Bending properties of rotary nickel-titanium instruments

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Objective. We sought to compare the bending properties of different rotary nickel-titanium instruments and to investigate the correlation between their bending moments and their cross-sectional surface areas.
Study design. Resistance to bending was determined according to International Standards Organization publication 3630-1. The sample size was 10 files for each type, taper, and size. The cross-sectional surface area of all instruments was determined by using scanning electron microscope photographs of the cross section. The images were scanned and the area was calculated by using special software. Data were analyzed by using analysis of variance and the Student *t* test and the Newman-Keuls test for all pairwise comparisons. The strength of the correlation between the bending moment and the cross-sectional area was determined by computing the Pearson product moment correlation.
Results. Bending moments were significantly lower for ProFile and RaCe files than for all other files ($P < .05$). K3 files were significantly less flexible than all other instruments ($P < .05$). The correlation between stiffness and cross-sectional area was highly significant ($r = 0.928$; $P < .0001$).
Conclusion. Nickel-titanium files with tapers greater than .04 should not be used for apical enlargement of curved canals because these files are considerably stiffer than are those with .02 or .04 tapers.
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In International Standards Organization (ISO) publication 3630-1,[1] as well as in the American National Standards Institute/American Dental Association Specification Nos. 28 and 58,[2,3] several mechanical requirements for root canal instruments are listed (eg, resistance to bending). The resistance to bending of a root canal instrument is determined by fixing the instrument at its tip along a length of 3 mm and bending it. The bending moment at an angle of 45° is measured.[1]

The resistance to bending of root canal instruments influences the results of instrumentation in curved canals. Instruments with increased flexibility cause fewer undesirable changes in the shape of curved canals than those with greater resistance to bending. This increase in flexibility is achieved either by different design features of the instruments or by the use of nickel-titanium alloys.[4-7]

The bending properties of endodontic hand instruments are mainly influenced by their cross-sectional design.[4,5,7] Camps and Pertot[5] showed that stainless steel instruments with a square cross section had significantly larger bending moments than files with a rhombus-shaped cross-sectional design, which had significantly higher bending moments than instruments with a triangular cross section. According to these researchers, there was an exponential relationship between file size and bending moment.[5] Camps et al[4] conducted a study on the relationship between file size and stiffness of nickel-titanium files and found that the square cross section K-Files had a significantly larger bending moment than the triangular cross section K-Files. Again, an exponential relationship between file size and bending moment was observed for triangular and square cross section K-Files.[4] Schäfer and Tepel[7] used custom-made prototypes of endodontic stainless steel instruments characterized by 5 different cross-sectional shapes and 3 different numbers of flutes to investigate separately the relationship between the bending properties and the cross-sectional design on the one hand and the number of flutes on the other hand. According to their results, the prototypes with a rhombus-shaped cross-sectional design had less resistance to bending than the prototypes with other cross-sections.[7] The square cross section prototypes had significantly greater bending moments than did all other instruments.[7]

In contrast to endodontic hand instruments, surprisingly little is known about the bending properties of continuously rotating nickel-titanium instruments. Pongione et al[8] compared the bending properties of .06, .08, .10, and .12 tapered GT Rotary files (Dentsply Maillefer, Ballaigues, Switzerland) with those of .04 and .06 tapered ProFiles (Dentsply Maillefer). The GT Rotary files were found to be less flexible than ProFile instruments.[8] Calas et al[9] conducted a study on the

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Table I. Instruments used in this evaluation

Instruments	*Manufacturers*	*Tapers*	*Sizes*
FlexMaster	VDW (Munich, Germany)	.02	25, 30, 35
		.04	25, 30, 35
		.06	25, 30, 35
Hero 642	Micro Méga (Geneva, Switzerland)	.02	25, 30, 35
		.04	25, 30
		.06	25, 30
K3	Kerr (Orange, Calif)	.04	25, 30, 35
	SybronEndo/Kerr	.06	25, 30, 35
ProFile	Dentsply Maillefer (Ballaigues, Switzerland)	.04	25, 30, 35
		.06	25, 30, 35
RaCe	FKG (La Chaux-de-Fonds, Switzerland)	.04	25, 30, 35

bending properties of Hero (Micro Méga, Geneva, Switzerland), ProFile, and Quantec (Tycom, Irvine, Calif) instruments with tapers of .02, .04, and .06. Hero files were found to be stiffer than Quantec instruments.[9]

The purpose of this study was to evaluate the bending properties of 5 different rotary nickel-titanium instruments with different tapers and sizes. Another goal of this investigation was to analyze the cross-sectional surface areas of these instruments to determine whether the cross-sectional surface area of rotary files can be seen as the predominant parameter affecting their bending properties.

