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Effect of dentine cutting efficiency on the lateral force created by torque-controlled rotary instruments

Deari, S ; Zehnder, M ; Al-Jadaa, A

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Effect of dentine cutting efficiency on the lateral force created by torque-controlled rotary instruments

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Running title: Lateral instrumentation force

Keywords: austenite, martensite, root canal, intracanal lateral force

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Abstract

Aim To study the impact of dentine cutting efficiency of rotary instruments on the lateral force they create when instrumenting simulated root canals in bovine dentine.

Methodology Lateral cutting efficiency of austenitic files (ProTaper Universal) was compared to that of counterparts of a reported identical geometrical design with a martensite phase component (ProTaper Gold) in bovine dentine discs ($n = 6$). Instrument shapes were studied using digital microscopy. The intracanal lateral force exerted by the two systems in simulated premolars ($n = 9$) made from bovine incisor roots containing a standardized narrow root canal of 16 mm length was monitored using a testing apparatus equipped with a torque-controlled endodontic motor/handpiece. Data were compared using parametric statistics, alpha error = 0.05.

Results The geometrical design of the two systems under investigation was found to be identical. The martensitic nickel-titanium rotary files had a significantly (t -test, $P < 0.05$) higher lateral cutting efficiency than austenitic counterparts. This difference, however, did not impact the lateral force that was created when instrumenting simulated premolar root canals. Furthermore, lateral force peaks were generated with the progressively tapered instruments under investigation towards the full working length. Even though a glide path was prepared, the first instrument in the full-length sequence (S1) created the highest lateral force (ANOVA/Tukey's HSD, $P < 0.05$).

Conclusions The current experimental set-up allows the study of the lateral force generated during root canal instrumentation. This force was not influenced by the dentine cutting efficiency of the instruments under investigation, but rather by their geometrical design.

Introduction

Nickel-titanium rotary instrumentation has gained wide popularity in the endodontic community over the past decades (Bird *et al.* 2009). Whilst there are numerous studies dealing with forces acting on motorized endodontic instruments (Hülsmann 2019), there is little information on the forces these instruments exert on the canal walls and roots (Gambarini *et al.* 2019).

Most if not all contemporary instrumenting systems prepare the main canals according to Herbert Schilder's core shaping goal: a funnel that can easily be irrigated and then filled (Schilder 1974). This implies that the individual instruments to achieve this objective are tapered. However, the larger instruments in this design became rather stiff, and thus transport curved root canals (Weiger *et al.* 2003, Kunert *et al.* 2010). Manufacturers have tackled this problem by altering the structure of the nickel-titanium used to produce their instruments from pure austenite to compositions with a martensite phase component (Peters *et al.* 2017). Martensitic files have a reduced propensity to straighten curved canals (Duque *et al.* 2017). However, a second and perhaps under-estimated problem with tapered rotary instruments is their wedging effect within the root canal and the impact on the root (Blum *et al.* 1998, Lertchirakarn *et al.* 1999). Whilst the theory that instrumentation may commonly create microcracks in the root dentine has been disputed (Arias *et al.* 2014, De-Deus *et al.* 2014), the lateral force exerted by root canal procedures, e.g. cold lateral compaction of gutta-percha, has nevertheless been associated with vertical root fractures (Morfis 1990). In this context, it is conceivable that files that cut dentine more efficiently exert a lower wedging effect than counterparts that cut less, because they remove more dentine as they advance. Interestingly and perhaps unexpectedly, rotary instruments with a martensite phase component tend to have a higher cutting efficiency than purely austenitic files (Morgental *et al.* 2013, Vasconcelos *et al.* 2018).

The aims of this study were: 1) to compare geometrical file shapes between ProTaper Universal and ProTaper Gold (Dentsply Sirona Endodontics, Ballaigues, Switzerland), i.e. purely austenitic files and counterparts of the same reported design with a high martensite phase component; 2) to assess the lateral dentine cutting efficiency of these instruments; and 3) to measure the lateral force they exert when instrumenting simulated root canals. The last experiments were conducted in a specifically designed testing apparatus, allowing an endodontic torque-controlled motor/handpiece to be employed, and standardized roots with corresponding narrow root canals made from bovine teeth. The hypothesis underlying this research was that files that cut better should also exert less lateral force, because their

wedging effect may be reduced.

