Analysis of Apical Transportation and Canal Centering Ability During Root Canal Preparation by Using Cone-Beam Computed Tomography (in Vitro Study)

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Abstract

Objective: One of the goals of root canal preparation is to clean and shape the root canal system while maintaining the original configuration. So, it is essential to keep the instruments centered on providing a correct enlargement, Canal transportation is a common sequel caused by instrumentation, the purpose of this study was to evaluate the canal shaping efficacy of WaveOne® Gold, NiTiflex, and a stainless-steel K-files by CBCT.

Methods: Sixty extracted curved single root premolars were selected, from Shorsh dental center and private clinic and divided into three equal groups. Before preparation, all samples numbered and scanned by CBCT. Then, the first group (n=20) were prepared with WaveOne Gold rotary file, the second group (n=20) were prepared by NiTiFlex hand file, and the third group (n= 20) were prepared by stainless steel files. Canal transportation and centering ability before and after root canal shaping assessed using CBCT and Adobe Photoshop CS3 Extended. The amount and direction of canal transportation in the apical third of each instrument determined in three axial sections of 2mm, 3mm, and 4mm from the apex, while the centering ability of each instrument determined in 5 axial sections of 2mm, 4mm, 6mm, 8mm, and 10mm from the apex. The three groups were statistically compared using one way ANOVA test.

Results: It was reviled that there were no statistically significant differences in the magnitude of canal transportation between three groups ($p > 0.05$) at 2 mm, 3 mm as well as 4 mm from the apex, while in group one (WaveOne Gold) showed significantly lower mean canal transportation as compared to other two groups. The centering ability was statistically significant in 2 mm axial section, WaveOne Gold had better-centering ability than NiTiFlex and Stainless steel hand file. While in other sections the difference was non-significant.

Conclusions: The difference between the three groups was non-significant regarding transportation, while in apical part WaveOne Gold has better-centering ability than the other two groups.

Keywords: *Apical transportation, Centering ability, CBCT, Waveone gold.*

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Introduction

Root canal treatment considered as the most widely accepted treatment modality for pulpally involved teeth. Successful endodontic therapy depends on many factors. The most critical step in any root canal treatment is root canal preparation. Root canal preparation is not only important but also demanding for the clinician. A uniform taper with increasing diameter from the endpoint to the orifice is required to obtain the desired clinical outcome[1].

Maintaining the original shape of the canal is also essential; otherwise, canal aberrations such as transportation will be created. However, severely curved canals or multiple curved root canals are challenging situations, especially with traditional hard instruments made of stainless steel[2]. Where the file try to deviate from the original axis of the canal, and the root canal treatment in this situation is more challenging and lead to the production of errors[3].

As the need for trying to reduce procedural errors, rotary Nickel-Titanium instruments have introduced to the market, which considers as an important innovation in endodontic treatment[4]. It has many advantages when compared with stainless steel instruments, NiTi instruments follow the original canal axis and less procedural errors are create, maintain working length during preparation, allow the preparation to be more centered, better tapered with reducing instrumentation time[5].

Different types and design of rotary NiTi instruments introduced to the market with different properties like cutting angle, cross-section, helical angle, flutes, radial grooves, and edge, over the previous years. In 2011, WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) was announced as a single-file technique[6], followed by a new generation that provides more safety, effortless efficiency, and simplicity. This vastly improved system has been branded as WaveOne Gold.

WaveOne Gold instruments are created by using a new DENTSPLY proprietary thermal process, producing a super-elastic NiTi file. The process of gold finishing done after manufacturing procedure, by heat-treating the ground NiTi files and cooled slowly. From a technical viewpoint, the heat treatment modifies the transformation temperatures, and this has a positive effect on the instrument properties, which produce a file with improved flexibility and strength[7].

Many methods had been used to evaluate the quality of root canal instrumentation, like using conventional dental radiograph, Scanning Electron Microscopy (SEM) and histological sectioning[8,9].

Because of the destructions of the specimens in methods mentioned above and complicated examination of different parameters of root canal preparation assessed in this study. The Cone-beam computed tomography (CBCT) is used as it is a non-invasive diagnostic tool and provide a three-dimensional image with low dose radiation and permits evaluation of detailed images using different settings. It is beneficial to be used for comparing pre and post-instrumentation images for detecting transportation and centering ability of the instruments[10].

