Endodontic File Design and Dynamics in Automated Root Canal Preparation

Concepts, Materials and Methods

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ABSTRACT

Many treatment failures in endodontics are caused by problems that occurred during canal preparation. This article reviews principles of endodontic instrument design and analyzes the design as it relates to an automated handpiece. After a review of the problems of automation, there will be an introduction of a new automated handpiece and a new modified file known as the Anticurvature File.

Root canal preparation is considered the most critical, demanding and time consuming phase of endodontic treatment. The outcome of endodontic treatment is largely dependent upon the quality of canal preparation. Many treatment failures are caused by problems that occurred during the canal preparation.

During the past three decades, the role of canal preparation in endodontic therapy has significantly changed from a simple medicinal procedure, where a variety of medicaments were used to disinfect, sterilize or mummify the pulp tissue, to a more complex mechanical and biologic procedure with well-defined criteria. The new emphasis on the mechanical nature of root canal preparation can be easily appreciated by reviewing the variety of terms used in defining the procedure; such as chemo-mechanical instrumentation[1] or cleansing and shaping[2].

Traditionally, the root canal preparation is performed manually, which is time consuming, difficult and often strenuous. Another limitation of manual instrumentation is its inability to clean the canal thoroughly. Manual instrumentation often leaves areas of the root canal unprepared[3] or unsmoothed[4]. In spite of these disadvantages, manual root canal preparation is most common because it enables the clinician to control the endodontic instrument, thus increasing the safety and predictability of treatment results.

To simplify the root canal preparation and reduce the stress and operative time, many automated endodontic handpieces have been developed[5,6,7]. They are designed to transform a continuous rotary motion in the handpiece motor to either an alternating quarter turn movement or to a combination of longitudinal and quarter turn movements. The main purpose of these mechanical handpieces is to reproduce the basic motions of manual instrumentation. The effectiveness of the different types of automated instruments has been investigated and questioned by many authors[8,9]. To improve the efficiency and safety of the automated endodontic handpiece, the clinician should be knowledgeable about the specific design characteristics and engineering principles governing the use of the endodontic hand files, as well as files used in conjunction with mechanical or automated handpieces.

The purpose of this article is to:

1. Review basic engineering principles of endodontic instrument design and their modes of operation.

2. Analyze the relationship between endodontic file design and automated handpieces.
3. Review the problems of endodontic automation and introduce a new endodontic automated handpiece known as the Canal Finder System and a new modified automated file known as the Anticurvature File.

Endodontic Instruments

Endodontic reamers and files are made by grinding a round wire to produce a triangular, quadrangular or rhomboid shaft. The shaft is then twisted in a counterclockwise rotation which gives cutting efficiency during the clockwise rotation of the instrument[10]. The degree of torsion or twisting differentiates reamers from the K-type files. The shape of the shaft cross-section will give the instrument its specific physical property and govern its cutting efficiency (Fig. 1). For example, instrument sizes 40-120 have a triangular shaft cross section and have the following characteristics:

1. 40% less metal than the quadrangular instruments and are therefore prone to fracture.
2. Conform easier to a curved canal because of their flexibility[11,12].
3. Reduced elastic memory, thus reducing torsion resistance.
4. Prone to bending.
5. Improved ability to remove debris due to the increased flute depth.
6. Increased cutting efficiency as a result of a 60 degree cutting edge angle.

On the other hand, instruments with a quadrangular cross-section (endodontic instrument sizes 8-40) have the following characteristics (Fig. 2):

1. 64% more metal, thus less flexible.
2. Rigid, thus more resistant to bending.
3. Shallow flutes, thus carry less debris[13].
4. Less cutting efficiency because of 90 degree cutting edge angle (Fig. 4).

