Dynamic torque analysis of rotary and reciprocating instruments during root canal instrumentation in simulated canals by an endodontist or a general dentist

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Abstract

Background: Excessive torque is associated with engine-driven file fracture.

Aims: The aim of this study to evaluate the real-time torque of rotary and reciprocating instruments, working time, and the occurrence of procedural errors during root canal preparation of simulated canals by an endodontist and a general dentist.

Methods: Thirty-six commercially available simulated “J-shaped” root canals in resin blocks were used. Instrumentation was performed using WaveOne, WaveOne Gold, ProTaper Next, Reciproc, Reciproc Blue, and Mtwo. The real-time torque analysis and the number of times the maximum torque applied to the instrument were evaluated. Images were obtained to assess the occurrence of procedural errors, and working time was recorded.

Statistical Analysis: The one-way analysis of variance with a Bonferroni post hoc test, Mann Whitney test and the t-test was used for statistical analysis (P < 0.05).

Results: Reciprocating instruments showed lower values in the number of times that reached maximum torque and percentage time in the area of critical torque, with significant differences compared to rotary instruments (P < 0.05). Operators influenced torque values only with rotary motion instruments. There was no significant difference in mean working time between the operators or instruments. No fracture of instruments or canal transportation occurred.

Conclusions: Rotary instruments were associated with higher peaks in real-time torque variation during the preparation of simulated root canals.

Keywords: Endodontics; fracture; kinematics; reciprocation; root canal preparation; torque

INTRODUCTION

Engine-driven nickel–titanium (NiTi) instruments are proposed to enhance the quality of root canal preparation, since they provide more predictable root canal preparation and shorter operative time, together with more comfort for
operator and patient.\textsuperscript{[3]} To simplify root canal preparation and reduce procedural errors, manufacturers are constantly offering enhanced endodontic instruments with new designs, kinematics, and thermal treatments.\textsuperscript{[2]}

Despite the advantages provided by the superelasticity of the NiTi alloy, instrument fracture remains a concern.\textsuperscript{[3]} File fracture can have a negative effect on the technical outcomes of root canal treatment procedures per se and in some cases may lead toward litigation.

Endodontic files are submitted to various forces during root canal instrumentation, such as flexion, torsion, tension, and apical pressure, and fracture may occur due to flexural and/or torsional stress.\textsuperscript{[4]} Although bending stress is significant in terms of fatigue, the main cause of NiTi rotary instrument fracture is excessive torsional stress.\textsuperscript{[5]} In fact, locking the tip of a rotary file will increase the torsional stress and may lead to its fracture. Manufacturers recommend different speeds and maximum torque values, often close to the limit of elasticity, for files of different diameters.\textsuperscript{[6]} The maximum torque is usually reached when the file passes through canal curvatures.\textsuperscript{[7,8]} Values close to the maximum torque can be considered as critical areas since the large amount of torque generated can induce instrument fracture or dentinal cracks.\textsuperscript{[6,8]} To minimize file fracture, motors with torque control have been suggested,\textsuperscript{[9]} together with the use of specific parameters normally recommended by the manufacturers. Fracture-associated forces may be intensified when the operator encounters unfavorable morphological conditions, such as calcified root canals and severe curvatures.\textsuperscript{[10]}

To understand NiTi instrument fractures, some aspects should be considered, such as the ability of the operator to use novel technologies, the stress generated by the file during the procedure, the number of times the instrument is used, and its resistance to cyclic fatigue, among others.\textsuperscript{[11-13]} A limited number of studies have evaluated the influence of operator experience on the shaping ability and iatrogenic errors or torque values for different NiTi systems.\textsuperscript{[14,15]} Understanding the role of the operator in the use of different endodontic instruments may help to better understand factors related to file failure during root canal preparation.

Therefore, the purpose of this study was to evaluate the real-time torque (i.e., average percentage time [s] in the critical area of torque and mean number of times that the maximum torque was reached) of different rotary and reciprocating instruments, the overall preparation time, and the occurrence of procedural errors during root canal preparation of simulated canals in resin blocks by an endodontist and a general dentist. The null hypothesis tested was that there are no differences in dynamic torque when comparing rotating and reciprocating endodontic instruments and operators during the preparation of simulated root canals.

**METHODS**

Thirty-six transparent resin blocks (IM do Brasil, São Paulo, Brazil) with “J-” shaped artificial root canals, standardized round cross-sections (ISO 15, taper 0.02), and a total length of 16 mm, of which 12 mm represents the straight coronal part, and 4 mm the curved apical portion, with an angle of curvature of 32° for the latter, were used for the present study. Root canal preparations were performed by a specialist in endodontics with more than 15 years of experience, or a less-experienced general dentist (<1 year from graduation), with each operator preparing 18 simulated root canals in total.

