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Evaluating the cutting efficiency of NiTi instruments with reciprocating motions

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Aim: This study tested a setup for *in vitro* experimental analysis of axial forces and torque during the preparation of artificial canals using nickel-titanium reciprocating endodontic files.

Methods: The cutting efficiency of Reciproc (RC) and WaveOne (WO) reciprocating size 25/.08 instruments (n = 10) was evaluated, taking into account their dimensional and geometrical features. Measurements of the diameter at each millimeter from the tip, pitch length, helical angle, and cross-sectional design and area were assessed. Cutting efficiency tests were carried out on a specific bench device by measuring the torque and axial force required during artificial canal shaping. Statistical analysis was performed using one-way ANOVA ($\alpha = 0.05$).

Results: The WO samples showed larger A3 mean values than did the RC instruments ($p < 0.0001$), despite having equal diameters at 3mm from the tip (D3) ($p = 0.521$). The mean values of pitch length were higher for RC than for WO instruments ($p < 0.0001$), with consequently smaller helical angles ($p < 0.0001$). For the cutting efficiency tests, the required torque was lower for the RC group when compared to the WO group, but it was significant only in the first stage of insertion in the artificial canals ($p = 0.008$). Regarding the apical force, the RC instruments reached higher values when compared to the WO instruments ($p = 0.04$) in the second stage of cutting action. **Conclusion:** Reciproc instruments demonstrated statistically higher cutting efficiency when compared to WaveOne instruments.

Uniterms: cutting efficiency; M-Wire; reciprocating motion; Reciproc; WaveOne.

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INTRODUCTION

It has been proposed that a single-file reciprocating technique may simplify instrumentation protocols and reduce the learning curve for students and professionals[1]. This technique has shown favorable performance with respect to preparation and bacterial reduction[2] while considerably the risk of cross-infection[3]. In addition, a reciprocating motion has been postulated to reduce the possibility of unexpected file fracture due to flexural fatigue and torsional overload as compared to instruments that work under continuous rotation[1,4]. Reciproc (RC) (VDW, Munich, Germany) and WaveOne (WO) (Dentsply-Maillefer, Ballaigues, Switzerland) instruments, which are characterized by different geometric features, are both designed to work in reciprocating motion. By this movement, the instrument rotates in one direction and then reverses direction before completing a full rotary cycle[5,6].

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The cutting capacity of a root canal instrument depends on a complex interrelationship between different parameters, such as cross-sectional design, chip removal capacity, helical and rake angles, metallurgical properties, and surface treatments of the instruments[7–10]. Weighing the amount of material cut by the instrument[11,12], measuring the wear depth in acrylic plates using profilometry[13,14] or preparation time,[15,16] microcomputed tomographic imaging[17] or direct evaluation by a clinician during preparation[18] are all examples of different methodologies used to investigate the cutting behavior of endodontic instruments. Although extensively studied, there is no consensus regarding the most adequate criteria to establish this property of endodontic instruments. The torque and apical force required for the penetration of the instrument inside an artificial canal have proved to be reasonable variables for measuring the cutting efficiency of rotary instruments[19].

The aim of this study was to use this newly designed *in vitro* testing platform to assess the cutting properties of reciprocating files. The geometric and dimensional characteristics of the evaluated instruments were also determined to correlate them with the measured parameters.

MATERIAL AND METHODS

Reciproc R25 (VDW GmbH, Munich, Germany) and WaveOne Primary instruments (Dentsply Sirona, Ballaigues, Switzerland), both 25/.08 and 25mm in size, were studied. Before mechanical tests, ten instruments of each type, as received from the manufacturers, were photographed using a high-resolution digital camera (20D; Canon, Tokyo, Japan) to assess their dimensional characteristics. The measurements were made using Image Pro Plus 6.0 (Media Cybernetics, Silver Spring, MD). Lines were drawn on both sides of the instrument's images, and the outermost diameter at each millimeter from the tip was measured. The same method was used to determine pitch length and helical angle, i.e., the angle between the blades and the long axis of the instrument. Scanning electron microscopy (SEM) images (JSM 6360; Jeol, Tokyo, Japan), taken with 400x magnification from polished cross-sectional surfaces cut out with a metallographic saw (Isomet 1000; Buehler, Lake Bluff, IL), were used to determine the cross-sectional areas at 3 mm from the tip (A3) and the measurements of the rake angle of the studied instruments. According to the manufacturer, WO instruments undergo a change in cross-sectional geometry along their active part, where the section characterized by the triple helix would assume a convex triangular shape.

