Evaluation of mechanical properties of coronal flaring nickel-titanium instruments

Theodoro Weissheimer (theodoro.theo@hotmail.com)
Universidade Federal do Rio Grande do Sul Faculdade de Odontologia https://orcid.org/0000-0001-6810-1877
Marcus Vinícius Reis Só
Universidade Federal do Rio Grande do Sul Faculdade de Odontologia
Murilo Priori Alcalde
Universidade do Sagrado Coracao
Julia Barrionuevo Cortez
Universidade do Sagrado Coracao
Ricardo Abreu da Rosa
Universidade Federal do Rio Grande do Sul Faculdade de Odontologia
Rodrigo Ricci Vivan
Universidade de Sao Paulo Faculdade de Odontologia de Bauru
Pedro Henrique Souza Calefi
Universidade de Sao Paulo Faculdade de Odontologia de Bauru
Marco Antonio Hungaro Duarte
Universidade de Sao Paulo Faculdade de Odontologia de Bauru

Research article

Keywords: bending stiffness, coronal flaring, nickel-titanium, torsional resistance

Posted Date: August 7th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-49258/v1

Abstract

Background: The aim of this study was to evaluate the bending and torsional resistance of the following instruments: Mtwo 25.07, Navigator W-XN, ProTaper SX, MK Orifice Shapper and MK Sequence 17.12.

Methods: One hundred instruments were used (n=20). Resistance to bending (n=10), torque and angular deflection (n=10) at the failure of new instruments were measured according to ISO 3630-1. The fractured surface of each fragment was examined by scanning electron microscopy (SEM). Data were analyzed using 1-way analysis of variance and Tukey tests.

Results: Torsional resistance values of MK Sequence were higher than the other groups (P<.05). No differences were observed among Mtwo 25.07, W-XN and MK Orifice Shapper (P>.05) and ProTaper SX, which presented the lowest values (P<.05). Mtwo 25.07 showed the highest angular deflection (P<.05). W-XN and ProTaper SX presented no significant difference (P>.05). ProTaper SX and MK Orifice Shapper also showed no significant differences (P>.05). MK Sequence 17.12 instruments had the lowest angular deflection values (P<0.5). There were significant differences among all the groups in bending stiffness test (P<.05), but ProTaper SX had the lowest torque to bend (P<.05). MK Sequence 17.12 presented the larger cross-sectional area at 3mm from the tip. SEM analysis showed similar and typical features of torsional failure for all instruments tested.

Conclusions: In conclusion MK Sequence 17.12 had the highest torsional fracture resistance. Mtwo 25.07 showed higher angular deflection capacity, and ProTaper SX the lower bending stiffness.

Background

Nickel-titanium (NiTi) rotary instruments transformed the root canal preparation [1]. Also, thermal treatments, different geometries, and kinematic changes allowed more predictable prepares [2–6]. For most of them, a crown-down approach is recommended. Thereby, a coronal flaring is indicated previously to the negotiation of the middle and apical third to remove interferences from the root canal orifice [7].

Coronal flaring NiTi instruments are usually presented in a shorter length and greater taper. These features aim to promote early access of irrigants, facilitating the establishment of patency and the apical file size determination, reducing the apical extrusion of debris and the fracture of instruments [7–10]. Compared to coronal flaring stainless steel instruments, NiTi files are more flexible [11]. However, are still subject to failures that can lead to complications during treatment. Instrument fracture can occur through two different mechanisms. First, when the instrument rotates in a curved canal, areas of tension/compression stress are generated until flexural fatigue fracture occurs. Second, when the instrument binds to dentin, while its rotation remains. In this case, plastic deformation or a torsional fracture occurs [12–16].

Although NiTi coronal flaring instruments are not used in curved canals, these instruments are used in brushing motion to remove dentinal projections opposite to the furcation area [17], and also in narrow and constricted canals facilitating the action of subsequent instruments [18]. Therefore, a certain resistance is needed for its efficacy. So, despite the extensive literature concerning the properties of NiTi instruments [19–25], there is a lack of information about the properties of NiTi coronal flaring instruments.

