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Changes in root canal morphology in simulated curved canals over-instrumented with a variety of stainless steel and nickel titanium files

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Abstract

The purpose of this project was to observe the amount of apical and mid-curve transportation produced by a range of nickel titanium (NiTi), titanium alloy and stainless steel (SS) files. Tests were carried out in simulated curved root canals produced in epoxy resin blocks. Seven commercially available file types were tested using sizes 15 to 40. Instrumentation was carried out to 1 mm beyond the apex. Changes in canal dimensions were measured at 10× magnification under a shadowgraph.

There were substantial differences in the amount and the pattern of apical and mid-curve transportation produced. The amount of transportation increased with each subsequent size of file. Under the same conditions, nickel titanium files produced significantly less transportation than stainless steel files. The least apical transportation was obtained with the NiTi Mity Turbo and the most by the SS K file and SS Hedstrom file. The least mid-curve transportation was produced by the NiTi Mity Turbo and the most by the SS Hedstrom file.

Key words: Endodontics, files, root canals, shaping, nickel titanium.

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Introduction

The aim of root canal preparation is to clean and shape the root canal while maintaining its spatial relationship within the root.[1,2] The desired result is a uniformly tapering canal with a definite apical seat which facilitates the insertion of a hermetic seal at the obturation stage.[3] This is especially difficult in curved canals, where procedural errors such as apical transportation,[4-6] elbow formation,[6,7] ledging,[8] strip perforation,[9] perforation[10] and instrument fracture[2] can occur.

Various techniques have been used to avoid or minimize these errors. Step-back,[10,11] crown-down,[12] balanced force,[13] anti-curvature,[14] double-flare,[1] modified double-flare,[4] and sonic/ultra-sonic techniques have all been advocated to reduce complications, though none has been universally accepted as the answer to the maintenance of root canal curvature. Similarly, modification to instrument tip design,[15] and flute alterations[11] have not provided a solution to the management of the apical section of the curved root canal.

A limiting factor in all these techniques has been the excessive stiffness of the larger endodontic file sizes which produces distortion or straightening of the canal during instrumentation. Stiffness increases rapidly with increasing size of instrument.[16] For many years manufacturers have been endeavouring to produce files with greater flexibility by varying instrument design and materials of manufacture. Recently, files made from nickel-titanium alloy have

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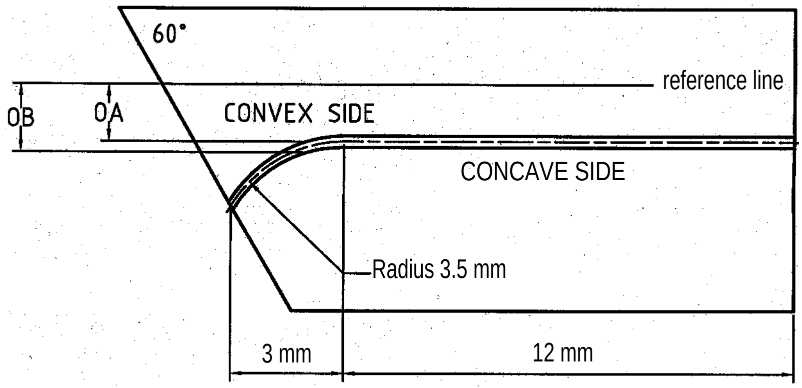


Fig. 1. – Dimensions of the epoxy block used for testing. The canal is shown as a heavy dark line. The reference line from which all measurements were taken is also shown. OA is the measurement from the reference line to the convex side of the canal, and OB is the measurement to the concave side.

become available.[17] A nickel-titanium (NiTi) alloy was developed for maritime use in Maryland, USA, and became known as 'Nitinol' (NiTi Naval Ordnance Laboratory, where it was manufactured). The two outstanding characteristics of NiTi alloy are its super elasticity and shape memory effect.[18-21] Nickel-titanium has a lower modulus of elasticity (lower stiffness) and a very large capacity for elastic (recoverable) deformation.[21] Walia and co-workers[22] performed an initial investigation on the bending and torsional properties of size 15 Nitinol files and found that these files had two to three times more elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture, compared with size 15 stainless steel files manufactured by the same process. These characteristics suggest that files made from nickel-titanium should be superior for the instrumentation of curved root canals when compared with stainless steel files. That is, the greater flexibility possessed by nickel titanium files should allow instrumentation to be completed with less changes to the canal shape. Preliminary studies by several authors[2,9,23] support this proposal.