Endodontic Reamer

An endodontic reamer (Fig. 3) is a wire twisted to give ½-1 flutes per millimeter along the cutting segment of the instrument. The 20 degree incline of the flutes from the axis of the instrument, called the helical angle, makes the instrument efficient in rotation (reaming) and inefficient in filing. The use of a reamer is dangerous as it may unwind, leading to breakage if the clinician applies pressure during rotation. The use of reamers has to be limited to wide canals or to the straight portions of curved canals and with the use of minimal lateral pressure[15].

The K-File

The K-file (Fig. 4) is manufactured by twisting a round wire in a counterclockwise motion with a tight 2-2.5 flutes per millimeter along the cutting segment of the file. The helical angle is between 35 and 40 degrees, making the file more effective in filing. Because of the tight pitch, the file will not advance too fast forward upon pressure. Therefore, it is excellent for canal negotiation. When pressure is applied along the axis of a free, unrestricted K-file, the force is transformed into a helicoid movement, combining a rotational and longitudinal motion. The degree of friction or resistance will determine the rotational and/or longitudinal movements of the file, and thus its cutting efficiency. When the file cannot rotate, its cutting efficiency in filing is increased.

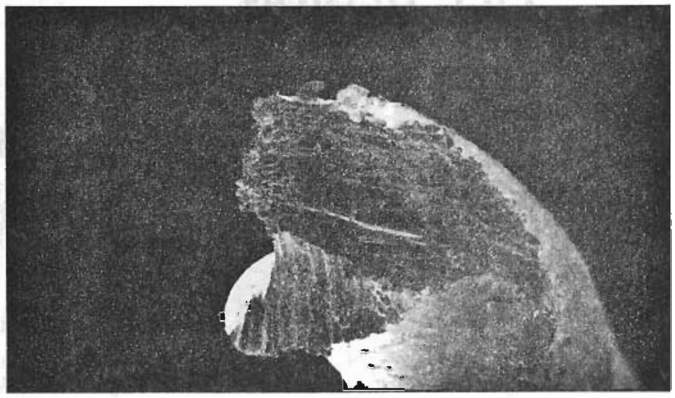

Figure 1. Triangular K-file cross section x 75. Triangular K-file shows the deformation of the blades due to torsion—the cutting angle is positive in clockwise rotation—negative in counter-clockwise rotation. The 60 degree angle of the blade is very sharp and the flutes are deep and contain more debris.

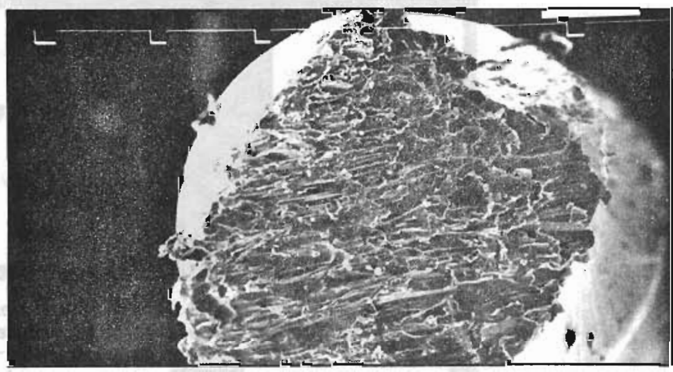

Figure 2. Quadrangular K-file x 50. The cross section shows less deformation of the blades, the cutting angle is slightly positive clockwise and negative counterclockwise—the flutes are not deep and the 90 degree angle of the blade is not very efficient.

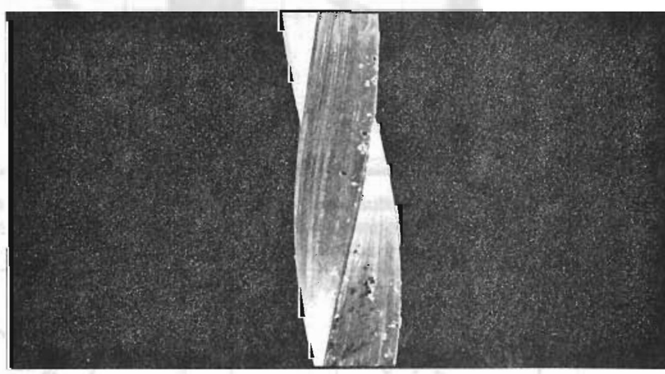

Figure 3. Due to the helical angle of 18 degrees, the reamer is active during a rotational movement (reaming), and inactive during a longitudinal movement (filing).

