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Torsional and stiffness properties of nickel–titanium K files

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Summary

The purpose of this study was to compare stiffness and resistance to fracture of four brands of nickel titanium K files. Instruments of sizes 15 to 40 were tested according to ANSI/ADA Specification No. 28. Resistance to fracture was determined by twisting and measuring the maximum torque and angular deflection at failure. Stiffness was determined by measuring the moment required to bend the instrument 45°. The permanent deformation angle remaining between the tip and the flutes of the instruments after bending ceased was also recorded. Nickel titanium K files satisfied and far exceeded specification standards for stiffness. They also satisfied and exceeded the standards for angular deflection at failure. They met or exceeded the maximum torque at failure standards in all sizes except for the size 40 of the Maillefer Niti, and the size 30 of the Mac Spadden Niti. Nickel titanium K files presented a null permanent deformation angle. Clinical studies are required to evaluate the influence of low bending moment on other properties such as breakage and canal transportation.

Keywords: Endodontic file, Nickel, Stiffness, Titanium, Twist

Introduction

Nickel titanium alloys (Niti) present many interesting properties: a shape memory effect, superelasticity, good biocompatibility and high corrosion resistance (Yoneyama *et al.* 1993a). Surgical applications such as shape memory intramedullary nails, shape memory bone plates and many others have been reported (Yoneyama *et al.* 1993b). One of the most successful applications in the dental field is superelastic Niti arch wires for orthodontics.

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For many years orthodontists have been using nickel titanium (Niti) wires because of their excellent flexibility and their resistance to stress fatigue (Andreasen & Hilleman 1971). Today four distinct products are available: Nitinol (NI for nickel, TI for titanium and NOL for Naval Ordinance Laboratory (Lipshatz *et al.* 1992)), cobalt-substituted nitinol (Andreasen & Hilleman 1971), Chinese Niti (Burston *et al.* 1985) and Japanese Niti (Mihura *et al.* 1986). Twenty-four brands of Niti orthodontic wires are available in UK supply houses (Robinson 1992). Despite its valuable properties, the use of Niti in endodontics has been limited for years (Walia *et al.* 1988). Recently, a wide variety of new Niti endodontic instruments have been brought onto the market. A Niti version of the Canal Master U (Brasseler, Savannah, GA, USA) is now available. Compared with stainless steel Canal Master U, its flexibility is at least seven times higher in all sizes (Camps & Pertot 1994). The Lightspeed (Lightspeed technology Inc., San Antonio, TX, USA) and the Sensor files (NT Co. Inc., Chattanooga, TN, USA) are new instruments, with a special design, to be used in a low-speed handpiece. The Lightspeed remains centered in the curvature owing to its very short cutting blades (Glosson *et al.* 1995). In addition to these special instruments some classical K files made with this new metal have also been produced, but no study has reported on their torsional properties.

The purpose of this study was to evaluate the torsional and stiffness properties of Niti K files and to compare results with a stainless steel K file.

Materials and methods

Five types of file were tested and stainless steel Colorinox K files served as the control (Maillefer SA, Ballaigues, Switzerland). Four types of Niti K files were tested: Brasseler (Savannah, GA, USA), JS Dental (JS Dental Inc, Ridgefield, CT, USA), Mac Spadden (NT Co Inc, Chattanooga, TN, USA) and Maillefer (Maillefer SA, Ballaigues, Switzerland). For each type of file the instruments in sizes 15 to 40 were tested according to ANSI/ADA Specification No. 28. Ten instruments of each size were tested for resistance to fracture by twisting and for stiffness by bending. For the twist test, maximum torque and angular deflection were measured at the time of instrument fracture. For the stiffness test, bending moment was measured when the instrument attained a 45° bend. Four parameters were measured: the maximum torque at failure (in g.m) in clockwise rotation which represented the moment when failure occured; the maximum angular deflection at failure in clockwise rotation (in degrees) which represented the number of degrees at which the instrument failed; the maximum bending moment (in g.m) required to bend the instrument 45°; and the permanent deformation angle which represented the angle between the tip of the instrument and its cutting blades after the 45° bending ceased.