Over-instrumentation can occur as a procedural accident during root canal instrumentation if, for example, the canal length is incorrectly assessed or if some instrumentation has been carried out prior to length determination. Procedural accidents such as this are unfortunate and often produce distortion of canal morphology to such an extent that major problems are experienced, for example, failure to produce an apical seat. Recently, Serene and co-workers[18] reported that, while disruptive changes in root canal morphology occurred when a canal was over-instrumented with a stainless steel file, over-instrumentation with nickel-titanium files resulted in 'acceptable canal morphology'. This was confirmed by Lam.[24] While patterns of apical and mid-curve transportation have been described in the literature, there has been no comparative study of the effects of different file products on the morphology of over-instrumented apices.

The aim of this study was twofold: firstly, to compare the amount of apical and mid-curve transportation which occurred in simulated canals when canals were instrumented beyond the apex with a range of files of differing shapes and materials of manufacture; secondly, to observe the changes in canal morphology which were characteristic for each of the file types under study. Instrumentation of simulated root canals in plastic blocks[11] was chosen as an appropriate method to compare the cutting behaviour of these files. Canals were over-instrumented to 1 mm beyond the apex.

Materials and methods

Epoxy resin was cast around annealed pre-curved size 15 silver points to produce curved canals in clear plastic blocks with a Vickers Hardness Number of 35 (Fig. 1). Standardized curvatures were obtained by shaping the points to match a template. To ensure accuracy, this was checked at 10× magnification using a shadowgraph projector.§ The shape consisted of a 12 mm straight portion and a curved 3 mm apical portion (Fig. 1). The radius of the arc for the curved portion of the canal was 3.5 mm. This produced a canal curvature of approximately 30 degrees.[25] The plane of the curve was parallel to one face of the block.

Once the resin had set, the block was trimmed at 60 degrees to the long axis of the block just exposing the tip of the silver point (apex of the root canal). The silver point was removed and the block was trimmed so that the axial length of the root canal was 15 mm. The length and form of the simulated root canal was checked using projection at 10× magnification onto the template. The coronal opening of each simulated root canal was widened with a number 3 round bur to a depth of 2 mm, followed by a size 2 Gates-Glidden bur to a depth of 8 mm, in order to facilitate instrumentation and to create a reservoir for the irrigant (light machine oil).

§Nikon Shadowgraph Model C, Nikon, Tokyo, Japan.

Table 1. Files tested

Stainless steel Hedstrom files	Antaeos, USA
Stainless steel K files	Antaeos, USA
Stainless steel K Flexofiles	Maillefer, Switzerland
Stainless steel Safety Hedstrom files	Kerr, USA
Nickel titanium Mity Hedstrom files	JS Dental, USA
Nickel titanium Mity Turbo files	JS Dental, USA
Titanium alloy Micro-Titane files	Micro-Mega, France

Thirty-five blocks were prepared, checked for correct dimensions and numbered randomly from one to 35, so that five canals were used for each instrument type.

Instrumentation was carried out using seven types of file as shown in Table 1. Thirty-five sets of files comprising six sizes of each file type (15, 20, 25, 30, 35, 40) were randomly allocated, one set to each block, so that during the course of the experiment each instrument was used only once. Files were operated through prefabricated brass stops to ensure that the working length of the instrument was always 1 mm longer than the length of the canal. All files, commencing at size 15 file, were introduced into the canal with a gentle clock-winding movement until the tip was extruding 1 mm beyond the apex. Blocks were hand held and instrumentation was achieved using a pull stroke. The instrument was gently placed back into position and the stroke repeated. A total of ten strokes was used for each file size. The procedure was repeated for the larger files. All instrumentation was carried out by one operator.