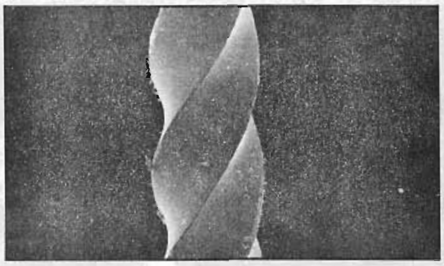

Figure 4. K-file x 75. The helical angle of 40 degrees makes the instrument active in filing and inactive in rotational reaming movements.

Figure 5. Hedstrom file (Maillefer) x 150. With a helical angle of approximately 70 degrees.

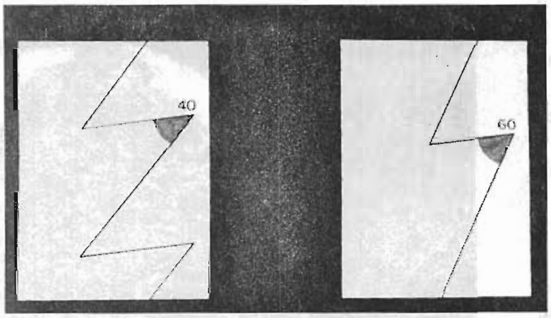

Figure 6. Schematic illustration of the cutting blade angle. A 40 degree angle is more efficient in filing than a 60 degree angle.

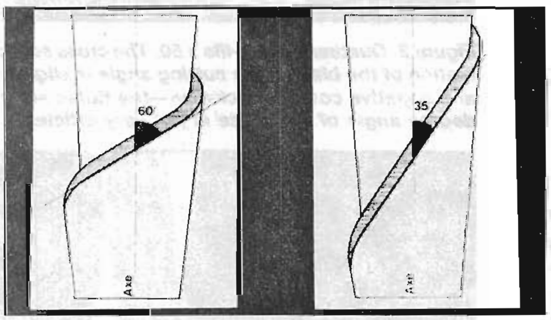

Figure 7. The influence of helical angle on instrument cutting efficiency. With a 60 degree angle, a file is active in filing, while a 35 degree angle produces activity in reaming.

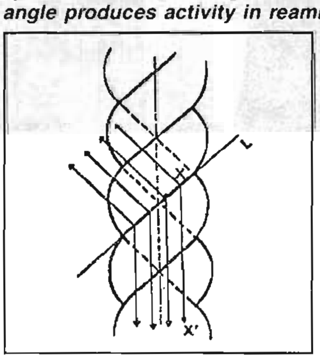

Figure 8. When a blade (L) meets dentin, the forward motion (vector XX) produces resistance. The direction of this force is perpendicular to the blade which produces friction.

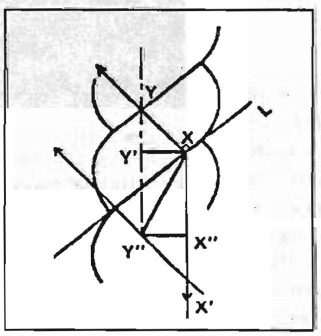

Figure 9. The intensity of the resistance is low (vector XY). The forces are XX' and XY. The file will move in an helicoid motion with: a linear displacement (XX'') and a rotation (XY').

Method of Use

The K-type file is used to determine canal patency and curvature. Ideally the file is inserted into the canal with a longitudinal pressure and clockwise rotation. Canal negotiation is influenced by root anatomy, curvature and calcification.

