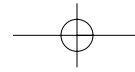
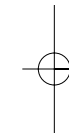
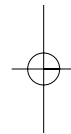


Mastering Endodontic Instrumentation



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John T. McSpadden, D.D.S.

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Dedication/Acknowledgements

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Someone once asked, "Which is worse, ignorance or apathy?" The answer was, "I don't know and I don't care." This book is not for them. This book is about developing expertise and employing knowledge for those that aspire to become the best.

Introduction:

The two primary goals for root canal instrumentation are:

1. To provide a biological environment that is conducive to healing
2. To provide a canal shape that is conformable to sealing.

At this stage of endodontic development, common to all instrumentation techniques is the use of endodontic files. Although not universally used, rotary instrumentation is gaining universal interest. The purpose of this book is to provide information gained from extensive research to facilitate the most efficient use of rotary instruments, without the threat of failure, while conforming to the clinician's treatment ideals.

I am convinced the investment in time required for understanding the physics of rotary instrumentation technology can save hundreds of hours, hundreds of mistakes and hundreds of thousands of dollars—benefits

rarely attainable. The greatest benefit, however, of utilizing design concepts is enhancing the quality of treatment while enjoying the practice of excellence.

One should not, however, succumb to a predisposition that concepts resulting in a reduction of time are necessarily a compromise. Just because threading a needle may require multiple attempts and require more time than being successful on the first attempt does not mean that the extra time renders it more worthy than immediate success; regardless of the time invested, the result is a threaded needle.

Ask the question: If every single action you made during instrumentation resulted in the greatest benefit possible in the most efficient manner, how would it change the quality and profile of your practice? Most would agree that the ability to replace repetitious, unnecessary and counterproductive actions, with only the most effective actions, would be true excellence. However, it certainly

Although a dramatic reduction in time required to accomplish instrumentation may be the consequence of this understanding, it should be emphasized that this is not the result of quickness or ergonomics. Rather, it is due to increased control and the ability to anticipate the optimum approach as well as eliminate the less than optimum, the unnecessary and sometimes counterproductive components of a technique.

could not be done with the information available. Most would also agree that there is no one source dedicated to this kind of information. Currently, accessible information is practically limited to cookbook type instructions with virtually no rationale of rotary instruments and techniques. Instructions for new rotary files are generally comprised of a few concise technique recommendations, making the assumption that these will be adequate to prevent compromising endodontic treatment while attempting to convince the practitioner to employ yet another unique design of instruments. Consequently,

and an easy technique that could be used as a routine. Many were attracted by claims that techniques, having the fewest instruments, facilitated canal preparation. Most found a functional comfort level quickly, with their initial choices, occasionally added their own modifications, and as experience was acquired, ventured to use other instruments and techniques. Most eventually gravitated toward a level of satisfaction.

Lacking both the benefit of a teacher and any prescribed step-by-step technique, my initial design and use of this new modality for canal preparation, required the continu-

Unaware of the benefits of the extraordinary, the ordinary benefits limited the development of the practice and the practitioner continued to operate with the needless threat of failure and/or the unnecessary consumption of time. This book is for those who want to progress beyond that point.

endodontists often needlessly spend most of their chair time preparing root canals with the accompaniment of uncertainty, mediocrity or an arduous attempt at achieving the ideal. Understanding essential information provides the means for expertise. The problem is most will never study information, as it becomes available, to know the difference. Some, however, who are willing to invest the time required for understanding the dynamics of instrumentation will certainly save thousands of hours of chair time, significantly increase their income, and have the satisfaction that they are providing excellence for their patients.

Those who have incorporated rotary instrumentation into their practice understandably looked for a simple system of files

ous attempt to thoroughly understand the physics of rotary instrumentation. The "doing" required careful visualization of all the consequences of actions before they were performed. Ironically this exercise proved uniquely advantageous over the regimented procedures most have had to follow and soon I developed the understanding for instrumenting complicated anatomies with relative ease. The expeditious accomplishment of instrumentation caused inexplicable guilt, but challenged my ingrained notion so common to dentists, that speed was a compromise. That notion was replaced with the realization that expertise and efficiency are synonymous and both are relative to the level of understanding.

Unfortunately, I attempted to convey instructions by teaching conventional step-by-step techniques rather than the understanding I had acquired and that clinicians could have easily learned. I thought, and was told, that dentists only wanted to know how rather than why. The reality, however, is as the introduction of new products increases and voices of advocates confuse those choices, coupled with the fact that products become obsolete before they can be thoroughly evaluated, the need for understanding the principles of all products, especially rotary instrumentation, becomes apparent. As scientific evaluations encompass only a small portion of the total functionality of instrumentation, and as more instruments are described only in terms of their unique features, the need for consolidation of information becomes indispensable for the endodontist who strives to exercise judgments and skills beyond those afforded by the set of instructions as a beginner or the satisfaction level of the consummate user. A basic understanding of the scientific principles of instrumentation needs to be the foundation of expertise rather than instructions or recommendations that seem to lead to multiple and temporary conclusions.

With understanding, there is no need to rely on time consuming and costly trial and error experience. It is easy to forget that it requires ten years to have ten years of experience. Neither is there a need to rely on the ability to decipher conflicting explanations of noted authorities. With understanding, improvements in the quality of care occur more quickly and consistently. The need is to make understanding accessible. The longer we continue practicing without appreciating

the rudimentary principles and characteristics of instrumentation, the greater the gap between newer technologies and understanding becomes and the less we use the full potential technology has to offer. The purpose of this presentation is to provide and consolidate the principles necessary for understanding the design of instruments and for developing the rationale necessary to formulate and use present and future instruments to their greatest benefit in relation to the canal anatomy.