For the twist test (maximum torque and angular deflection at failure), prior to testing, the handle of each instrument was removed where it met the shaft. The shaft end was then clamped in a chuck connected to a reversibly geared motor revolving at 2 r.p.m. (Baure CM 2024, St Aubin, Switzerland). A digital display and amplifier controlled the operation of the motor. Three millimetres of the tip of the instrument were clamped in another chuck with brass jaws connected to a digital torque meter memocouple (Maillefer SA) and to a strip chart (LINSEIS L 4100) for recording. The digital torque meter memocouple measured torque with an accuracy of ± 1 g.cm and angular deflection with an accuracy of ±2°. The files were then tightened between the two chucks moving freely on two large horizontal parallel rods.

For stiffness tests (maximum bending moment and permanent deformation angle) the same equipment was used with a few modifications. The handle of the instrument was not removed and its tip was inserted 3 mm into a chuck, which was perpendicular to the axis of the geared motor. The amplifier was set at an angular deflection of 45° at which point the test stopped automatically. The bending moment was then measured and recorded automatically by the memocouple. The permanent deformation angle was read directly on the strip chart.

As the number of samples of each size tested was less than 30, a normality test was performed for each instrument type, size and measurement in order to verify distribution normality and variance equality. An analysis of variance (ANOVA) was performed to compare the torque, angular deflection, bending moment and permanent deformation angle of the instruments. Duncan's multiple range test compared data relating to each type of file. Significance was determined at the 95% confidence level. This analysis was performed with a microcomputer statistics program (PCSM, Delta consultants, Lyon, France).

Results

For each group the normality test showed a normal distribution and as variance equality was verified ANOVA could be performed.

Resistance to fracture by twisting

Maximum torque at failure. Except for the size 40 of the Maillefer Niti, and the size 30 of the Mac Spadden Niti, all instruments met or exceeded the ANSI/ADA No. 28 standards (Table 1). For all of types of file, maximum torque at failure increased with file size. ANOVA showed a statistically significant difference among the torques at failure of the five types of file ($P<0.001$). Duncan's test showed that, except for size 15, Colorinox K files presented a higher torque at failure than all the Niti files (Table 2). The Niti files showed no statistically significant difference for sizes 20, 25 and 35. For size 15 files, Maillefer Niti and JS Dental Niti presented the lowest torque at failure. Among the size 30 files Mac Spadden Niti file presented the lowest torque at failure, and for size 40 the Maillefer Niti and Mac Spadden Niti files presented the lowest torque at failure.

Table 1 Means (standard deviations) of the torque at failure, in g.m, of the five brands of K files (n = 10 in each size) and minimum values of the ANSI/ADA specification No. 28

	15	20	25	30	35	40
Maillefer Niti	1051 (144)	1873 (104)	3330 (265)	5361 (494)	7042 (642)	8118 (314)
Brasseler Niti	1909 (280)	2407 (222)	3243 (329)	6629 (295)	9682 (636)	14270 (948)
JS Dental Niti	1448 (89)	2727 (134)	3517 (242)	6638 (268)	8431 (928)	1216 (879)
Mac Spadden Niti	1830 (71)	2211 (161)	3409 (509)	4064 (330)	7824 (327)	9999 (137)
Colorinox	2033 (167)	3788 (271)	6273 (355)	9390 (535)	13121 (767)	18769 (1132)
ANSI/ADA No. 28	800	1800	3000	4500	6500	1000

Table 2 Duncan's grouping of the torque at failure. Groups with the same letter were not significantly different

	15	20	25	30	35	40
Maillefer Niti	A	A	A	B	A	A
Brasseler Niti	B	A	A	B	A	B
JS Dental Niti	AB	A	A	B	A	B
Mac Spadden Niti	B	A	A	A	A	A
Colorinox	B	B	B	C	B	C

Table 4 Duncan's grouping of the angular deflection at failure. Groups with the same letter were not significantly different

	15	20	25	30	35	40
Maillefer Niti	A	AB	A	A	A	AB
Brasseler Niti	A	A	B	A	B	A
JS Dental Niti	B	C	B	B	C	B
Mac Spadden Niti	B	C	B	B	C	C
Colorinox	A	B	B	C	C	C

Maximum angular deflection at failure. All files satisfied and exceeded Specification No. 28 minimum values for angular deflection at failure (Table 3). Whatever the type of file, maximum angular deflection at failure did not increase with file size. ANOVA showed a statistically significant difference among the angulations at failure of the five types of file ($P<0.001$). Duncan's tests showed that JS Dental and Mac Spadden presented the highest angular deflection at failure for the sizes 15, 20, 25 and 35 (Table 4). For sizes 15, 30 and 40, Maillefer and Brasseler Niti files presented the lowest angular deflection at failure. Except for sizes 15 and 20, the Colorinox files presented the highest angular deflection at failure.

