4)

Intergroup comparison of cutting pattern with different methods at the level of 3 mm showed that maximum cutting was yielded with Hand ProTaper (HPT) (mean 0.11±0.14) followed by a lesser but equal amount of cutting by ProFile and ProTaper Gold with a mean of 0.5, and least cutting was achieved with a hand file (mean 0.4±0.05).

Pre and Post instrumentation comparison of RDT in CBCT at 5 mm (Table 5, 6)

Intergroup comparison of cutting pattern with different methods at the level of 5 mm showed that maximum cutting was yielded with Hand ProTaper (mean 0.11±0.11) followed by a lesser but equal amount of cutting by ProFile and Hand K file with a mean of 0.08, while ProTaper Gold yielded least cutting (mean 0.06±0.05).

Pre and Post instrumentation comparison of RDT in CBCT at 7 mm (Table 7, 8)

Intergroup comparison of cutting pattern with different methods at the level of 7 mm showed Mean value of cutting is maximum for Hand ProTaper (mean 0.12) followed by ProTaper Gold (0.08), ProFile (0.06), and least for Hand file (0.04).

Descriptive statistics of all the groups for different methods (all levels combined) (Table 9, 10, Graph IV)

Intergroup comparison of comprehensive mean cutting score by different methods showed that mean value of cutting is maximum for Hand ProTaper (mean 0.12)

Table 2. Grouping of samples

Groups	Instrumentation	Taper	Number of samples
1	SS Hand K files	2%	10
2	Ni-Ti Hand ProTaper	Progressive	10
3	Ni-Ti ProFile	4%	10
4	Ni-Ti ProTaper Gold	Progressive	10

Ni-Ti: Nickel-titanium, SS: Stainless steel

Table 3. Descriptive values of cutting pattern by different methods at 3 mm

					Kruskall Wallis test result			
	N	Mean	SD	SE	Mean rank	Chi-square	df	Sig.
Hand File	40	0.04	0.05	0.01	68.35	6.249	3	0.01
Hand ProTaper	40	0.11	0.14	0.02	93.32			
ProFile	40	0.05	0.05	0.01	83.26			
ProTaper Gold	40	0.05	0.04	0.01	77.06			

*p-value significant at level 0.05, SE: Standard error, df: Degree of freedom, Sig.: Significant

Table 4. Multiple comparison of cutting pattern by different methods at 3 mm

Gr 1	Gr 2	u	p
Hand File	Hand ProTaper	568	0.02*
	ProFile	622	0.08
	ProTaper Gold	724	0.46
Hand ProTaper	ProFile	681	0.25
	ProTaper Gold	638	0.12
ProFile	ProTaper Gold	748.5	0.62

*The mean difference is significant at the 0.05 level. Gr: Group, u: Mann-Whitney U test results

followed by ProTaper Gold (0.06) and ProFile (0.06) and least for hand file (0.04).

Discussion

The area of radicular dentin which plays an important role in fracture resistance is the pericervical dentin. This area is known as the critical zone, roughly 4 mm above the crestal bone and extending 4 mm apical to the crestal bone, which is important for three reasons: ferrule, fracturing, and proximity of dentin tubule orifice inside to out. Long–term retention of tooth and resistance to fracturing are directly related to the amount of residual tooth structure.[13, 14] So, the more dentin is kept, the longer tooth is kept.[15]

Residual dentin thickness indicates the mechanical limits of instrumentation to enlarge the diameter of the root canal to approximately predetermined values that would not significantly weaken the dentinal walls.[16] The strength of the root is directly related to the residual dentin thicknesses. So, it is utmost importance to preserve the sound dentin. At least 1 mm of root dentin should remain in all root aspects along its entire length after all intra-radicular procedures are completed.[17]

The trend to tapered canal shapes for cleaning efficacy and obturation mechanics has been a slow and measured conversion during the last 2 decades. Step-back and/or crown-down strategies for shaping have been the established paradigm for creating tapered shapes during the last 20 years.[18]

The advent of predefined tapered shapes to root canals was given great impetus with the introduction of nickel-titanium instruments as this strong and highly flexible alloy has allowed innovations in taper and flute design, which had been impossible with SS instruments.[19] The super-elasticity has furthermore made it possible to carry out extremely conservative shapes, better centered, with less canal transportation and therefore respecting the original anatomy of the root canal.[20-22] In addition, increased taper combined with nickel-titanium alloy allowed more predictable use of rotary methods to provide consistent canal shapes (Short et al 1997).[19]