Cutting efficiency was assessed by measuring the torque and apical force at a constant insertion rate in experiments (n = 10 for each instrument type) performed with a recently developed laboratory bench device (19). Prefabricated, autoclave-safe epoxy blocks (Dentsply Maillefer, Ballaigues, Switzerland), 17 mm in length and artificial canals with a 5 mm curvature radius, were fixed individually in an acrylic base coupled to the upper chuck of the test machine. A hand-piece connected to an endodontic motor (X-Smart Plus, Dentsply Maillefer, Ballaigues, Switzerland) was attached to a fixed acrylic apparatus set in the base of the machine (AN8032; Analógica, Belo Horizonte, MG, Brazil), to guarantee the same hand-piece position in each test. A new resin block, previously explored with #10 and #15 manual 25mm K-type files (Dentsply-Sirona, Ballaigues, Switzerland) using water lubrication, was used for each tested file.

Instrumentation testing was done without irrigation to avoid the adverse effects reported in resin blocks[20]. The opening of the artificial canal was positioned downward to help remove the material and prevent the compaction of chips. The possible heating of the blocks due to friction during instrumentation was assessed by inserting a type K thermocouple in the resin block at 0.5 mm from the canal wall in the region of the last 3mm to reach the working length. Temperature was monitored using a digital thermometer (Figure 1) (51 II, Fluke Corporation, Everett, WA).

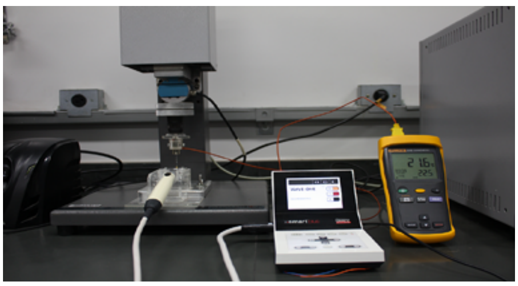

Figure 1 - Test device showing the positioning of the endodontic hand-piece in the acrylic base, the endodontic motor, the thermocouple attached to the resin block, and the digital thermometer.

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The motor was set according to specific programs for each system, while the canal was set to move down against the instrument at a speed of 0.09 mm/s. To simulate clinical conditions, the shaping of the canal was performed in two stages, an initial preparation of 13.5 mm and then a preparation of the last 3mm of the canal, to reach a total working length of 16.5 mm. Between the two cutting cycles, recapitulations were done with a #10 K file, and the instruments were cleaned using a paintbrush.

A digital multimeter (DMM4020 Tektronix, Beaverton, OR) was coupled to the motor in order to measure the maximum electric current delivered to the hand-piece during instrument displacement along the length of the artificial canal. A calibration curve was constructed using the torque control from the endodontic motor, and a torque–versus–electric current direct relation was obtained by linearization of the data points, fitted according to Eq. (1) (below) with a correlation $R^2 = 0.99$.

$$\text{Torque (N·cm)} = 4.82 \cdot \text{Current } (\mu A) - .20 \qquad (1)$$

As the artificial canals have a pre-enlarged coronal region, where there is no contact between the instrument and the canal walls, torque records began during the shaping of the final 10mm.

The test machine's load cell recorded the apical force, measured in Newtons (N), exerted by the instrument along the canal length. The torque and apical force curves were averaged using OriginPro 9.0 software (OriginLab, Northampton, MA). Data were analyzed using a one-way analysis of variance at a 95% confidence level.