Therefore, the aim of this study was to evaluate the bending stiffness and torsional (maximum torque load and angular deflection) resistance of five instruments, Mtwo 25.07 (VDW, Munich, Germany), Navigator W-XN 25.07 (Wizard Navigator, Medin, NovéMěsto na Moravě, Czech Republic), ProTaper SX (Dentsply Tulsa Dental Specialties, Tulsa, OK), MK Orifice Shapper 17.08 (MK Life Medical and Dental Products, Porto Alegre, Brazil) and MK Sequence 17.12 (MK Life Medical and Dental Products, Porto Alegre, Brazil), with different cross-sectional design, tip size, taper, diameter of the core and with or without thermal treatments, to obtain more knowledge about these instruments and to promote more excellent safety in clinical practice. The null hypothesis tested were: 1. there are no differences in the torsional resistance among the files; 2. there are no differences in the bending stiffness among the files.

Methods

Sample size calculation was performed before the mechanical testing using G*Power v.3.1 for Mac (Heinrich Heine, University of Düsseldorf, Düsseldorf, Germany) and by selecting the Wilcoxon–Mann-Whitney test. The alpha-type error of 0.05, beta power of 0.95, and N2/N1 ratio of 1 were also stipulated. The test calculated a total of eight samples for each group as the ideal size for noting significant differences. However, an additional 20% of the total instruments was used to compensate for possible atypical values that might lead to sample loss.

A total of 100 NiTi instruments were used for this study. The samples were divided into five groups (n = 20), as follows: Mtwo 25.07, Navigator W-XN 25.07, ProTaper SX, MK Sequence 17.12, and MK Orifice Shapper 17.08. All the instruments had a length of 19 mm, except Mtwo 25.07, which had 25 mm length. Previously to the mechanical tests, all files were inspected under a stereomicroscope (Carls Zeiss, LLC, EUA) at 16x magnification to detect possible defects or deformities; none were discarded.

Torsional Fatigue Test

The torsional tests were performed, based on ISO 3630-1 (1992), as previously reported [2]. A total of 10 instruments were used in each group. The test was performed to measure the maximum torque and angular deflection until instrument failure using a specific program (MicroTorque; Analógica, Belo Horizonte, Minas Gerais, Brazil) and a torsional machine. Before testing, the handles of all of the instruments were removed at the point where they were attached to the torsion shaft. In order to reduce bias, the non-cutting part of the Mtwo 25.07 instruments were cut to a standard length of 19 mm, maintaining the cutting part intact. The end of the shaft was clamped into a chuck connected to a geared motor. The first three millimeters of the instrument tips were clamped in another chuck with brass jaws to prevent sliding. The torque values were assessed by measuring the force exerted on a small load cell by a lever arm linked to the torsion axis. The geared motor operated in clockwise rotation, at speed set to

2 rpm for all the groups. Continuous recording of torque and angular deflection were monitored, and the ultimate values were measured.

Bending Stiffness Test

This test was performed using a testing apparatus (MicroTorque, Analógica) built according to the pertinent specification ISO 3630-1, as previously reported [24]. A total of 10 instruments of each group were used to evaluate the flexibility, and the maximum strength demanded to bend the files at 45° with its long axis.

Instruments were fixed at 3 mm from the tip perpendicular to the axis of the geared motor. The bending angle (45°) was measured and controlled by a resistive angular transducer connected to a process controller. Again, in order to reduce bias, the bending stiffness test for Mtwo 25.07 instruments were performed at the 19 mm mark. The strength demanded to bend the instruments was automatically measured by the load cell and recorded.

Scanning Electron Microscopy Evaluation

After the torsional test, the instruments were assessed by scanning electron microscopy (SEM) evaluation (JEOL, JSM-TLLOA, Tokyo, Japan) to determine the topographic features of the fragments. The files were cleaned in an ultrasonic cleaning device (Gnatus, Ribeirão Preto, São Paulo, Brazil) in distilled water for 3 minutes before SEM evaluation. The fractured surface of the instruments submitted to the torsional test was examined at x200 and x1000 magnification in the center of the surface.

Statistical analysis

Shapiro–Wilk test showed that the data presented a normal distribution. The one-way analysis of variance (ANOVA) and Tukey tests were used for multiple and individual comparisons. The Prism 6.0 software (GraphPad Software Inc., La Jolla, CA, USA) was used as the analytical tool, and the level of significance was set at 5%.

Results

Table 1 presents the mean and standard deviations of torsional fatigue (torque maximum torsional strength and angular deflection) and bending stiffness for each instrument. The MK Sequence 17.12 had significantly higher torsional strength values than all the other groups ($P < .05$). There was no difference among Mtwo 25.07, W-XN and MK Orifice Shapper ($P > .05$). The ProTaper SX instruments had the lowest torsional strength ($P < .05$).

