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Properties of Mechanical Endodontic Instruments and the Quality of the Simulated Canal Preparation

Właściwości narzędzi maszynowych a jakość opracowania kanałów symulowanych

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A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation; D – writing the article; E – critical revision of the article; F – final approval of article

Abstract

Background. Successful root canal treatment is associated with correct canal preparation. The quality of mechanical preparation depends on many factors. Researchers are still looking for the optimal methods and instruments for this purpose.

Objectives. The aim of the research project was to analyze the structure and work of mechanical files and the effect of simulated canal preparation with a single curvature.

Material and Methods. The study involved the reciprocal files: WaveOne[®] (Dentsply Maillefer) and Reciproc[®] (VDW) and the rotary file ProTaper Next[®] (Dentsply Maillefer). The study used 30 resin blocks (Endo-Training-Bloc[®], Dentsply-Maillefer) of the artificial canals with a single curvature (ie. L-type canals). Photographs were taken before and after preparation. Using computer images were imposed on and measurement points set. The amount of material removed was determined as the distance between the measuring point and the wall of the canals after the preparation.

Results. The greatest mean changes in the working length were observed in the group Reciproc, the smallest in the group ProTaper Next. The highest average amount of material in all groups was removed from the inner wall of the central part of the canal. The greatest value was achieved in the WaveOne group. The lowest value was obtained in the group Reciproc. The best canal centralization was obtained at 8 mm from the apical foramen, the worst at 5–6 mm.

Conclusions. The tested instruments prepare simulated canals in a satisfactory manner, but do not provide optimum results. Therefore, preparing the canals of complex anatomy with a large file and a large taper carries the major risk of complications. Comparison of WaveOne, Reciproc and ProTaper Next system based on a sequence of files showed statistically significant differences (Dent. Med. Probl. 2016, 53, 4, 476–482).

Key words: mechanical instruments, simulated canals, canal centralization.

Słowa kluczowe: narzędzia maszynowe, kanały symulowane, centralizacja kanału.

The development of modern endodontics has caused the appearance of new machine instruments on the dental market for the preparation of root canals. They are mainly characterized by diminution of the instrument sequence, as well as a shortened amount of time needed to widen the canal. Endodontic treatment can, therefore, be more comfortable for both the patient and the dentist. From clinical experience, mechanical canal preparation is much easier and faster than

working with hand files. Canal widening takes just minutes; however, this does not mean that this stage of preparation is considered to be complete. The saved time may be used to begin irrigation by ultrasonic instruments, resulting in a better cleaned canal system. In the case of straight canals, after short mechanical preparation, the dentist may proceed to the chemical part of the treatment that is appropriately prolonged. A cone tapering from the pulp chamber to the apex is

the most desired shape of the canal. Preparation of curved canals is performed by files previously bent according to the canal curvature or by flexible files which adjust to the natural shape of the canal. Failure to comply with these rules leads to straightening of the canal and the creation of the so-called periapical aberration. According to Peters et al. [1], a variety of root canal anatomy has a greater impact on the changing shape of the canal during the preparation than the choice of instruments.

The aim of the study was to analyze the relationship between the construction of various machine instruments, their performance and the result of the simulated canal preparation with single curvature.

Material and Methods

The study involved WaveOne[®] (Dentsply Maillefer) and Reciproc[®] (VDW) reciprocating files, as well as the rotary ProTaper Next[®] system (Dentsply Maillefer) (Fig. 1). Thirty resin blocks (Endo-Training-Bloc, Dentsply Maillefer) with hollow canals containing a single curvature (L-shaped canals) were used in the study, according to the method developed by Dummer et al. [2]. Depending on the machine instrument, three groups of 10 blocks were created. In the first group, canals were prepared with WaveOne Primary files, canals in group 2 they were prepared using Reciproc R2 5 files, while in group 3, ProTaper Next files X1 and X2 were used. A Silver[®] (VDW) micromotor and an Xsmart PLUS[®] handpiece with a 6 : 1 reduction (Dentsply Maillefer) were applied. Prior to preparation, blocks were numbered from 1 to 10 by a diamond drill turbine. A single operator us-

Fig. 1. Instruments: WaveOne Primary, Reciproc R2 5 and ProTaper Next X1 and X2 files

ing all the files only once prepared all the canals. Before establishing the working length, the canals were filled with black ink (Astra SA). Blocks with filled canals were photographed with Canon EOS 600D[®] using TAMRON[®] AF 18200 mm f/3.56.3 Di II LD Aspherical (IF) MACRO Zoom Lens with MeiKe Extension Ring with length adjustment. Before taking photographs, blocks were fixed on a negatoscope. After each use, the file was cleaned from chips and each canal was irrigated using 5 mL of water. After the preparation, blocks were fixed in an identical position and photographed. Images were recorded in the JPEG files at a resolution of 72 × 72 dpi. A total of 60 images of blocks with L-shaped canals were taken. When all the images were completed (before and after the canals were prepared), they were superimposed onto each other using GIMP 2.8.6. This program adjusts image fixed elements allowing for precise placement of one image onto another. Thirty superimposed images of L-shaped canals were obtained in total (Fig. 2).

