Efficiency of Different Nickel-Titanium Endodontic File Systems in Cleaning and Apical Transportation of Simulated Curved Root Canals

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The use of nickel-titanium instruments have become an important part of the root canal treatment, in order to facilitate the cleaning and shaping of root canals, because the incorrect utilization of the endodontic files during endodontic treatment may produce unwanted procedural errors. The aim of this study was to evaluate on simulated curved root canal models the cleaning efficiency and the apical transportation in three reference areas of the root canal files, ProTaper (Dentsply Maillefer), K3XF (Sybron Endo) and HyFlex (Coltene Endo) systems, compared to the hand K-files (DentsplyMaillefer). According to our results, rotary file systems are more efficient than the hand files, in cleaning the root canal.

Keywords: endodontic file systems, cleaning efficiency, apical transportation

The international endodontic literature reports that the success rate of the endodontic retreatment varies between 70-95% [1].

This has been calculated as the percentage of successfully treated teeth comparative to all the teeth with follow-up examination or included in the study [2].

The factors that lead to the success or failure of the endodontic treatment vary and can involve root canal anatomy, bacterial infection resulting from inadequacies in cleaning, shaping and three dimensional filling of the endodontic system, iatrogenic events or reinfection of the root canals when the coronal seal is lost, after the completion of the root canal treatment [3].

Endodontic therapy involves the removal of the dental pulp and the infected mineralized structures, the subsequent shaping, cleaning, decontamination by using irrigating solutions and the filling of the decontaminated canals [4]. Each step has its own rules which need to be respected in order to obtain the expected results [1,5].

Endodontic files are used to shape the root canals. Shaping the root canals offers various instruments and techniques, from which the clinicians must choose. The hand files, manufactured from stainless steel, were firstly introduced in the early 1900 [6].

In 1975 the first report on potential use of Ni-Ti alloys for endodontic file confection appears. The first Ni-Ti rotary files appear around 1993 [5].

Ni-Ti is called an exotic metal because it does not conform to the normal rules of metallurgy. The Ni-Ti alloys used in root canal treatment contain approximately 56% (wt) nickel and 44% (wt) titanium [7]. The resultant combination is a 1:1 atomic ratio (equiatomic) of the major components, and, similar to other metallic systems, the alloy can exist in various crystallographic forms. Nearequiatomic Ni-Ti alloys contain 3 microstructural phases (ie, austenite, martensite, and R-phase), the character and relative proportions of which determine the mechanical properties of the metal [8].

Ni-Ti alloy has special characteristics of superelasticity and shape memory. The superelasticity of Ni-Ti allows deformations of as much as 8% strain to be recoverable in comparison with a maximum of less than 1% with stainless steel. This unusual property is the result of stressinduced martensite transformation. External stresses transform the austenitic crystalline form of Ni-Ti into a martensitic crystalline structure that can accommodate greater stress without increasing the strain [9]. In figure 1is presented 3D view of austenite and martensite structures of the NiTi compound [10].

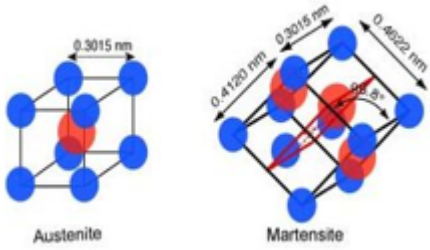

Fig. 1. Austenite and martensite structures of the NiTi compound

As a result of its unique crystalline structure, a Ni-Ti file has superelasticity (ie, the ability to return to its original shape after being deformed). Simply stated, NiTi alloys currently are the only readily available and affordable materials with the flexibility and toughness for routine use as effective rotary endodontic files in curved canals. Superelasticity occurs in association with a reversible phase transformation between austenite and martensite. Therefore, the transformation temperatures have a critical influence on the mechanical properties and the behaviour of Ni-Ti, which can be altered by small changes in composition, impurities, and heat treatments during the manufacturing process [9]. This distinct property of Ni-Ti alloys has created a revolution in the manufacture of endodontic instruments [11].

Over the past 2 decades, Ni-Ti instruments have become an important part of the armamentarium for root canal treatment. They are increasingly used by generalists and specialists to facilitate the cleaning and shaping of root canals [12].

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Compared to stainless steel hand instruments - the use of which is difficult because of the complicated techniques and the need of many instruments - the Ni-Ti rotary files are more standardized and allow a more uniform preparation [11].

The rotary file systems apparently have more advantages than their *old brothers* which puts them in first place when choosing the right instrument for shaping the root canals [13].

Ni-Ti systems differ from each other in their design, like their cutting angle, number of blades, tip design, conicity and cross-section. These characteristics influence their flexibility, cutting/cleaning efficacy, the torsional resistance and the performance of the instruments in curved and narrow root canals [14].

