RESEARCH

Comparative Evaluation of Canal Transportation and Centering Ability of Various Ni-Ti Rotary Systems in Retreatment of Curved Root Canals

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ABSTRACT

Comparative Evaluation of Canal Transportation and Centering Ability of Various Ni-Ti Rotary Systems in Retreatment of Curved Root Canals

Background: The aim of the present study was to evaluate the canal transportation and centering ability of ProTaper , HeroShaper and two Ni-Ti rotary systems developed for retreatment ProTaperRetreatment and R-Endo.

Methods: One hundred twenty mesial canals of mandibular molars with curvatures between 30-40 degrees and radii of curvatures between 4-9 mm were embedded in a modified muffle system. The teeth were randomly divided into 8 groups (n=15). The roots were sectioned horizontally at 3, 6 and 9 mm from the working length. Cross-sections were digitally photographed under standardized conditions. Half of the root canals were prepared with ProTaper and the rest with HeroShaper. Postoperative photographs were obtained. Root canals were obturated with the respective gutta-percha cones of the systems and AHPlus sealer. Following retreatment with four systems, photographs were assessed for the canal transportation in 8 directions, and centering ratio.

The data were analyzed with Friedman test for repeated measurements, Kruskal Wallis test for intergroup comparisons and Dunn's multiple comparison test for subgroup comparisons, and significance was set at $P < 0.05$.

Results: Initial shaping with ProTaper resulted in more significant transportation than HeroShaper ($p<0.05$). After retreatment, R-Endo yielded negative transportation values in the apical and mid-sections. In canals prepared with ProTaper, in the apical and coronal root sections ProTaperRetreatment, and in the mid-sections ProTaper revealed more acceptable re-shaping results. In the canals prepared with HeroShaper, after retreatment, transportation and centering ability were relatively efficient with HeroShaper in the apical and mid-sections; and with ProTaper in the coronal sections.

Conclusion: All systems caused a certain amount of transportation and eccentricity. Protaper, ProtaperRetreatment and HeroShaper showed similar re-shaping performance with regard to the initial shaping procedure. However, R-Endo yielded insufficient root canal cleaning in the apical and mid-sections.

KEYWORDS

Centering Ability, Ni-Ti Rotary Instruments, Retreatment, Transportation

ÖZ

Eğri Kök Kanallarının Tedavi Tekrarında Farklı Ni-Ti Döner Alet Yöntemlerinin Transportasyon ve Merkezde Kalma Etkinliklerinin Karşılaştırmalı Olarak İncelenmesi

Amaç: Bu çalışmanın amacı ProTaper , HeroShaper ve kök kanal tedavisi tekrarı için geliştirilmiş ProTaperRetreatment ve R-Endo Ni-Ti sistemlerinin kanal transportasyonu ve merkezde kalma kabiliyetini değerlendirmektir.

Gereç ve Yöntemler: Eğim açıları 30-40 derece, eğim yarıçapları 4-9 mm arasında değişen alt büyükazı dişlerinin 120 meziyal kanalı modifiye bir mufla içine gömülmüştür. 15'er dişten oluşan 8 grup oluşturulmuştur. Dişlerin çalışma uzunluğundan 3, 6 ve 9 mm mesafelerde yatay kesitleri alınmıştır. Kesitlerin standart şartlar altında dijital fotoğrafları elde edilmiştir. Kanalların yarısı ProTaper, diğer yarısı ise HeroShaper ile şekillendirilmiştir. Postoperatif fotoğraf alınmasını takiben kanallar sistemlerin kendilerine ait güta-perka konları ve AHPlus patı ile doldurulmuştur. Standart şartlarda dijital kontrol radiyografileri alınmıştır. Dört sistemle kanal tedavisi tekrarı sonrasında alınan fotoğraflar 8 yönde transportasyon ve merkezleme oranı açısından değerlendirilmiştir.

İstatistiksel değerlendirmede tekrarlayan ölçümlerde Friedman testi, gruplar arası karşılaştırmalar için Kruskal Wallis, alt grupların karşılaştırması için Dunn çoklu karşılaştırma testleri kullanılmış ve anlamlılık düzeyi $P < 0.05$ olarak belirlenmiştir.