The aim of this in vitro study was to evaluate and compare the mechanical preparation of three different file systems: WaveOne® Gold reciprocating file, NiTiflex file, and stainless steel file by assessing apical transportation and centering ability using Cone-Beam computed tomography.

Materials and methods

Seventy-six extracted single root second premolars with fully formed apex and curved root collected from Shorsh dental center and private clinic for the study, teeth extracted for other reasons than for the study. The teeth were disinfected by using 3% sodium hypochlorite (NAOCL) and stored in normal saline solution at room temperature. A periapical radiograph was taken by digital X-ray (HDX, Korea), (exposure time was 0.36 seconds) for all teeth in both mesiodistal and buccolingual direction to exclude the teeth with the presence of any calcified root canals, previous root canal treated, internal and external resorption.

Schnider method was used to determine the degree of root curvature[11], by drawing a line parallel to the long axis of the tooth; the second line drawn from the apical foramen to the point of the first line that leaves the long axis of the tooth, teeth with more than 10° were selected for this study and sixteen teeth excluded from inclusion criteria.The remaining sixty teeth were numbered and randomly divided into three groups of 20 teeth each, which named (group 1, group 2 and group 3).

Standard access cavities made by using round diamond burs and Endo Z bur, with a high-speed handpiece and air-water spray cooling. The working length was determined using #10 and #15 K-Flexofiles, which placed into the root canals until being visible at the apical foramen. The working length set 1mm short of the apex for each sample.

All teeth embedded in acrylic resin by using a cylindrical plastic container. A cylindrical container of approximately 15mm was prepared from a disposable plastic syringe (3ml) which was cut horizontally by using fine diamond disk mounted on contra angled handpiece. A special mold was created with type III dental plaster to standardize the position of the teeth during CBCT image acquisition. Six wood box made with (10 cm x 10 cm x 2 cm), to serve as a template to insert the dental plaster. Both wood boxes and acrylic resin covered with separating medium to facilitate the removing of them, the plaster was mixed and poured into the wood boxes, and ten samples inserted in each template consistently.

After setting of the plaster, the number of each sample wrote in the upper surface of the plaster with the permanent pencil, the line drawn in the buccal surface of the teeth extending to the surface of the plaster to facilitate the positioning of the samples in the correct position[12].

All the teeth were scanned using CBCT (NewTom Giano Verona, Italy) with 90 kilovoltage power, three milliamperes, by using filed of view 8cm by 11cm. Each mold horizontally fitted to chin support in the way that the occlusal plane was parallel to the plate; This was done to confirm standardization of the specimens for the CBCT image before and after root canal instrumentation.

Root canal instrumentation

Group1: WaveOne® Gold Reciprocating file, (Dentsply, Maillefer, Ballaigues, Switzerland), were used for shaping the canals.

Group 2: NiTi K-file (NITIFLEX), (Dentsply, Maillefer, Ballaigues, Switzerland). were used for shaping the canals.

Group 3: pre-curving stainless steel K-file (Dentsply, Maillefer, Ballaigues, Switzerland) were used for shaping the canals.

For all groups, each instrument was used only for the preparation of two canals, and only five canals were instrumented at each time to minimize the operator fatigue. Root canals were irrigated 2 ml of 3% NaOCl (Techno Dent, Greece) solution 3 mm short of the working length after using each file. At the end of the biomechanical preparation %17, EDTA (Spident, Korea) was inserted to the canal for 3 minutes, and the canals were irrigated again with 2 mL 3% NaOCl as final irrigation.

Group 1- WaveOne® Gold Reciprocating file, (Dentsply, Maillefer, Ballaigues, Switzerland)

Twenty teeth prepared with WaveOne® Gold file according to manufactures instructions, before preparation with the wave one gold file, the number 10 K file was inserted to the canal to determine the path of the canal, after that the proglider file was adapted to the x-smart motor and inserted into the canal to determine the patency of the canal. After using the proglider file, the size of wave one gold file determined. In most of the canal, the only primary file was used (size25), after adapting of the file to the x-smart motor and adjusting the setting. The file inserted into the canal with the presence of the sodium hypochlorite with gentle inward pressure in 2 to 3 passes, The WaveOne Gold file engages 150 degrees counterclockwise (CCW) and 30 degrees clockwise(CW), turning 360 degrees after three cycles of reciprocation. When the file reached the working length, it was removed and checked the flutes for dentinal chips to ensure complete preparation.

Group 2 NiTi K-file (NITIFLEX), (Dentsply, Maillefer, Ballaigues, Switzerland)

The second group was prepared with nickel-titanium hand file by using step-back technique as described by Mullaney.