Choosing the adequate file system and shaping technique is very important especially in periapical infections. A poorly chosen instrument or technique can lead to errors in different stages of the endodontic treatment. One of the most common errors which occur during cleaning and shaping is the apical (canal) transportation [6].

According to the *American Association of Endodontists*, canal transportation is defined as the removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation. Apical (canal) transportation may lead to the appearence of other unwanted procedural accidents, such as ledge formation or perforation of the root canals [15].

The aim of this study was to evaluate on simulated curved root canal models the cleaning efficiency and the apical transportation of three of the most used Ni-Ti rotary file systems: ProTaper (DentsplyMaillefer), K3XF(Sybron Endo) and HyFlex (Coltene Endo) compared to the conventional stainless steel hand K-files (Dentsply Maillefer).

Experimental part

Materials and methods

In our study we used forty root canal models S4 series, U1- with a canal curvature of 30 degrees, marked with a red paint inside of a transparent plastic block, produced by the Japanese Nissin Dental. The root canal models can be used in endodontic area as training methods for practicing the opening of pulp chamber, root canal enlargement, root length measurement or root canal filling (fig. 2).

Fig. 2. The root canal model S4 series, U1 (Nissin Dental, Japan)

The simulated canals used in this study, were divided randomly in four groups, which were enlarged by utilization of four different file systems, as follows (fig. 3):

Fig. 3.The file systems used in the study: K-file, Hy Flex, K3XF and ProTaper (first, the patency of the simulated canals was controlled using an ISO number 10 K-file)

- the first group of ten simulated canals was prepared using hand files: K-file (DentsplyMaillefer);
- the second group using the HyFlex rotary files (Coltene Endo);
- the third group using K3XF (Sybron Endo);
- the fourth group using the ProTaper system (Dentsply Maillefer).

The simulated canals were prepared by the same operator, using the step-back technique in the first group and by following the guidelines of each producer in the other three groups. The last hand file used was an ISO number 40 in the first group. In the second and third group rotary files size 40 and taper .04 were used for shaping. In the fourth group the ProTaper system was used in the recommended sequence up to file F4 (40.06) to shape the simulated canals. Rotary files were used at 300 rotation/min . Distilled water was used to irrigate the canals.

Photographs were taken from each simulated canal after root canal preparation in fixed position using a Sony a6000 camera. The pictures were then imported in the Adobe Photoshop software and three reference areas were designated on each canal. The reference areas were chosen to analyze the cleaning efficacy of the different file systems at different points of the root canals: close to the apical foramen (A-1 mm from the apex), in the maximum curvature (B-5 mm from the apex) and at the middle/coronal third of the root canal (C-15 mm from the apex). The aim was to determine which file system is the most effective at which area of the root canal during shaping (fig. 4).

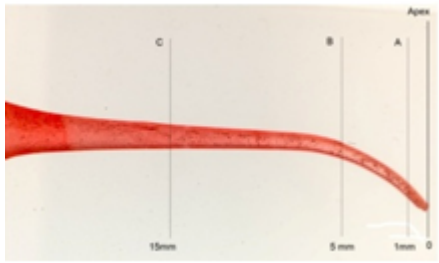

Fig. 4. A photograph of a simulated root canal with the three reference areas

Subsequently the previously saved pictures were imported in the ImageJ- a Java-based image processing program developed at the National Institutes of Health- which makes possible to solve many image processing and analysis problems, such as multiple imaging system data comparisons. We used this programe in our study in order to obtain the pixel count of a selected area. Thus we could select the prepared surface of the canal (white area) and count its' pixels and compare it to the whole root canals' number of pixels. Using the obtained values we calculated the percentage of the cleaned area. This operation was made for each canal and for each reference area of every canal, in the reference areas, all the time the same sized rectangle was cropped and saved as a new picture.

The apical transportation was measured on each simulated canal in each group using the latest generation of optical microscope Vision Swift Duo with 20x magnitude and the values were stated in mm. The torsion of the edge was measured between the axis of the canal before penetration and the axis of the cleaned canal.

The means of the obtained values in the four groups were compared to each other and statistical analysis was performed using ANOVA test and Bonferroni's Multiple Comparison Test. Statistical significance level was set at a value of $p<0.005$.

	K-file Dentsply Maileffer	HyFlex Coltene Endo	K3XF Sybron Endo	Pro Taper Dentsply Maileffer
Total	49.80%	62.99 %	39.30 %	58.05 %
A	46.41 %	57.21 %	28.29 %	37.15 %
B	64.55 %	70.00 %	68.63 %	55.36 %
C	22.92 %	69.11 %	39.06 %	80.14 %

Table 1
THE CLEANED AREA IN THE WHOLE LENGTH OF THE ROOT CANAL AND AT THE THREE REFERENCE AREAS

Results and discussions

After shaping the root canal models by using the four file systems, the found results stated in percentages are presented in iable 1.