Bulgular: İlk şekillendirmeden sonra ProTaper, HeroShaper'dan daha fazla transportasyonla yol açmıştır ($p<0.05$). Yeniden tedaviden sonra R-Endo, apikal ve orta kısımlarda negatif transportasyon oluşturmuştur. ProTaper ile hazırlanan kanallarda, apikal ve koronal kök kısımlarında ProTaperRetreatment; orta kısımlarda ProTaper daha kabul edilebilir sonuçlar ortaya koymuştur. HeroShaper ile hazırlanan kanallarda ise apikal ve orta kısımlarda HeroShaper, koronal kısımlarda ise ProTaper ile tedavi tekrarı transportasyon ve merkezleme kabiliyeti açısından daha başarılı bulunmuştur.

Sonuç: Bütün sistemler belli miktarda transportasyona ve merkezden kaymaya neden olmuştur. Protaper, ProtaperRetreatment ve HeroShaper ilk şekillendirmenin hangi aletle yapıldığına bağlı olarak benzer şekillendirme performanıs sergilemiştir. Ancak R-Endo apikal ve orta kesitlerde kök kanalının temizliğinde yetersiz kalmıştır.

ANAHTAR KELİMELER

Kanal Tedavisi Tekrarı, Merkezde Kalma, Ni-Ti Döner Alet, Transportasyon

INTRODUCTION

Root canal preparation involves eliminating canal contents along with the infected dentin from the root canal system and removing previous filling materials within the canal in retreatment cases.[1] Preparation should maintain the original path of the root canal and the position of the apical foramen. Once the

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instrumentation is completed, the root canal is expected to have a uniformly tapered funnel shape with increasing diameter from the tip to the orifice, allowing for effective disinfection and obturation.[2] It could be challenging to achieve this goal, especially when preparing severely curved root canals.[3] Asymmetrical material removal during shaping may lead to undesirable outcomes such as canal transportation, straightening, or canal deviation.[4-6] The introduction of rotary nickel-titanium (Ni-Ti) instruments has offered a solution to these mishaps by reducing the incidence of procedural errors, allowing faster, safer, and easier shaping even in curved canals, while maintaining the original canal shape.[1,7-9]

Various methods have been used to examine the changes in the root canal configuration after instrumentation.[10-13] However, accurate measurement of transportation may be difficult since there is no gold standard for assessment, and each method has its own advantages or disadvantages.[12] Advanced imaging methods such as high-resolution cone-beam computed tomography (CBCT), and micro-computed tomography (micro-CT) are recently available to study the changes in the canal geometry.[11,14,15] However, the major limitations in using these imaging modalities are the time-consuming scanning, expensive equipment, and high degree of computer expertise required for 3D reconstruction.[11-14] Furthermore, the requirement for remarkable computational power and storage space for scanning and data analysis result in small group sizes in many micro-CT studies.[16]

On the other hand, the technique described by Bramante et al.[10] is simple, inexpensive, and based on the evaluation of reassembled cross-sections taken from embedded roots in the muffle before and after shaping procedures. The pre- and post-instrumentation of the root canal sections can be compared with the help of the measurements by superimposing the photographs on the computer.[17-19] The technique allows analyzing the deviations in the horizontal direction as well as the ability of the instrument to remain centered within the canal.[18-20]

Despite the high success rate reported in root canal treatments, non-surgical retreatment is the preferred treatment option in case of failure.[21,22] In retreatment cases, one of the prerequisites for disinfection of the root canal system is the removal of the existing root filling material.[23] Gutta-percha and sealer combination is the frequently used materials for root canal obturation.[24] Removal of gutta-percha from the root canals can be accomplished with hand files, rotary Ni-Ti instruments, or Ni-Ti systems specially developed for retreatment purposes.[22,25-29]