This technique consists of two stages: the first stage is preparing the apical part and determining the master apical file (MAF), while the second stage is preparing the remaining of the canal by stepping back with increasing the size of the file.

The gates glidden bur no.2 and no.3 were used before preparation to pre-coronal enlargement of the canal. After determining the initial apical file (IAF), the canal was prepared by sequence to 3 sizes larger than (IAF). Apical enlargement was made with instrument size up to no. 30 to determine the master apical file, and the canal was stepped back with five files, with the sequence larger file than MAF and 1mm short of the working length. With using the MAF as a recapitulation between the files to ensure the patency of the canal[13].

Group 3- Pre-curving stainless steel K-file (Dentsply, Maillefer, Ballaigues, Switzerland)

The third group was prepared with pre-curving manual stainless steel file by using step back technique as described by Mullaney. The file must be pre-curved before inserting the file into the canal by using an orthodontic plier to adapt the shape of the canal[14].

Image analysis

After instrumentation, the teeth were re-positioned into the plaster block in the same position and post CBCT image were obtained of the teeth with the same parameter as in pre-instrumentation. Both pre and post-CBCT image evaluated using NNT viewer software to determine the apex and the long axis of each tooth.

Five axial sections obtained at 2 mm, 3 mm, 4 mm, 6 mm, 8 mm, and 10 mm and screenshots. The images from pre- and post-instrumentation CBCT images were compared using Version 10.0 Adobe Photoshop CS3 Extended software (Adobe System Inc., San Jose, CA), by using (magnetic lasso tool) to determine the outline of the canal and outline of the tooth for each sample. After that the canal colored with black color and the tooth colored with white color, then the distance from the canal to the outer surface of the tooth in both mesial and distal side was measured by using a ruler tool after image calibration.

Cone beam computed tomography measurement

Evaluation of Apical transportation

The evaluation of apical transportation was followed according to Gambill et al.

The amount of canal transportation was determined by measuring the shortest distance from the edge of the un-instrumented canal to the periphery of the root (mesial and distal) and then comparing this with the same measurements obtained from the instrumented images[15].

For both pre and post instrumentation CBCT, three axial sections obtained at 2mm, 3mm and 4 mm. The images saved to the folder in the computer, The pre- and post-instrumentation images were compared using Version 10.0 Adobe Photoshop CS3 Extended software (Adobe System Inc., San Jose, CA). The following formula was used for detection of transportation at each level for both groups: (m1-m2)-(d1-d2) as shown in Figure 1:

(m1): is the distance from the outer surface of the root to the inner surface of the tooth before preparation in the mesial side.

(d1): is the distance from the outer surface of the root to the inner surface of the tooth before preparation in the distal side.

(m2): is the distance from the outer surface of the root to the inner surface of the tooth after preparation in the mesial side.

(d2); is the distance from the outer surface of the root to the inner surface of the tooth before preparation in the distal side.

0 – means no canal transportation

Value other than 0 means transportation has occurred in the canal

A negative value indicates transportation towards the distal

A positive value indicates transportation towards mesial[15].

Evaluation of centering ability

The evaluation of centering ability was done according to Gambill et al. For both pre and post instrumentation five axial sections were obtained at 2mm, 4mm, 6 mm,8mm, and 10mm images which compared using Version 10.0 Adobe Photoshop CS3 Extended software. The following formula used for the calculation of centering ability at each level for both groups:

(m1-m2) ÷ (d1-d2) or (d1-d2) ÷ (m1-m2)

The smaller number would become the numerator (m1-m2) or (d1-d2) if these numbers were unequal. Using this formula, a result of 1 for the centering ratio would indicate perfect centering[15].

Statistical analysis

The means and standard deviations calculated for three groups. One way ANOVA test was used to determine the difference between groups and the Tukey significant difference post hoc test was performed to find any significant differences between groups. The analysis did with IBM® SPSS® Statistics 24.0 Software (SPSS Inc. in Chicago IL). A P-value <0.05 was considered as the statistically significant level.

Results

Apical transportation

The mean and standard deviation values for canal transportation are presented in (Table 1)

Based on the present study, the apical transportation between three groups (Waveone gold file, NiTiFlex file, and stainless steel hand file) in section 2mm, 3mm and 4mm, was occurred but the difference between them was non-significance.