Prior to instrumentation, a line parallel to the long axis of the canal was scribed on one face of each block as a reference for measurements. All measurements were made using the shadowgraph at 10× with micrometer controlled table traverse, reading to 1 μm. Measurements of the distances between the scribed line and both sides of the canal were taken initially and after successive stages of instrumentation. Measurements were taken at the apex and at 1 mm intervals to 4 mm along the canal. In this way, changes in canal profile with instrumentation could be determined to a precision of 1 μm. The amount of canal transportation was calculated and recorded for each block at each position in the canal after each instrumentation step. The mean values for deviation of the canal at the apex (0) and distances 1, 2, 3, and 4 mm successively from the apex were plotted. Measurements were recorded, and the mean values for transportation were plotted on graphs.

The mean values for deviation of the canal at the apex (0) and distances 1, 2, 3 and 4 mm successively from the apex were plotted for each file type (Fig. 2). Deviations at each distance for each file size were statistically analysed using ANOVA separately for the convex and concave curves. Mean deviations at the apex and 2 mm from the apex were also plotted against file size for each file type (Fig. 3).

After instrumentation was completed for each file size, shadow prints at 10× magnification were made for illustration by projection through the plastic block directly onto photographic paper using a photographic enlarger.

Results

Photographic projections showing the progressive changes in canal shape produced by instrumentation by the different files are shown in Fig. 4. Graphic representation of the measurements of deviation produced on convex and concave sides for each file type at various distances from the apex are illustrated

Table 2. Summary of significant differences (from ANOVA) of mean deviations between file types for each file size at the apex and 1 mm from the apex on the convex side

Size	Apex	1 mm from apex
15	ns	ns
20	SSKF,SSH,SAF>MH,MT*	ns
25	SSKF,SSK,SSH>MH,MT* SAF,TMT>MT	ns
30	SSK,SSKF,SSH>MH,MT* SAF,TMT>MT	SSK>rest* SSKF>TMT
35	SSK,SSKF>TMT,MH,MT* SSH>MT	SSK,SSKF>MT,TMT
40	SSK>SSH,SAF,MH,TMT,MT* SSKF>MH,TMT,MT SSH>TMT,MT	SSK>rest* SSKF>TMT

Abbreviations: ns=not significant, SSH=stainless steel Hedstrom files, SSK=stainless steel K files, SSKF=stainless steel K Flexofiles, TMT=titanium alloy Micro-Titane files, MH=nickel titanium Mity Hedstrom files, MT=nickel titanium Mity Turbo files, SAF=stainless steel Safety Hedstrom files.
*Significant difference at 1% level of significance.

Table 3. Summary of significant differences (from ANOVA) of mean deviations between file types for each file size at the apex and 2 mm from the apex on the concave side

Size	Apex	2 mm from apex
15	ns	SSH>SSKF,MH,SAF, MT,SSK*
20	ns	SSH,TMT>rest*
25	SAF different to rest* MH,MT>SSKF	SSH,TMT>rest*
30	MT>SSK,SSKF,SAF† TMT>SSKF,SAF	SSH>SSKF,SAF,MT, MH,SSK* TMT>SSK
35	MT>MH,SSK,SAF,SSKF†	SSH>SSK*
40	ns	SSH>MH,MT,SSKF,SSK* TMT,SH,MH,MT>SSK

Abbreviations: ns=not significant, SSH=stainless steel Hedstrom files, SSK=stainless steel K files, SSKF=stainless steel K Flexofiles, TMT=titanium alloy Micro-Titane files, MH=nickel titanium Mity Hedstrom files, MT=nickel titanium Mity Turbo files, SAF=stainless steel Safety Hedstrom files.
*Significant difference at 1% level of significance.
†Significant difference at 5% level of significance.