At the first reference area (A) set at 1 mm from the apex significant differences were found between the four groups (fig. 5).

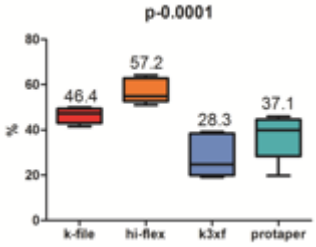

Fig. 5. Statistical analysis at 1 mm from the apex

Using Bonferonni's Multiple Comparison Test, significant differences were found between the first (K-file) and the third (K3XF), the second (Hy Flex) and the third (K3XF) and the second (Hy Flex) and the fourth group (Pro Taper).

At 5 mm from the apex (B) the statistical analysis showed no differences between the four groups (fig. 6).

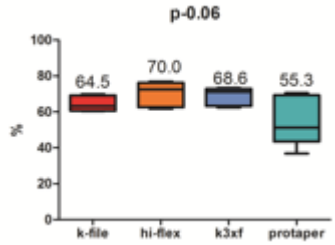

Fig. 6. Statistical analysis at 5 mm from the apex

The highest mean was found in the second group, where the canals were cleared using the Hy Flex system (Coltene Endo) compared to the lowest mean found in the fourth group where the Pro-Taper system (Dentsply, Maillefer) was used.

At 15 mm from the apex (C) of the simulated canals the differences between the four groups were significant (fig. 7). Each group was significantly different from the other.

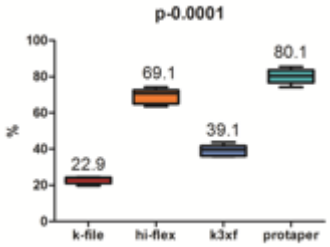

Fig. 7. Statistical analysis at 15 mm from the apex

When analyzing the cleaning efficacy in the whole root canal the highest means were found in the second and fourth group-with the Hy Flex and the Pro Taper systems used for preparation (fig. 8), the only group-pair where no significant difference appeared according to Bonferonni's test.

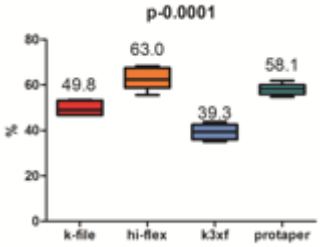

Fig. 8. Statistical analysis of the cleaning efficiency of the four file systems in the whole length of the root canal model

The other groups had significantly smaller mean values (fig. 9).

The apical transportation average values, expressed in millimeters are presented in table 2.

According to Bonferonni's Multiple Comparison test and to the performed statistical analysis, the results were statistically significant between the second group, where canals were shaped using the HyFlex system and the other three groups (K-file, K3XF and Pro Taper) (fig. 10).

One-way analysis of variance			
P value	< 0.0001		
P value summary	***		
Are means signif. different? (P < 0.05)	Yes		
Bonferroni's Multiple Comparison Test	Mean Diff.	Significant? P < 0.05?	Summary
k-file vs hi-flex	-13,19	Yes	***
k-file vs k3xf	10,50	Yes	**
k-file vs protaper	-8,242	Yes	*
hi-flex vs k3xf	23,69	Yes	***
hi-flex vs protaper	4,950	No	ns
k3xf vs protaper	-18,74	Yes	***

Fig. 9. Results of Anova Test and Bonferonni's Multiple Comparison Test in the whole length of the root canal

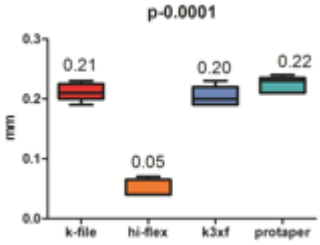

Fig. 10. Results of the statistical analysis

Comparing the cleaning efficiency of the file systems according to the whole root length, we found statistically significant differences between the studied groups. The HyFlex and ProTaper systems shaped the simulated root canals in a considerably higher percentage- almost 63 % and 59 %- compared to the hand files (49%). K3XF shaped the whole length of the root canal only in 39 %.

At the three defined reference areas the used file systems showed different ability of shaping the canals. In the coronal third of the root (at 15 mm from the apex) the most efficient file system was the ProTaper (almost 80%), followed by HyFlex. The stainless steel hand files cleaned only 23% of this area. At 5 mm of the apex, which was the second

	K-file	HyFlex	K3XF	ProTaper
Apical transportation	0.21	0.05	0.20	0.22

Table 2
APICAL TRANSPORTATION VALUE IN THE FOUR GROUPS

reference area, situated in the maximum curvature of the simulated root canal model, we found no statistically significant differences between the cleaning efficacies of the four file systems. The last reference area was set at 1 mm from the apex, where the HyFlex system had the highest cleaning efficacy (57.2%), followed by the K-file. The other two rotary file systems cleaned the area in a lower percentage- K3XF in only 28.3 % and ProTaper in 37.1 % and transported the canal significantly.