Materials & methods

Assessment of file geometry

An individualized holder with fixing screws was created from an aluminum block to maintain the instruments under investigation in comparable position. Standardized photos at a magnification of 3.5x were obtained utilizing a camera attached to a microscope (YF 2010, Dongguan Yihui Optoelectronics Technology Co. Ltd., Guangdong, China). These photos were then super-imposed using an image program (Photoshop CC 2018, Adobe Inc, San Jose, CA, USA) to check for any variations in geometrical design between ProTaper Universal and ProTaper Gold.

Lateral cutting efficiency on dentine

Using a saw microtome (Leica SP1600, Nussloch, Germany) under water cooling, 1-mm thick enamel-dentine discs were dissected from bovine incisor crowns (Fig. 1, a). The teeth were obtained from 3 y-old animals, which were slaughtered for food production by a certified provider. Using such teeth for research is exempt from the necessity to obtain an approval by the local ethics committee. The discs obtained were split in a coronal-apical direction in two pieces (Fig. 1, b). The paired dentine parts were mounted separately on cylindrical acrylic holders (20*25 mm) with their incisal edges (enamel) facing down (Fig. 1, c). Six pairs of samples were prepared and preserved in physiological saline solution (0.9% NaCl) at 5°C until use.

A wireless endodontic motor/handpiece (VDW CONNECT Drive, VDW GmbH, Munich, Germany) running on proprietary software via an iPad (Apple, Cupertino, CA, USA) was mounted to a free-falling holder. The holder allowed a free movement in the vertical direction only. The holder was mounted to a linear slide system (Parker Positioning Systems, Parker Hannifin, Cleveland, OH, USA), which allowed the rotary instrument to be adjusted in the horizontal direction. The force the mounted handpiece exerted in the vertical direction by its weight was 2.7 N. The head of the handpiece was aligned perpendicularly to the enamel-dentine disc surface (Fig. 1, d).

Two batches of Pro-Taper F2 instruments Universal and Gold (Dentsply Sirona Endodontics) were tested on paired dentine specimens ($n = 6$) for their cutting efficiency at 15 mm from the tip (Fig. 1, d). The torque and rotation speed for each instrument were set according to the manufacturer's recommendations. Each instrument for each point test was allowed to rotate in

direct contact with the dentine disc for 3 min under continuous water irrigation of 1.5 mL/min. Digital photographs of the samples were then taken with a metal ruler positioned at the dentine disc level as a reference. Analysis of the cutting depth in the dentine discs was performed using image J program (NIH, Bethesda, MD, USA).

Simulated premolars and root canals

Eighteen bovine tooth roots with a minimal length of 16 mm from single-rooted bovine incisors were used for this part of the study. The crown and the root canal aspect of each root was removed by horizontal and longitudinal cuts, respectively (Fig. 2, a), using a saw microtome (Leica). The paired lateral root parts (Fig. 2, b) were embedded in acrylic resin (Paladur; Kulzer, Hanau, Germany) in a cylindrical mould (Fig. 2, c), so that they could be reassembled (Fig. 2, d). Before reassembly, an artificial canal of 0.2 mm width and depth was milled into the whole central length in one of the parts using a precision workbench equipped with a standardized drill (Brasseler GmbH, Lemgo, Germany; ISO: 806 104 354524 140). The simulated premolar roots obtained containing a standardized, narrow root canal were stored in physiological saline solution at 5°C until further use.

Testing apparatus

The files under test were applied in a CONNECT Drive wireless endodontic motor/handpiece (VDW). The handpiece was attached to a linear slide system (Parker Positioning Systems), which, in turn, was mounted and fixed to an electric cylinder actuator (EPCO-25-50-10P-ST, FESTO, Esslingen, Germany). The setup allowed a controlled up and down movement in the y axis (pecking motion) and a free rotation in the z axis to reduce possible horizontal stresses through the handpiece (Fig. 3, a-c).