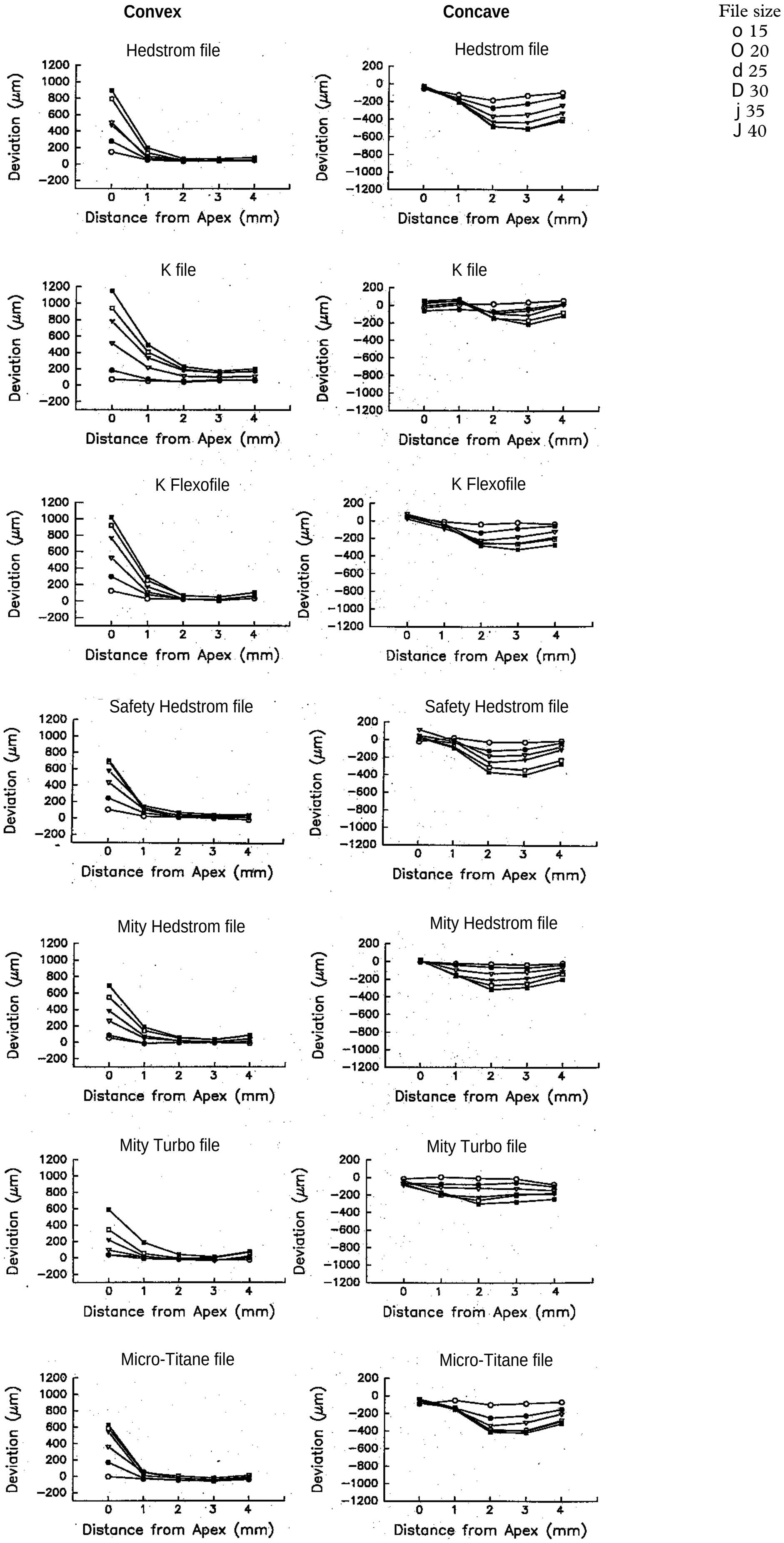


Fig. 2. – Graphical representation of the measurements of deviation produced on convex and concave sides by instrumentation of the simulated canals for each file type. Distance from the apex in millimetre intervals is shown on the X axis.