RESULTS

The two reciprocating file systems used in this study have different designs: RC shows an S-shape and WO a concave triangular shape cross-section, as shown in Figure 2. The mean values of D3 and A3 (±standard deviations) are shown in the insets. Although no statistically significant differences with respect to D3 ($p > 0.05$) were present, WO instruments displayed significantly higher mean values of A3 than RC ($p < 0.00001$). At 3mm from the tip, WO instruments showed six cutting edges, but only three of these seemed to be able to contact dentin walls. In the RC instruments, two sharp cutting edges could be observed. Pitch length increased along the active part of both instruments. In general, RC showed larger pitch lengths than did WO instruments ($p < 0.0001$). As an indirect consequence, mean helical angle values in the active part of Reciproc instruments were smaller than for WaveOne, ($p < 0.0002$).

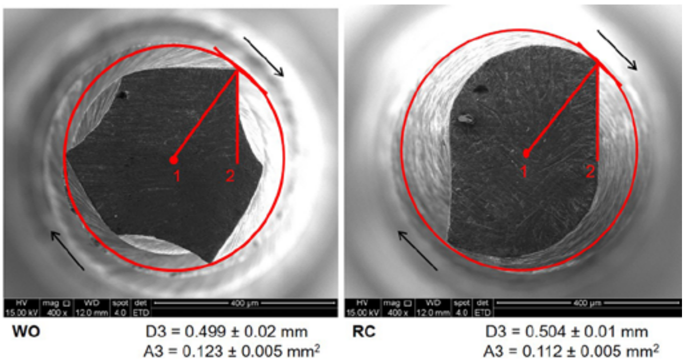

Figure 2 - SEM images of WaveOne and Reciproc cross-sections at 3mm from the instrument tip. The rake angles are drawn on the images. Also shown are the average values and standard deviations of R3 and A3.

During the cutting tests, no instrument fractures or canal obstructions were observed. The block temperature increased from 21° to a maximum of 25°, with the highest increase observed for WO instruments. Mean curves of the torque required by the RC and WO instruments in the first (A) and second (B) stages of displacement into the artificial canals are shown in Figure 3. Compared to the WO system, RC instruments exhibited lower torque values during the first and second stages of the cutting efficiency test but with a significant difference only observed in the first stage ($p = 0.008$). Mean curves of the axial force (N) (Figure 4) in the first (C) and second (D) stages of penetration into the artificial canals show that WO instruments displayed higher force values at the end of the first stage of the study and RC instruments at the second stage. However, the difference in mean axial force between the systems was statistically significant only in the second penetration stage (p = 0.04).