Hand instrumentation with 0.02 SS K files is a time-tested, easy and economical method for root canal treatment, but they are not available in different taper and flute designs. With the innovations in Ni-Ti instruments that are now available in different tapers and flute designs, canal preparation has become easier and more predictable. ProTaper is multiple taper instruments that

Table 5. Descriptive values of cutting pattern by different methods at 5 mm

					Kruskal Wallis test result			
	N	Mean	SD	SE	Mean rank	Chi-square	df	Sig.
Hand File	40	0.08	0.03	0.01	91.96	9.413	3	0.024
Hand ProTaper	40	0.11	0.11	0.02	87.55			
ProFile	40	0.08	0.08	0.01	79.91			
ProTaper Gold	40	0.06	0.05	0.01	62.58			

*p-value significant at level 0.05, SE: Standard error, df: Degree of freedom, Sig.: Significant

Table 6. Multiple comparison of cutting pattern by different methods at 5 mm

Gr 1	Gr 2	u	p
Hand File	Hand ProTaper	782	0.862
	ProFile	680	0.246
	ProTaper Gold	479.5	0.002*
Hand ProTaper	ProFile	724	0.463
	ProTaper Gold	576	0.031*
ProFile	ProTaper Gold	627.5	0.096

The mean difference is significant at the 0.05 level

*Statistically significant difference. Gr: Group, u: Mann-Whitney U test results

are available in both hand-operated version and engine-driven. Instrumentation with Hand ProTaper and rotary ProTaper in this study has given an opportunity to compare a similar instrument design with two different instrumentation techniques. Since ProFile is a constant taper instrument, it has provided an opportunity to compare a rotary constant tapered instrument with a variable tapered ProTaper Gold instrument.

The use of ProTaper Gold in our study has given us a chance to compare conventional Ni-Ti rotary instruments with heat-treated controlled memory Ni-Ti rotary instruments.

The gold standard of comparison is with that of the time-tested conventional step-back technique with the ISO standard 0.02 tapered stainless steel K-files.

In a study by Jafarzadeh et al.[23] the frequency of ledge, formation tends to increase if the canal curvature was more than 20 degree, also curvature of canal effects the cutting efficiency of instruments. Hence single rooted mandibular premolar teeth with single straight canal and single apical foramen were used in this study.

There are a number of methods available to compare the cutting efficiency of various instruments in preparing root canals, and these include plastic blocks,[24] radiographic techniques,[25] histological sections,[26] serial sectioning, scanning electron microscope[27] and silicone impressions of instrumented canals.[28]

One of the latest innovations in the industrial and medical field is the use of CBCT for study purposes, this scientific tool could develop a potential in endodontic research as well. It is a practical and non-destructive technique for the assessment of root dentin thickness before and after shaping, according to Gluskin et al.[11] It provided horizontal cut-planes along root length at the right angle to the long axis of the canal, which helps in providing standardized sections of all specimens. With a thickness of 0.1 mm, these numbers of sections allowed accurate evaluation of any changes in dentin thickness along the root length.[29]

CBCT image analysis software CS allows pre-instrumentation and post- instrumentation measuring of remaining root dentine thickness and hence calculations of the amount of removed dentin during cleaning and shaping of the root canal. There are also no instrumentation problems passing through sections that could affect the instrumentation outcomes. Also, CBCT scans allow easy measurement of canal changes because each image has an accurate scale, decreasing the potential of a radiographic or photographic transfer error and avoiding complicating procedures, destructive sectioning of the specimens, or loss of the root material during sectioning.[30]

In the present study, the maximum amount of root dentin removal was done by Hand ProTaper instruments at 3 mm. There was a statistically significant difference between Hand ProTaper (p value≤0.05) and 2% Hand K files at apical 3 mm. These findings correlate with Rao et al.[31] who found that K files removed a lesser amount of dentin apically. The results were complementary to the findings of Reddy et al.[32] and Yoshmine et al.[33], who found that conventional hand instrumentation with 0.02 tapered SS K files removed the least amount of dentin but in contrast to study done by Shahriari et al.[34] who demonstrated found that SS hand instruments removes more amount of dentin in all the sections as compared to ProFile rotary instruments and this difference in the cutting pattern may be due to the curved root canals included in their study.

