Flute design of endodontic instruments: its influence on cutting efficiency

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The cutting efficiency of four brands and three sizes of endodontic files and reamers was evaluated. The force generated by the test instruments during rotary enlarging of predrilled holes in bovine femur was measured as a function of time. Graphic integration of the resulting tracings provided a measure of the energy. The energy for each instrument was divided by the volume of the material removed during cutting. Mean energies per unit volume (joules/mm^3) were compared statistically (ANOVA) to elucidate the relationship between flute design and cutting efficiency.

The cutting efficiency of an endodontic file or reamer involves a complex interaction of variables, such as metallurgical properties; cross-sectional configuration of shaft; sharpness of flutes; flute design (number of flutes, helical angle [angle between flute and longitudinal axis of file]), rake angle (angle between cutting edge and surface being cut); tip design, lubrication during cutting; wear resistance; chip removal capability; and mode of use.

Numerous studies have been undertaken to evaluate the cutting efficiency of various endodontic files and reamers. Craig and Peyton,[1] Sampeck,[2] and Sargent and Stemler[3] examined some physical properties of endodontic cutting instruments. The dynamics of cutting dentin, in particular, was examined separately by Lindhe[4] and Shoji.[5] Through microscopic analysis, they found that dentin is removed in the form of small chips. Microscopic analysis of the root canal walls after cutting procedures has also been reported by Davis and others,[6] Fromme and Reidel,[7] and Webber.[8]

The superior cutting ability of triangular cross-sectional instruments has been well documented.[5,9-11] Generally, the greater effectiveness of triangular instruments is attributed to the fact that a smaller blade angle (60 degrees) contacts the surface being cut rather than a 90-degree blade angle, as in the case of square cross-sectional instruments.

Various methods have been used to qualitatively evaluate cutting efficiency. These methods include microscopic analysis of rubber-base intracanal impressions,[12] measurements of applied torque,[9] the depth of cut under loading,[10] changes in specimen hole diameters,[11] specimen penetration times,[13] and specimen weight loss.[8]

Some of these investigations involved hand-powered instrumentation, whereas others used motorized instrumentation. The Giromatic motorized handpiece, in particular, was often used to power the endodontic instruments under investigation.[13-19]

The adoption of the ADA specification no. 28 for endodontic files and reamers[20] in 1976 was a significant step toward standardizing the manufacture, and thus the performance, of endodontic instruments. However, at that time, insufficient data existed to base any recommendations for root canal instrument flute design or to reproducibly measure the relative cutting efficiency of a given endodontic instrument. The purposes of this study were to evaluate the relative cutting efficiency of selected root canal instruments made by various manufacturers and to determine the relationship between the flute design of a root canal instrument and its cutting efficiency.

MATERIALS AND METHODS

Four brands of endodontic files and reamers were evaluated for cutting efficiency: Union Broach (Vereinigte Dentalwerke, Munchen, West Germany), Premier (Vereinigte Dentalwerke, Munchen, West Germany), Unitek (Unitek Corp, Monrovia, Calif), and Star (Maillefer,—Ballaigues, Switzerland). All instruments were obtained from retail supply sources and were thus representative of those in general use worldwide.

Files and reamers in sizes 30, 50, and 70 from each manufacturer were tested in runs of six instruments per size, totaling 144 instrument runs (Table 1).

The instruments were mounted in a quarter-turn endodontic contra-angled handpiece (Giromatic, Micro-Mega, Besancon, France) by means of latch-type adaptors (Union Broach Corp, NY). The contra-angle was held by a straight-shafted sleeve (Ultra-Centric,

Table 1 • Number of flutes and cross-sectional configuration for three sizes of files and reamers.

