Original Article

The relevance of operative torque and torsional resistance of nickel-titanium rotary instruments: A preliminary clinical investigation

Gianluca Gambarini, Gabriele Miccoli, Maurilio D'Angelo, Marco Seracchiani, Federico Valenti Obino, Rodolfo Reda, Luca Testarelli

Department of Oral and Maxillo-Facial Sciences, "Sapienza" University of Rome, Rome, Italy

Abstract

Introduction: The aim of the present study is to evaluate the torsional resistance and the operative torque of two different files and to introduce the concept of "torque range", that indicates the difference between torque at failure and operative torque.

Materials and Methods: 20 ProTaper Next® (PTN) X1 and 20 EdgeFile® X7 17.04 were randomly divided into two equal groups ($n = 10$) and were subjected to the following two tests: operative torque recorded during root canal shaping of a single-rooted mandibular premolar and a torsional test performed at 300 rpm while the apical 3 mm of each file were firmly secured. The torque range was calculated from the difference between "Operative torque" and "torque at fracture." A statistical *t*-test was performed to determinate the difference. Statistical significance was set at $P < 0.05$.

Results: EdgeFile X7 instruments reached the working length significantly faster and with less torque generated ($P < 0.05$) compared to PTN. In torsional static resistance (torque at failure), the two files demonstrated no significant different values ($P > 0.05$). The range between the mean values of maximum torque at failure and operative torque, "torque range," was twice bigger for EdgeFile X7 instruments.

Conclusions: The EdgeFile X7 has a wider "torque range" when compared to PTN X1. This new concept could be a relevant innovation to match *in vivo* and *in vitro* studies and to obtain a more clinically relevant result.

Keywords: Nickel–titanium instruments, operative torque, torque range, torsional resistance

Address for correspondence: Dr. Marco Seracchiani, Via Caserta 6, 00161, Rome, RM, Italy.
E-mail: marco.seracchiani@gmail.com

Submission: 19-12-19 **Revision:** 15-01-20 **Acceptance:** 24-03-20 **Web Publication:** 27-08-20

INTRODUCTION

Nickel–titanium (NiTi) endodontic instruments are subjected to fracture due to two main causes: flexural and torsional.[1,2] Repeated compressive and tensile cyclic stresses produced while the instrument is inserted and rotated in the canal, could determine flexural or cyclic fatigue failure.[3,4] Torsional failures occur when the tip or another apical part of the instrument is locked inside the canal while the upper portion of the instrument continues to rotate until the torsional limit of the instrument is overtaken.[5,6]

Access this article online	
Quick Response Code:	Website: www.saudiendodj.com
	DOI: 10.4103/sej.sej_157_19

How to cite this article: Gambarini G, Miccoli G, D'Angelo M, Seracchiani M, Obino FV, Reda R, *et al*. The relevance of operative torque and torsional resistance of nickel-titanium rotary instruments: A preliminary clinical investigation. Saudi Endod J 2020;10:260-4.

The involvement of cyclic fatigue resistance on NiTi rotary instruments intraoperative breakage has been studied extensively.[7-13] On the other hand, there are less information available on torsional resistance tests and only minimal information available on operative torque.[14-16] Operative torque can be defined as the amount of torque needed by instruments to progress inside the canal, cut dentine and remove debris: it is a dynamic measurement that depends also on time needed and the technique used to reach the working length.[16]

Currently, the most used method for evaluation of static rotational resistance is the testing the instruments as described by the International Organization for Standardization (ISO) 3630-1.[17] According to this standard, to generate a continuous torsional load, 3-mm file tip was fixed and rotated with the speed of 2 rpm. This method was developed in the 19th century with the purpose of testing torsional resistance of manual stainless steel files, but, probably, is not anymore valid for testing the NiTi rotary instruments that, in clinical practice, rotate at much higher speed than 2 rpm. In the literature, there is no agreement about the influence of rotational speed on the torsional resistance of the instruments.[18] Values of torque at failure from ISO tests were used to determine torque settings in torque-controlled motors. However, the idea of being safe during instrumentation because of the use of the preset torque value is not completely accurate because in the clinical practice, the torque values is a measurement of the torsional load from the full length of the instrument, while the ISO test measures the torsional load at a specific level (3 mm from the tip).[19]