In large and straight canals, the file will penetrate easily with limited rotation. In narrow canals, the file should be advanced by applying a combined longitudinal pressure and clockwise rotational movement followed by a limited counterclockwise motion. This action is continued until the file reaches the appropriate working length.

The following guidelines are suggested to properly negotiate a canal:

1. Avoid applying excessive longitudinal pressure because it will bend the file.
2. Avoid excessive rotation because the engaged part of the instrument will undergo torsion with subsequent unwinding of the flutes[16,17].
3. Avoid the traditional alternate quarter turn rotation of the file.
4. Tactile sense should determine the amount of apical pressure and rotation degree of the file[18].

The following guidelines are suggested when the K-file is used in canal preparation:

1. Consider the hardness of the dentin and rigidity of the file and its torsional and bending resistance properties.
2. The file must be held firmly to avoid any self-rotation which can result in ledging or creation of a new canal.
3. The amplitude of the filing motions should be dependent on the hardness of the dentin, degree of friction between the file and canal walls and the bending resistance of the file[19].
4. The file should not be used in a pushing stroke, as it will transport debris and dentinal chips apically.
5. The file should be placed apically with minimal friction.
6. Upon withdrawal, the file should be pressed strongly against the wall to be filed.

The Hedstrom File

The Hedstrom file is an efficient instrument which is manufactured in a variety of designs (Fig. 5). The correlation among its proper clinical uses, physical properties and characteristics is seldom discussed or presented by the manufacturer. For proper and safe use of the Hedstrom file, the clinician should understand its intricate design and physical properties, and how and when to use it in a canal preparation[19,20].

The Hedstrom file has two major functions:

1. A negotiation function to establish the canal patency.
2. A filing function to enlarge, shape, and clean the root canal.

This file is manufactured by grinding a round wire, creating a continuous helicoid grove along the wire. The pitch is tighter than on a K-file. The helical angle is around 75 degrees, which makes the instrument inactive in rotation upon pushing, and active upon pulling motion.

The design can be easily modified. For example, the flutes can be deeper, which will increase the flexibility of the instrument (however, the file will be less resistant to breakage). The cutting edge of the blades can be sharper, increasing the cutting efficiency (Fig. 6). The helical angle can be smaller; the flutes will thus have more inclination and the instrument will be able to cut in rotation (Fig. 7). The cutting angle can be positive, increasing the cutting efficiency of the file.

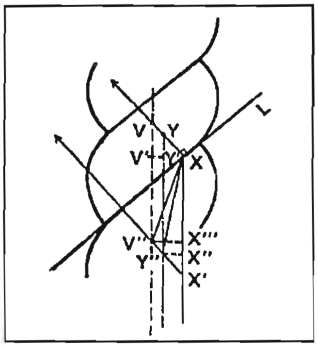

Figure 10. The intensity of resistance is higher (vector XV). The resultant between the two forces is represented by vector XV: more rotation (vector XV') and less linear displacement (vector XX''')

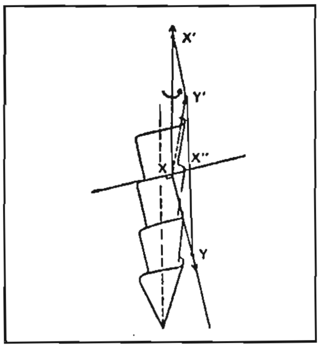

Figure 11. The pulling motion (vector XX') gives a resistance XY on the blade, the resultant of the two forces is represented by vector XY', which brings the file in a helicoid motion in response to the resistance. The release system allows the file to direct its blades on the part of the canal in which resistance is found.

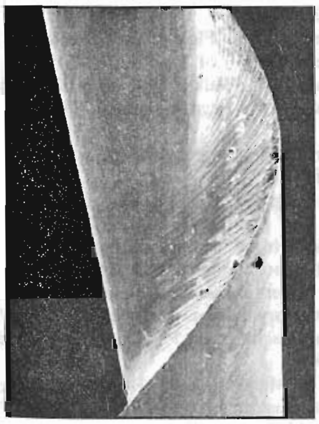

Figure 12. The Anticurvature File (ACx300). File flutes with a positive cutting angle and very sharp blades.