Manufacturer	Instrument type	No. of flutes	No. 30 cross section	No. flutes	No. 50 cross section	No. flutes	No. 70 cross section
Union Broach	File	26	Triangle	21	Triangle	16	Triangle
	Reamer	15	Square	13	Triangle	9	Triangle
Premier	File	25	Triangle	22	Triangle	16	Triangle
	Reamer	12	Square	13	Triangle	9	Triangle
Star	File	33	Square	21	Triangle	21	Triangle
	Reamer	15	Square	10	Triangle	7	Triangle
Unitek	File	25	Triangle	21	Triangle	19	Triangle
		27	Square				
	Reamer	17	Square	14	Triangle	9	Triangle

Kerr Mfg Co, Romulus, Mich). Each instrument was separated from its handle with a carborundum disk before it was mounted in the adaptor.

The handpiece was powered by an electric motor (Electro-torque, Kerr Mfg Co, Romulus, Mich) controlled by a variable rheostat. The rheostat was adjusted to yield a speed of 1,650 rpm as verified with a stroboscopic light (Strobotac, Type 1531A, General Radio Co, Concord, Mass).

The handpiece was secured to the descending head of an Instron Testing machine (Model TTC, Instron Corp, Park Ridge, Ill) (Fig 1). The Instron was operated at the following settings: head speed = 0.1 inch/min; chart speed = 1.0 inch/min; full scale = 1,000 gm and load cell = 200 lb.

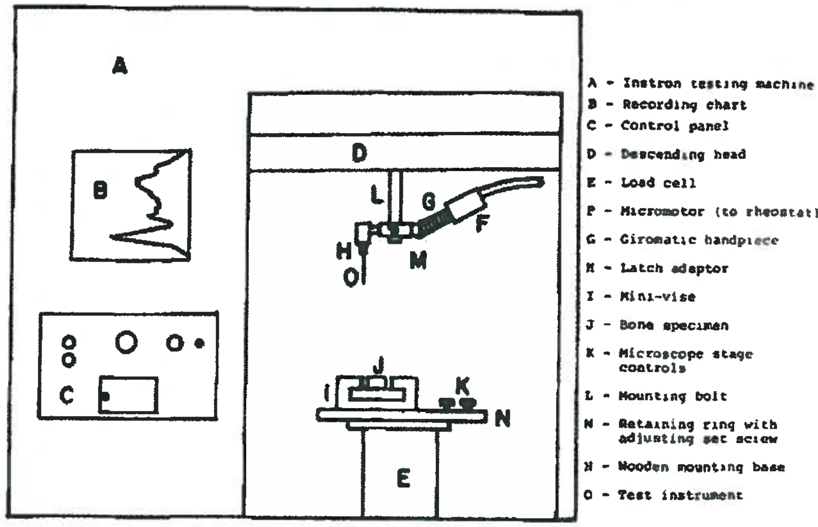


Fig 1—Schematic diagram of experimental assembly.

Specimen preparation and storage

Slices of bovine femur were cut perpendicular to the long axis of the shaft using a 9-inch diameter carborundum disk cut-off wheel (Surfmet Grinder, Buehler, Ltd, Evanston, Ill) (Fig 2). The slices were cut to an initial thickness of approximately 4.3 mm and then reduced on a belt sander to a uniform thickness of 4.0 ± 0.1 mm. Preliminary runs disclosed that a 4-mm thickness produced forces that were reproducible and were easily measured by the apparatus and that pilot holes could be successfully drilled without undue breakage of drill bits.

After preparation of the slices, each slice was quartered. The quarters were then edge-sanded so that four nearly rectangular specimens resulted. The nearly rectangular shape was necessary to obtain two parallel sides for accurate and reproducible clamping in the jaws of the vises used to hold the specimens for drilling the pilot holes