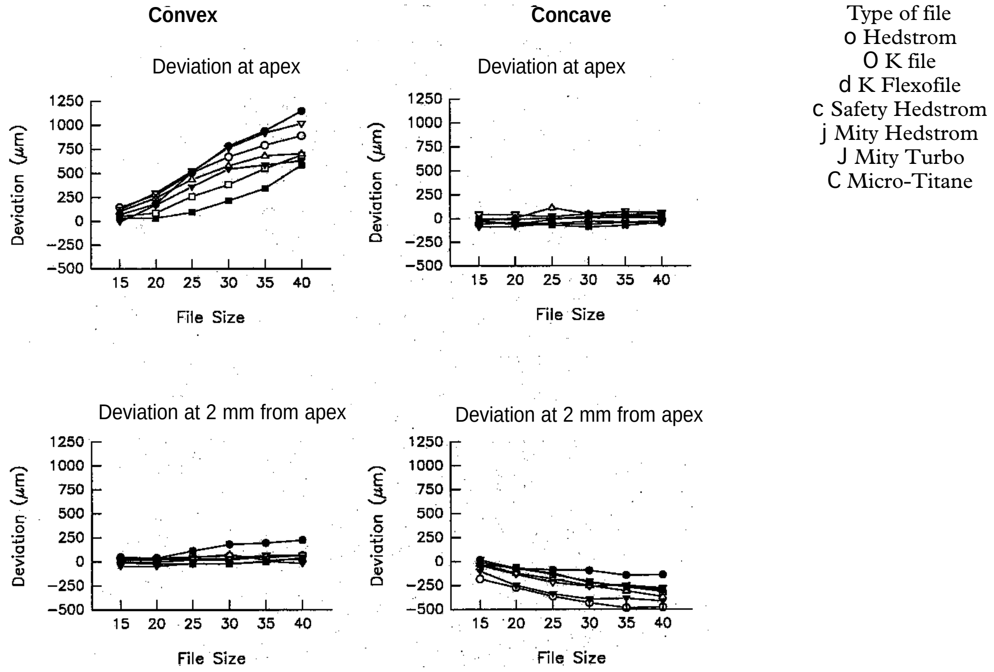


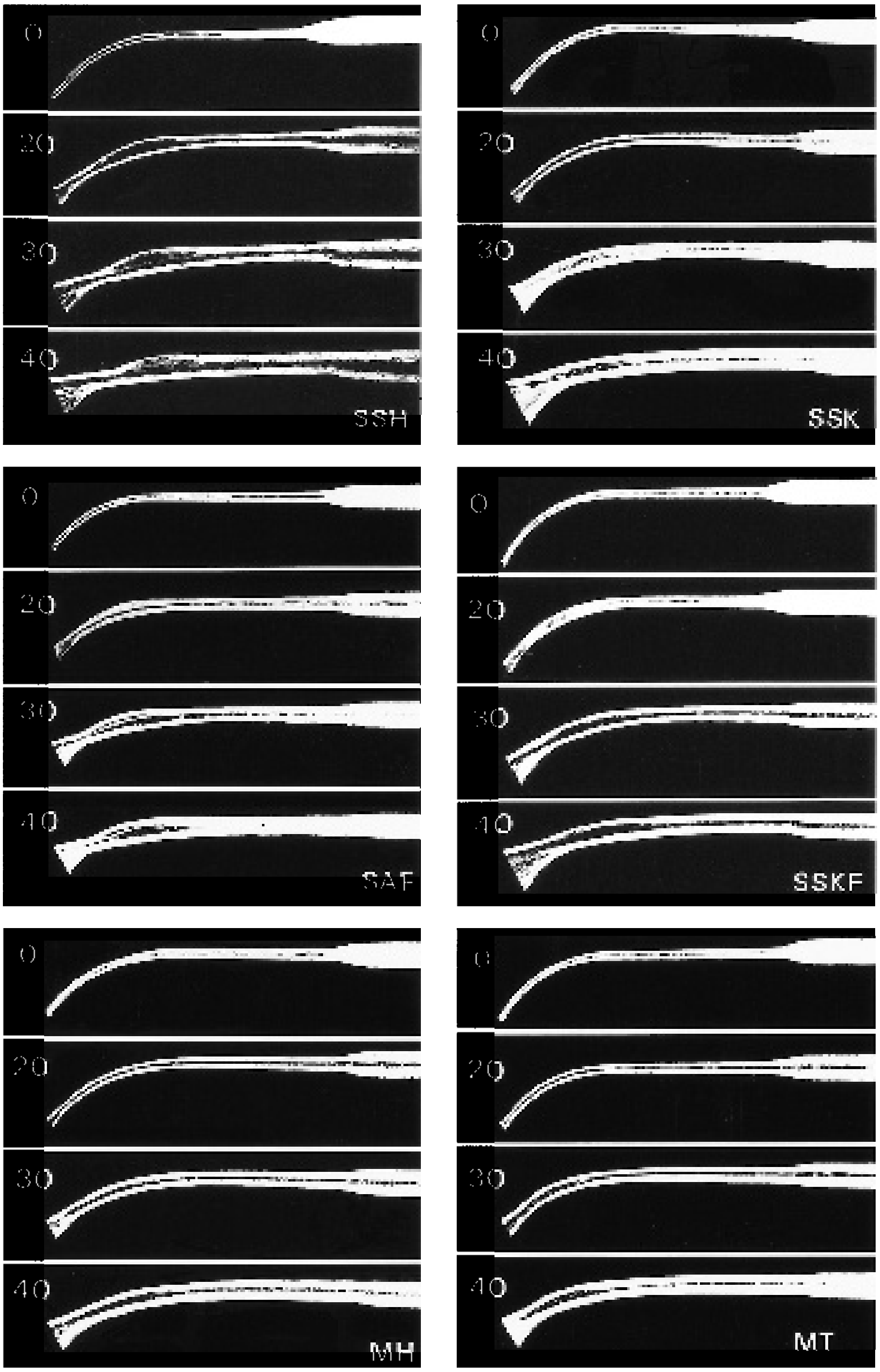
Fig. 3. – Graphic representation of the progressive deviation produced at the apex and at a point 2 mm from the apex following instrumentation by files of size 15, 20, 25, 30, 35 and 40.