Table 1
Mean values of Torque (N.cm), angular deflection (°) and Torque (N.cm) at bending moment of instruments tested.

Instruments	**Torque (N.cm)**		**Angular Deflection**		**Bending**	
	Mean	SD	Mean	SD	Mean	SD
Mtwo 25.07	1.13^{a}	0.15	440.8^{a}	44.35	0.57^{a}	0.05
W-XN	1.11^{a}	0.13	387.6^{b}	22.23	0.81^{b}	0.07
SX	0.57^{b}	0.06	$365.1^{b,c}$	22.43	0.43^{c}	0.04
Sequence 17.12	1.69^{c}	0.06	305.2^{d}	7.28	1.56^{d}	0.06
Orifice Shapper	1.19^{a}	0.12	343.7^{c}	45.06	0.73^{e}	0.07
SD, standard deviation.						
Different superscript letters in the same column indicate statistical differences among groups (P < .05).						

After the angular deflection assessment, Mtwo 25.07 had the highest values when compared with all the groups (P < .05). There was no difference between W-XN and ProTaper SX (P > .05) and between ProTaper SX and MK Orifice Shapper (P > .05). The MK Sequence 17.12 instruments had the lowest angular deflection values (P < .05).

The bending test showed that there were differences among all the instruments (P < .05). The MK Sequence 17.12 had the highest strength to bend, followed by W-XN, MK Orifice Shapper, and Mtwo 25.07. The ProTaper SX instruments had the lowest torque to bend than all the groups (P < .05).

Table 2 presents the metal mass volume analysis on the first 3 mm of the tip of the instruments, there were differences among all the files (P < .05). The MK Sequence 17.12 had the highest metal mass volume, followed by MK Orifice Shapper, W-XN, and Mtwo 25.07. The ProTaper SX instruments had the lowest metal mass volume than all the groups (P < .05). All of the files showed abrasion marks and fibrous dimples near the center of rotation for torsional fracture (Fig. 1).

Table 2

Mean values of metal mass volume (mm$^{3)}$) on the 3 mm of the instruments tip.

Instruments	**Volume of metal mass (mm^3)**	
	Mean	SD
Mtwo 25.07	0.095^b	0.0010
W-XN	0.110^c	0.0070
SX	0.055^d	0.0038
Sequence 17.12	0.185^a	0.0063
Orifice Shapper	0.145^e	0.0051
SD, standard deviation.		
Different superscript letters in the same column indicate statistical differences among groups ($P < .05$).		

Discussion

Coronal flaring promotes more excellent safety during endodontic treatment, reducing the amount of debris extruded through apical foramen and the fracture of preparation instruments [7, 8]. It also facilitates the action of chemical solutions, the establishment of patency, the determination of root canal length, and apical preparation diameter [9, 10]. However, such instruments are subject to torsional tension during their use that can lead to file fracture. This occurrence can compromise the endodontic procedure. Therefore, the study of its mechanical properties is essential.

In this study, the record of torsional fatigue resistance and angular deflection were provided by a specific program (MicroTorque; Analógica) until the moment of fracture. The first 3 mm of the tip of the instrument were clamped for testing because this portion is the most susceptible to fracture [15]. Regarding the torsional test, the results showed that the MK Sequence 17.12 file ($P < .05$) showed the highest torsional strength. Probably, these results could be related with the greater taper of this instrument, which probably favored a larger cross-sectional area when compared to the other groups.

In a complementary evaluation, the cross-section of each instrument in D3 was evaluated under SEM, and the area was measured through software (AutoCAD; Autodesk Inc, San Rafael, CA, USA) [5]. ProTaper SX presented the smallest area (0.055mm3), followed by Mtwo 25.07 (0.095mm3), W-XN (0.110mm3), MK Orifice Shapper (0.145mm3), being the most extensive area verified in MK Sequence 17.12 (0.185mm3). Previous studies have shown that the mechanical properties of the instruments are influenced by the cross-section, taper, helical angle, and pitch length. Also, the lower the radial distance between the periphery and the center of the core, the higher will be the stress supported by the instrument in torsion. So, files with larger cross-sections present higher torsional resistance [3, 16]. Although this instrument has a heat-treated alloy, a study that verified the properties of a coronal flaring file, with and without heat treatment, concluded that this is not a factor that influences this outcome [4]. There were no differences between the instruments Mtwo 25.07, W-XN, and Orifice Shapper ($P > .05$). ProTaper SX presented the lower torsional strength ($P < .05$) probably due to the smaller cross-sectional area among the tested instruments.