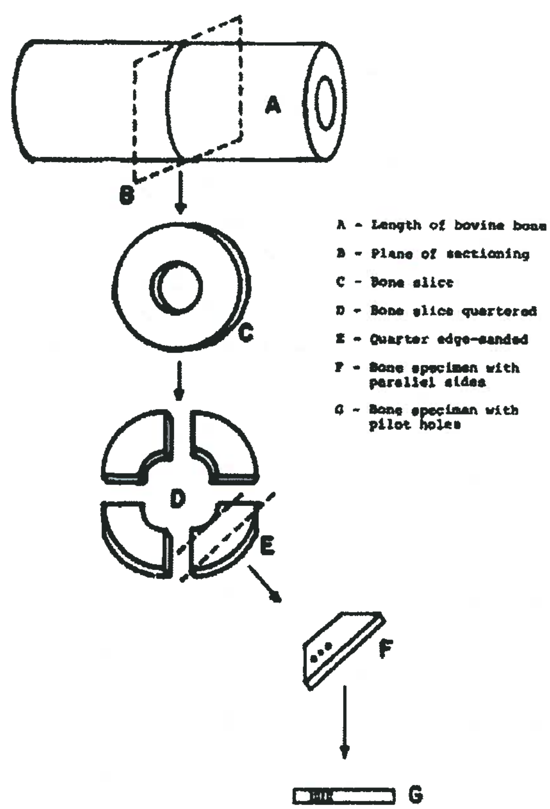


Fig 2—Preparation of bone specimens.

and for the instrument test runs on the Instron.

Pilot holes were prepared in the specimens to serve as simulated root canals (Fig 2). An individual pilot hole was always smaller in diameter than the test instrument descending through the pilot hole. High-speed steel bits were used to drill the pilot holes.

The bone specimens were maintained perpendicular to the descent of the drill bits during drilling of the pilot holes.

The specimens were kept moist throughout the preparation of the pilot holes, and the drill bits were lubricated with water during drilling. When not in use, the bone specimens were kept frozen. Before they were used they were thawed in water kept at room temperature.

The bone specimens were clamped into a miniature vise, which was attached to a microscope stage. Vertical alignment of the test intrument was accomplished by movement of the stage in both the x and y directions of the horizontal plane. The vise and microscope stage were bolted to the table of the Instron's 200-lb load cell (Fig 3).

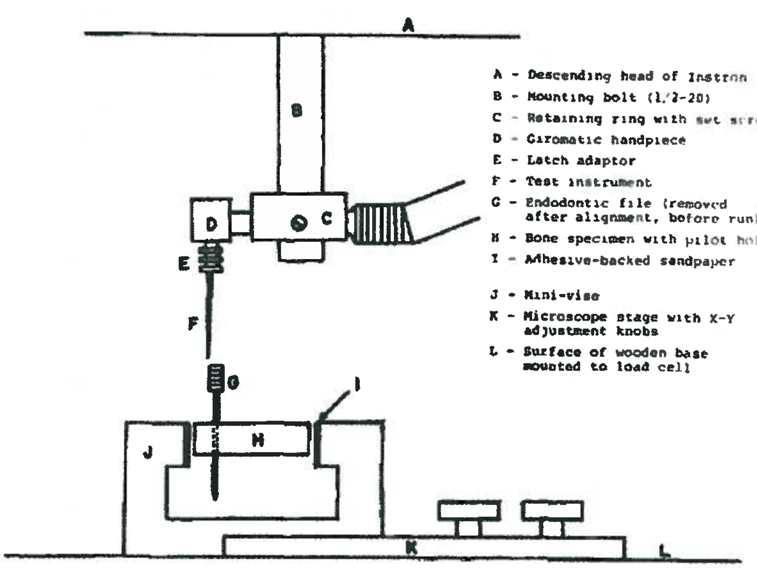


Fig 3—Vertical alignment of test instrument with pilot hole.