MATERIAL AND METHODS

All instruments tested in this study are listed in Table I.

Composition of nickel-titanium alloy

We performed x-ray energy-dispersive spectroscopy using a Philips PSEM-500 scanning electron microscope and an EDAX PV 9100 microscope (Philips Electronics N.V., Eindhoven, The Netherlands) to analyze the composition of the nickel-titanium alloy used for the different instruments. One instrument of each type, taper, and size was used to quantitatively identify the chemical composition. The concentrations of the different elements are given in mass percentages.

Measurement of file diameters

The dimensional measurements used in this study were described in detail previously.[10,11] Twelve instruments of each type, taper, and size were investigated, and the mean diameters and tapers were calculated. The measurements of diameters of files were performed with a measuring microscope accurate to 0.001 mm (UWM; Leitz, Wetzlar, Germany). The instruments were mounted in a special microscope attachment to secure their orientation. The instruments were measured at 2 measuring points situated 3 mm and 13 mm from the tips. The taper of each file was calculated by using these 2 diameters.

Resistance to bending

Resistance to bending was determined with a testing apparatus corresponding to that mentioned in ISO publication 3630-1.[1] Before testing, each instrument's handle was removed where it met the shaft. The tip of the instrument was inserted into a chuck to 3 mm, perpendicular to the axis of the geared motor running at a speed of 2 rpm in a clockwise motion. A torque meter (Dino Plot P6501a502; Novotechnik, Ostfildern, Germany) was attached to the machine. The torque meter was first adjusted to a 0 reading to measure the bending moment. The special bending device was then adjusted until it came into contact with the instrument. The bending moment was automatically measured in gramme centimetre (gcm) and continuously recorded on a XY Recorder (WX 4301; Watanabe Instruments, Tokyo, Japan).

The sample size was 10 for each type, taper, and size in accordance with the instructions given by ISO publication 3630-1.[1] Statistical analysis was performed with commercial software (MedCalc 5.0; MedCalc Software, Mariakerke, Belgium). Differences between the instruments with respect to their bending moments were analyzed by using analysis of variance and the Student *t* test and the Newman-Keuls test for all pairwise comparisons ($P < .05$). The strength of the correlation between the bending moment and the measured area of the cross section was determined by computing the Pearson product moment correlation (r).

Calculation of cross-sectional surface area

The cross-sectional area of all instruments was determined by using photographs of the cross section.

Table II. Composition of rotary nickel-titanium instruments (the concentrations are given in mass percentages)

Instruments	*Ni*	*Ti*	*Fe*	*Al*	*Co + Cr*
FlexMaster	55.28	44.42	0.03	Max. 0.01	0.24
Hero	54.37	45.32	0.04	Max. 0.01	0.26
K3	54.55	45.12	0.04	Max. 0.01	0.27
ProFile	54.26	45.42	0.04	Max. 0.01	0.26
RaCe	55.25	44.49	0.03	Max. 0.01	0.21

Ni, Nickel; Ti, titanium; Fe, iron; Al, aluminum; Co, cobalt; Cr, chromium.

One instrument of each type, taper, and size was embedded in resin (Technovit 4000; Kulzer, Bad Homburg, Germany) and cut at the 3.0 mm working diameter with an ISOmet 11-1180 low-speed saw (Buehler, Lake Bluff, Ill). All samples were photographed by using a scanning electron microscope (Philips PSEM-500) at a magnification of 160×. Images were scanned at 600 dots per inch, and the cross-sectional surface area was calculated by using Scion Image for Windows software (public domain image-processing and analysis program; National Institutes of Health). The software automatically calculated the cross-sectional area (in square inches) with a relative error of 0.01%.

RESULTS

Composition of nickel-titanium alloy

The compositions of the different instruments are listed in Table II. All instruments contained 55-Nitinol. The differences in composition obtained were all within the precision of measurements.