The bovine root halves simulating a premolar were then inserted into a custom-made holder. The sample holder assembled the two parts for displacement-free force measurement. This holder was attached to a force gauge on one side (Mecmesin, Brütsch-Rüegger, Urdorf, Switzerland) to allow the measurement of force in the x axis (Fig. 3, d). The file was positioned at the canal entrance in a vertical direction parallel to the canal long axis with the help of the precision screw of the linear slide system, which allowed a controlled file positioning in the x axis. The exerted lateral force to the simulated premolar root could be detected by the measuring device (Mecmesin, Brütsch-Rüegger, Urdorf, Switzerland). A custom program interface (Forcelog, University of Zurich, Zurich, Switzerland) enabled the control of the actuator movement and the recording of the detected measurements in

electronic form. The program allowed the control of insertion speed, insertion depth and time intervals between the pecking motions.

Instrumentation

Canals were instrumented using the settings for each individual instrument recommended by the manufacturer (note: these settings, i.e. rotational speed and torque, do not differ between ProTaper Universal and ProTaper Gold). The testing apparatus was set so that the vertical (crown-down) feed of the files was in 4-mm increments. This was to simulate the pecking motions that are recommended in clinics. Testing parameters were standardized based on preliminary trials, including the lateral forces that were obtained by a human operator (author S.D.). Instrumenting simulated root canals prepared as described above by manipulating the wireless endodontic handpiece as done in clinics, she generated maximum lateral force values within the range of the results presented below. In the apparatus, the file insertion speed was set up to 0.5 mm/s, which did not activate the auto-reverse mode in the preset program of the handpiece.

The canal was initially enlarged using a size 016 Pathfile (Dentsply Sirona Endodontics) to working length (16 mm). Subsequently, the files in the respective sequence were used. The Sx file was used for 2 crown-down motions, i.e. to a working length of 8 mm. Subsequently, all the other files were applied in four 4-mm steps to the full working length of 16 mm (Fig. 3, insert). Between each of these crown-down steps and between instruments, the file was cleaned with a cotton gauze swab and the simulated root canal was irrigated for 15 s with 1 mL of a 3% NaOCl solution (Dr. G. Bichsel AG, Interlaken, Switzerland). Lateral forces exerted by these files, i.e. S1, S2, F1, F2, and F3 were recorded.

Sample size calculation and data analysis

Sample size for the two main experiments (lateral cutting and lateral force) were calculated based on the mean values and standard deviations of the first triplicates, with a power of 80% and a Type I error rate of 5%. Data analysis was performed using a statistics program (jmp, SAS Institute, Cary, NC, USA). All the data here were distributed normally (Shapiro-Wilk test), and are presented as means and standard deviations. Mean values between the two systems were compared using Student's *t*-test. Mean lateral forces exerted by the files were plotted against insertion depth using Excel for Mac (Version 16.16.17, Microsoft, Redmond, WA, USA). A factorial analysis of variance (two-way ANOVA) was run to assess the effects of nickel-titanium phase and the type of instrument in the sequence (S1 to F3) on the

maximum lateral force that was created during instrumentation to working length. This analysis also assessed the interaction between those factors. Subsequently, the mean maximum force for each individual type of instrument was compared within the same nickel-titanium phase using one-way ANOVA followed by Tukey's HSD test for multiple comparisons. The alpha-type error was set to 5% in all these analyses ($P < 0.05$).

Results

The assessments of file geometry using digital microscopy confirmed that the two systems under investigation had identical geometrical design, i.e. size, taper, pitch, and helix angles, for the respective instruments in the sequence (Fig. 4). The purely austenitic F2 instruments (Pro Taper Universal, Dentsply Sirona Endodontics) cut an average of 0.88 ± 0.12 mm of dentine in 3 min. This was significantly ($P < 0.05$) less than the counterparts with the martensite phase component (Pro Taper Gold, Dentsply Sirona Endodontics), 1.49 ± 0.45 mm.

The factorial analysis revealed that the lateral force created by the different instruments in the sequence did not differ between the two nickel-titanium phases ($P > 0.05$). On the other hand, the type of instrument in the sequence did have a highly significant ($P < 0.001$) effect on this outcome (Table 1). When comparing the different files with each other in each system, it was revealed that the S1 file caused significantly ($P < 0.05$) higher lateral forces compared to all the other files (Table 2). Moreover, plotting the mean lateral forces against the insertion depth of the instrument, it was revealed that the S1 instrument was the only one that caused two peaks, between 8 and 12 mm and between 12 and 16 mm (Fig. 5). All the other instruments exerted lateral force only in the last pecking motion, i.e. immediately before they reached full working length.