R-Endo (Micro-Mega, Besançon, France) and ProTaper Universal Retreatment System (Dentsply Maillefer, Ballaigues, Switzerland) are specific instruments for removing filling materials during retreatment. The R-Endo system (RE) has four instruments with a triangular cross-section, inactive working tip, and three equally spaced cutting edges. Re file is for flaring the first few millimeters of the canal. R1, R2, and R3, each dedicated to a specific root third, are used for removing the rest of the filling material. An optional Rs is available for finishing if required.[30] On the other hand, the ProTaper Universal Retreatment (PTUR) system comprises three files, D1, D2, and D3, the triangular cross-section of which is similar to the ProTaper shaping and finishing files (PT) (Dentsply Maillefer, Ballaigues, Switzerland). Every file is designed for a specific third of the root canal. The active working tip of the D1 file facilitates initial entry into the root canal filling.[27]

It is crucial to prevent new or further morphological changes in the root canal when removing the existing filling.[23] The success of retreatment was reported to be 86.8 % in cases in which the root canal morphology was respected during retreatment procedure, while it was 47 % in teeth with altered canal morphology after two years of follow-up.[31]

The literature has already revealed evidence of the efficacy of using Ni-Ti rotary and retreatment systems for retreatment cases. However, most of these studies have focused on the removal of gutta-percha from the root canals.[22,25,27,28,30,32] On the other hand, canal transportation during retreatment has rarely been investigated[15,29,33], while it has been mostly evaluated for primary root canal treatment.[13,18,34-39]

Therefore, this study aimed to evaluate the canal transportation and centering ability of PT and HeroShaper (HS, Micro-Mega, Besançon, France) Ni-Ti rotary systems and their specialized retreatment systems (PTUR and RE) on the retreatment of the curved mesial canals of extracted mandibular molars and compare the pre- and post-instrumented and the post-retreated canal geometries respectively with each other by using a modified Bramante technique.

MATERIALS AND METHODS

Sample selection

One hundred and twenty intact mature human mandibular molars with curved roots, extracted for unrelated reasons to the current study, were collected from the teeth pool of the Oral and Maxillofacial Surgery Department of the faculty. Teeth were stored in 0.1 % thymol solution until use.

The schematic representation of the study is shown in Figure 1. All procedures were performed by a single operator (EÇ).

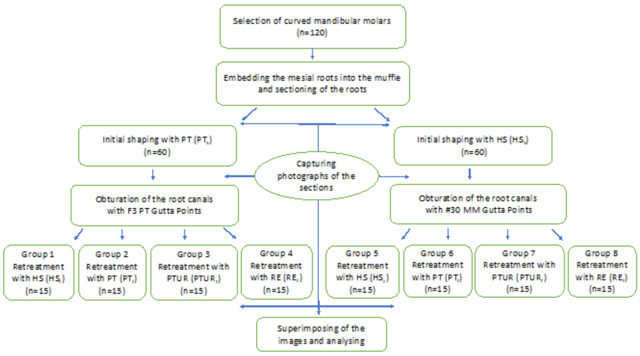

Figure 1

The schematic representation of the study

Specimen preparation and initial shaping

After preparation of the access cavity, a #10 stainless steel K- file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted into the root canal until the tip of the instrument was just visible at the apical foramen. Working length (WL) was calculated by subtracting 1 mm from this length. Standardized digital radiographs were taken in buccolingual and mesiodistal directions to determine the maximum curvature of the mesial root canals. According to the Pruett method[40], root canals having a canal curvature of 30-40 degrees and a radius of curvature between 4-9 mm were included in the study.

Based on the closed muffle system introduced by Bramante et al.[10], 120 metal and 120 plastic muffles were prepared (Figure 2a and 2b). The mesial roots were vertically inserted into the metal muffles with their curvatures facing the same direction and embedded using a colorless acrylic resin. After polymerization and disassembly, each acrylic block was sectioned at 3, 6, and 9 mm from the apical foramen to coincide with the apical, middle, and coronal segments of the roots, using a low-speed saw (Isomet 1000; Buehler, IL, USA) (Figure 2c). In order to determine the initial shape of the root canals, pre-instrumentation photographs of the root sections were captured through a custom setup, using a digital camera (Canon EOS 300D; Canon INC., Tokyo, Japan) with a macro lens (Tamron SP 90 MM F/2.8 Di Macro) (Figure 2d and 2e).