Stiffness test

Maximum bending moment. The bending moment of all of the instruments, in all sizes, satisfied and were below the maximum values set out in the specifications (Table 5). ANOVA showed a statistically significant difference among the angulations at failure for the five types of file ($P<0.001$). Duncan's tests showed that bending moments were significantly greater for Colorinox than for Niti files in all sizes (Table 6). The nickel titanium instruments were about eight times more flexible than those made with stainless steel. Except for size 40, no statistically significant differences were found between the bending moment of the four brands of Niti files. Of the size 40 files, Maillefer and Mac Spadden presented the lowest bending moment.

Permanent deformation angle

All the Niti instruments showed a null permanent deformation angle: when the stress ceased the instruments went back to their original position without modification. The Colorinox presented a permanent deformation angle that increased with file size (Table 7).

Discussion

Under the conditions of this study nickel titanium instruments satisfied ANSI/ADA specification No. 28 standards. Only the size 40 Maillefer Niti and the size 30 the Mac Spadden Niti files presented reduced torque values at failure: these files may be brittle and must be used carefully.

Stainless steel K files presented a higher torque at failure than Niti K files but with the same rotation at failure. If the tips of the stainless steel files were locked in the canal they were more resistant to fracture than Niti K files. This is surprising as Niti is a superelastic metal (Kapila & Sachdeva 1989) and undergoes less permanent deformation than stainless steel when subjected to the same amount of stress (Hudgins *et al.* 1991) (Fig. 1). For instance, Canal Master U made with Niti presents a rotation at failure superior to that of stainless steel Canal Master U (Camps & Pertot 1994) and its handle can be turned several times before breakage occurs. This is probably because of the machining procedures (Seto *et al.* 1990) which are more important with K files than with Canal Master U and generate more stress within the metal.

Table 3 Means (standard deviations) of the angular deflection at failure, in degrees, of the five brands ($n = 10$ in each size) of K files and minimum values of the ANSI/ADA specification No. 28

	15	20	25	30	35	40
Maillefer Niti	756 (74.31)	661(61.86)	637.7 (97.24)	512 (40.55)	480.9 (36.83)	521.6 (61.49)
Brasseler Niti	643 (95.87)	479.4 (66.14)	815.9 (70.98)	563 (37.38)	641.3 (139.8)	490.8 (86.38)
JS Dental Niti	1218 (77.22)	933.3 (104.9)	777.3 (56.12)	781.9 (115.7)	947.9 (127.9)	688.1 (149.38)
Mac Spadden Niti	1116 (85.7)	944.1 (68.54)	852.7 (63.35)	778.4 (66.31)	961.9 (131.58)	850 (211.65)
Colorinox	673.17 (86.83)	799.31 (132.44)	799.14 (129.11)	978.44 (195.68)	894.4(133.18)	839 (160.66)
ANSI/ADA No. 28	360	360	360	360	360	360

Table 5 Means (standard deviations) of the bending moment at 45° of the five brands of K files (n=10 in each size) and maximum values of the ANSI/ADA specification 28

	15	20	25	30	35	40
Maillefer Niti	438 (53)	834 (65)	1535 (160)	2157 (110)	2779 (155)	3545 (175)
Brasseler Niti	796 (100)	1103 (112)	1700 (179)	2940 (118)	4594 (313)	7005 (471)
JS Dental Niti	689 (48)	1338 (110)	1877 (193)	3231 (992)	4143 (479)	5866 (480)
Mac Spadden Niti	878 (52)	987 (73)	1668 (237)	1593 (132)	3600 (452)	4348 (695)
Colorinox	2232 (181)	4254 (244)	7095 (376)	11174 (575)	15587 (612)	21983 (811)
ANSI/ADA No. 28	5000	8000	12000	15000	19000	25000