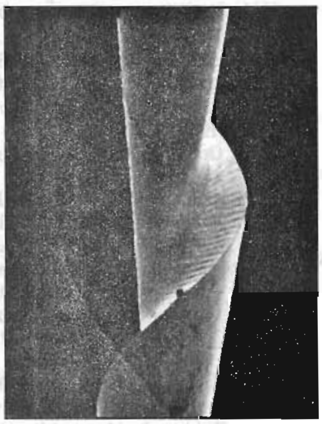

Figure 13. Anticurvature File (x 75). The AC-File showing deep flutes with 40 degree helical angle and positive cutting angle.

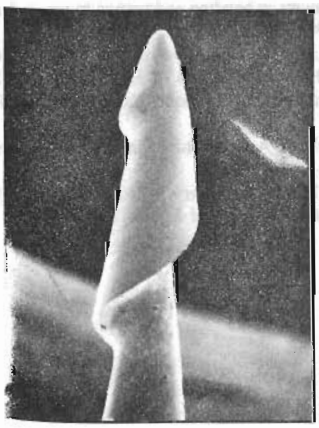

Figure 14. The Anticurvature File tip (x 75). The tip is a guide, (the first flute has a negative cutting angle and the tip is rounded). A long, rounded and inactive tip with a negative cutting angle makes the first flute less cutting.

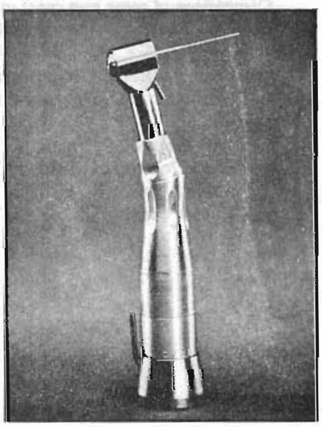

Figure 15. The Canal Finder System (CFS) with a canal-regulated automated endodontic handpiece with the Anticurvature File.

Automation of Endodontic Instruments
The Canal Finder System and the Anticurvature Files

In analyzing the different movements of the endodontic file during canal negotiation, enlargement and preparation procedures, one will find a complicated composite of movements which can be thought of as a negotiation movement (to establish the canal patency) and a filing movement (to enlarge, shape and clean the canal). To duplicate or reproduce these movements mechanically, one must consider the design and physical properties of the endodontic instrument and the canal curvature patency, size, calcification or blockage. To accomplish this, two methods are suggested.

1. Vary the degree of the longitudinal forward motion as governed by the amount of resistance encountered by the automated file flutes.
2. Allow the file to rotate freely along its long axis.

The "Canal Finder" Endodontic Handpiece

To reproduce the basic manual movements, a longitudinal movement should be mechanically produced in order to duplicate the filing motions and bring the filing debris coronally. Furthermore, the intensity of the longitudinal movement should be varied according to the amount of resistance encountered within the canal. To reach this goal, a forward impulse is given to the file with amplitude dependent on the level of resistance encountered by the file flutes within the canal. The file will be either free to move forward (if there is no resistance within the canal), or will be restricted in movement (if there is minimal resistance), or will stop completely (if there is high resistance).

The minimal amplitude should be related to the pitch of the instrument, so that the cutting effect on the dentin will be uniform all along the canal walls. The pitch of the instrument should provide 2-2.5 flutes per millimeter. The amplitude of longitudinal movement of the file should between a maximum of 1.0mm (if the flutes encounter no resistance) and a minimum of 0.3mm (with resistance or blockage).