Angular deflection is associated with how much the instrument tolerates elastic and plastic deformation before breaking in torsional motion. This characteristic may be a safety factor in clinical practice because plastic deformation can be verified before a fracture occurs when the instrument is removed from the canal [6]. High values of angular deflection mean considerable strain before the moment of failure [25]. The highest angular deflection values were presented by Mtwo 25.07. This result may be due to the characteristics of the NiTi alloy and the instrument geometry. MK Sequence 17.12 showed the lowest values, probably associated with the large diameter of the instrument. Other studies reported that instruments with larger metal mass volume tend to present lower flexibility and lower angular deflection to fracture, which could explain the results of this study [2, 3]. Thus, the first null hypothesis was rejected.

Bending stiffness is related to instrument performance when used in curved canals [6]. However, in cervical flaring instruments, this property is related to the flexibility to perform brushing movements against dentinal projections [4, 17]. The results showed that there were differences among all the groups compared, rejecting the second null hypothesis of the study. MK Sequence 17.12 needed the highest strength to bend and ProTaper SX the lowest. Again, taper and the cross-sectional area are factors related to such property [24]. Although Ataya et al. have shown that coronal flaring heat-treated instruments presented lower bending stiffness when compared to the same file without heat treatment [4], our results were different probably because the tip diameter, taper, and cross-section of the heat-treated instruments used in this study were different from those previously tested.

The highest torsional strength and bending stiffness of MK Sequence 17.12 indicates that these instruments would probably suffer less risks regarding torsional fracture in narrow and constricted canals and would be able to remove dentin projections more efficiently. On the other hand, the greater angular deflection presented by Mtwo 25.07 could be beneficial to clinicians, indicating that there was plastic/permanent deformation and imminent fracture before it occurs [6]. Future studies should be performed comparing the results of these mechanical tests with the clinical performance of these instruments.

Conclusion

Within the limitations of this study, the characteristics of the instruments, such as cross-sectional designs, tip size and taper, had a great influence on the mechanical properties of the instruments tested. Heat treatment was not a determining factor. Our results showed that MK Sequence obtained the highest torsional fracture resistance when compared to other instruments. Mtwo 25.07 presented higher angular deflection capacity and ProTaper SX the lower bending stiffness.

List Of Abreviations

NiTi: nickel-titanium; SEM: scanning electron microscopy.

Declarations

Ethics approval and consent to participate:

Not applicable.

Consent for publication:

Not applicable.

Availability of data and materials:

All data generated or analyzed during this study are included in this published article.

Competing interests:

The authors declare that they have no competing interests.

Funding:

This study was supported by the State of São Paulo Research Foundation (FAPESP 2018/23452-8) as part of the scientific initiation of Julia Barrionuevo Cortez.

Authors' contributions:

MPA, JBC, PHSC participated in the laboratory phase and in the acquisition of the SEM images. MVS, MPA, RAR, RRV and MAHD performed the SEM image analysis and statistical analysis of the data. TW discussed the findings and drafted the article. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

References

1. Peters OA. Current challenges and concepts in the preparation of root canal systems: A review. J Endod 2004. 30:559–567.
2. Alcalde MP, Duarte MAH, Bramante CM, Tanomaru-filho M, Vasconcelos BC, Só MVR, et al. Torsional fatigue resistance of pathfinding instruments manufactured from several nickel-titanium alloys. Int Endod J 2018. 51:697–704.