Discussion

The current study confirmed that the martensitic nickel-titanium rotary files under investigation indeed have a higher lateral cutting efficiency than austenitic counterparts. This difference, however, did not impact the lateral forces that were created when instrumenting simulated premolar roots from bovine dentine. Therefore, the hypothesis of this study was rejected. Furthermore, the current results illustrated lateral force dynamics generated with the progressively tapered instruments under investigation. The highest forces were caused close

to working length. Even though a glide path was prepared, the first instrument in the full-length sequence (S1) created the highest lateral forces.

In the current study, files with the exact same geometrical design but different NiTi phases that are currently on the market were assessed: ProTaper Universal (pure austenite) and ProTaper Gold (“gold” phase martensite). Earlier studies on parameters related to automated canal instrumentation in dentine used standardized milled root canals in coronal third molar dentine (Boessler *et al.* 2007) or natural human root canals (Arias *et al.* 2017). For the current study, that was not suitable, as the focus was on the lateral forces that were exerted to the root dentine. An attempt was made to create simulated premolars with a standardized, realistic working length over the whole machined (i.e. cutting) aspect of the instrument, which is 16 mm. The use of bovine dentine due to its availability and the possibility to generate standardized specimens allowed reliable data comparison. However, because the current data was not obtained in human teeth, results cannot be extrapolated to clinics. Simulated human roots made from bovine dentine, on the other hand, are routinely used for mechanical tests, e.g. on the abrasiveness of dentifrices, with rather similar results compared to human specimens (Imfeld 2001). A further limitation of this investigation is that, whilst lateral forces could be measured directly, the roots had to be split to do so. The simulated premolar roots were split in a bucco-oral direction, because this is where wedging forces peak during the insertion of round tapered instruments (e.g. spreaders for lateral compaction), and hence fractures occur (Lertchirakarn *et al.* 2003, Chai & Tamse 2012)

The current results confirm an earlier report on the lateral cutting efficiency of ProTaper Gold versus Universal (Vasconcelos *et al.* 2018). Moreover, the manufacturer’s claim that the geometries of the files in these systems is identical was confirmed (Fig. 4), which has not been done before. However, the present study deviates from most earlier studies on instrumentation in that it was focused on the forces that root canal instrumentation generates towards the root structure rather than on the instrument itself (Peters *et al.* 2017). A new apparatus was devised that allows simulated clinical preparation, specifically the use of a torque-controlled endodontic handpiece. The current set-up is comparable to a testing device that was used to measure the movements and related forces exerted by a human operator to a human tooth (Diop *et al.* 2009). In the latter set-up, however, the focus was on the correlation between apically-directed force and torque. Forces that were measured in the x direction were not splitting forces, but rather laterally directed forces generated by the operator when performing the preparation. These forces were measured using transducers attached to the tooth holder. Interestingly, the same group of investigators did focus on splitting forces to

simulated tooth roots using a similar set-up in earlier studies (Blum *et al.* 1998), but never tested shaping instruments in this manner. Other authors used strain gauges attached to the root surface, and compared the relationship between apically directed force to strain on the root surface and ultimately, root fracture (Lertchirakarn *et al.* 1999). They found that the forces exerted by lateral compaction are not sufficient to create vertical root fractures. However, if pre-existing infractions exist, things may be different. Blum *et al.* (1998) measured peak horizontal forces of 0.6 kg, i.e. approximately 6 N in a testing apparatus allowing their direct measurement during root canal filling. This would be 50% less than the corresponding force created by the S1 instrument under current conditions. How these forces relate to tooth surface strain is not known and should be studied in future projects to further elucidate the topic under investigation. It should also be cautioned that the way the S1 instrument was used in the current study was not necessarily in the spirit of its manufacturers, who recommend “brushing” outward strokes and caution when approaching working length (Clauder & Baumann 2004). Whether the average user follows these recommendations, however, is debatable. The issue of preserving root structure appears to be timely. Laboratory studies have suggested that tapered root canal preparations may render roots prone to root fracture (Krikeli *et al.* 2018). Dental companies apparently also considered this. There appears to be a trend towards less-tapered instruments. The current data would add an element to this discussion in that it was shown that also the shape of the rotary instrument and its use in a sequence has a direct effect on the forces that are created during instrumentation. Future studies could use the current set-up to compare the lateral forces that are created by different instrumenting systems, and how/whether these forces can be influenced by settings of the motor. Moreover, it should be assessed how these forces relate to the propagation of pre-existing microcracks in the root.