The root sections were then reassembled in their original position and transferred to the muffle for fixation. Roots were randomly divided into two groups (n=60). The first group was shaped with ProTaper Starter Kit up to F3 (size 30, 9 % taper) (PT$_s$). The other 60 root canals were shaped using HeroShaper rotary instruments according to the order to be followed in the 'difficult' root canals (HS$_s$). The shaping was completed with a size 30, 4 % taper (#30, 0.04) file. All samples were irrigated with 2 ml of 5 % sodium hypochlorite between each instrument. Subsequently, the root sections were disassembled and the post-instrumentation photographs were taken as previously described (Figure 2f).

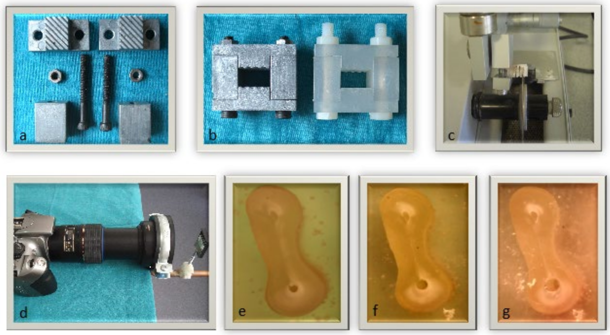

Figure 2

The experimental setup. (a) Removable pieces of the modified muffle system, (b) The complete muffle system: metal and plastic, (c) Sectioning of the acrylic-block, (d) Photography setup, (e) An image taken from the middle portion prior initial shaping, (f) following instrumentation, (g) after retreatment.

Root canal obturation

The root canals were obturated with AH Plus (Dentsply, De Trey, Zurich, Switzerland) using a single cone technique. As master gutta-percha, F3 (#30) ProTaper Gutta-percha Points (Dentsply, Maillefer) were used in PTs, and size 30 MM-GP points (MicroMega) in HSs groups. The access cavities were sealed with a temporary filling (Cavit, 3M-Espe, Germany). The roots were transferred to plastic muffles that allow radiographic imaging. The quality and the apical extend of the filling were checked by buccolingual and mesiodistal radiographs. The specimens were then stored at 37 °C and 100 % humidity for 14 days to allow complete setting of the sealer.

Retreatment procedures

According to the retreatment system to be used, PT$_s$ and HS$_s$ groups were randomly distributed into four subgroups. Thus, a total of eight experimental groups (n=15) was obtained.

In groups 1 and 5 root canals were retreated with HS (HS$_r$); in groups 2 and 6 with PT (PT$_r$); in groups 3 and 7 with PTUR (PTUR$_r$) and in groups 4 and 8 with RE (RE$_r$), respectively.

All instruments were used in a speed and torque-controlled motor (ATR Tecnika Torque Control Motor, Dentsply, Pistola, Italy) according to the manufacturers' instructions. The root canals were irrigated with 2 ml of 5 % sodium hypochlorite between each instrument.

In groups 1 and 5 (HS_r); after the removal of coronal gutta-percha with the Endo Flare (#25, 0.12) up to 1/2 of the WL, the HS files were used in the following sequence: #20, 0.06 file up to 2/3 of the WL followed by #20, #25, and #30, 0.04 at WL.

In groups 2 and 6 (PT_r); the files were used in the following sequence: F3 (#30, 0.09) up to 1/2 of the WL, F2 (#25, 0.08) up to 2/3 of WL followed by F1 (#20, 0.07), S1 (#17, 0.02), S2 (#20, 0.04), F1 (#20, 0.07), F2 (#25, 0.08) and F3 (#30, 0.09) at WL.

In groups 3 and 7 ($PTUR_r$); the files were used in the following sequence: D1 (#30, 0.09) instrument was used for coronal, D2 (#25, 0.08) for middle, and D3 (#20, 0.07) for apical third. Reshaping of the canals was completed by using S1, S2, F1, F2, and F3 at WL.