NiTi rotary files should ideally operate with constant speed and under constant load when the martensite start clinical stress is reached, to maximize their efficiency.[15,16] Unfortunately, root canals are very different in terms of diameters, trajectories, hardness of dentin, etc.[20-22] As a consequence, the operative torque can vary significantly and continuously, i.e., in narrow canals, rotary instruments are subject to higher torsional stresses than in the wider canals, to cut dentin and remove debris. Moreover, the clinical use of the instruments (i.e., amplitude of pecking motions, brushing, and applied precision) is different for each clinician, and it may result in different blade engagement and torsional stresses during intracanal instrumentation. Very few studies are available about operative torque during intracanal usage, also because different canal anatomies may result in different torsional stresses.[15,16]

Ideally, to optimize the performance, a NiTi rotary instrument should require low operative torque values and exhibits high torque at failure resistance. In clinical practice, the wider is the range between these values, the safer and easier is the intracanal instrumentation. For these reasons, comparing instruments by testing only operative torque or torsional resistance could be at least, poorly clinical relevant or even misleading, because the two values alone are not an exhaustive indication of instruments *in vitro* resistance or clinical performance. Based on this premise, the aim of the present study is to test two different NiTi files for comparing operative torque and torque at failure, showing the gap between these two different parameters in order to estimate a relationship between *in vivo* behavior and *in vitro* studies of rotary files.

MATERIALS AND METHODS

The following instruments from two different systems were tested and compared: ProTaper Next® (PTN) X1 (Dentsply Maillefer, Ballaigues, Switzerland) and EdgeFile® X7 (EdgeEndo, Albuquerque, New Mexico). For each brand, 20 instruments size 17.04 were randomly divided into two equal groups ($n = 10$) and were subjected to the following two tests:

Operative torque

Twenty patients requiring root canal treatment of a single-rooted mandibular premolar were selected from among those participating in a clinical research project on tooth anatomy of the Dental Clinic of La Sapienza University (Ethical committee 528/17). Informed consent was obtained from each patient. This clinical project used previously was done with cone-beam computer tomography to assess the number of canals and root canal morphologies. All teeth had one root and one canal with curvature smaller than 30°, according to Schneider's criteria.[23] Moreover, no sign of external or internal reabsorption was found. The 20 teeth with the above-mentioned criteria were divided into two similar groups of 10 each. Following proper rubber dam placement and clinical endodontic access procedures, a manual glide path was performed (#15 K-file) to the working length. Then each tooth was randomly assigned to one of the two rotary systems chosen for the study. For each tooth, a new PTN X1 17.04 or EdgeFile X7 17.04, depending on the assignment, was used. The files were rotated, according to the manufacturer's recommendation, clockwise at 300 rpm with 2 Ncm maximum torque by an endodontic torque recording motor (Kavo, Biberach, Germany). The torque value recording was performed every 1/10 s. Mean, maximum torque values (Ncm), and procedural time (seconds) were recorded.

Afterward, using the first NiTi rotary instrument, root canal preparation was completed following the manufacturers' guidelines using the following instruments of each system. After root canal treatment, the PTN X1 and EdgeFile X7 were observed under stereo optical microscope (Hitachi, Tokyo, Japan) at 20X to detect flute deformation or instrument separation.

Torque at failure

Ten instruments from each of the two groups were selected for this test. A repetitive torsional test was performed by the use of the torque-controlled, torque recording endodontic motor. The device was already validated in a previous study to assess the accuracy and reliability. A mixed autopolymerizing resin (DuraLay; Reliance Dental Mfg Co, Worth, IL) was used to produce a firm block that blocked the 3 mm tip of the file. This system was trapped using a vise. Each file was rotated clockwise at a speed of 300 rpm until fracture occurred. The torque limit was set at 5.5 Ncm, to ensure recording measurements ranging from 0.1 to 5.5 Ncm. The integrated software of the motor was used to record the values of torque at failure.

Torque range

The results of torque at failure and mean operative torque of each instrument were substracted using a spreadsheet to obtain "the torque range" (Ncm). The operative torque and the torque at failure data were statistically analyzed using spreadsheet software and one-way ANOVA with the significance level set at 5%.