Niti K files presented a bending moment five or six times lower than stainless steel K files: they are five or six times more flexible. The poor flexibility of stainless steel or carbon steel endodontic instruments turns curved canal preparation into a daily challenge. A flexible instrument may avoid canal transportation during enlargement. Conversely, a nonflexible instrument leads to errors during preparation such as ledges, zips, canal and apical foramen transportation and strip perforations. Canal preparation with this type of instrument is time consuming because of the importance of the forces generated on dentine by the instrument, and the opposite forces generated by dentine reacting on the instruments. Furthermore, these forces generate stresses along the cutting blades which may result in instrument breakage. The Niti K files presented a lower torque at failure than stainless steel K files, which is a disadvantage, but their bending moment is so low that they may be safer clinically. Studies must be undertaken to evaluate canal transportation during curved canal preparation with Niti K files together with the incidence of instrument breakage.

Niti K files presented a null permanent deformation angle. On the contrary, stainless steel K files presented a permanent deformation angle ranging from 9.94° to 18.14°. This means that if the tip of a stainless steel file is bent at a 45° angle and left free, it does not go back to its position but maintains an angle of 10° with the flutes. This presents a disadvantage in a linear motion, during instrument withdrawal (Wildey *et al.* 1992), but most of all in rotary motion. The stress generated by the rotation of an instrument in a curved canal is increased by the

Table 6 Duncan's grouping of the bending moment. Groups with the same letter were not significantly different

	15	20	25	30	35	40
Maillefer Niti	A	A	A	A	A	A
Brasseler Niti	A	A	A	A	A	B
JS Dental Niti	A	A	A	A	A	B
Mac Spadden Niti	A	A	A	A	A	A
Colorinox	B	B	B	B	B	C

Table 7 Means (standard deviations), in degrees, of the permanent deformation angle of the K files, Colorinox

File size	Mean (SD)
15	9.94 (6.99)
20	11.95 (8.87)
25	13.5 (8.03)
30	15.33 (5.96)
35	15.33 (5.96)
40	18.14 (4.77)

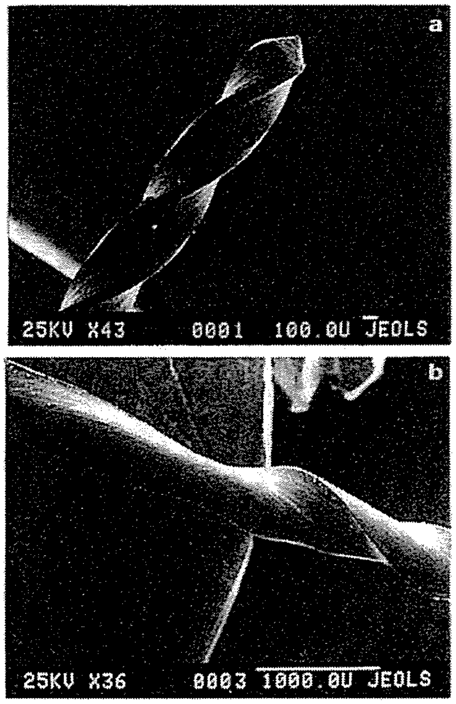

Fig. 1 (a) A scanning electron microscope view of a Maillefer Niti K file tip before deformation. (b) A scanning electron microscope view of the flutes of a Maillefer Niti K file that underwent inelastic deformation without fracture.

permanent deformation angle: its tip undergoes a stress equal to the canal curvature added to the permanent deformation angle. It would be interesting to know whether stainless steel K files intended for rotary motion (Roane *et al.* 1985), such as Flex-R, present a permanent deformation angle.

Niti K files presented interesting stiffness properties that ought to remain unchanged by sterilization procedures (Mayhew & Kusy 1988). Temperatures of about 600°C are required to effect a change in flexibility (Lee *et al.* 1988). The encouraging features presented by Niti K files in this study must be followed by studies that investigate the effects on canal curvature, efficiency, and clinical resistance to fracture.

Conclusions

1. Nickel titanium K files satisfied ANSI/ADA specification No. 28 values for moment at failure, except for size 40 Maillefer Niti, and size 30 Mac Spadden Niti.
2. Nickel titanium K files satisfied ANSI/ADA specification No. 28 values for rotation at failure and for bending moment at a 45° angle.
3. Nickel titanium K files presented a lower torque at failure than the stainless steel K files and the same rotation at failure.
4. Nickel titanium K files presented a bending moment five times lower than stainless steel K files and a null permanent deformation angle.

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