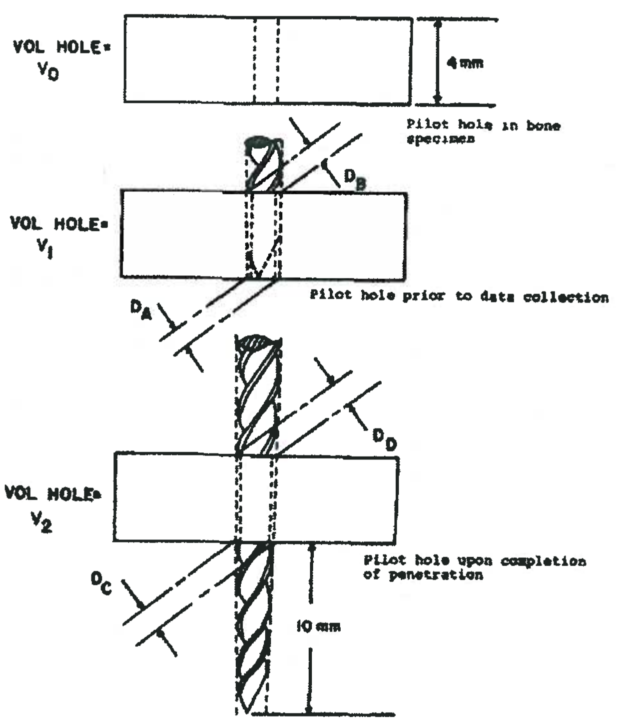


Fig 4—Schematic diagram of volume changes and diameter changes during instrument runs.

Instrument test runs

The test file or reamer was allowed to descend into the pilot hole until the tip of the instrument became visible on the underside of the bone specimen. At that point, the descent was momentarily stopped, the chart was zeroed, and data collection was begun and continued until 10 mm of the test instrument protruded from the underside of the bone specimen (Fig 4). The chart recorded the force (gm) as a function of time (minutes) generated by the test instruments during cutting at a constant rate of descent. The areas under the resulting tracings were determined with the aid of a planimeter (Keuffel and Esser Co, Morristown, NJ) and provided a measure of the energy needed to compare relative cutting efficiencies of the instruments under investigation (Fig 5).

The dimensions of D_1 and D_2 (Fig 6) for each instrument tested were obtained by direct measurement with a

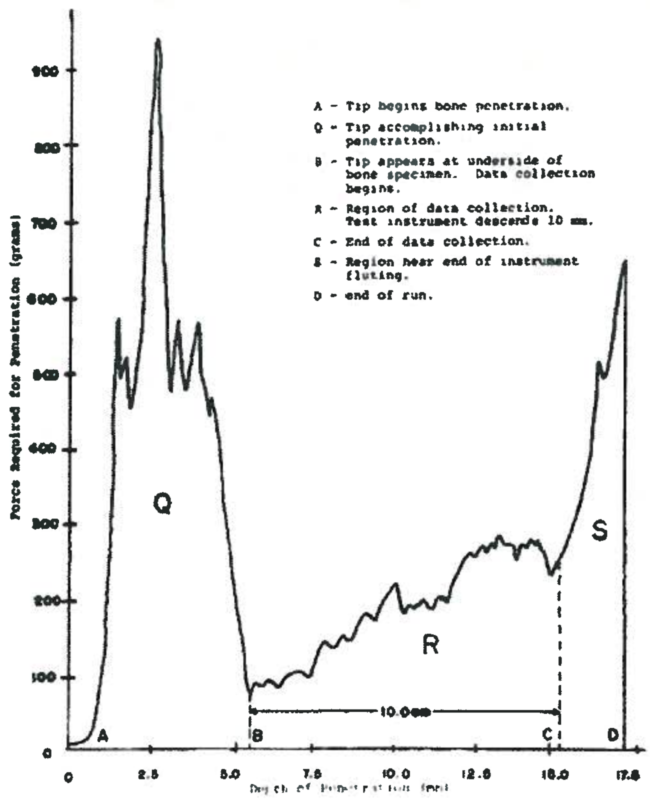
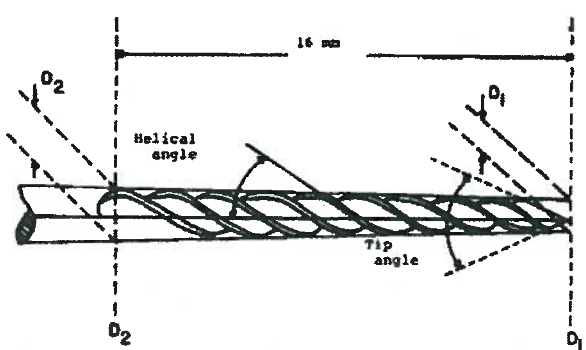


Fig 5—Sample graph from Instron testing machine (size 50 Union Broach file).