In section 2mm and 4mm, the degree of canal transportation was high in NiTiFlex and less in Waveone gold. In section 3mm stainless steel showed

high apical transportation and Waveone gold showed less transportation.

The occurrence of apical transportation was less in Waveone gold than the other two groups in section 2mm, 3mm, and 4mm, but in section 2mm and 4mm, the amount of apical transportation was greater in NiTi hand than pre-curved stainless steel file.There were 23 teeth with no deviation, 23 teeth deviation toward the distal

Table 1: Mean of apical transportation (mm) and standard deviation among the groups and root section levels.

Root section levels	WaveOne® Gold reciprocating file	NiTiFlex file	Stainless steel file	P.Value
2mm	-0.025±0.12	0.10±0.215	0.065±0.309	0.271
3mm	-0.010±0.090	0.075±0.305	0.130±0.243	0.182
4mm	-0.045±0.08	-0.20±-.167	0.025±0.183	0.169

Table 2: Canal transportation direction among groups.

Groups	Mesial	Distal	No deviation
WaveOne® Gold	14	23	23
NiTiFlex	25	22	13
Stainless steel	31	23	6

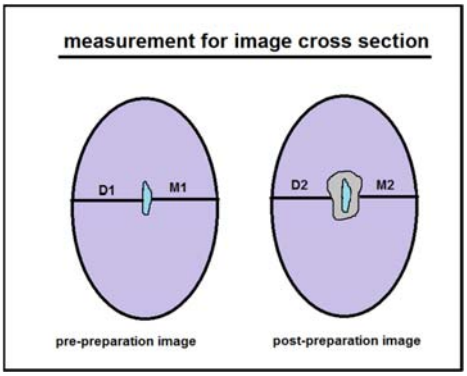

Figure 1: Diagrammatic representation of instrumentation measurement.

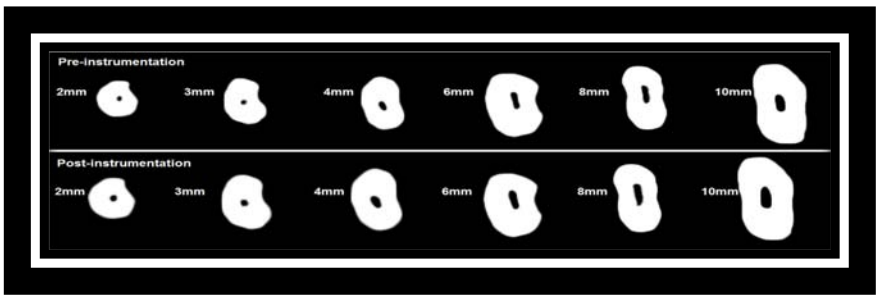

Figure 2: Pre and post-instrumentation CBCT image for WaveOne® Gold reciprocating file at different axial cross-sections.

and 14 teeth toward the mesial aspect in Waveone gold. While in NiTiFlex 13 teeth present with no deviation, 25 teeth toward the mesial aspect and 22 teeth toward the distal aspect. But in stainless steel file only six teeth present with no deviation, 23 teeth transported toward the distal and 31 teeth toward the mesial aspect as shown in (Table 2).

significant. In addition to that, according to Tukey`s post hoc test, the level of significance in WaveOne Gold compared to NiTiFlex was (0.417), and compared to stainless steel was (0.010). So according to this result, WaveOne Gold had better-centering ability in comparison with the other two groups. But in 4mm, 6mm, 8mm, and 10mm axial section the mean and SD of WaveOne Gold were higher and showed better

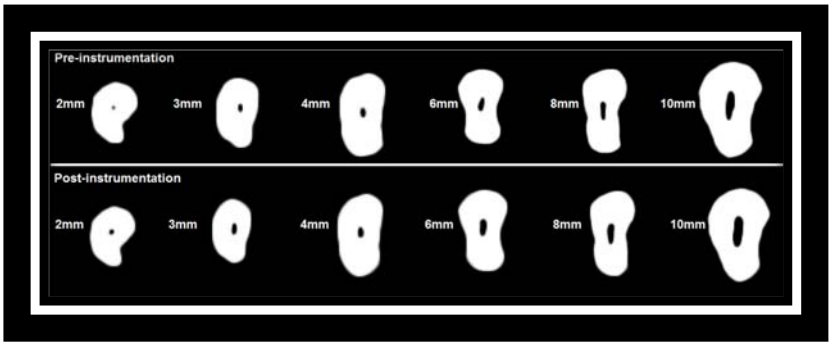

Figure 3: Pre and post-instrumentation CBCT image for NiTiflex hand file at different axial cross-sections.