Our results are comparable to what others found in similar studies [16].

Considering the obtained results towards the used file systems for shaping the whole root canal length and at the other two reference areas, set in the maximum curvature of the root canal and in the coronal third, the HyFlex and ProTaper system showed better results than the other rotary file system, the K3XF and the hand K-files. This suggests that rotary files are more efficient in cleaning the root canals. Thus by using hand K-files similar results can be obtained as by using several rotary file systems [6,13].

The appearance of the Ni-Ti file systems represented a big step forward in endodontic treatment. The shaping technique of the root canals became easier and the time needed for treatment shortened considerably [5]. As well as advantages, these systems also have some disadvantages. The files are more flexible than the conventional hand files manufactured from stainless steel. Although the increased flexibility is an advantage, in curved root canals these files have the tendency to straighten-so the apical zone of the root canal could remain inefficiently cleaned and apical transportation can be produced [17].

The less apical transportation was produced by the HyFlex system compared to the other three groups [18,19].

Our results obtained in vitro on simulated root canals with a curvature of 30 degrees demonstrated the same tendency to transport the canal in case of two of the most used rotary file systems: K3XF (0.20 mm) and ProTaper (0.22 mm). These results were almost similar to the canals prepared by using hand K-files (0.21 mm). The obtained data is comparable to the data found in other studies.In root canals with a similar curvature as the used simulated canals (30^0) Yang et al. [20], found a canal transportation of 1.20+/- 0.74 mm in case of ProTaper, Schafer et al. [21] 2.84+/- 2.40 mm in case of K3 and Guelzow et al. [22], a 0.7+/- 0.9 mmwhen using stainless-steel hand files. The HyFlex system turned out to be the most efficient in cleaning the apical zone of the curved root canals, apical transportation being only 0.05 mm. These results are similar to these of Zhao et al [23] and Saber et al [19].

In our study the most efficient system turned out to be the HyFlex rotary files by presenting the highest mean when analyzing the cleaning efficacy at the reference area set at 1 mm from the apex and the lowest when evaluating the value of canal transportation. According to the results in curved canals the use of the HyFlex system should be preferable instead of the K3XF and ProTaper rotary systems and the conventional stainless steel K-files.

Hand files remain in shadow compared to rotary file systems, mainly because of the more complicated and time consuming preparation technique. The efficiency of cleaning the root canals is almost the same in case of stainless steel files as in case of the Ni-Ti systems [17]. The described technique is comparable to techniques used in other similar studies [24,25].

After Shen et al. [11], the mechanical properties of the Ni-Ti alloy can be improved by altering the microstructure via cold work and heat treatment. Therefore, new Ni-Ti endodontic files with superior properties can be developed through special thermomechanical processing, which is a metallurgical process that integrates hardening and heat treatment. The performance and mechanical properties of Ni-Ti instruments are influenced by factors such as cross-section, flute design, raw material, and manufacturing processes. Many improvements have been proposed by manufacturers during the past decade to provide clinicians with safer and more efficient instruments [12].

Endodontic retreatment is a procedure that removes the filling materials from the root canals followed by their cleaning, shaping and obturation [26].

There is a wide variation of results among endodontic solvents tested in the literature. This happens because there is not a standard model to perform the tests; each author is establishing the materials that will be tested, interval of time, temperature and the devices used to measure the results, by using his own criteria [6,14].

The researches of Boariu et al [27], referring to the comparative analysis of samples after the retreatment of the root canal, showed that almost all the samples retreated with two different Ni-Ti rotary systems (ProTaper Universal and K3 Endo), and Gates Glidden burs combined with hand K-files in a crown-down technique, with or without the association of Eucalyptol, demonstrates that at the present time, no retreatment method allows a complete removal of the root canal filling material from the endodontic space.

During endodontic therapy, an important desirable effect of treatment is to induce periapical recovery, repair of periradicular tissues, and stimulation of osteogenesis and of cementogenesis [28,29].

Conclusions

Although some rotary file systems are more efficient in cleaning the root canals, hand files still remain a good alternative during endodontic treatment.

Rotary files can be preferred mainly because the simplicity of the techniques and the shorter time needed for shaping the canals.

The most obvious difference was noticed in the value of the produced apical transportation between the K3XF and ProTaper systems compared to the HyFlex system in the curved root canal models.

This is the reason why a good clinician should always take into consideration the canal anatomy when choosing the adequate rotary file system.

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