Terminology	- D_1 and D_2 expressed in hundreds of a mm.
Diameters	D_2 = D_1 plus 0.32 mm.
Taper	- .02 mm per mm.
Tip angle	- $75^\circ \pm 15^\circ$ included angle
Tolerance	- $\pm$ 0.02 mm.
Working Length of Blade (D_1 to D_2)	- 16.0 mm

Fig 6—Official specification for standardized root canal instruments.

micrometer. The precision of the micrometer was ± 0.01 mm.

A light microscope was used to determine the number of flutes and the cross-sectional configuration for each instrument type and size of each brand tested (Table 1).

Method of obtaining cutting efficiencies from the graphic data

Figure 5 is a sample graph obtained during one run of a size 50 file (Union Broach). The portion of the graph labeled Q represents the force required during initial penetration of the instrument tip. At point B, this penetration had been completed, and the tip no longer contributed to the cutting forces obtained during the remainder of the run. Data collection thus began at point B and continued until it reached point C, an interval that corresponds to a 10-mm descent of the test instrument (R portion). The portion of the graph labeled S represents the final segment of the test run, corresponding to the end of the fluted portion of the test instrument. The area included in the R portion was obtained with the use of a planimeter (by tracing the boundaries of the curve) in units of (gm/mm) and then converted to joules. These raw energies were divided by the volume of bone removed during the run to obtain the energy per unit volume of bone removed.

RESULTS

Table 2 contains the calculated mean energies per unit volume for all the instrument runs. The following comparisons are based on a statistical analysis of the data at $P \leq .01$. A comparison of the groups of instruments of all sizes (group of sizes 30, 50, and 70) showed these differences:

Table 2 • Mean energies per unit volume expended during instrument runs.*

Brand	Instrument†	Mean energy/V (joules × 10^{-6}/mm^3)	SD
Union Broach	30F	468.3	69.4
	30R	168.9	22.0
	50F	674.3	156.2
	50R	351.6	65.5
	70F	598.3	100.6
	70R	227.1	46.1
Premier	30F	421.1	74.0
	30R	200.7	53.0
	50F	516.1	93.0
	50R	248.6	33.9
	70F	624.8	70.6
	70R	189.5	43.6
Star	30F	315.3	104.9
	30R	301.7	42.2
	50F	423.0	48.4
	50R	346.9	95.7
	70F	597.7	157.2
	70R	313.0	103.2
Unitek	30F (square)	1004.1	198.3
	30F (triangular)	436.3	73.6
	30R	254.7	43.2
	50F	531.4	80.3
	50R	366.1	98.1
	70F	560.8	142.2
	70R	306.0	70.9

*From R portion (Fig 5).
†F = file, R = reamer.

—There were no significant differences between files and reamers for all brands. Reamers were more efficient than files as a whole.

—There were significant differences between files and reamers of each particular brand. Reamers displayed greater cutting efficiency than files. In general, there were no significant differences in cutting efficiency of files in comparing any two brands. The only exception was that Star files were significantly more efficient than Union Broach files. In general, there were no significant differences in cutting efficiency of reamers in comparing any two brands. The only exception was that Premier reamers were significantly more efficient than Star and Unitek reamers.

—Groups of instruments of particular sizes from all brands were compared, and these differences were observed: reamers were significantly more efficient than files; size 30 files were more efficient than sizes 50 and 70 files; sizes 30 and 70 reamers were more efficient than size 50 reamers.