In groups 4 and 8 (RE_r); the Rm (#25, 0.04) was used to create a pilot hole, followed by Re (#25, 0.12) to remove the gutta-percha at the coronal 1-3 mm of the root canal. R1 (#25, 0.08) was used up to 1/3 of WL, followed by R2 (#25, 0.06) up to 2/3, and R3 (#25, 0.04) until the WL. Preparation was completed using Rs (#30, 0.04) file at WL.

The root sections were then removed from the muffle and transferred to the setup for capturing post-retreatment images (Figure 2g).

Image analysis

The pre-instrumentation (original canal shape), post-instrumentation and post-retreatment images taken from apical, middle and coronal sections of each root were superimposed using Adobe Photoshop Elements 2.0 (Adobe Systems Incorporated, San Jose, CA) program and recorded in JPEG format (Figure 3a). After marking the root canal spaces on the three images from each cross-section, an image processing software program (ImageJ 1.37v, National Institutes of Health, USA) was used to determine the center points of the root canal spaces. A pre-prepared millimetric ruler was placed on the superimposed images and the origin of the ruler was positioned at the center of the original shape of the root canal. The amount of transportation in 8 directions such as inner, outer, center, periphery, inner center, outer center, inner periphery and outer periphery was measured and recorded in mm (Figure 3b).

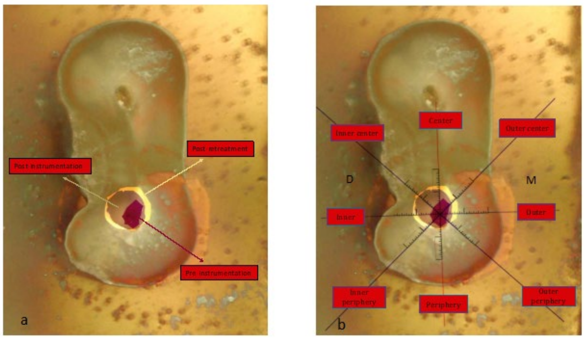

Figure 3

Representative image of superimposed root sections. (a) Pre-instrumentation, post-instrumentation and post-retreatment canal geometries, (b) Millimetric ruler in eight directions. "Outer" corresponds to the mesial side (M) of the root canal representing the outer aspect of the curvature. "Inner" corresponds to the distal side (D) of the root representing the inner aspect of the curvature. "Center" refers the direction toward the other canal in the same root. "Periphery" refers to the periphery of the root in the buccal or lingual direction.

Calculation of canal transportation and centering ability

The amount of transportation between post-instrumentation (2) and pre-instrumentation (1) images (T1), post-retreatment (3) and post-instrumentation images (T2), post-retreatment and pre-instrumentation images (T3) were calculated as follows:

$T1 = X2 - X1$, $T2 = X3 - X2$, and $T3 = X3 - X1$, where X represented the measured transportation. The same formula was used for eight directions. The value of $T = 0$ means that there is no transportation; $T > 0$ gives the amount of transportation; and $T < 0$ indicates that the instruments did not shape the canal in that direction.

The centering ratio (CR), which indicates the ability of the instrument to stay centered in the canal was calculated according to the formula[41]: $X1 / X2$ or $X2 / X1$ depending on which X has the bigger value. X1 and X2 represented the amount of transportation in opposite directions where the maximum transportation was observed. CR value as 1 indicates the perfect centralization, while values close to 0 indicates the lower centering ability of the instrument.

Statistical analysis

The data were statistically analyzed with NCSS-PASS 2007 Statistical Software (NCSS, LLC, Kaysville, Utah, USA) program with a significance level set at $p<0.05$. Mean±standard deviation (SD) values were estimated. Friedman test was used for repeated measurements of multiple groups, Kruskal Wallis test for intergroup comparisons and Dunn's multiple comparison test for subgroup comparisons.

RESULTS

Pre-instrumentation and post-instrumentation evaluation (T1):

In all of the root segments and directions, PT revealed higher transportation values than HS.

In the coronal sections: The maximum transportation was detected on the inner (PT_s = 0.295±0.181 and HS_s = 0.207±0.139) and inner center (PT_s = 0.334±0.217 and HS_s = 0.166±0.212) directions.

In the middle sections: The minimum transportation was observed in the center direction (PT_s = 0.164±0.169 and HS_s = 0.07±0.09). The difference between PT_s and HS_s was statistically significant except for the periphery direction ($p<0.05$).