RESULTS

About the operative torque tests, EdgeFile X7 instruments reached the working length significantly faster ($P < 0.05$) compared to PTN, respectively in 7.12 ± 2.30 and 12.96 ± 3.60 s. None of the recorded torque values exceeded the selected torque limit, but PTN instruments required mean and maximum torque values significantly higher ($P < 0.05$) than EdgeFile X7. For EdgeFile X7, mean torque was 0.17 (0.03) Ncm and maximum torque was 1.19 (0.71) Ncm, while PTN X1 mean torque was 0.29 (0.87) Ncm and maximum torque was 1.88 (0.13) Ncm. No instrument exhibited flute deformation or underwent intra-canal failure during clinical use.

In terms of torsional static resistance (torque at failure), the two files demonstrated no significant different values ($P > 0.05$). The mean torque at failure for EdgeFile X7 was 0.57 (0.1) Ncm, while PTN X1was 0.51 (0.1) Ncm.

The range between the mean values of maximum torque at failure and operative torque for both instruments: this "torque range" was twice bigger for EdgeFile X7 instruments. The range for EdgeFile X7 was 0.40 (0.57–0.17) Ncm, while PTN X1 was 0.22 (0.51–0.29) Ncm.

DISCUSSION

In the present study, an innovative evaluation of NiTi rotary instruments' mechanical properties was performed using a new parameter: the so-called "torque range". This is a new concept that comprehends both operative torque and resistance to torsional stress, and it is calculated by subtracting the values of torsional resistance to the values of operative torque. It has more clinical relevance than the single tests because it shows the correlation between torsional stresses during instrumentation and instruments' resistance to them. Such a correlation can mimic more precisely the *in vivo* clinical behavior of NiTi rotary instruments subjected to torsional stress during the shaping procedures. The higher the value, the safer is the range of clinical use. Data were obtained from two different tests, one *in vivo* and one *in vitro*. The operative torque was assessed using a recently developed methodology, that records and compares the operative torque generated by the two chosen different rotary systems during the preparation of the canals of mandibular premolars *in vivo*.[15,16] Torsional resistance was measured *in vitro* on the same instruments by a methodology is derived from previous studies.[24,25] The main difference with the traditional ISO standardized test is that the chosen speed in the present study was the clinical one (300 rpm), while ISO tests are conducted at 2 rpm.

Results from the present study showed that:

1. The performance of the two tested NiTi instruments can be affected by the design and the manufacturing processes. Despite similar dimensions, the EdgeFile X7 instruments were able to reach the working length in significantly less time with a significantly smaller amount of torque, when compared to PTN
2. Design and manufacturing process play a less significant role in the torsional resistance of the two tested NiTi instruments, which was mostly influenced by dimensions and metal mass. Major changes in the design and manufacturing process could obviously have a more significant impact on the torsional resistance of NiTi rotary files[26-28]
3. Due to the smaller amount of operative torque needed, the EdgeFile X7 instruments exhibited a wider "torque range." This is a positive property because it provides them a safer range of clinical use[15,16]
4. The maximum torque values recorded during intracanal usage are higher than the torque needed to break the same instrument when the tip is blocked. These data confirm that during intracanal

instrumentation torsional stresses are distributed all along the instruments' working portion. Moreover, it demonstrates the importance of not blocking the instrument inside the canal, because this could easily and rapidly lead to the breakage of the rotary instruments.[29,30]

The torque range is a new parameter based on two different tests; therefore, it gives more clinical information than the single tests. For example, an instrument could exhibit a low torsional resistance but be very efficient in cutting, thus generating very low operative torque values. If these values are lower than the peak torque at failure, the instrument always operates in a safety range, and theoretically, it is safer than another instrument, which exhibits a higher peak torque at failure but requires much more operative torque to reach the working length. Since this parameter is calculated from the two above mentioned parameters, the limitations of this new parameter, the torque range, are the limitations of the single tests. Indeed the main limit of the *in vitro* torsional resistance is that is usually calculated at 3 mm from the tip (as specified by ISO 3630.1),[17] but in clinical practice, torsional stress can be applied in a different portion of the instrument, which have different resistance. Instead, the limitation of the operative torque is its dependency on canal anatomy: A more complex case, (i.e., calcified, narrow, and thin canals) could generate more torsional stress, therefore, increase the operative torque. A wider canal, softer dentin could elicitate much lower operative torque values. In the present study, operative torque was tested in very similar canals to ensure a valid comparison between the two tested instruments.