—Within a group of instruments of a particular size, these conclusions could be drawn at $P \leq .05$:

Size 30 instruments. Star files and reamers were more efficient than corresponding instruments of Union Broach and Premier. Union Broach reamers were more efficient than Unitek reamers. The Unitek file of square cross-sectional configuration was less efficient than the Unitek file of triangular cross section (two commercial size 30 Unitek files were available of different cross-sectional configuration) and also less efficient than files of all other brands tested.

Size 50 instruments. Star files were more efficient than files of Unitek or Union Broach. Unitek files were more efficient than reamers of Union Broach and Unitek.

Size 70 instruments. Star reamers were less efficient than reamers of Union Broach and Premier. Premier reamers were more efficient than Unitek reamers.

DISCUSSION

The main purpose of this study was to determine the relationship between the flute design of a root canal instrument and its cutting efficiency. Ideally, instruments identical in all respects, except for flute design, would be subjected to standardized uniform cutting performance tests, so that any observable differences in cutting efficiency could be directly attributed to the differing flute designs of the various test instruments that were being compared.

With regard to the test instruments themselves, however, it was not possible to obtain instruments identical in all respects, except for the flute design. The manufacturing complexities involved in the creation of such instruments are so great as to discourage the active participation of foreign and domestic manufacturers. Consequently, a variation in flute design, namely, number of flutes per instrument, was achieved by comparing files of a given nominative size with reamers of the same nominative size for several brands. Theoretically, those instruments should have differed only in the number of flutes per instrument, as both files and reamers of the same nominative size should adhere to the same specifications (ADA specification no. 28) for D_1, D_2 and taper (Fig 6). In actuality, however, there were often differences between the instruments: the twisting process performed by different manufacturers varies. This manufacturing variation often leads to variations in D_1, D_2, and taper. The number of flutes contained in a given nominative size instrument varies between manufacturers (Table 1). Some size 30 instruments were not available in a triangular cross-sectional configuration (Table 1). The manufacturers often did not adhere to ADA specification no. 28 relative to D_1, D_2, and taper.[21]

The lack of adherence to ADA specification no. 28 was one of the most uncontrolled variables in this study. Because the instruments under comparison were not the same size, they removed different amounts of bone during the test runs, and thus performed different amounts of work (Fig 4). The differing energies associated with this work were, thus, not necessarily attributed to flute design at all. Consequently, to arrive at a consistent basis for comparison of the energy expended during a given test run, the energy per unit volume of bone removed was calculated for each instrument run by dividing the raw energy obtained from the area under the Instron graphs (Fig 5) by the volume of the bone removed during the run generating that area. Statistical analyses[21] were performed on these individual energy per unit volume values to determine differences in cutting efficiency between groups of instruments.

An examination of the results disclosed differences in cutting efficiency between sizes of a given brand, between sizes of different brands, between files and reamers of a given brand, and between files and reamers of different brands. Several explanations for these differences are possible. The sharpness of the cutting edge ground on the wire blank may vary, both between brands and within different sizes of the same brand. Even though the cross-sectional configuration of the wire blanks may be the same, it has been shown[8,13] that significant differences in sharpness can be present between root canal instruments without light microscope or SEM evidence of these differences. The helical angle between instruments may vary, especially between files and reamers. A reamer, with fewer flutes per millimeter, has a smaller helical angle (Fig 6). As the helical angle of the instrument decreases, the rake angle becomes progressively more negative, a situation that Lindhe[4] concluded will result in more efficient cutting.

The space for debris collection may vary, especially between files and reamers. The reamer, with fewer flutes per millimeter, has more space between its flutes than a file of the same nominative size. Consequently, the reamer would, perhaps, not experience as early or as greatly the detrimental effects of clogging of the chip removal sluiceways of the instrument. Support for this theory can be obtained from testing machine curves for files and reamers. The slope of the R portion with regard to files (Fig 5) is generally greater than the R slope for a corresponding reamer, indicating the need for comparatively more energy as the run proceeds in the case of files. This greater expenditure of energy may be a result of the need to overcome frictional forces created by the clogged flutes.