Table 7. Descriptive values of cutting pattern by different methods at 7 mm

					Kruskal Wallis test result			
	N	Mean	SD	SE	Mean rank	Chi-square	df	Asymp. sig.
Hand File	40	0.04	0.03	0.01	58.18	24.652	3	0.000
Hand ProTaper	40	0.12	0.09	0.01	106.82			
ProFile	40	0.06	0.05	0.01	70.89			
ProTaper Gold	40	0.08	0.06	0.01	86.11			

*p-value significant at level 0.05, SE: Standard error, df: Degree of freedom, Asymp. sig.: Significant difference between the means

Table 8. Multiple comparisons of cutting pattern by different methods at 7 mm

Gr 1	Gr 2	u	p
Hand File	Hand ProTaper	323	0.00*
	ProFile	669	0.21
	ProTaper Gold	515	0.01*
Hand ProTaper	ProFile	437	0.00*
	ProTaper Gold	587	0.04*
ProFile	ProTaper Gold	648	0.14

*The mean difference is significant at the 0.05 level. Gr: Group, u: Mann-Whitney U test results

The increasing taper instruments or shaping files(s) have enhanced flexibility in the middle region and at the tip. The decreasing taper instruments or finishing files (F) have larger taper and diameter in the apical 3 mm region, which makes them stiff.[35] This can also explain the higher cutting of ProTaper instruments as found in our study at apical 3 mm level.

The higher cutting by HPT may be due to the that this file prepares the apical area for an extended period of time, and the rotational movement of the file is an operator controlled variable factor thus leading to more cutting of dentin as compared to rotary files, which contacts the apical area for a lesser period of time and also rotational speed and torque are fixed.

Post-instrumentation dentin thickness at 5 mm level showed that progressively tapered (Hand ProTaper) instrument has removed more amount of root dentin as compared to constant tapered (ProFile). These findings were in accordance to Yang et al.[6] and Uyanik et al.[30], who reported that owing to larger cross sectional areas in coronal and middle parts, ProTaper removed more dentin in these areas when compared to the constant tapered instrument.

ProTaper Gold showed least amount of dentin removal as compared to Hand ProTaper (p value 0.031) and SS hand K file (p value 0.002), and the difference was statistically significant. This is in correlation with Gagliardi et al.[36], who have stated that the more flexible alloy of ProTaper Gold, enhanced through a proprietary heat treatment technology, imparts a reduced restoring force and allows these instruments to remain more centered in the canal and have greater ability to maintain dentin thickness than conventional ProTaper. The least dentin removal by ProTaper Gold might be explained that Ni-Ti files manufactured using the Gold-Wire heat treatment method have increased flexibility compared to the files made of M-wire or conventional Ni-Ti files, thus producing minimal reaction forces on the canal wall.

Intergroup comparison of dentin removal at 7 mm showed maximum cutting by Hand ProTaper followed by ProTaper Gold, ProFile, and least for SS hand files.

These results were in accordance with Mahran et al.[37], who found that total dentin removal during canal instrumentation was significantly more with the ProTaper system. However, in their study ProTaper removed less cervical dentin as compared to hand files which was due to the use of GG burs with hand K files. But in contrast to our study Yin et al.[38] found that more dentin was removed with hand-files, and this was due to the use of GG burs in the hand file group and also the inclusion of c shaped canals in their study.

As the present study was an in-vitro study, thus the conditions could not simulate the natural oral conditions where angulations and ease of operator are also important determining factors effecting root canal preparation.

Also, in our study, samples taken for endodontic instrumentation were only straight canals with curvature less than 20°, but as the canal curvature increases cutting pattern might change because of the metallurgical characteristics of instrument i.e., stainless steel, conventional Ni-Ti or metallurgically enhanced heat treated instruments, Thus cannot be applied to all teeth.

Conclusion

- From the findings of this study, it can be concluded that SS 0.02 k file shows most conservative dentin removal at the apical and cervical region but more significantly in the apical part when compared to hand ProTaper, ProFile, and ProTaper Gold.

Table 9. Comprehensive data for different methods (all surface and levels combined)

	Mean	Std. deviation	Median	Mean rank	Chi-square	df	Asymp. Sig.
Hand File	0.054	0.04	0.050	217.3	19.066	3	0.000
Hand ProTaper	0.112	0.12	0.075	287.3			
ProFile	0.063	0.06	0.050	232.8			
ProTaper Gold	0.062	0.06	0.050	224.6			

Sig*p-value significant at level 0.05, df: Degree of freedom, Asymp. Sig.: Significant difference between the means

Table 10. Multiple comparison of comprehensive cutting scores by different methods

Gr 1	Gr 2	u	p
Hand File	Hand ProTaper	5107	0.000*
	ProFile	6684	0.336
	ProTaper Gold	7019	0.735
Hand ProTaper	ProFile	5507	0.002*
	ProTaper Gold	5370	0.001*
ProFile	ProTaper Gold	6945	0.635

*p-value significant at level 0.05, Gr: Group, u: Mann-Whitney U test results

- Hand ProTaper removed a significantly greater amount of dentin as compared to rotary ProTaper Gold despite having the same design features.
- ProTaper Gold removed more amount of dentin as compared to ProFile, but the difference is not statistically significant, irrespective of the difference in their tapers.
- Engine-driven Ni-Ti instrumentation techniques causes lesser removal of root dentin as compared to hand instrumentation and have better maintained the anatomy of root.