In the apical sections: Transportation was predominantly on the outer periphery (PT_s = 0.251±0.163 and HS_s = 0.135±0.083) and periphery directions (PT_s = 0.242±0.196 and HS_s = 0.136±0.114) and the difference between the groups was significant ($p<0.05$).

In terms of canal centering ratio, there was no significant difference between PT_s and HS_s groups in any of the root segments ($p>0.05$). However, none of the instruments stayed centered (0<CR< 1).

Post-retreatment and post-instrumentation evaluation (T2):

In the coronal sections: A significant difference was found between PT_r (0.189±0.258) - RE_r (-0.106±0.244) and also PT_r - HS_r (-0.057±0.195) on the inner periphery direction of HS_s ($p<0.05$). Positive transportation was only detected in the inner periphery aspect of PT_s.

In the middle sections: In all of the groups and directions the value of the transportation was negative with the RE instrument, whereas it was positive with the PT instrument. No significant difference was detected among HS_r, PT_r and $PTUR_r$ in any of the directions. Significant differences were only detected in the comparison of RE with other subgroups.

In PTs, the differences were significant except for the outer and inner periphery directions ($p<0.05$). In HSs, the amount of transportation was statistically different in the center, outer, inner, and inner center directions ($p<0.05$).

In the apical sections: RE_r yielded negative values in all directions. In most of the specimens positive valued transportations were observed after retreatment with PTUR and HS in PT_s and HS_s, respectively.

None of the instruments was able to stay centered in the root canal. No significant difference was found among the instruments in any root segment ($p>0.05$). The maximum and minimum centering ratio values ranged between 0.087±0.12 and 0.253±0.245.

Post-retreatment and pre-instrumentation evaluation (T3):

In the coronal sections: The amount of transportation was significantly greater in PT_r (0.416±0.217) than other subgroups on the inner periphery direction of HS_s. There was a significant difference between HS_r (0.048±0.201) - PT_r (0.416±0.217) and HS_r - $PTUR_r$ (0.321±0.229) on the inner center direction ($p<0.05$). There was no significant difference between the subgroups of the PT_s ($p>0.05$) in which transportation was always > 0.

In the middle sections: RE was the only system in which negative transportation values were observed compared to the initial anatomy of the root canal. In the PT_s group, the amount of transportation with PT_r was statistically greater than RE_r on the center, outer center, and inner center directions and greater than HS_r on the center direction ($p<0.05$). In HS_s group, a significant difference was found between PT_r (0.2±0.16) - RE_r (0.013±0.156) and HS_r (0.206±0.136) - RE_r on the inner direction ($p<0.05$). There was no significant difference between PT_r and $PTUR_r$ in any sections.

In the apical sections: Retreatment with RE yielded the highest negative transportation values, while HS and PTUR revealed positive transportation values. The amount of transportation was not statistically different among HS_r, PT_r and $PTUR_r$ in any direction. Significant differences were only detected in the comparison of RE with other subgroups.

In HSs group, the only significant difference was found on the outer and outer center directions between HS_r (0.124±0.156 and 0.2±0.192, respectively) and RE_r (-0.037±0.15 and -0.012±0.133, respectively) on the outer and outer center directions, ($p<0.05$).

In centering ratio comparisons, the only significant difference was found between HS_r (0.131±0.13) and RE_r (0.34±0.16) in the coronal sections of PT_s group ($p<0.05$). For all groups, the centering ratio values were ranged between 0.127±0.195 and 0.368±0.34.

DISCUSSION

Two Ni-Ti rotary systems (ProTaper and HeroShaper) and their retreatment systems (ProTaper Retreatment and R-Endo) were compared with regard to canal transportation and centering ability among pre-instrumentation, post-instrumentation, and post-retreatment geometries of the root canal. The canal transportation is associated with some factors such as the degree and radius of the canal curvature or the design of the file.[6] However, testing the instruments on natural dentin was considered beneficial for representing realistic situations.[42] To mimic the clinical conditions, mesial canals of extracted mandibular molars with a canal curvature of 30-40 degrees and a

4-9 mm radius were selected for the study.