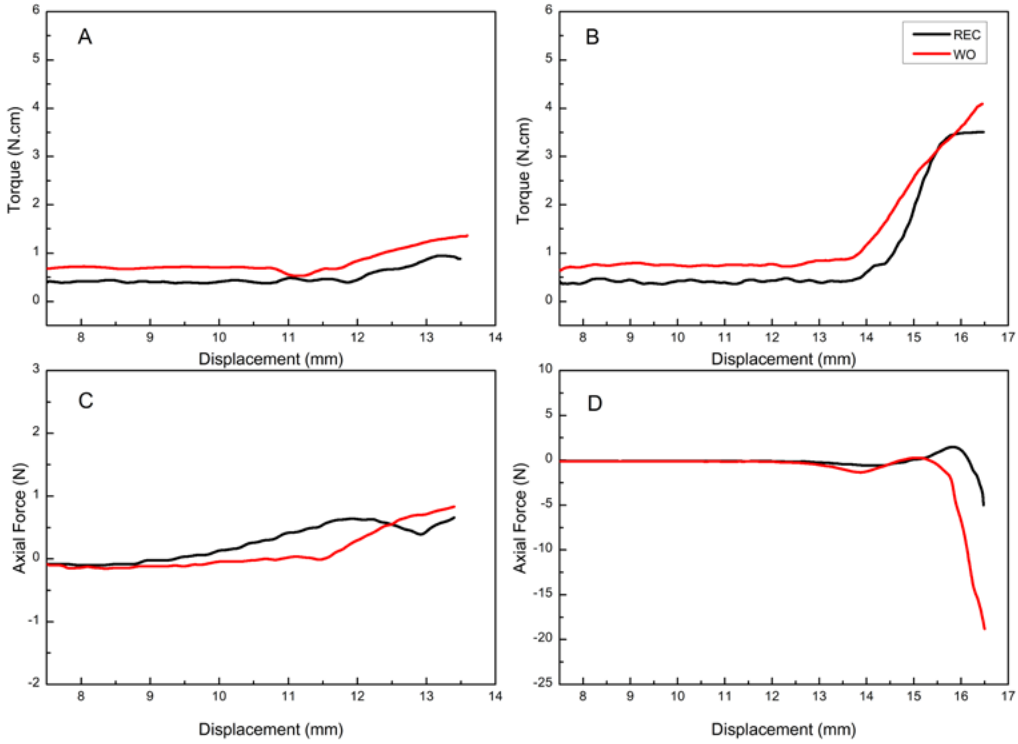

Figure 3 - Mean curves of torque required by the instruments during the insertion tests into the artificial canals in the first (A) and second (B) stages; mean curves of axial force in the first (C) and second (D) stages of the test.

DISCUSSION

Various methods are used to evaluate cutting efficiency of endodontic instruments behavior because of the complex and multiaxial mechanical forces applied during endodontic canal preparation[19, 21]. In this study, cutting efficiency was established through two parameters, torque and axial force, to correlate them with geometric and dimensional characteristics of two endodontic instruments using a reciprocating motion, Reciproc and WaveOne. Using a constant insertion rate and a fixed rotation speed set by the endodontic motor guaranteed a constant cutting speed, thus making the analysis of the cutting properties of the endodontic instruments dependent almost exclusively on their geometric characteristics. Following recommendations found in the literature[20], care was taken to avoid instrumentation problems, such as the packing of chips and instrument blocking.

Acrylic blocks were used for instrumentation, and these provide some advantages regarding sample standardization, particularly the length, curvature, and diameter of the artificial canals[19]. According to Kum[22], many rotary instruments do not have sharp cutting edges but remove dentin by the grinding action. The effect of this grinding action is unknown in resin, but the heat generated may sometimes soften the resin material. However, the possibility of softening the resin blocks because of heating during instrumentation without lubrication was discarded in this study, as the increase in the measured temperature was not significant.

Torque values required during root canal shaping depend on a variety of factors, and perhaps the most important one is the extension of the contact area between the instrument and dentinal walls. The greater the extent of contact and the consequent friction created, the higher the required torque[23]. Higher required torque values mean, in fact, a lower cutting efficiency[19]. WaveOne instruments showed a lower cutting efficiency based on this parameter, although this was only statistically significant in the first test stage. Some geometric characteristics interfere in the mechanical behavior of the instruments. As the pitch length is smaller in comparison to RC, WO instruments have am increased pitch number in the active part. This promotes a greater contact with the canal walls, increasing the amount of torque required for the cutting action during penetration in both stages of the test. The pitch length of the instruments also has an indirect relationship with the helical angle, with shorter pitch lengths reflecting higher values of helical angles.

In another report in which the Reciproc R25 demonstrated a greater cutting efficiency than the WaveOne Primary file[24], it was suggested that the cross-sectional design had a greater influence on the cutting efficiency than the movement amplitude. In fact, the geometry of the cross-section has been identified as a decisive factor that directly influences the behavior of endodontic instruments[25-26]. A smaller cross-section creates a larger area between the instrument and the canal walls[25]. This extra space allows for a greater apprehension of debris, facilitating the removal in the coronal direction. With nearly equal diameters at 3mm from the tip, WO had a mean A3 value that was significantly higher ($p < 0.0001$) than that observed for RC instruments. A plausible explanation for this may lie in the cross-section geometric profile of these instruments. Image analysis showed a triple helix cross-section in WaveOne and an S-shape cross-section in the Reciproc system. Cross-sections with larger areas may not provide sufficient room for debris to be displaced and subsequently removed from the canal. Thus, the permanence of debris in the canal would hinder the cutting action on the dentinal walls, requiring higher torque for its apical movement within the canal[27], as happened in this study, with the Wave-One larger triangular cross-section reducing its cutting ability when compared to Reciproc.