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Conflict of Interest: None declared.

References

1. Yang GB, Zhou XD, Zheng YL, Zhang H, Shu Y, Wu HK. Shaping ability of progressive versus constant taper instruments in curved root canals of extracted teeth. Int Endod J 2007;40(9):707-714 doi:10.1111/j.1365-2591.2007.01296.x
2. Guelzow A, Stamm O, Martus P, Kielbassa AM. Comparative study of six rotary nickel-titanium systems and hand instrumentation for root canal preparation. Int Endod J 2005;38(10):743-752 doi:10.1111/j.1365-2591.2005.01010.x
3. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30(8):559-567 doi:10.1097/01.don.0000129039.59003.9d
4. Cohen S, Hargreaves KM. Pathways of Pulp, 9th Edition, St. Louis, Missouri: Mosby Inc.; 2006:p301
5. Sam JE, Kumar AA, Maheswari SU, Raja J, Seelan RG, Balaji TR. Comparison of shaping ability of three different rotary instruments in simulated root canals using computer image analysis: An *in vitro* study. J Indian Acad Dent Spec Res 2015;2:8-12 doi:10.4103/2229-3019.166098
6. Yang GB, Zhou XD, Zhang H, Wu HK. Shaping ability of progressive versus constant taper instruments in simulated root canals. Int Endod J 2006;39(10):791-799 doi:10.1111/j.1365-2591.2006.01151.x
7. Himel VT, Ahmed KM, Wood DM, Alhadainy HA. An evaluation of nitinol and stainless steel files used by dental students during a laboratory proficiency exam. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79(2):232-237 doi:10.1016/s1079-2104(05)80289-6
8. Esposito PT, Cunningham CJ. A comparison of canal preparation with nickel-titanium and stainless steel instruments. J Endod 1995;21(4):173-176 doi:10.1016/S0099-2399(06)80560-1
9. Glossen CR, Haller RH, Dove SB, del Rio CE. A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-Flex endodontic instruments. J Endod 1995;21(3):146-151 doi:10.1016/s0099-2399(06)80441-3
10. Ruddle CJ, Machtou P, West JD. Endodontic canal preparation: innovations in glide path management and shaping canals. Dent Today 2014;33(7):118-123
11. Gluskin AH, Brown DC, Buchanan LS. A reconstructed computerized tomographic comparison of Ni-Ti rotary GT files versus traditional instruments in canals shaped by novice operators. Int Endod J 2001;34(6):476-484 doi:10.1046/j.1365-2591.2001.00422.x
12. Garip Y, Günday M. The use of computed tomography when comparing nickel-titanium and stainless steel files during preparation of simulated curved canals. Int Endod J 2001;34(6):452-457 doi:10.1046/j.1365-2591.2001.00416.x
13. Kutesa-Mutebi A, Osman YI. Effect of the ferrule on fracture resistance of teeth restored with prefabricated posts and composite cores. Afr Health Sci 2004;4(2):131-135
14. Goto Y, Nicholls JI, Phillips KM, Junge T. Fatigue resistance of endodontically treated teeth restored with three dowel-and-core systems. J Prosthet Dent 2005;93(1):45-50 doi:10.1016/j.prosdent.2004.09.026
15. Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010;54(2):249-273 doi:10.1016/j.cden.2010.01.001
16. Zuckerman O, Katz A, Pilo R, Tamse A, Fuss Z. Residual dentin thickness in mesial roots of mandibular molars prepared with Lightspeed rotary instruments and Gates-Glidden reamers. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96(3):351-355 doi:10.1016/s1079-2104(02)91710-5
17. Katz A, Wasenstein-Kohn S, Tamse A, Zuckerman O. Residual dentin thickness in bifurcated maxillary premolars after root canal and dowel space preparation. J Endod 2006;32(3):202-205 doi:10.1016/j.joen.2005.10.048
18. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18(2):269-296
19. Short JA, Morgan LA, Baumgartner JC. A comparison of canal centering ability of four instrumentation techniques. J Endod 1997;23(8):503-507 doi:10.1016/S0099-2399(97)80310-X
20. Thompson SA. An overview of nickel-titanium alloys used in dentistry. Int Endod J 2000;33(4):297-310 doi:10.1046/j.1365-2591.2000.00339.x
21. Koch K, Brave D. Real world endo: design features of rotary files and how they affect clinical performance. Oral Health 2002;February:39-49
22. Vaudt J, Bitter K, Kielbassa AM. Evaluation of rotary root canal instruments *in vitro*: a review. ENDO-Endodontic Practice Today 2007;1(3):189-203