Inclusion of the original canal anatomy following instrumentation is a requirement for a properly cleaned and shaped root canal.[43] To assess this criterion and evaluate the possible deviations in the original root canal, the current study used a modified Bramante technique. Among several methods used to investigate the shaping efficacy, the Bramante technique offers the advantages of being simple and inexpensive, easy to learn, and allowing comparison with the uninstrumented canal while providing a qualitative and statistical analysis of root canal instrumentation.[10,18,35] This technique is commonly used to examine the canal alterations before and after instrumentation.[10,35,37] However, the present study was the first, using the Bramante technique for assessment of canal transportation after instrumentation and re-instrumentation procedures. While the shaping procedure was accomplished with PT and HS instruments, specially developed instruments (PTUR and RE) were used for retreatment besides PT and HS rotary files. Although the latter two were designed for root canal shaping, they tend to be used for retreatment purposes.[28,32,44,45]

Influence of shaping procedures on canal deviation was determined based on the amount of transportation and centering ratio assessments. Usually, canal transportation was evaluated from the mesiodistal and buccolingual aspects of the curvature.[36] However, as the teeth did not display their maximum curvature in those planes, only a projection could be measured instead of actual transportation.[46] Therefore, linear measurements of the canal transportation were performed in eight different directions in the apical, middle and coronal segments of the root canals (Figure 3b). This implementation enabled obtaining detailed information on the localization and exact direction of the canal transportation.

After initial shaping, HS_s group recorded less canal transportation and provided better compliance to the original canal shape than PT_s group. This observation was in agreement with previous studies.[37,38] Transportation amount of 0.3 mm is considered critical in curved canals due to its negative influence on the apical leakage and prognosis.[34] Although the amount of transportation with PT instruments was significantly greater than HS in most of the directions, it was under that critical point in all sections, except for the center and inner center directions in the coronal sections of PT_s group. Instruments with a great taper could cause more canal transportation than less tapered instruments due to their lower flexibility.[16,39] The greater transportation with PT can be attributed to the progressive taper and sharp cutting edges of the instrument.[13,36] The transportation direction changed from inner and inner center to periphery and outer periphery towards apical sections in both groups. This finding, indicating that the apical transportation was towards the outer aspect of the curvature with both systems, has also been confirmed in previous studies.[35,37,47] Statistical analysis for canal centering showed no significant difference among the groups ($p>0.05$). However, none of the systems maintained total centricity in the root canal ($0<CR<1$), as was reported in previous studies.[13,37,45]

During retreatment canal transportation may exhibit some major problems as well as in the shaping process, including remaining filling material and microorganisms along the unshaped inner walls of the curvature.[23] The incidence of transportation in retreatment cases was reported as 20 %.[31] However, information about canal transportation after retreatment is rare, since most of the published data concentrated on the removal of the filling material from the root canals.[27,28,30,32] In the few studies examining canal transportation, only the pre- and post-retreatment canal geometries were compared, almost neglecting the changes on the original canal anatomy.[15,29,33,44] Therefore, the current study evaluated transportation after retreatment based on the deviations between the post-retreatment / post-instrumentation and post-retreatment / pre-instrumentation canal geometries.

In T2 evaluations, all four systems caused a certain amount of negative transportation in different root segments and directions. The negative transportation values indicate ineffective removal of gutta-percha and root canal wall dentin. Consistent negative transportation values observed with RE could be interpreted as the failure of the instrument to remove gutta-percha entirely and contact the root canal wall all around. On the other hand, transportation was > 0 with PT in the middle sections. Larger size and taper might be expected to support more filling material removal and greater canal transportation.[48] Although the tip sizes were the same, the differences in the tapers and cross-sections of the instruments might have influenced the current results. The amount of transportation was significantly different between the RE_r subgroups in the outer periphery direction of the apical sections, in favor of HS_s group ($p<0,01$). Once a deviation in the original canal anatomy has been displayed, it may become even more pronounced during subsequent preparations for retreatment.[23] During initial shaping with PT, more transportation than HS in the outer periphery direction may have resulted in insufficient material removal of RE in PT_s group. According to our results, retreatment with PTUR induced greater transportation than RE in the apical and middle sections. This finding contrasts with a recent study which reported a similar amount of canal transportation with PTUR and RE.[29] This discrepancy may be due to the final shaping procedure performed with a #30, 0.07 instrument in both groups in the mentioned study.