Measurement of file diameters

The results of the dimensional measurements are summarized in Table III. As can be seen in Table III, the diameter and taper of an instrument can often coincide with a higher or lower file size or taper than intended. The most distinct deviation from the intended taper was in .06 tapered Hero size 25 files. In fact, the taper of these files was only 5.14%, not 6%. If a file measured outside the tolerance, in nearly all cases the mean D_3 and D_{13} measurements were on the small side.

Resistance to bending

The bending moments (Figure) of all instruments tested are summarized in Table IV. Statistically, bending moments were significantly lower for ProFile and RaCe instruments—withRaCe files being significantly lower than ProFile instruments—in all sizes and tapers than for the other files tested ($P < .05$). K3 files were significantly less flexible in all sizes and tapers than were the other instruments ($P < .05$).

Cross-sectional surface area

The results for the calculated cross-sectional areas are presented in Table IV. The Pearson product moment correlation was calculated to examine the correlation between the bending moment of the instruments and the measured cross-sectional surface area. The correlation coefficient (r) was 0.928 (95% confidence interval for r: 0.853-0.966). The P value resulting from this test was $P < .0001$, which revealed a highly significant correlation between the bending moment and the cross-sectional area.

DISCUSSION

Resistance to bending of root canal instruments depends on their metallurgic properties (eg, different alloys) and their geometric shapes.[4,5,7,12,13] Because meaningful data concerning the influence of different geometric shapes can be obtained only by comparing instruments made from the same alloy, the composition of the different nickel-titanium rotary instruments was investigated here. For all files, the resultant combination was an equiatomic ratio of the major components nickel and titanium (Table II). The generic term for this alloy is *55-Nitinol*.[14]

Moreover, file dimensions may have a crucial effect on the bending properties of endodontic instruments. No international or national standards are currently available for rotary instruments with tapers greater than .02, so we decided to evaluate the diameters and resulting tapers of the rotary nickel-titanium files on the basis of the ISO standard in publication 3630-1.[1] In this standard, the diameter and taper of different types of instruments are carefully prescribed. According to the results obtained here (Table III), all .02 tapered files were within the ISO guidelines. In contrast, in the groups of .04 and .06 tapered files, the ProFiles and the Hero instruments had few sizes measuring outside the tolerance. These files were all on the small side. The .04 tapered FlexMaster file size 30 was the only instrument that had a greater-than-allowed measurement at D_3, but the D_{13} measurements were mostly within the acceptable range. The RaCe files had the most even measure-

Table III. Mean diameters (D_3 and D_{13}) and calculated tapers of all instruments (all values in mm)

Tapers	Instruments	Sizes	Diameters (mm) D_3	Diameters (mm) D_{13}	Tapers	Acceptable range* D_3	Acceptable range* D_{13}
.02	FlexMaster	25	0.294 ± 0.011	0.499 ± 0.005	0.205 ± 0.011	0.310 ± 0.020	0.510 ± 0.020
	Hero	25	0.312 ± 0.009	0.513 ± 0.006	0.201 ± 0.011		
	FlexMaster	30	0.353 ± 0.005	0.558 ± 0.009	0.205 ± 0.009	0.360 ± 0.020	0.560 ± 0.020
	Hero	30	0.358 ± 0.008	0.573 ± 0.005	0.215 ± 0.013		
	FlexMaster	35	0.400 ± 0.004	0.601 ± 0.005	0.201 ± 0.004	0.410 ± 0.020	0.610 ± 0.020
	Hero	35	0.410 ± 0.006	0.612 ± 0.008	0.202 ± 0.001		
.04	FlexMaster	25	0.355 ± 0.003	0.757 ± 0.004	0.402 ± 0.002	0.370 ± 0.020	0.770 ± 0.020
	Hero	25	0.370 ± 0.006	0.776 ± 0.010	0.406 ± 0.007		
	K3	25	0.360 ± 0.004	0.760 ± 0.003	0.400 ± 0.005		
	ProFile	25	0.325 ± 0.008	0.722 ± 0.006	0.397 ± 0.007		
	RaCe	25	0.369 ± 0.012	0.762 ± 0.004	0.393 ± 0.036		
	FlexMaster	30	0.470 ± 0.003	0.800 ± 0.002	0.397 ± 0.001	0.420 ± 0.020	0.820 ± 0.020
	Hero	30	0.400 ± 0.008	0.798 ± 0.008	0.398 ± 0.008		
	K3	30	0.400 ± 0.003	0.810 ± 0.006	0.410 ± 0.006		
	ProFile	30	0.384 ± 0.004	0.784 ± 0.004	0.400 ± 0.004		
	RaCe	30	0.421 ± 0.008	0.807 ± 0.012	0.386 ± 0.007		
	K3	35	0.458 ± 0.003	0.859 ± 0.004	0.401 ± 0.005	0.470 ± 0.020	0.870 ± 0.020
	Profile	35	0.455 ± 0.005	0.859 ± 0.005	0.404 ± 0.002		
	RaCe	35	0.465 ± 0.013	0.859 ± 0.019	0.394 ± 0.011		
.06	FlexMaster	25	0.413 ± 0.004	1.023 ± 0.004	0.610 ± 0.010	0.430 ± 0.020	1.030 ± 0.020
	Hero	25	0.427 ± 0.005	0.941 ± 0.004	0.514 ± 0.007		
	K3	25	0.423 ± 0.005	1.023 ± 0.004	0.600 ± 0.004		
	ProFile	25	0.386 ± 0.006	0.987 ± 0.004	0.601 ± 0.005		
	FlexMaster	30	0.470 ± 0.004	1.084 ± 0.007	0.614 ± 0.006	0.480 ± 0.020	1.080 ± 0.020
	Hero	30	0.489 ± 0.011	0.995 ± 0.005	0.506 ± 0.011		
	K3	30	0.479 ± 0.004	1.078 ± 0.003	0.599 ± 0.005		
	ProFile	30	0.463 ± 0.005	1.050 ± 0.005	0.587 ± 0.004		
	FlexMaster	35	0.515 ± 0.004	1.119 ± 0.003	0.604 ± 0.003	0.530 ± 0.020	1.130 ± 0.020
	K3	35	0.526 ± 0.004	1.129 ± 0.007	0.603 ± 0.005		
	ProFile	35	0.510 ± 0.007	1.113 ± 0.008	0.603 ± 0.007		