23. Jafarzadeh H, Abbott PV. Ledge formation: review of a great challenge in endodontics. J Endod 2007;33(10):1155-1162 doi:10.1016/j.joen.2007.07.015

24. Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. J Endod 1975;1(8):255-262 doi:10.1016/S0099-2399(75)80037-9

25. Walton RE. Histologic evaluation of different methods of enlarging the pulp canal space. J Endod 1976;2(10):304-311 doi:10.1016/S0099-2399(76)80045-3

26. Mizrahi SJ, Tucker JW, Seltzer S. A scanning electron microscopic study of the efficacy of various endodontic instruments. J Endod 1975;1(10):324-333 doi:10.1016/s0099-2399(75)80012-4

27. Seidler B. Root canal filling: an evaluation and method. J Am Dent Assoc 1956;53(5):567-576 doi:10.14219/jada.archive.1956.0211

28. Bramante CM, Berbert A, Borges RP. A methodology for evaluation of root canal instrumentation. J Endod 1987;13(5):243-245 doi:10.1016/S0099-2399(87)80099-7.

29. Reddy KS, Prasad SD, Kumar CS, Reddy VR, Basa MH, Karteek S. Comparison of remaining root dentine thickness after three rotary instrumentation techniques by cone beam computerised tomography: an *in vitro* study. J Res Adv Dent 2014;3,3S:32-39

30. Ozgur Uyanik M, Cehreli ZC, Ozgen Mocan B, Tasman Dagli F. Comparative evaluation of three nickel-titanium instrumentation systems in human teeth using computed tomography. J Endod 2006;32(7):668-671 doi:10.1016/j.joen.2005.12.015

31. Rao MS, Shameem A, Nair R, Ghanta S, Thankachan RP, Issac JK. Comparison of the remaining dentin thickness in the root after hand and four rotary instrumentation techniques: an *in vitro* study. J Contemp Dent Pract 2013;14(4):712-717 doi:10.5005/jp-journals-10024-1389

32. Reddy MS, Reddy P V, Reddy T J, Balagopal S, Amalavathy K, Reddy G J, Harini T, Reddy S S. An *in vitro* study to determine fracture resistance of tooth roots after different instrumentation techniques. J NTR Univ Health Sci 2016;5(3):192-199 doi:10.4103/2277-8632.191839

33. Yoshimine Y, Ono M, Akamine A. The shaping effects of three nickel-titanium rotary instruments in simulated S-shaped canals. J Endod 2005;31(5):373-375 doi:10.1097/01.don.0000140568.40462.43

34. Shahriari S, Abedi H, Hashemi M, Jalalzadeh SM. Comparison of removed dentin thickness with hand and rotary instruments. Iran Endod J 2009;4(2):69-73

35. Bergmans L, Van Cleynenbreugel J, Beullens M, Wevers M, Van Meerbeek B, Lambrechts P. Progressive versus constant tapered shaft design using NiTi rotary instruments. Int Endod J 2003;36(4):288-295 doi:10.1046/j.1365-2591.2003.00650.x

36. Gagliardi J, Versiani MA, de Sousa-Neto MD, Plazas-Garzon A, Basrani B. Evaluation of the shaping characteristics of ProTaper Gold, ProTaper NEXT, and ProTaper Universal in curved canals. J Endod 2015;41(10):1718-1724 doi:10.1016/j.joen.2015.07.009.

37. Mahran AH, AboEl-Fotouh MM. Comparison of effects of ProTaper, HeroShaper, and Gates Glidden Burs on cervical dentin thickness and root canal volume by using multislice computed tomography. J Endod 2008;34(10):1219-1222 doi:10.1016/j.joen.2008.06.022

38. Yin X, Cheung GS, Zhang C, Masuda YM, Kimura Y, Matsumoto K. Micro-computed tomographic comparison of nickel-titanium rotary versus traditional instruments in C-shaped root canal system. J Endod 2010;36(4):708-712 doi:10.1016/j.joen.2010.01.003