All procedures were performed under x6 magnification using an operating microscope (OPMI PICO, Zeiss, Oberkochen, Germany). First, the canals were negotiated with a stainless steel #10 K-file (Dentsply Sirona, Ballaigues, Switzerland), which was introduced into the canal until its tip was visible at the apical foramen. A predetermined working length of 15 mm was used for all samples.

The canals were randomly allocated using a computer algorithm program (http://random.org) into six groups, according to the mechanical preparation technique used, as follows: four reciprocating systems: WaveOne (Dentsply Sirona), Reciproc (VDW, Munich, Germany), WaveOne Gold (Dentsply Sirona), and Reciproc Blue (VDW) and two rotary systems: ProTaper Next (Dentsply Sirona) and Mtwo (VDW). All files were operated with a 6:1 speed reduction handpiece powered by the X-Smart IQ cordless motor (Dentsply Sirona), which records a final report showing graphs depicting the time (s) at which the instrument reached and remained at the critical area of torque and the number of times that the maximum torque was applied to the instrument. The preset program of the motor was used when available, otherwise, a bespoke setting, based on the manufacturer’s instruction, was used. Real-time torque values were displayed on a tablet computer screen (iPad Mini, Apple Inc., Cupertino, California, USA) throughout the assays. The operators were blinded to the torque values. The motor was used with auto-reverse torque setting. The reciprocating instruments were operated with a slow pecking motion, whereas the rotary ones were used in a brushing motion, with an amplitude of <3 mm. Instruments with a nominal size of 0.25 mm at D0 of the different systems were used to standardize the apical preparation. The reciprocating instruments were used with a single instrument concept for shaping, whereas for rotary instruments, two different
Instruments were used using the instrument of the same sequence with a nominal size of 0.20 mm at D0 before the final instrument. Each instrumentation system was used to prepare three simulated root canals, and files were discarded after one use. During the preparation, 3 ml of distilled water for irrigation was placed with Endo-Eze needle (Ultradent Products, South Jordan, UT, USA), 2 mm shorter than the working length between file usage. The time of the procedure was recorded for each system and operator, using a chronometer, starting from the first irrigation of the canal and ending when the working length was reached by the last file.

Images from the blocks were made before and after instrumentation to evaluate the occurrence of procedural errors, using the integrated High Definition Video Camera (Zeiss) coupled to an operating microscope. The images were taken at a right angle (90°) in regard to the root canal curvature. Following the superimposition of the before-and-after instrumentation images, the occurrence of procedural errors (i.e., blockages, ledging, zipping, stripping, and instrument breakage) was assessed by an experienced endodontist, who was blinded to the group allocation of the resin blocks.

The one-way analysis of variance with a Bonferroni post hoc test was used to compare the differences in torque values between instruments used by each operator. The Mann–Whitney test was used to compare the difference in the torque values of each instrument in the comparison between the general dentist and the specialist. The t-test for independent samples was performed to compare the difference in the procedure times between operators. The level of significance was set at $P < 0.05$. Data were analyzed using the Statistical Package for the Social Sciences, version 20 (SPSS, Chicago, IL, USA).

**RESULTS**

Percentage time (s) in the critical area of torque was as follows: general dentist – ProTaper Next, 11.0 ± 1.0; Reciproc, 0.67 ± 0.58; Mtwo, 3.33 ± 1.15; WaveOne, 1 ± 0.0; Reciproc Blue; and WaveOne Gold, 0 ± 0; and specialist – ProTaper Next, 4.0 ± 2.65; Reciproc, 1.0 ± 0.0a; Mtwo, 5.33 ± 0.58c; and WaveOne, Reciproc Blue, and WaveOne Gold; 0 ± 0. Descriptive statistics and depicted in Figure 1, whereas the results of the statistical analysis are reported in Table 1. The mean number of times that maximum torque was reached for the different instruments and operators is reported in Figure 2. The time required for the procedures is reported in Table 2.

There was no statistically significant difference in the time required for the procedures between the two operators and instruments with the same kinematics ($P > 0.05$) [Table 2]. No procedural errors occurred in the study.

**DISCUSSION**

The present study established that, in our experimental setup, operator experience influenced real-time torque only for rotary instruments. Furthermore, the kinematics of the file motion was the most important factors associated with variations in torque, whereas instrument design and/or metallurgy of the NiTi had limited influence. Therefore, the null hypothesis was rejected. It is worth noting that NiTi instruments, apart from the type of alloy and kinematics, differ in their cross-section and shear angle, among others. In the present study, the Mtwo presented with a high mean of the number of times that maximum torque was reached, which may be associated with its design, including an S-shaped cross-sectional design and a positive rake angle with two cutting edges.

Benchtop studies in this field have a potential clinical translation. In fact, clinical studies suggest that less experienced operators using rotary files (i.e., the ProTaper system) caused more fracture and plastic deformation of files when compared with an endodontist, but this was not the case when WaveOne was used. Similarly, the results of our study are in agreement with those evaluating dynamic torque and the force applied during the preparation of simulated root canals by Tokita.
et al.,[19] using a different methodology, which concluded that reciprocating kinematics might have advantages in reducing the generation of tension caused by screwing forces when compared to continuous rotation.