Conclusion

The current experimental set-up allows the study of the lateral force generated during root canal instrumentation. This force was not influenced by the dentine cutting efficiency of the instruments under investigation, but rather by their geometrical design.

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Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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Captions

Figure 1. Lateral cutting assessment: 1-mm dentine disc prepared from a bovine incisor crown (a). Disc after splitting in a corono-apical direction (b). Dentin part mount to cylindrical acryl with enamel facing down (c). The wireless motor/handpiece head was aligned perpendicularly to the dentine specimen (d).

Figure 2. Simulated premolar preparation and testing. Bovine tooth crown and root canal aspects removed by horizontal and longitudinal cuts (a), resulting in paired lateral root parts (b). Root parts were embedded in acryl (c), and re-assembled after a standardized straight canal of 16 mm length had been prepared (d).

Figure 3. Testing apparatus consisting of a wireless endodontic motor/handpiece mounted on a handpiece holder (a) connected to a linear slide system (b) and the electric cylinder actuator (c) The sample holder was connected to a force gauge (d) for displacement-free force measurement. Speed, intermissions, and depth of in-and-out movements of the rotary instruments under investigation were controlled by a computer program. Insert: canal after full preparation (to F3) to the working length (16 mm).

Figure 4. File shapes: files fixed in comparable position (a), and superimposed images (b). These overlays confirmed the identical geometrical design between ProTaper Universal and ProTaper Gold.

Figure 5. Lateral force measured under the conditions of the current study plotted against the insertion depth of the file. The full working length was 16 mm, insertion depth was 4 mm per increment (pecking motion) at a speed of 0.5 mm/s.

Table 1 Results of the factorial analysis (two-way ANOVA) assessing the influence of nickel-titanium phase* and the type of instrument in the sequence on the maximum lateral forces created during instrumentation, and the interaction between those factors

Source	NParm	DF	Sum of squares	F ratio	Prob > F
Nickel-titanium	1	1	6.7	0.45	0.51
Instrument	4	4	523.0	8.70	< 0.001
Interaction	4	4	73.9	1.23	0.31

* ProTaper Universal are purely austenitic rotary files, whilst ProTaper Gold counterparts have a martensitic phase component. Nparm = number of parameters in the model; DF = degrees of freedom; Prob = probability.

Table 2 Maximum lateral force values in N (means $\pm$ SD) observed in the instrumenting sequence according to nickel-titanium phase* and instrument

Instruments	S1	S2	F1	F2	F3
PT Universal	13.4 $\pm$ 3.7 ^A	9.5 $\pm$ 6.0 ^{AB}	8.3 $\pm$ 3.0 ^{AB}	7.3 $\pm$ 3.3 ^B	10.2 $\pm$ 3.4 ^{AB}
PT Gold	15.8 $\pm$ 4.5 ^a	9.6 $\pm$ 2.9 ^b	6.9 $\pm$ 3.8 ^b	10.1 $\pm$ 4.1 ^b	11.4 $\pm$ 6.5 ^b

* ProTaper (PT) Universal are purely austenitic rotary files, whilst ProTaper Gold counterparts have a martensitic phase component. The instruments have the same geometry. Data sets that share an identical superscript letter did not differ from each other at the 5% level within the same system (one-way ANOVA, Tukey's HSD).

(a)

(b)

File insertion depth vs. lateral force

x-axes: insertion depth (mm)
y-axes: mean lateral force (N)
 $n = 9$

— ProTaper Gold
— ProTaper Universal

S1

S2

F1

F2

F3