in Fig. 2. The amount of transportation at the apex for different files differed from that at the mid-curve. The SS K and SS Hedstrom files produced similar amounts of apical transportation, but the Hedstrom file produced significantly more mid-curve transportation than that obtained by the K file.

A characteristic pattern of canal deviation was created with each file type. Nickel titanium files (Mity Turbo and Mity Hedstrom) produced the smoothest canal contours. While there was a distinct change in canal shape with increasing size of instrument used, instrumentation with these files produced a canal configuration which was smooth in outline. Apical zip and elbow formation appeared minimal compared with stainless steel files, particularly up to size 30. Stainless steel Hedstrom files produced most elbow formation and a 'trumpeting' of the apex. Stainless steel K files produced deviation over the full length of the canal with little elbow formation but with the larger sizes the shape produced displayed appreciable reverse taper. That is, the canals appeared narrowest at the orifice but increased in size toward the apex. With SS Hedstrom files a definite constriction was produced coronal to the apical flare. The morphology of the canal shape produced by the Safety Hedstrom was similar to that produced by the SS Hedstrom. Instrumentation with Safety Hedstrom files was found to be difficult, even with the smaller sizes. A number of canals were ledged to the point where instrumentation could not be completed. Instrumentation with K Flexofiles produced a canal shape similar to a K file but with a more pronounced elbow. Canal shapes produced by Micro-Titane files were similar to the Flexofile but with less apical flare.

The significant differences obtained from analysis of variance of deviations between file types for each file size at selected positions in the canal are summarized in Tables 2 and 3. For the convex side (Table 2), mean deviations at the apex and 1 mm from the apex were the only positions that showed a significant effect due to file type. In accordance with data illustrated in Figure 3, mean deviations at the apex and 2 mm from the apex are presented in Table 3 for the concave side. The position at 2 mm from the apex was considered to be representative of the region from 2-4 mm from the apex on the concave side.

Instrumentation produced significant transportation of the canal on the convex side of the apex and on the concave side of the curved portion of the root canal (Fig. 2). The greatest transportation occurred at the apex and 2 mm from the apex (Fig. 2). Transportation produced at the concave side of the apex, and the convex side of the curved portion, was minor (Fig. 2). Transportation increased with each subsequent size of file for all instruments (Fig. 4). At the apex, the SS Hedstrom and SS K file produced the greatest amount of apical transportation while the Mity Turbo and Mity Hedstrom produced the least (Fig. 3). The deviations at 2 mm from the apex produced by SS Hedstrom and Micro-Titane at size 25 were significantly greater than all other files.