3. Zhang EW, Cheung GSP, Zheng YF. Influence of cross-sectional design and dimension on mechanical behavior of nickel-titanium instruments under torsion and bending: A numerical analysis. J Endod 2010. 36:1394–1398.
4. Ataya M, Ha J, Kwak SW, Abu-Tahun IH, El Abed R, Kim H-C. Mechanical Properties of Orifice Preflaring Nickel-titanium Rotary Instrument Heat Treated Using T-Wire Technology. J Endod 2018. 44:1867–1871.
5. Pedullà E, Lo Savio F, Boninelli S, Plotino G, Grande NM., La Rosa G, et al. Torsional and Cyclic Fatigue Resistance of a New Nickel-Titanium Instrument Manufactured by Electrical Discharge Machining. J Endod 2016. 42:156–159.
6. Lopes HP, Gambarra-Soares T, Elias CN, Siqueira JF, Inojosa IFJ, Lopes WSP, et al. Comparison of the mechanical properties of rotary instruments made of conventional nickel-titanium wire, M-Wire, or nickel-titanium alloy in R-phase. J Endod 2013. 39:516–520.
7. Topçuoğlu HS, Üstün Y, Akpek F, Aktı A, Topçuoğlu G. Effect of coronal flaring on apical extrusion of debris during root canal instrumentation using single-file systems. Int Endod J 2016. 49:884–889.
8. Ferreira CM, Gomes FDA, Ximenes T, Alves M, Neto T, Arruda TE, et al. Influence of reuse and cervical preflaring on the fracture strength of reciprocating instruments. Eur J Dent 2017. 11:41–47.
9. Schroeder K, Walton R, Rivera E. Straight Line Access and Coronal Flaring: Effect on Canal Length. J Endod 2002. 28:474–476.
10. Tennert C, Herbert J, Altenburger MJ, Wrbas KT. The effect of cervical preflaring using different rotary nickel-titanium systems on the accuracy of apical file size determination. J Endod 2010. 36:1669–1672.
11. Schäfer E, Schulz-bongert U, Tulus G. Comparison of Hand Stainless Steel and Nickel Titanium Rotary Instrumentation: A Clinical Study. J Endod 2004. 30:6–9.
12. Cheung GS, Oh S, Ha J. Effect of Torsional Loading of Nickel-Titanium Instruments on Cyclic Fatigue Resistance. J Endod 2013. 39:1593–1597.
13. Lee J, Kwak SW, Ha J. Mechanical Properties of Various Glide Path Preparation Nickel-titanium Rotary Instruments. J Endod 2019. 45:199–204.
14. Oh S, Ha J, Kwak SW, Ahn SW, Lee W, Kim H-C. The Effects of Torsional Preloading on the Torsional Resistance of Nickel-titanium Instruments. J Endod 2017. 43:157–162.
15. Capar ID, Kaval ME, Ertas H, Sen BH. Comparison of the cyclic fatigue resistance of 5 different rotary pathfinding instruments made of conventional nickel-titanium wire, M-wire, and controlled memory wire. J Endod 2015. 41:535–538.
16. Zhang EW, Cheung GSP, Zheng YF. A mathematical model for describing the mechanical behaviour of root canal instruments. Int Endod J 2011. 44:72–76.
17. Morgental RD, Vier-Pelisser FV, Kopper PMP, De Figueiredo JAP, Peters OA. Cutting efficiency of conventional and martensitic nickel-titanium instruments for coronal flaring. J Endod 2013. 39:1634–1638.

18. Ehrhardt IC, Zuolo ML, Cunha RS, De Martin AS, Kherlakian D, De Carvalho MCC, et al. Assessment of the separation incidence of Mtwo files used with preflaring: Prospective clinical study. J Endod 2012. 38:1078–1081.
19. Elsaka SE, Elnaghy AM, Badr AE. Torsional and bending resistance of WaveOne Gold, Reciproc and Twisted File Adaptive instruments. Int Endod J 2017. 50:1077–1083.
20. Shen Y, Tra C, Hieawy A, Wang Z, Haapasalo M. Effect of Torsional and Fatigue Preloading on HyFlex EDM Files. J Endod 2018. 44:643–647.
21. Elnaghy AM, Elsaka SE. Torsional resistance of XP-endo Shaper at body temperature compared with several nickel-titanium rotary instruments. Int Endod J 2018. 51:572–576.
22. Silva EJNL, Vieira VTL, Belladonna FG, Zuolo A de S, Antunes H dos S, Cavalcante DM, et al. Cyclic and Torsional Fatigue Resistance of XP-endo Shaper and TRUShape Instruments. J Endod 2018. 44:168–172.
23. Higuera O, Plotino G, Tocci L, Carrillo G, Gambarini G, Jaramillo DE. Cyclic Fatigue Resistance of 3 Different Nickel-Titanium Reciprocating Instruments in Artificial Canals. J Endod 2015. 41:913–915.
24. Nakagawa RKL, Alves JL, Buono VTL, Bahia MGA. Flexibility and torsional behaviour of rotary nickel-titanium PathFile, RaCe ISO 10, Scout RaCe and stainless steel K-File hand instruments. Int Endod J 2014. 47:290–297.
25. Lopes HP, Elias CN, Vedovello GAF, Bueno CES, Mangelli M, Siqueira JF. Torsional Resistance of Retreatment Instruments. J Endod 2011. 37:1442–1445.