The new parameter is able to differentiate more precisely the clinical "safety" of two instruments which exhibited similar peak resistance to torsional stress. Since it is a new and original parameter, no comparison can be made with previous published studies. Furthermore, very few studies were published concerning operative torque and the majority of them are *in vitro*.[15,16] More studies were published about *in vitro* maximum torque at failure, but in many cases, similarly to results of the present study, no statistically significant difference can be found when comparing instruments with the same dimension.[28]

The present study also provided proper values that could (operative torque and peak torque at failure) be used clinically to program torque setting inside endodontic motors for the two tested instruments. In clinical practice, torsional load can be limited by the torque-controlled endodontic motor settings realized with the aim to prevent the overcoming of the torsional load limit of the instruments.[19] Unfortunately, the correct preset torque values for each instrument are very difficult to be determined. If too high, it may not be able to automatically reduce the risk of torsional fracture and the safety becomes only related to clinicians' skills of avoiding over engagement and/or blockage of the file. If too low, during clinical use, rotary NiTi instruments could be overloaded by repeated locking and release depending on the torque-control of the motor.[19] Shaping narrow canals could provide higher torsional stress than the wider ones, so the chance of experiencing such repetitive torsional loads would be increased.

CONCLUSIONS

To optimize clinical performance, a NiTi rotary instrument should require low operative torque values and exhibit high resistance to torque at failure, or exhibit a wider "torque range" between the two values. The EdgeFile X7 has a wider "torque range" when compared to PTN X1. This new concept could be a relevant innovation to match *in vivo* and *in vitro* studies to obtain a more clinical relevant result. This new parameter can be used to further correlate *in vitro* and *in vivo* values and to obtain a more clinical relevant result.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

REFERENCES

1. Di Nardo D, Galli M, Morese A, Seracchiani M, Ferri V, Miccoli G, *et al.* A comparative study of mechanical resistance of two reciprocating files. J Clin Exp Dent 2019;11:e231-5.
2. Cheung GS. Instrument fracture: Mechanisms, removal of fragments, and clinical outcomes. Endod Topics 2009;16:1-26.
3. Plotino G, Testarelli L, Al-Sudani D, Pongione G, Grande NM, Gambarini G. Fatigue resistance of rotary instruments manufactured using different nickel-titanium alloys: A comparative study. Odontology 2014;102:31-5.
4. Plotino G, Grande NM, Mazza C, Petrovic R, Testarelli L, Gambarini G. Influence of size and taper of artificial canals on the trajectory of NiTi rotary instruments in cyclic fatigue studies. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;109:e60-6.
5. Gambarini G, Tucci E, Bedini R, Pecci R, Galli M, Milana V, *et al.* The effect of brushing motion on the cyclic fatigue of rotary nickel titanium instruments. Ann Ist Super Sanita 2010;46:400-4.
6. Silva EJ, Giraldes JF, de Lima CO, Vieira VT, Elias CN, Antunes HS. Influence of heat treatment on torsional resistance and surface roughness of nickel-titanium instruments. Int Endod J 2019;52:1645-51.
7. Arias A, Macorra JC, Govindjee S, Peters OA. Correlation between temperature-dependent fatigue resistance and differential scanning calorimetry analysis for 2 contemporary rotary instruments. J Endod 2018;44:630-4.
8. Miccoli G, Gaimari G, Seracchiani M, Morese A, Khrenova T,

Di Nardo D. *In vitro* resistance to fracture of two nickel-titanium rotary instruments made with different thermal treatments. Ann Stomatol (Roma) 2017;8:53-8.