The effect of flute design appears to overshadow even the influence of cross-sectional configuration, in some cases. Table 1 indicates that for size 30 instruments, all manufacturers produced square cross-sectional reamers, whereas three of four produced triangular cross-sectional files in this size. It has been shown that triangular cross-sectional instruments are generally more efficient cutting instruments than their square cross-sectional counterparts,[5,9,11] yet, in the case of these size 30 instruments, the reverse occurred. This reversal is apparently due to the increased cutting efficiency associated with the flute design of a reamer. Further confirmation of this phenomenon can be seen by comparing the two varieties of Unitek size 30 files (square cross section vs triangular cross section). As they are both files, they have approximately the same number of flutes (Table 1), and yet the cutting efficiency of the triangular cross-sectional instrument is approximately 2½ times as great as its square counterpart (Table 2). Thus, when the number of flutes is constant, cross-sectional configuration greatly influences the cutting efficiency of a root canal instrument, but when the number of flutes varies, cross-sectional configuration does not always exert this profound effect on cutting efficiency. Rather, the number of flutes, namely, the flute design, can begin to assume the predominant role.

The significant differences in rotary cutting efficiency seen between files and reamers suggest that a file could, perhaps, be made a more efficient cutting instrument if it more closely approached a reamer with regard to the number of flutes on the instrument. Reference to Table 1 indicates that reamers generally have 30% to 50% fewer flutes that corresponding files. A triangular cross-sectional instrument somewhere between current files and reamers with regard to the number of flutes would, perhaps, provide the optimum combination of cross-sectional design, helical angle, rake angle, and chip removal capability.

SUMMARY

Four brands of endodontic files and reamers were evaluated for cutting efficiency: Union Broach, Premier, Star, and Unitek. All instruments were obtained from retail supply sources, and thus, were representative of those in general use worldwide.

Files and reamers in sizes 30, 50,

and 70 from each manufacturer were tested in runs of six instruments per size, totaling 144 instrument runs.

Cutting efficiency was evaluated as a function of the force required for the test instrument to penetrate a predrilled, slightly undersized channel prepared in a sample of bovine bone of constant thickness and constant horizontal orientation. Penetration was accomplished for a specified distance at a constant rate of descent, using an Instron testing machine. During the penetration, the test instrument was vertically aligned parallel to the predrilled channel (to within 1 degree). The test instrument underwent simulated root canal enlarging motions, provided by a quarter-turn oscillating endodontic handpiece (Giromatic) under the continual lubrication of a water spray. Graphs of the force required for each run were generated. The areas under the graphs were obtained with a planimeter and converted to standard energy units. The volume of bone removed during each run was calculated and divided into the raw energy obtained for that run, yielding the energy per unit volume of bone removed for each run. Statistical tests were performed to compare the energy per unit volume of bone removed for each run. Instruments were grouped according to size, brand, and flute configuration (file or reamer). The statistical data provided the significance of the relative cutting efficiencies of the groups, both within and between the groups.

CONCLUSIONS

—The reamer group tested was significantly more efficient than the group of all files tested.

—The reamer group from any one brand was significantly more efficient than the group of files from the same brand or any other brand.

—The file group (sizes 30, 50, and 70 combined) was generally about the same according to cutting efficiency for all brands.

—The reamer group (sizes 30, 50, and 70 combined) was generally about the same according to cutting efficiency for all brands.

—Smaller instruments (size 30) were generally more efficient than larger ones (sizes 50 and 70) of the same flute configuration.

—The effect of flute design on cutting efficiency can, in some cases, overshadow the effect of cross-sectional configuration.

—The Unitek size 30 file of square cross section was significantly less efficient than the Unitek 30 file of triangular cross section and also less efficient than all the other brands of size 30 files tested.

—The experimental apparatus used in this investigation was satisfactory for the determination of the relative cutting efficiencies of root canal instruments.

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