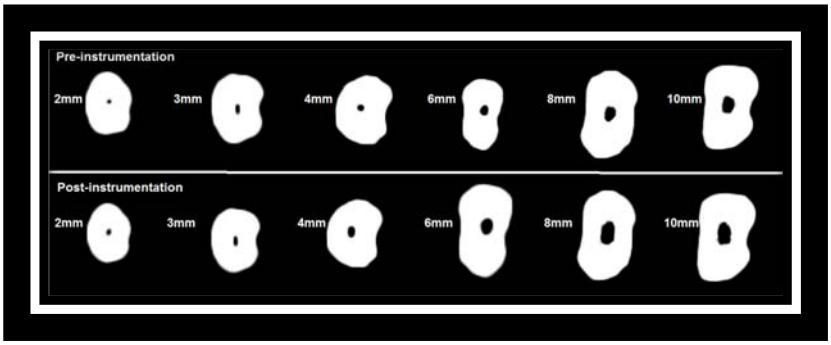

Figure 4: Pre and post-instrumentation CBCT image for Stainless steel K-file at different axial cross-sections.

Table 3: Mean of centering ability (mm) and standard deviation among the groups and root section levels.

Root section levels	WaveOne® Gold Reciprocating file	NiTiFlex file	Stainless steel file	P.Value
2mm	0.652±0.287	0.582±0.323	0.409±0.193	0.018
4mm	0.701±0.226	0.653±0.286	0.655±0.274	0.621
6mm	0.651±0.276	0.567±0.284	0.559±0.293	0.288
8mm	0.732±0.250	0.678±0.311	0.642±0.296	0.675
10mm	0.578±0.244	0.719±0.269	0.705±0.268	0.085

Centeringability: The mean and standard deviation values for centering ratio are presented in (Table 3). Among the three groups, in 2mm axial section, the WaveOne Gold (0.652±0.287) was best centered in the canals than NiTiFlex (0.582±0.323) and stainless steel (0.409±0.193), and the difference was statistically

centering of the instruments followed by NiTiFlex and stainless steel subsequently, but the difference was non-significance.While in 10mm axial section NiTiFlex high centered in the canal followed by stainless steel and wave one gold.

The occurrence of apical transportation was less in Waveone gold than the other two groups in section 2mm, 3mm, and 4mm, but in section 2mm and 4mm, the amount of apical transportation was greater in NiTi hand than pre-curved stainless steel file.

There were 23 teeth with no deviation, 23 teeth deviation toward the distal and 14 teeth toward the mesial aspect in Waveone gold. While in NiTiFlex 13 teeth present with no deviation, 25 teeth toward the mesial aspect and 22 teeth toward the distal aspect. But in stainless steel file only six teeth present with no deviation, 23 teeth transported toward the distal and 31 teeth toward the mesial aspect as shown in (Table 2).

Discussion

The objective of endodontic treatment is to create a tapered form with maintaining the original shape of the canal. Some errors may occur during instrumentation such as transportation, zips, perforation, and elbow formation[16].

Numerous ways used to evaluate the preparation of the teeth with a satisfactory result like radiograph, scanning electron microscope, stereomicroscope and photoshop[17-19]. But the methods that obtain a good result without the destruction of the specimens are preferred like CBCT[20] and micro-computed tomography (MCT)[21]. CBCT can provide a 3D image with a low dose of radiation, also because of the possibility of choosing a smaller field of view (FOV) compared to the medical CT scans, the resulting images have higher resolutions, and therefore are more accurate and have a higher diagnostic capability[1]. In the present study, the apical transportation and centering ability by using three different types of the file evaluated by using Cone-Beam Computed tomography, because the crowns were preserved to simulate clinical situations. Due to the limitations of acrylic resin blocks which show low microhardness and abrasion behavior, natural extracted teeth are more suitable for the assessment of the efficacy of endodontic instruments[22].

The American Association of Endodontists defined canal transportation as: '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; may lead to ledge formation and possible perforation'[23].

Transportation means removing the tooth structure outside the original shape of the canal[24], so it has a direct effect in determining the outcome and result of the endodontic treatment.

Apical canal transportation can lead to the destruction of the apical stop, and extrusion of debris and microorganism, which increase the risk of postoperative pain and failure of endodontic treatment[25].