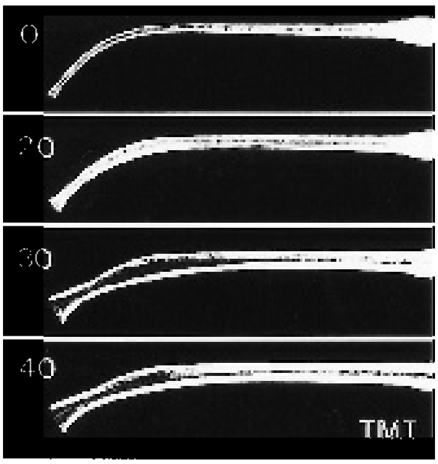


Fig. 4. – Photographic projections showing the progressive changes in canal shape produced by instrumentation for the files tested. File sizes are indicated by numbers 20, 30 and 40; uninstrumented canal by 0. File types are indicated as below:
SSH=Stainless steel Hedstrom file
SSK=Stainless steel K file
SAF=Stainless steel Safety Hedstrom file.
SSKF=Stainless steel K Flexofile
MH=NiTi Mity Hedstrom file
MT=NiTi Mity Turbo file
TMT=Titanium Micro-Titane file

Discussion

An endodontic file has an inherent stiffness. Bending of the file during the instrumentation of a curved canal produces consequent lateral forces which increase the cutting at points where these forces are applied. Therefore, it is to be expected that in curved canals cutting will be greatest at the convex side of the apical portion of the canal (Fig. 1) and on the concave side of the mid-curve of the canal. Weine and co-workers[11] in 1975 observed that every file tended to straighten canals and the results of the present study confirmed this view, with the positions of maximum transportation being at the apex, and at 2-4 mm from the apex for the canal shape studied.

For the file sizes examined, the amount of transportation increased with the size of file for all file types. The degree of canal transportation is influenced not only by the stiffness of the file, but also by its cutting effectiveness. While it was clearly demonstrated that the transport produced by the Mity Turbo and Mity Hedstrom was significantly less than that from the stainless steel instruments, it was not possible to determine which of these above factors were the most important in the production of the significant differences observed.

Although there may be some differences between the cutting effectiveness of the instruments tested, and this may have had an influence on the results, the reduced transport produced by the nickel titanium files remains unequivocal, and can be taken as support for the expectation of superior clinical behaviour in the maintenance of apical anatomy and contour. In addition, the nickel titanium instruments performed much better than the stainless steel instruments in maintaining the overall profile in the test blocks.

Over-instrumentation represents the worst case scenario where filing has been carried out unintentionally through the apex, for example, during initial pulp removal or where preparation length has been incorrectly estimated. Nevertheless, over-instrumentation does occur in some cases during endodontic therapy. This paper examined the effects of such instrumentation on curved root canals and established that nickel titanium files perform significantly better than stainless steel files with respect to the maintenance of the canal shape when instrumentation is carried through the apex.

It is interesting to speculate on what effect the canal shapes produced in this study would have on obturation techniques in over-instrumented canals. With SS Hedstrom, Mity Turbo and Safety Hedstrom, a definite stop forms about 1 mm from the end of the canal. In theory it should be easier to fill these canals without overfill provided a large size master point was used, whereas some difficulty in canal obturation would be expected in those canals instrumented with K files and Flexofiles where a negative taper appeared to be prepared.

Using the methodology described in this paper, it has been possible to compare the effect of instrumentation with different instruments. Whether the results of this study can be interpreted as accurately representing differences that would occur in natural teeth is difficult to ascertain. However, transparent plastic blocks incorporating simulated root canals have been used for many years in dental education[26] and in endodontic research.[11,27-31] Ahmad[28] has evaluated the cutting efficiency of ultrasonic instrumentation on curved canals in resin blocks and natural teeth, and could not determine any qualitative nor quantitative differences in the manner of removal of material along the length of the canal. The use of resin blocks rather than natural teeth has the advantages of allowing the size and shape of the canals to be standardized, and making it possible to produce standardized measurements and prints of the canals before, during and after instrumentation. The use of only five blocks for each instrumentation type is justified by the small values of standard deviation obtained in this study.

Conclusions

1. A characteristic pattern of canal deviation was created by each file type. Nickel titanium files produced the most regular canal shape.

2. Instrumentation produced significant transportation of the canal on the convex side of the apex, and on the concave side of the curved portion of the root canal. The greatest transportation occurred at the apex and 2 mm from the apex. The transportation produced at the concave side of the apex and the convex side of the curved portion was minor.

3. Apical and mid-curve transportation increases with file size for all types of instrument.

4. The least apical transportation was obtained with the Mity Turbo, and the most by SS K files and SS Hedstrom files.

5. The least mid-curve deviation was produced by the Mity Turbo and the greatest by SS Hedstrom.

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