Current endodontic motors allow the monitoring of real-time torque, to allow clinicians to control these values during root canal preparation, leading toward subsequent adjustments if required. Baratto-Filho et al.[20] similarly monitored real-time torque variations with the X-Smart IQ motor using the WaveOne Gold and Reciproc Blue systems in mandibular molars but with a single operator. In accordance with our study, the median torque values reported were comparable for these reciprocating instruments. It should be noted that in the present study, torque values were measured at the clutch of the instrument, as in most of the previous similar studies.[3]

The limited number of operators and samples for the different subgroups, as well as the fact that preparations were performed in resin blocks, can be considered as an important limitation of the present study. We would like to highlight that significant differences were found when comparing time in the critical torque area and the number of adjustments if required. When comparing rotary and reciprocating instruments, Troiano et al.[25] observed that operator experience did not influence the shaping ability in simulated root canals. Furthermore, Muñoz et al.[26] evaluated the learning of inexperienced operators in the shaping of simulated root canals using R25 instruments, and it was concluded that the reciprocating systems are easy to learn, with six simulated root canals being sufficient to achieve competency with this procedure. The apical pressure applied by the operators was not evaluated in the present study. From the clinical standpoint, it should be reasonable to expect that a broad inter- and intra-operator variation occurs in regard to apical pressure, which would affect the torque values during engine-driven root canal preparation.

Preparation time was not influenced by operator type or the thermal treatment of the files, but it was associated with the kinematics used, which is in agreement with

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**Table 1: Average percentage time (s) in the critical area of torque during preparation and standard deviation according to the preparation technique and the operator (n=3) per group**

| Instrument          | General dentist (SD) | Specialist (SD) |
|---------------------|----------------------|-----------------|
| R25                 | 11.0±1.0a            | 3.33±1.65c      |
| R25 Blue            | 4.0±2.65a            | 1.0±0.0ab       |
| WaveOne             | 1±0.0b               | 0±0a            |
| Reciproc Blue       | 0±0a                 | 0±0b            |
| WaveOne Gold        | 0±0a                 | 0±0b            |

*Mann-Whitney U-test, **Different letters indicate significant difference at the ANOVA one-way with a Bonferroni post hoc test (P<0.05). ANOVA: Analysis of variance.*

**Table 2: Average time of preparation (s) and standard deviation with the different instruments between general dentist and specialist (n=3) per group**

| Instrument          | General dentist    | Specialist       |
|---------------------|--------------------|------------------|
| R25                 | 105.3 (25.7)       | 125.3 (13.4)     |
| R25 Blue            | 106.3 (21.0)       | 133.3 (16.6)     |
| WaveOne Primary     | 88.0 (6.9)         | 110.0 (5.0)      |
| WaveOne Gold Primary| 76.7 (27.5)        | 100.7 (3.1)      |
| Mtwo                | 125.0 (11.1)       | 141.5 (0.7)      |
| ProTaper Next       | 145.3 (7.2)        | 144.7 (14.2)     |

No significant differences were found when comparing the different groups at the t-test for independent samples (P<0.05)

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**Figure 2:** Mean of the number of times that maximum torque was reached for the different instruments and operator.
previous studies. In a previous study that included a specialist with more than 10 years of experience and a graduate student, the preparation time was reduced when the reciprocating instruments were used.[24] Furthermore, Bürklein et al.[25] evaluated the use of reciprocating single-file systems (Reciproc and WaveOne) with and without heat treatment in severely curved canals and concluded that there was no difference in the average preparation time.

The occurrence of iatrogenic errors was null in our study regarding instrument fracture or canal transportation during the preparation of the simulated root canals. It can be associated with the use of new instruments, as well as the control of torque and speed by the motor. This is in agreement with a clinical study by Bueno et al.,[12] who conducted a longitudinal clinical study of the incidence of fracture of reciprocating instruments used for the preparation of up to three posterior teeth by three experienced specialists. The authors observed a low incidence of instrument fracture, which occurred only in 3 out of 1130 root canals treated.

The clinical significance of using engine-driven files at the torque values assessed in the present study requires further understanding. However, the importance of monitoring dynamic torque should be reiterated, since procedural errors, such as instrument fracture, have been associated with treatment failure.[20] At the same time, root canal preparation involves the removal of dentin using relatively sharp instruments,[3] causing a reduction of the remaining tooth structure, and potentially, promoting the formation of root cracks.[3,6]

**CONCLUSIONS**

Rotary instruments were associated with higher peaks in real-time torque variations during the preparation of simulated root canals when compared to reciprocating files. Torque variations were influenced by the operator only for the rotary sequences. There were no significant differences between systems regarding mean time of preparation and occurrence of accidents in our experimental setup.

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**Conflicts of interest**

There are no conflicts of interest.

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