Finally, in order for a file to move forward, it needs to be free to rotate along its long axis. This is accomplished by a release system built in the handpiece mechanism to free the file, enabling it to choose its rotational path depending on the friction between the flutes and the canal wall. To simplify the above, the forces will be projected on one plane in space. If we consider a force represented by a vector xx applied longitudinally at the point x of a blade, the file will move in a forward direction according to the intensity of xx, and without deviation during the motion. The result will be different when the blade meets dentin. At this moment, a force of resistance will occur on the forward motion. The direction of this force is perpendicular to the blade which produces the friction (Fig. 8), and its intensity depends on the hardness of the dentin. If the resistance is low (represented by a vector xy), the forces xx' and xy will yield a resultant force xy", and will move the file in a helicoid motion with (Fig. 9):

—a linear displacement xx", which is shorter than the displacement xx'.

—a rotation xy'.

If the intensity of resistance is higher (represented by the vector xv), it yields a resultant between the two forces (represented by the vector xv"), in which the file is moving in a helicoid motion with (Figs. 10, 11):

—more rotation (vector xv)

—less linear displacement (vector xx)

If the two diagrams are compared, the following conclusions can be made:

—When the friction of dentin on the file flutes increases, the rotational movements increase and the longitudinal movements decrease. When the friction decreases so does the rotation, but the longitudinal movements will increase.

—All automated file movements are dependent upon and correlated to the amount of friction between the file and the canal wall dentin.

—If the file is moving in the direction of the resultant of the two forces, there will not be any stress on the file.

—If the long axis of the file is not fully free, transverse forces will stress the file leading to its fracture[22].

The Anticurvature File

The advantages of the new endodontic automated handpiece is largely dependent on the efficient and safe characteristics of the new automated Anticurvature File (AC-File)[23]. The Anticurvature File (Fig. 12) is basically a Hedstrom file which has been modified to be used with automated endodontic handpieces and its most significant advantage is its ability to file a curved canal efficiently, safely and with no serious complications such as ledging or breakage. The AC-File has increased cutting efficiency because of its 40 degree, sharp blade (Fig. 13); and the flute depth is more pronounced to enable the instrument to bring the filing debris coronally.

The AC-File design allows the instrument to negotiate, operate and maintain the normal canal curvature. Once pre-curvated or inserted into a curved canal, the AC-File flutes will open on the external side of the curve and the cutting angle becomes more aggressive in filing. Furthermore, the file tip will travel away from the external wall into the canal lumen, preventing any ledge formation on the external wall. Simultaneously, the flutes on the internal wall of the curved canal will tighten and the cutting angle will become more positive, and thus less cutting. The other important safety feature of the Anticurvature File is the shape and design of the file tip, which is a longer and more rounded than traditional files. Futhermore, the first flute has a negative cutting angle-making it less aggressive (Fig. 14).

The variation of automated file amplitude between 1.0mm and 0.3mm is based upon the canal anatomy, and the AC-File will file most efficiently when lateral pressure is applied. Thus selective and directional filing can be accomplished against the thick and safe canal walls, avoiding the thin, easy-to-perforate walls, a situation often encountered with overzealous circumferential filing.

Conclusions

The Canal Finder endodontic handpiece (Fig. 15) and the Anticurvature File can help the clinician in the following situations:

1. Anticurvature filing of thin, narrow and curved roots.
2. Safe and selective removal of the cervical dentinal zone constructions or calcifications which usually interfere with proper root canal preparation.
3. Safe and selective enlargement into the external thick walls of the canal, thus leading the file into the canal curvature[24].
4. By virtue of its thorough water flow, the prepared canal is continuously flushed and kept moist and free from dentinal chips and debris.
5. By virtue of the non-cutting and inactive tip of the AC-File, canal wall ledging and file breakage is practically impossible when used properly. The file tip design and canal-regulated automation of the handpiece together guide and maintain the file tip within canal, thus maintaining canal patency while enlarging the canal.
6. Operative time and operator/patient stress are reduced.

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