After the images were superimposed by means of a computer program, measuring points were determined. They were obtained by drawing circles centered on the apex of the canal before the preparation. The first circle had a radius of 1 mm and each subsequent circle was 1 mm larger. Ten obtained circles provided 10 measuring points on the inner and outer wall of the ca-

Fig. 2. Before and after canal preparation photographs

Fig. 3. Measurement of material removed from canal walls

nal. Measuring points were located at the intersections of circles and the canal walls before and after the preparation. The amount of the removed material corresponded to the distance between the measuring point and the wall of the canal after the preparation. Measurements were carried out perpendicularly to the canal wall before preparation. The method of determining the measuring points was proposed by Schäfer and Lohmann [3]. The results were presented using Microsoft Excel.

Evaluation of the canal preparation started with the estimation of the working length using an endodontic ruler before and after preparation at a magnification of $\times 3.7$ to the nearest 0.25 mm. The amount of the removed material was measured in 18 measuring points on the inner and outer canal wall. The perpendicular line was drawn from each measuring point to the canal wall after its preparation. Then it was measured in a computer program at $\times 400$ magnification of the image to the nearest 0.01 mm. The amount of the removed material on the inner wall of the canal was determined as M1 and the outer wall as M2 (Fig. 3).

The centering ability signifies such a way of the canal preparation, which allows the file to be placed along its long axis. It is expressed by the formula $M1 : M2$, which is a quotient of the amounts of the material removed on the opposite sides of the canal (expressed in millimeters). A value equal to 1 was considered to indicate perfect centralization and values approaching 0 indicated the weakest centralization [4] (Fig. 4).

To elaborate on the collected data, descriptive and statistical inference methods were used. The Mann-Whitney test was used to compare two independent samples. In order to compare the frequency of particular characteristic varieties in the study groups, the χ^2 test was applied. To compare a few independent groups, the Kruskal-Wallis test,

Fig. 4. View of ideal centralization in the apical area in L-type canal (Reciproc group)

a nonparametric equivalent analysis of variances for the single classification, was used. In order to compare several dependent samples, the Friedman test, which is an equivalent to the non-parametric one-way analysis of variance for repeated measurements, was applied.

Results

The shortening of the working length (WL) occurred the least often in the ProTaper Next group (fraction 0.20). In contrast, it most frequently appeared in the Reciproc group (fraction 0.6). Despite the fact that in each group the means differed considerably (Table 1), those groups did not differ significantly in the distribution of the results or in the value change ($p > 0.05$). The highest mean amount of material in the L-shaped canals in all groups was removed from the inner wall of the central part, i.e. at a distance of 4–7 mm from the apex. The highest value was achieved in the WaveOne group (0.433 ± 0.115). The lowest value was obtained in the Reciproc group (0.373 ± 0.067). In the periapical part (1–3 mm), ProTaper Next files obtained the lowest mean value (0.100 ± 0.043) (Table 2).

Table 1. The average loss of the working length in L-type canals

Groups	The average loss of the working length (mm)
	L-canals
WaveOne	0.175 ± 0.206
Reciproc	0.275 ± 0.275
ProTaper Next	0.075 ± 0.169
Comparison	$H = 3.710; p > 0.05$

Table 2. Amount of material removed from the inner wall L-type canals in WaveOne, Reciproc and ProTaper Next groups

Distance from the apical foramen (mm)	Groups								
	WaveOne			Reciproc			ProTaper Next		
	x	Me	SD	x	Me	SD	x	Me	SD
1	0.093	0.088	0.024	0.100	0.101	0.047	0.086	0.081	0.023
2	0.103	0.101	0.024	0.133	0.126	0.046	0.089	0.091	0.016
3	0.130	0.129	0.026	0.198	0.197	0.042	0.126	0.106	0.064
4	0.297	0.329	0.071	0.321	0.315	0.037	0.284	0.282	0.070
5	0.484	0.532	0.086	0.420	0.424	0.048	0.446	0.437	0.040
6	0.522	0.548	0.086	0.417	0.416	0.048	0.461	0.459	0.057
7	0.430	0.446	0.072	0.33p3	0.324	0.061	0.377	0.376	0.065
8	0.346	0.353	0.054	0.262	0.263	0.046	0.312	0.314	0.064
9	0.274	0.269	0.048	0.232	0.231	0.060	0.262	0.271	0.058
10	0.226	0.219	0.043	0.221	0.227	0.062	0.229	0.235	0.062