*All values are in millimeters.

ments. However, these files were persistently on the small side of the acceptable tolerances, resulting in slightly smaller tapers than indicated. With respect to the mean taper of all files tested, the Hero files had large variations. Extreme recordings were obtained for Hero .06 tapered files sizes 25 and 30 (0.514 and 0.506, respectively).

It was remarkable to find how poorly some types of instruments are conforming to the dimensions and tapers indicated by the manufacturer. These results are in good agreement with earlier findings concerning the standardization of endodontic hand instruments[10,11] and rotary nickel-titanium files.[15] Until now, no ISO specification for endodontic instruments with a taper greater than the ISO standard .02 design has been available; moreover, it is obvious that there is a need for the development of international standards for size, taper, and acceptable tolerance limits of these rotary files. It can be assumed that the adoption of prescribed dimensions and tolerance limits may increase the efficiency of rotary instruments by reducing the undesirable effects of overlapping sizes[15] and may reduce the incidence of separation of rotary files. Certainly, this assumption warrants further investigation.

We examined the bending properties of rotary nickel-titanium instruments in light of the specifications in the ISO 3630-1 publication[1]; however, no maximum values were prescribed in this standard for files with a taper greater than the ISO standard .02 design. ISO maximum values for K-Files are 120 gcm (size 25), 150 gcm (size 30), and 190 gcm (size 35). The stiffness test revealed that the bending moments for all instruments were well below these maximum values (Table IV). For tapers of .04 and .06, the K3 files, sizes 25, 30, and 35, were significantly stiffer than all other files of the same taper and size ($P < .05$). In contrast, independent of the taper and size tested, ProFile and RaCe instruments were found to be significantly more flexible than the