In the present study, the Waveone gold recorded less apical transportation than two other groups; this may be related to the special characteristics of reciprocating WaveOne system which are M-Wire technology, file design, reciprocating action, single use for each file and the nature of NiTi alloy which has high flexibility when compared with stainless steel instruments[26].

The manufacturing process of WaveOne M-Wire technology stimulates greater flexibility when compared with the conventional stainless steel[27], along with its modified cross-sectional design which results in lower cutting efficiency and less chip space, thus less canal transportation[10,28]. Also, the reciprocating motion promotes higher flexibility and concentricity that contributing to a balanced action motion by repeated clockwise and counterclockwise rotation. This motion allows continuous release of the file when engaged to the inner surface of the root canal during the cutting and shaping procedure leading to a reduction in torsional stress by preventing binding of the file; thereby canal transportation is reduced[29].

Although the Waveone gold recorded less canal transportation, the difference between the three groups was non-significant, may be related to using different methodology, such as the nature and type of the tooth, method of evaluation and technique of instrumentation.

Canal transportation of more than 0.30 mm undesirably affects apical sealing and the outcome of root canal treatment[30], in this study the result of canal transportation was not more than 0.20 mm in all groups, this may be explained by using pre-curving stainless steel file and flexible NiTi file.

Regarding the impact of cervical pre-enlargement by using Gates Glidden drills in stainless steel group, may affect reducing the transportation in the canal because it prevents the excessive thinning of the root canals[31], this reduces the negative effect of instrumentation in endodontic treatment.

Based on the current study, it has concluded that using a pre curving stainless steel file in the curved canal has a positive effect in reducing apical transportation; this may be the explanation why the NiTiFlex produced more transportation than stainless steel file in 2 sections (2mm and 4mm).

In this study, there were 23 sections with no formation of transportation in WaveOne Gold group, followed by 13 sections of NiTiFlex group and 6 sections of stainless

steel groups, This explained by the size diameter of the file in wave one gold that size 25 file (primary file) used in most of the teeth. And regarding the deviations, most of the teeth deviated toward the mesial side and this agrees with the result obtained by Kim Hwang et al.[32], because the distal wall acts in the anti-furcation direction, pushing the instrument, particularly those of larger taper, to the mesial wall, opposed to this curvature.

Nagaraja and Murthy used CBCT to evaluate canal instrumentation by using Ni-Ti K files and ProTaper rotary Ni-Ti instruments; they showed non-significant differences between NiTi K file and ProTaper rotary Ni-Ti instruments regarding transportation in the apical area, which agrees with the result of this study[33].

This study consistent with the results obtained by Madani et al. they used K-Flexofile with passive step-back technique and K3 rotary instruments. The evaluation did by CBCT. They found the non-significant difference between the two groups regarding transportation[20].

Also, our result agrees with the result obtained by Parvathaneni Goel et al. which used stainless steel K-files, hand Ni-Ti, and Ni-Ti rotary files. They found a significant difference between three groups that Apical transportation was found to be greater in stainless steel group than other groups ($P<0.01$)[34].

The result of the current study disagrees with the result obtained by Hartmann Barletta et al. which compared stainless steel K-files, SS K-files coupled with an oscillatory system powered by an electric engine, and ProTaper NiTi rotary system powered by an electric engine. The result showed that the manual technique produced less canal transportation than the oscillatory and rotary techniques, and the result was statistically significant. This result may be related to the using different instrumentation technique (crown down technique) and pre-flaring of the cervical and middle canal thirds[22].

The centering ratio defined as an ability of the instrument to stay in the center of the canal during instrumentation and the dentine removal by the instrument is equally spread.

WaveOne Gold instruments were better than NiTiFlex file and stainless steel K-files when the centering ratio compared, and the difference was significant in 2mm axial section, this result can be clarified by the flexibility of the NiTi instrument, the size of the file and in WaveOne Gold fewer number of the file was used compared to other groups.

While in sections (4mm, 6mm, and 8mm) the difference was non-significant, but the WaveOne Gold had higher mean and better centered than NiTiFlex and a stainless steel file.

In the recent study, The WaveOne Gold group appeared to show less centering ability at 10 mm level when compared to other levels; This could be related to the introduction of such a large rotary file and taper with only the use of size 10 K-file.

Some studies have shown that the centering ratio of rotary Ni-Ti instruments was better than stainless steel files[35, 36]. A safe, non-cutting tip allows the instrument to move properly in the canal and, importantly, to remain centered within it[37].