9. Gambarini G, Piasecki L, Miccoli G, Gaimari G, Di Giorgio R, Di Nardo D, *et al*. Classification and cyclic fatigue evaluation of new kinematics for endodontic instruments. Aust Endod J 2019;45:154-62.
10. Gambarini G, Miccoli G, Seracchiani M, Khrenova T, Donfrancesco O, D'Angelo M, *et al*. Role of the flat-designed surface in improving the cyclic fatigue resistance of endodontic NiTi rotary instruments. Materials (Basel) 2019;12: pii: E2523.
11. Gambarini G, Miccoli G, Seracchiani M, Morese A, Piasecki L, Gaimari G, *et al*. Fatigue resistance of new and used nickel-titanium rotary instruments: A comparative study. Clin Ter 2018;169:e96-101.
12. Plotino G, Grande NM, Mercadé Bellido M, Testarelli L, Gambarini G. Influence of temperature on cyclic fatigue resistance of protaper gold and ProTaper universal rotary files. J Endod 2017;43:200-2.
13. Gambarini G, Galli M, Di Nardo D, Seracchiani M, Donfrancesco O, Testarelli L. Differences in cyclic fatigue lifespan between two different heat treated NiTi endodontic rotary instruments: WaveOne Gold vs EdgeOne Fire. J Clin Exp Dent 2019;11:e609-13.
14. Santos CB, Simões-Carvalho M, Perez R, Vieira VTL, Antunes HS, Cavalcante DF, *et al*. Torsional fatigue resistance of R-Pilot and WaveOne Gold Glider NiTi glide path reciprocating systems. Int Endod J 2019;52:874-9.
15. Gambarini G, Seracchiani M, Piasecki L, Valenti Obino F, Galli M, Di Nardo D, *et al*. Measurement of torque generated during intracanal instrumentation *in vivo*. Int Endod J 2019;52:737-45.
16. Gambarini G, Galli M, Seracchiani M, Di Nardo D, Versiani MA, Piasecki L, *et al*. *In vivo* evaluation of operative torque generated by two nickel-titanium rotary instruments during root canal preparation. Eur J Dent 2019;13:556-62.
17. ISO 3630-1:2008 Dentistry Root-Canal Instruments – Part 1: General Requirements and Test Methods. Available from https://www.iso.org/standard/37702.html. [Last accessed on 2020 Apr 11].
18. Ha JH, Kwak SW, Kim SK, Sigurdsson A, Kim HC. Effect from rotational speed on torsional resistance of the nickel-titanium instruments. J Endod 2017;43:443-6.
19. Gambarini G. Cyclic fatigue of nickel-titanium rotary instruments after clinical use with low- and high-torque endodontic motors. J Endod 2001;27:772-4.
20. Gambarini G, Piasecki L, Miccoli G, Gaimari G, Nardo DD, Testarelli L. Cone-beam computed tomography in the assessment of periapical lesions in endodontically treated teeth. Eur J Dent 2018;12:136-43.
21. Valenti-Obino F, Di Nardo D, Quero L, Miccoli G, Gambarini G, Testarelli L, *et al*. Symmetry of root and root canal morphology of mandibular incisors: A cone-beam computed tomography study *in vivo*. J Clin Exp Dent 2019;11:e527-33.
22. Al-Fouzan KS, AlManee A, Jan J, Al-Rejaie M. Incidence of two canals in extracted mandibular incisors teeth of Saudi Arabian samples. Saudi Endod J 2012;2:65-9.
23. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32:271-5.
24. Abu-Tahun IH, Ha JH, Kwak SW, Kim HC. Evaluation of dynamic and static torsional resistances of nickel-titanium rotary instruments. J Dent Sci 2018;13:207-12.
25. Shen Y, Cheung GS. Methods and models to study nickel-titanium instruments. Endod Topics 2013;29:18-41.
26. Yum J, Cheung GS, Park JK, Hur B, Kim HC. Torsional strength and toughness of nickel-titanium rotary files. J Endod 2011;37:382-6.
27. Ha JH, Kim SK, Cohenca N, Kim HC. Effect of R-phase heat treatment on torsional resistance and cyclic fatigue fracture. J Endod 2013;39:389-93.
28. Pedullà E, Lo Savio F, La Rosa GRM, Miccoli G, Bruno E, Rapisarda S, *et al*. Cyclic fatigue resistance, torsional resistance, and metallurgical characteristics of M3 Rotary and M3 Pro Gold NiTi files. Restor Dent Endod 2018;43:e25.
29. Gambarini G, Plotino G, Piasecki L, Al-Sudani D, Testarelli L, Sannino G. Deformations and cyclic fatigue resistance of nickel-titanium instruments inside a sequence. Ann Stomatol (Roma) 2015;6:6-9.
30. Park SY, Cheung GS, Yum J, Hur B, Park JK, Kim HC. Dynamic torsional resistance of nickel-titanium rotary instruments. J Endod 2010;36:1200-4.