Perfect centralization, which was noted to be utopic in curved canals[15], could not be achieved with any tested instruments. However, no statistical difference was demonstrated among centering abilities, which is in accordance with the results of a recent study evaluating three retreatment systems, including PTUR and RE.[49]

In T3 evaluations, although the difference was not mainly significant in the coronal sections, the canal transportation amount was greater in $PTUR_r$ and PT_r. The fact that the PT and PTUR instruments have similar taper and cross-sections explains the large transportation recorded with these instruments.[50] In the middle sections, RE_r appeared to be better in compliance with the original canal geometry. However, this misconception was due to the negative transportation values of RE on T2 assessments, indicating incomplete gutta-percha removal in many directions. In PT_s group, although the transportation towards the inner aspects with PT and PTUR was not significantly different from HS, it was remarkable that the transportation was slightly higher than the critical level with values ranging from (0.305±0.226) to (0.375±0.24). This finding was not observed in the HS_s group. From a clinical point of view, it is worth emphasizing that the reuse of large-tapered instruments in retreatment may cause undesirable changes in the original canal geometry. Though, when T2 and T3 evaluations were taken together, PT_r is assumed to be the only system that can completely remove gutta-percha in all directions while maintaining the original canal shape relatively, regardless of the system used for initial shaping. This finding, which questions the necessity of using special systems in re-retreatment, is compatible with the result of Alves et al., who reported similar gutta-percha removal efficacy of conventional (PT) and retreatment systems (PTUR).[32]

In the apical sections, the negative transportation value results obtained with RE suggest that the instrument failed to encompass the initial canal space after retreatment. The amount of transportation was not statistically different among HS_r, PT_r, and $PTUR_r$ in any of the directions. However, when T2 and T3 findings were evaluated together, it can be concluded that PTUR in the PT_s group and HS in the HS_s group are the most successful instruments regarding adequate gutta-percha removal and the original canal shape preservation. This finding emphasized the importance of instrument selection on retreatment cases. Using a large-tapered instrument in the apical section of a less tapered tooth may cause excessive canal transportation, while using a small-tapered instrument in a great tapered tooth may result in inadequate cleaning and filling material residue, compromising the success of the retreatment.

Regarding the centering abilities, the only significant difference was detected between HS_r (0.131±0.13) and RE_r (0.34±0.16) of PT_s group in the coronal sections ($p<0.05$). This finding may be associated with the pilot hole created by Rm, which may have enabled better penetration to gutta-percha.

According to the study results, it is not possible to address complete maintenance of the original form of the canal in retreatment with any of the systems. However, the knowledge of which systems were used for initial shaping could instruct the retreatment process. It may be advantageous to use smaller tapered instruments as in the HS group instead of large tapered instruments such as #30.07 as in PT or PTUR systems to produce less transportation. The shaping can be continued with larger files if needed. In cases with dense root canal filling, the use of the RE system may result in the incomplete removal of the root canal filling.

Among all endodontic procedures, non-surgical root canal retreatment will always keep its importance. However, the question of whether a specific system is necessary for the success of retreatment has still not found a definitive answer.[32] Research is underway for a system that provides optimum cleaning and shaping efficacy while maintaining original canal anatomy. Further studies are also needed to examine the effect of systems on canal transportation to reach conclusive results.

CONCLUSION

Within the limitations of this *in vitro* study;

1. All instruments caused transportation to a certain extent and failed to remain completely centered.

2. Initial shaping with PT led to greater transportation in comparison to HS.

3. RE yielded negative transportation values in the apical and mid-sections, indicating insufficient root canal cleaning.

4. Although the greater taper of PT and PTUR systems was expected to be advantageous regarding to re-instrumentation, HS exhibited similar performance with less canal transportation.

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CONFLICT OF INTEREST

The authors deny any conflicts of interest related to this study.

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