In the study to evaluate centering ability by using three different types of files (SS Flexofile K-files, NiTi Mity K-files, and NiTi NitiflexK-files) the authors conducted that the NiTiflex had better-centering ability than other groups which agree with the result of the current study than NiTiflex better in centering ability than SS file[38].

In another study, NiTiflex compared with stainless steel file for centering ability, the result showed that NiTiflex better centered in the apical part of the canal than SS which agrees with the result of the current study that NiTiflex has better centering ability at 2mm axial section[18].

There were no research articles that compared WaveOne Gold reciprocating file with Stainless steel or with NiTiFlex file, so it is difficult to compare WaveOne Gold file in this study with other studies. In addition to that, many studies used Wave One Gold file to instrumentation and compared it with other rotary files.

In the study, Barbosa-Ribeiro Albergaria et al. used ProTaper Universal and WaveOne file to evaluate shaping ability of the twenty human molars, the evaluation done by CBCT. There was more transportation in ProTaper than WaveOne, but the difference was non-significant regarding centering ability. This indicates that the WaveOne single-file system does not create excessive transportation compared with ProTaper, concluding that the reciprocating systems are an effective alternative and safe technique tend to be routinely used in endodontic treatment[39].

Conclusions

There was the non-significant difference between three groups regarding apical transportation, but WaveOne Gold at the apex has better centering ability than other groups.

References

1. 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):1219-22.

2. Zhang L, Luo H-x, Zhou X-d, Tan H, Huang D-m. The shaping effect of the combination of two rotary nickel-titanium instruments in simulated S-shaped canals. J Endod. 2008;34(4):456-8.

3. Abou-Rass M, Frank AL, Glick DH. The anticurvature filing method to prepare the curved root canal. J. Am. Dent. Assoc (1939). 1980;101(5):792-4.

4. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod. 1988;14(7):346-51.

5. Sonntag D, Delschen S, Stachniss V. Root-canal shaping with manual and rotary Ni-Ti files performed by students. Int Endod J. 2003;36(11):715-23.

6. Ye J, Gao Y. Metallurgical characterization of M-Wire nickel-titanium shape memory alloy used for endodontic rotary instruments during low-cycle fatigue. J Endod. 2012;38(1):105-7.

7. Webber J. Shaping canals with confidence: WaveOne GOLD single-file reciprocating system. Inte Dent. 2015;6(3):6-17.

8. Esposito PT, Cunningham CJ. A comparison of canal preparation with nickel-titanium and stainless steel instruments. J Endod. 1995;21(4):173-6.

9. Alencar AHGd, Dummer PM, Oliveira HCM, Pécora JD, Estrela C. Procedural errors during root canal preparation using rotary NiTi instruments detected by periapical radiography and cone beam computed tomography. Braz Dent J. 2010;21(6):543-9.

10. Gergi R, Arbab-Chirani R, Osta N, Naaman A. Micro-Computed Tomographic Evaluation of Canal Transportation Instrumented by Different Kinematics Rotary Nickel-Titanium Instruments. J Endod. 2014;40(8):1223-7.

11. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1971;32(2):271-5.

12. Flores CB, Machado P, Montagner F, Gomes BPFdA, Dotto GN, Schmitz MDS. A methodology to standardize the evaluation of root canal instrumentation using cone beam computed tomography. Braz J Oral Sci. 2012;11(2):84-7.

13. Baumgartner JC, Ingle JI, Bakland LK. Ingle's Endodontics. 6th ed. Hamilton: BC Decker Inc; 2008. 938.

14. Castellucci A. Schilder's technique for shaping the root canal system. Endodontics. 2005;1:438-69.

15. Gambill JM, Alder M, Carlos E. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. J Endod. 1996;22(7):369-75.

16. Gergi R, Rjeily JA, Sader J, Naaman A. Comparison of canal transportation and centering ability of twisted files, Pathfile-ProTaper system, and stainless steel hand K-files by using computed tomography. J Endod. 2010;36(5):904-7.

17. Jardine S, Gulabivala K. An in vitro comparison of canal preparation using two automated rotary nickel–titanium instrumentation techniques. Int Endod J. 2000;33(4):381-91.

18. Song Y, Bian Z, Fan B, Fan M, Gutmann J, Peng B. A comparison of instrument-centering ability within the root canal for three contemporary instrumentation techniques. Int Endod J. 2004;37(4):265-71.