The rake angles in the cross-section design were classified as positive, neutral, or negative[28]. The Reciproc instruments feature two cutting angles, both negative and sharper compared to WO instruments. The latter featured six edges but only three negative cutting angles. The observation that instruments with an S-shaped cross section and two sharp cutting edges (Mtwo and Reciproc) were associated with an enhanced cutting efficiency has also been observed in previous studies[9,16,24].

WaveOne instruments required higher axial forces in the first stage of the study. Their geometric characteristics, once again, can explain this behavior. Higher mean values of helical angles, and hence smaller pitch length next to the tip region, promoted greater contact with the canal walls, making them more prone to be screwed in[29]. The smallest area for debris escape near the tip of the WO instruments also influenced the higher values of axial force observed in the first stage of the study.

In the second stage of the test, during the preparation of the apical third of the artificial canal, the results for the axial force values displayed by the WO and RC instruments showed a steep decline, achieving considerably negative values. This behavior suggests that the artificial canal is being pulled, thus registering a negative value of axial force. The shorter pitch length observed in WO instruments, in addition to their higher helical angle mean values, explains this exacerbated "screwing-in" trend behavior, since negative values of axial force in this second test stage were significantly higher for WO than for RC ($p = 0.04$). Negative values of axial force were also found, leading to the conclusion that this also depends on the instrument's size and shaping of the root canal[21].

Artificial canals were shaped in a specific test platform in a process done without lubrication to avoid the generation of an adverse effect, such as an acrylic smear, and because the opening of the simulated canal was faced downward for the removal of material by falling out of the canal during instrumentation without compaction of chips in the apical area[30].

CONCLUSION

Within the limits of this *in vitro* study conducted on non-dentin material, the use of a constant insertion-rate methodology for measuring cutting ability proved to be effective and allows for the establishment of a direct influence of the instrument's geometric characteristics on the property. Reciproc instruments demonstrated higher cutting efficiency compared to WaveOne instruments. Parameters, such as cross-sectional geometry, pitch length, and especially the greater chip removal capability of the RC instruments associated with their two sharp edges, appear to be decisive in influencing the cutting behavior of these instruments. For a more clinical approach, further studies should be conducted with similar parameters applied to extracted teeth and the use of dynamic movement.

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Avaliação da eficiência de corte de instrumentos NiTi com movimento reciprocante

Objetivo: Este estudo testa uma configuração para análise experimental in vitro de forças axiais e torque durante o preparo de canais artificiais usando instrumentos endodônticos reciprocantes de níquel-titânio.

Métodos: Foi avaliada a eficiência de corte dos instrumentos reciprocantes tamanho 25 / 0,08 (n = 10) Reciproc (RC) e WaveOne (WO), levando em consideração suas características dimensionais e geométricas. Medidas do diâmetro a cada milímetro a partir da ponta, comprimento de pitch, ângulo helicoidal e desenho da área transversal e área foram avaliados. Testes de eficiência de corte foram realizados em um dispositivo de bancada específico, medindo-se o torque e a força axial exigidos durante a modelagem de canais artificiais. A análise estatística foi feita com ANOVA one-way ($\alpha = 0,05$).

Resultados: As amostras de WO mostraram valores médios A3 maiores do que os instrumentos RC ($p < 0,0001$), apesar de terem diâmetros iguais a 3 mm da ponta (D3) ($p = 0,521$). Os valores médios do comprimento do pitch foram maiores para o RC do que para os instrumentos do WO ($p < 0,0001$), com consequentemente menores ângulos helicoidais ($p < 0,0001$). Para os testes de eficiência de corte, o torque necessário foi menor para o grupo RC em comparação com o grupo WO, mas significativo apenas no primeiro estágio de inserção nos canais artificiais ($p = 0,008$). Em relação à força apical, os instrumentos RC alcançaram valores maiores em relação aos instrumentos WO ($p = 0,04$) no segundo estágio de corte.

Conclusão: Os instrumentos Reciproc demonstraram uma eficiência de corte estatisticamente superior em comparação com os instrumentos WaveOne.

Descritores: Eficiência de corte. M-Wire. Movimento reciprocante. Reciproc. WaveOne.