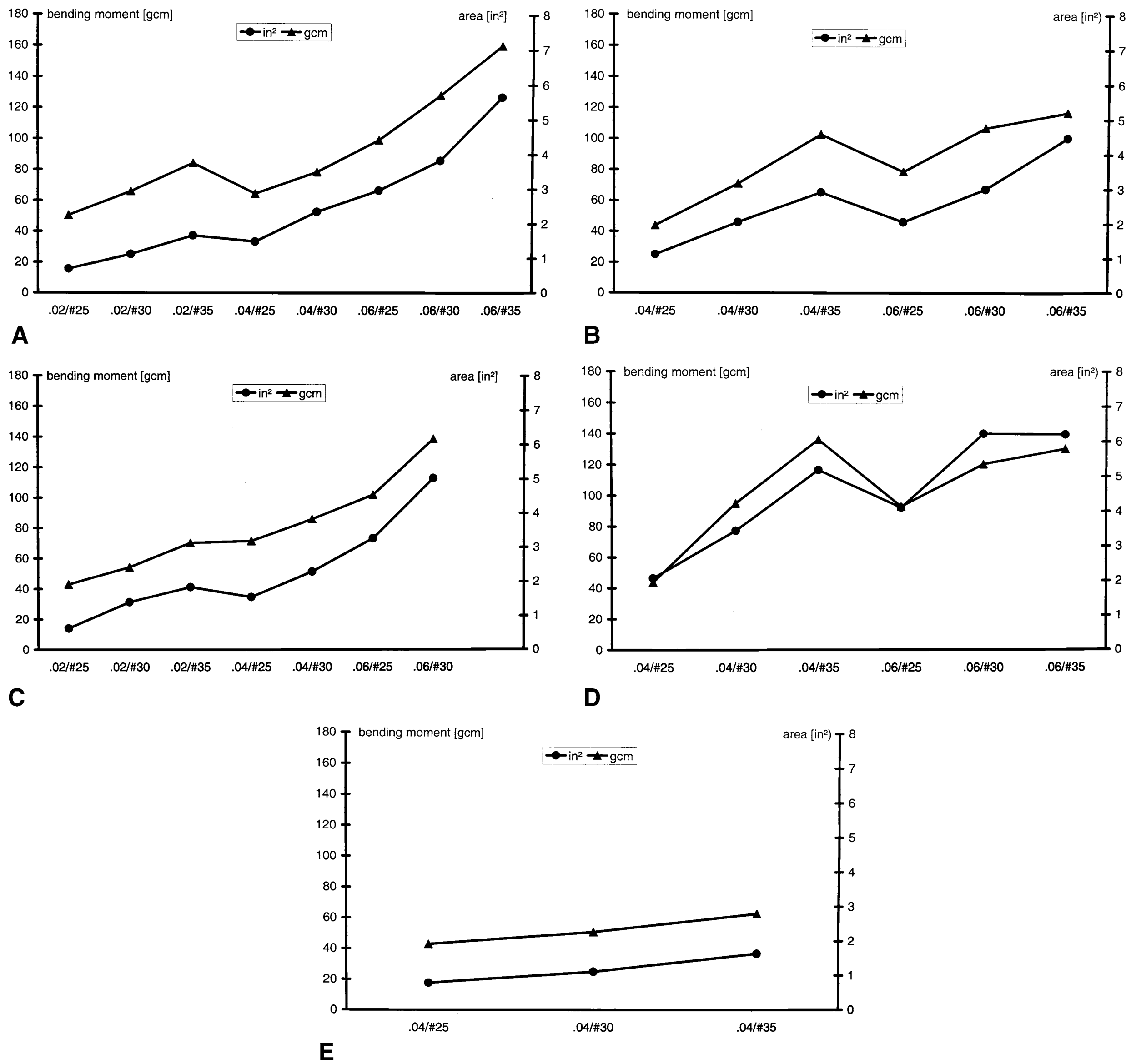

Figure. The relationship between stiffness and cross-sectional area of rotary nickel-titanium instruments. The *left axis* indicates the mean bending moments in gcm, whereas the *right axis* depicts the calculated cross-sectional surface area in square inches at a magnification of 160×. **A,** FlexMaster instruments. **B,** ProFile instruments. **C,** Hero instruments. **D,** K3 instruments. **E,** RaCe instruments.

other instruments ($P < .05$; Table IV), with RaCe files being significantly more flexible than ProFile instruments. These results corroborate those of previous studies.[8,9]

The low bending moments of all instruments tested are indicative that these files are extremely flexible, which is clinically very desirable. Because of their flexibility, the load on the cutting edges in a curved canal is reduced, which in turn reduces stress on the instrument and the possibility of fracture.[12] In addition, this superior flexibility reduces the risk of canal transportation during the enlargement of curved canals. However, in previous studies, it has been observed that some rotary nickel-titanium files created slight canal transportation toward the outer aspect of the curvature in the apical region of root canals.[16-18] Obviously, this canal transportation may be attributable to root canal preparation with instruments of greater taper, because these are considerably stiffer than are those of .02 or .04 tapers (Figure). Thus, manufacturers should be aware

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