19. Vincenzi V, Plotino G, Giansiracusa A, Pietrangeli E, Al Sudani D, Grande NM, et al. A SEM study of canal cleanliness after a new nickel-titanium rotary instrumentation technique. Ann Stomatol. 2011;2(1-2):19.

20. Madani Zs, Goudarzipor D, Haddadi A, Saeidi A, Bijani A. A CBCT Assessment of apical transportation in root canals prepared with hand k-flexofile and K3 rotary instruments. Iran Endod J. 2015;10(1):44.

21. Moore J, Fitz-Walter P, Parashos P. A micro-computed tomographic evaluation of apical root canal preparation using three instrumentation techniques. Int Endod J. 2009;42(12):1057-64.

22. Hartmann MSM, Barletta FB, Fontanella VRC, Vanni JR. Canal transportation after root canal instrumentation: a comparative study with

computed tomography. J Endod. 2007;33(8):962-5.

23. Eleazer P, Glickman G, McClanahan S, Webb T, Jusrman B. Glossary of Endodontic Terms. 9th edition. Chicago: American Association of Endodontists; 2016;47.

24. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod. 2004;30(8):559-67.

25. Siqueira Jr JF, Rôças IN, Favieri A, Machado AG, Gahyva SM, Oliveira JC, et al. Incidence of postoperative pain after intracanal procedures based on an antimicrobial strategy. J Endod. 2002;28(6):457-60.

26. Ehsani M, Zahedpasha S, Moghadamnia AA, Mirjani J. An ex-vivo study on the shaping parameters of two nickel-titanium rotary systems compared with hand instruments. Iran Endod J. 2011;6(2):74.

27. Pereira E, Peixoto I, Viana A, Oliveira I, Gonzalez B, Buono V, et al. Physical and mechanical properties of a thermomechanically treated NiTi wire used in the manufacture of rotary endodontic instruments. Int Endod J. 2012;45(5):469-74.

28. You S-Y, Kim H-C, Bae K-S, Baek S-H, Kum K-Y, Lee W. Shaping ability of reciprocating motion in curved root canals: a comparative study with micro–computed tomography. J Endod. 2011;37(9):1296-300.

29. Franco V, Fabiani C, Taschieri S, Malentacca A, Bortolin M, Del Fabbro M. Investigation on the shaping ability of nickel-titanium files when used with a reciprocating motion. J Endod. 2011;37(10):1398-401.

30. Wu M-K, Fan B, Wesselink PR. Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. J Endod. 2000;26(4):210-6.

31. Calhoun G, Montgomery S. The effects of four instrumentation techniques on root canal shape. J Endod. 1988;14(6):273-7.

32. Kim HC, Hwang YJ, Jung DW, You SY, Kim HC, Lee W. Micro-Computed Tomography and Scanning Electron Microscopy Comparisons of Two Nickel–Titanium Rotary Root Canal Instruments Used With Reciprocating Motion. Scanning. 2013;35(2):112-8.

33. Nagaraja S, Murthy BS. CT evaluation of canal preparation using rotary and hand NI-TI instruments: An in vitro study. J Conserv Dent. 2010;13(1):16.

34. Parvathaneni KP, Goel BR, Parvathaneni BD. A comparison of root canal preparations using stainless steel, Ni-Ti hand, and Ni-Ti engine-driven endodontic instruments an in vitro study. Bangladesh J. Med. Sci. 2010;9(4):223-30.

35. Short JA, Morgan LA, Baumgartner JC. A comparison of canal centering ability of four instrumentation techniques. J Endod. 1997;23(8):503-7.

36. Schafer E, Florek H. Efficiency of rotary nickel-titanium K3 instruments compared with stainless steel hand K-Flexofile. Part 1. Shaping ability in simulated curved canals. Int Endontic J. 2003;36(3):199-207.

37. Kandaswamy D, Venkateshbabu N, Porkodi I, Pradeep G. Canal-centering ability: An endodontic challenge. J Conserv Dent. 2009;12(1):3.

38. Carvalho LAP, Bonetti I, Borges MAG. A comparison of molar root canal preparation using stainless-steel and Nickel-Titanium instruments. J Endod. 1999;25(12):807-10.

39. Barbosa-Ribeiro M, Albergaria SJ, Malvar MdFG, Crusoé-Rebello IM, Gomes BPFdA, Carvalho FBd. Canal transportation and centering ability of curved root canals prepared using rotary and reciprocating systems. Braz J Oral Sci. 2015;14(3):214-8.