Table 3. The comparison in amount of material removed from the inner and outer canal wall in WaveOne, Reciproc and ProTaper Next groups

Group	Canal wall						Value test z	p-value
	inner			outer				
	x	Me	SD	x	Me	SD		
WaveOne	0.290	0.278	0.158	0.252	0.251	0.081	1.212	p > 0.05
Reciproc	0.264	0.266	0.115	0.194	0.180	0.074	3.280	p < 0.01
ProTaper Next	0.267	0.281	0.141	0.225	0.213	0.096	1.456	p > 0.05

On the outer wall of the canal in all groups, the least amount of material was removed within 4–7 mm from the apical foramen. The lowest mean was observed in the Reciproc group (0.139 ± 0.052). No statistically significant difference in the amounts of the material removed on the inner and outer wall of the canal was found in the WaveOne and ProTaper Next groups. However, in the case of the Reciproc group (Table 3), significantly more material was removed from the inner side than the outer one ($p < 0.01$).

Analyzing the distance from the apical foramen, it was observed that the use of the Reciproc files resulted in the most uniform material re-

moval on both canal walls. This mainly concerns the first three millimeters of the L-shaped canals.

Analysis of the results relating to the centralization of L-shaped canals in the WaveOne, Reciproc and ProTaper Next groups showed that the mean value = 1 was noted at a distance of 8 mm from the apical foramen. The means differing greatly from 1 were recorded at the distances of 5 mm and 6 mm (Fig. 5). The comparison of the canal centralization in the study groups showed statistically significant differences in the three measuring points. They were observed within 2 mm, 3 mm and 4 mm from the apex (Table 4).

Fig. 5. Centralization in L-type canals

Table 4. The comparison of canal centralization in WaveOne, Reciproc and ProTaper Next groups

Distance from the apical foramen (mm)	Value test H Kruskal-Wallis		Group comparison in pairs					
			WaveOne and Reciproc		WaveOne and ProTaper Next		Reciproc and ProTaper Next	
	H	p	z	P	z	p	z	p
1	0.814	0.666	–	–	–	–	–	–
2	8.495	0.0143	2.388	p > 0.05	0.254	p > 0.05	2.642	0.0248
3	16.140	0.0003	3.632	0.0008	0.330	p > 0.05	3.302	0.0029
4	7.249	0.0267	2.692	0.0213	1.346	p > 0.05	1.347	p > 0.05
5	4.199	0.123	–	–	–	–	–	–
6	1.365	0.505	–	–	–	–	–	–
7	0.612	0.737	–	–	–	–	–	–
8	0.405	0.817	–	–	–	–	–	–
9	0.281	0.869	–	–	–	–	–	–
10	2.557	0.278	–	–	–	–	–	–

Discussion

The common conviction that machine systems afford comfort in preparing a root canal and also fears on the part of clinicians associated with complications have prompted the authors of the present study to analyze the impact of machine instruments on the resulting shape of the canals. While reviewing the available mechanical systems on the market, the authors focused their attention on the innovative methods suggested by the manufacturers of dental instruments, which would facilitate the treatment procedure, ensure safety and save time. The choice of the research topic, therefore, resulted from the willingness to exclude factors that reduce the prognosis of root canal treatment at the stage of preparation.

The causes of complications during canal preparation include insufficient access to the canal, which may hinder the control of the working length [5, 6]. Straightening of the canal that leads to shortening the working length may also be related to the lack of clinical experience [7] or too much pressure exerted on the instrument during preparation [6]. While examining the correlation between the instruments and the so-called canal transportation, the material the instruments are made of, their properties, cross-section [8], the presence of acute tip [6], the technique of the root canal preparation [8–11], and the canal anatomy (curvature angle and radius) should be considered.

Choosing instruments with suitable characteristics can eliminate some of the above-mentioned factors. Tested files are made of the same alloy (a nickel titanium alloy, modified in M-wire technology) and have the same diameter at the apex (0.25 mm). In addition, all canals have been

prepared by one operator specializing in endodontic treatment. The used blocks, which have standardized simulated canals, are suitable for comparative studies [12].