Figures

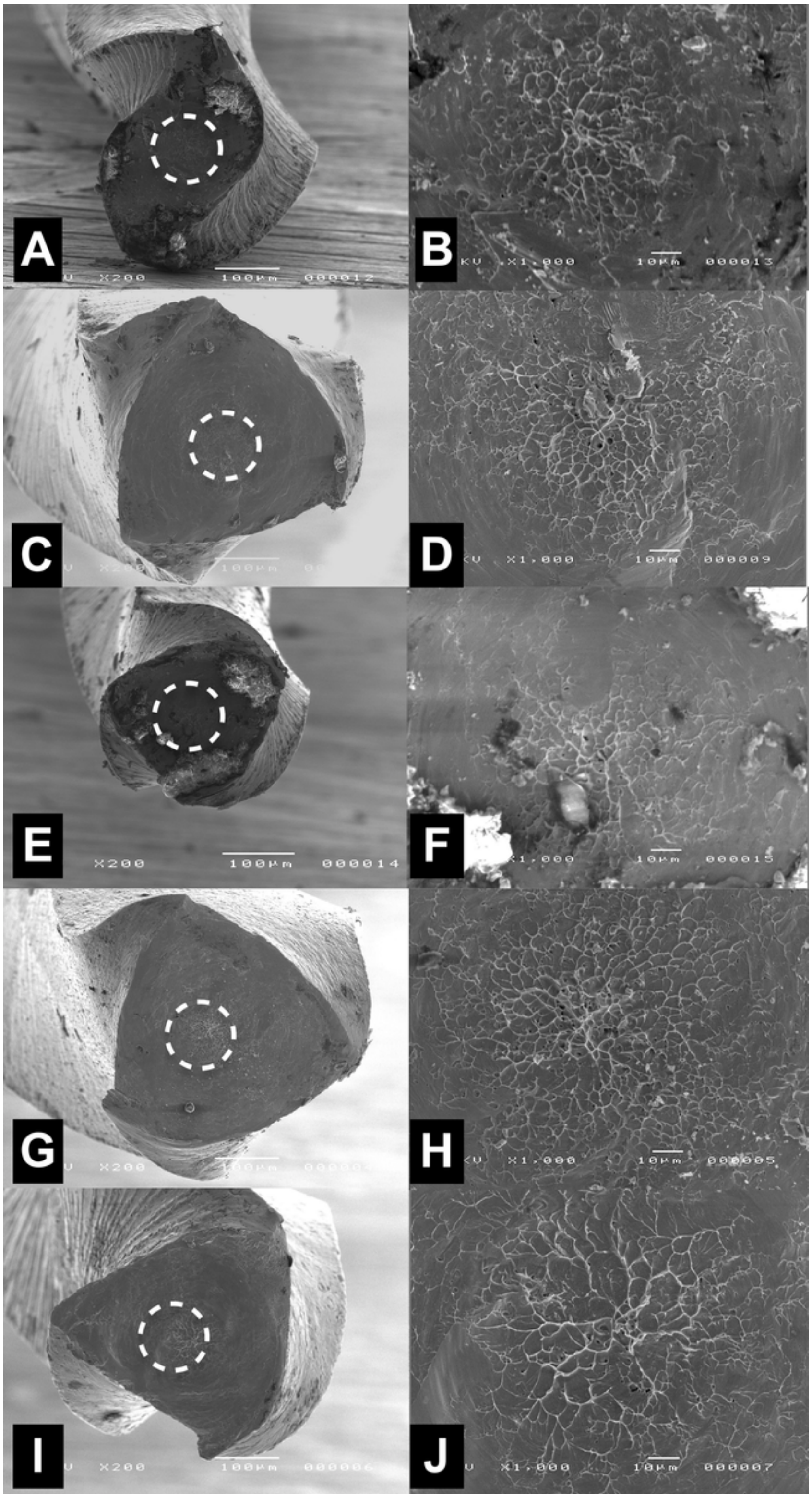

Figure 1

Scanning electron microscopy images of the fractured surfaces of Mtwo 25.07 (A and B), W-XN (C and D), SX (E and F), Sequence 17.12 (G and H) and Orifice Shapper (H and I) after torsional testing. The left column shows images with the circular boxes indicating concentric abrasion marks at 200x magnification; the right column shows concentric abrasion marks at 1000x magnification; and the skewed dimples near the center of rotation are typical features of torsional failure.