Preparation canals with a single curvature by instruments with a different type of movement and cross section affects the working length. The most shortened WL occurred in the Reciproc group. The largest reduction in the WL (about 0.75 mm) also occurred in this group. The original WL was most often maintained in the ProTaper Next group. A large taper of reciprocal files reveals a greater tendency to straighten the canal, and thus shortening the WL (L-canals). A smaller taper of ProTaper Next file could allow the canal to be prepared according to its original shape. Other causes of the WL loss may be associated with a wrong determination of WL by the endodontist. Worn out files with improper cutting ability of the canal walls and the use of instruments with a larger diameter of the tip may cause changes in the WL [13]. This is also observed in other studies [14].

Suitable cleaning of the apical region, while maintaining the original distance, in the case of curved canals, is a challenge for dental practitioners. Numerous discussions on this subject have inspired investigators to search for techniques to prepare canals that overcome the problems associated with the canal curvature [15, 16], the presence of deltas, canal straightening [17, 18] and complications in the form of aberration. Such complications weaken the therapeutic prognosis. Canal deformation results from the rigidity of the files, as well as the cross-sectional shape or canal system anatomy.

The amount of the removed material has been found to be the highest on the inner wall of the canal in its middle part. This is consistent with other

studies [19, 20]. This result could mean that some parts of the canal are cleaned too poorly, or others are overprepared, which is a result of file stiffness; in clinical conditions this can lead to the weakening of the root structure. The study shows that the preparation of the apical area in the L-shaped canals is the weakest by using the sequence of ProTaper Next files. Therefore, it should be considered whether the preparation can be finished with the use of the X2 file. According to Kerekes and Tronstad [21], the mean size of the physiological apical foramen is 0.30–0.35 mm. Its widening to larger sizes in order to remove infected dentin seems to be reasonable. Furthermore, due to the fact that $59.6\% \pm 14.9\%$ of oval canal walls remain intact despite widening them to the size of ProTaper # 4, the use of larger files should be considered [22]. According to the principle of saving tissues and protecting the root structure against fracture, the canal preparation to the size of 25 or 30 seems to be worth considering. In compliance with Haikel et al. [23], the preparation to size 25 eliminates microorganisms from the surrounding periapical tissues. The manufacturer of the examined files indicates that the choice of the file size depends on the primary apical diameter and shape of the physiological curvature of the canal. The study has, therefore, concluded that the cross-sectional shape, a different type of the file movement in the canal or a smaller taper of the ProTaper Next file contributed to the smaller loss of the WL, as well as a smaller amount of the material removed in the apical area.

According to Aydin et al. [24], differences in the structure of files affect the cutting ability. These include the distance between the coils as well as the positive cutting angle. The results of the study by Bürklein et al. [25], which were confirmed by Hülsmann et al. [26], show that a positive cutting angle (adequate for Mtwo and Reciproc) scrapes off the dentin chips without leaving them on the canal walls. Additionally, the S-shaped cross section of files provides a large space for the transport of chips from the apex. ProTaper and WaveOne instruments have radial contact surfaces rather than sharp cutting edges. According to the results of various studies, they contribute to rubbing den-

tin chips into the canal wall, thereby increasing the amount of the smear layer. Moreover, a large cross-section leaves little space for the drainage of debris [25]. The authors of comparative studies of BioRaCe and Reciproc instruments speculate that the BioRaCe files increased flexibility is the reason for its reduced transportation. They do not preclude the possibility of the effect of two very sharp cutting edges of the Reciproc file [27] on the results. Greater flexibility of BioRaCe files may result from their different cross-sectional shape [27, 28].

The comparison of the L-shaped canal centralization in the WaveOne, Reciproc and ProTaper Next groups showed statistically significant differences in the three measuring points. The Reciproc file obtained the best results in two points, while the WaveOne file had the best result in one point. It should be also noted that the overall results of centralization, however, were far from ideal. In other studies, the results of centralization are different from those obtained in our study [29]. This is probably due to the use of files with a variable taper, which is confirmed by Pasterniak-Júnior studies [30], in which RaCe files achieved the mean values ranging from 0.39 to 0.64, depending on the distance from the apical foramen. Canals were prepared by a sequence of files of different taper (from 10% in the orifice up to 2% in the apical area) with the crown-down technique. According to Paqué et al. [31], better centralization is related to the file construction, including constant taper, as well as its low value.

We conclude that the differences in the structure and movement of the files in the canal affect the obtained preparation shape. Tested instruments ensure simulated L-shaped canal preparation in a satisfactory manner; however, they do not provide optimum results. The concept of one file with a high and variable taper carries the risk of weaker centralization. The stage of mechanical preparation of root canals, which influences the therapeutic prognosis, is an essential part of the endodontic treatment. The search for the best method is still in progress. Therefore, the new machine systems require comparative studies, in which the advantages and disadvantages of their use can be determined.

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