As one examines the principles of rotary instrumentation, the cookbook type techniques that were once beneficial for initiating the use of rotary files in one's practice become overly simplistic. The ability to differentiate between the attributes and limitations of instruments and techniques become apparent. Rather than espousing a popular technique, understanding consigns only the appropriate technique that changes for every anatomy and case history. It is important not to confuse the characteristics of instruments with the techniques with which they have become associated. The advantages and disadvantages of techniques do not necessarily pertain to the instruments used. It is also important to understand that desired canal shapes can be prepared with virtually any series of instruments, but it is the risks and efficiency that varies from one instrument to another.

With understanding, approaches to different cases become too diverse to fall within any particular category other than canal anatomy. Even though the choices of instruments and techniques can become more numerous and complex for cleaning and shaping canals, the solutions become less compli-

cated and expedient. As one broadens the scope of understanding, skill is enhanced in a scientific manner and success becomes more predictable. The art of endodontics becomes the science of endodontics and expertise becomes the nature of the operator.

Since I receive royalties from several of the instruments discussed in this book, I am extremely sensitive to the fact that some might view any evaluations under my direction to be skewed by commercial interests. I can only say that the motivation that prompted me to seek ways to improve the quality of treatment, ways that ultimately developed virtually all innovations in our profession, is the same motivation that has led me to advance concepts for understanding. Even though every effort has been made to make any findings of testing be the result of following solid scientific protocol that can be easily duplicated, and all testing has been conducted by only using mechanical devices that operate independent of operator variables or subjectivity, this book does not pretend to be an authoritative treatise to validate or invalidate the claims for instruments or techniques. Rather, the results of testing are presented as tools to promote understanding, investigation and development. As understanding is developed, any commercial influence of these or any other testing results should become apparent regardless of the source.

While reading this book, you may notice that numerous popular recommendations for using rotary instrumentation will be challenged and exposed as intuitive concepts. One primary purpose of this book is to instill a sense of curiosity for the reasons of any concept. In fact, this book is a result

of other people's curiosity and is organized by asking questions that have at one time or another have been asked of me. The answers are transcripts of those communications or excerpts from lectures and are in a conversational mode for that reason. Addressing these questions is an exercise in determining which procedures enable the dentist to operate with scientific predictability for success. You may be interested to know that some of the following popular concepts are more intuitive, but are counter to scientific evidence:

1. Specific speeds of rotation should not be exceeded.
2. Complicated curvatures require slower speeds.
3. Use one continuous motion of file insertion until resistance is met.
4. Routinely follow the use of an instrument with another instrument having the same taper with a smaller tip size.
5. Routinely establish straight-line access.
6. Routinely carry a .04 or even a .06 taper file to working length.
7. A crown-down approach is always preferable to a step-back approach.
8. One millimeter of file advancement into the canal only results in one millimeter of additional engagement.

These and other concepts are often followed without question. The best use of this book is to use the questions as frameworks for examination. Although research on endodontic instruments cannot result in absolutes, understanding the results of research will pro-

vide significant predictability to be used as a guide for formulating techniques. You will note that it is only after a thorough examination of existing instrumentation concepts, in the context of one of the most extensive research projects ever undertaken, that any parameters are recommended for using instruments currently available and for designing prototype instruments for the future. Following those or any parameters should be consistent with your understanding. Any inconsistency may mean either a lack of understanding, or

hopefully, and more importantly, may mean that you have contributed in formulating an advanced concept for a new instrument or technique.

The hope for those reading this book is that they will use the information presented to visualize the actions of existing and future endodontic files and be able to coordinate their characteristics with canal anatomies. The aspiration is to help in attaining expertise. The consequence would be advancing the field of endodontics.



In 1977, Dr. McSpadden was exercising innovation. He was using mechanical instrumentation, the Dynatrac system, and mechanical obturation, the McSpadden Compactor System, both of which he invented. At that early date he was routinely using the microscope for all practice procedures.

Mastering Instrumentation

The next level of development of rotary instruments is continuously being introduced. Design concepts for various new instruments are important departures from previous designs. To fully comprehend the significance of design principles for advanced developments, it is necessary to determine the considerations by which all rotary endodontic files should be used and evaluated, then assess any new development in that context. This presentation offers those considerations and reviews the evolution of rotary instruments (assessing their advantages and limitations). Within this paradigm will be an understanding of design concepts that enables the practitioner to maximize endodontic skills for any technique available today and to most effectively use and evaluate advancements as they become available in the future. Armed with this knowledge, the practitioner gains independence from advocacy claims and the need for trial and error experience. More importantly, a more rational approach will be offered in providing expertise for treating their patients.

Section I: Mastering the Concepts

With the introduction of nickel titanium, mechanical root canal preparation has quickly become a widely accepted modality in endodontics. The enhanced preparation results and reduced preparation time of rotary nickel titanium files have prompted the rapid adoption of rotary instrumentation. Yet, in spite of added advantages and excellent canal cleaning and shaping ability, a lack of information has caused the formulation of techniques that limited the comprehensive benefits of rotary instrumentation. Even though instrumented canals may result in ideal appearances, information for accomplishing ideal instrumentation has not kept pace with the enhanced opportunities for efficiency, expertise, or the reduction of risks.

Particular canal shapes are often illustrated as being characteristic for certain file brands,

however, canal shapes are more dependent on the file dimensions, the sequence the files are used and the depths to which they are carried into the canal. Although a desired canal shape can be achieved with virtually all brands of rotary nickel titanium files, various techniques have been proposed to achieve this shape. Too often the designs of these techniques are determined by marketing where product promotion prevails over science. Consequently, the practitioner often experiences complications while conscientiously following instructions that disregard the complexities of anatomy.

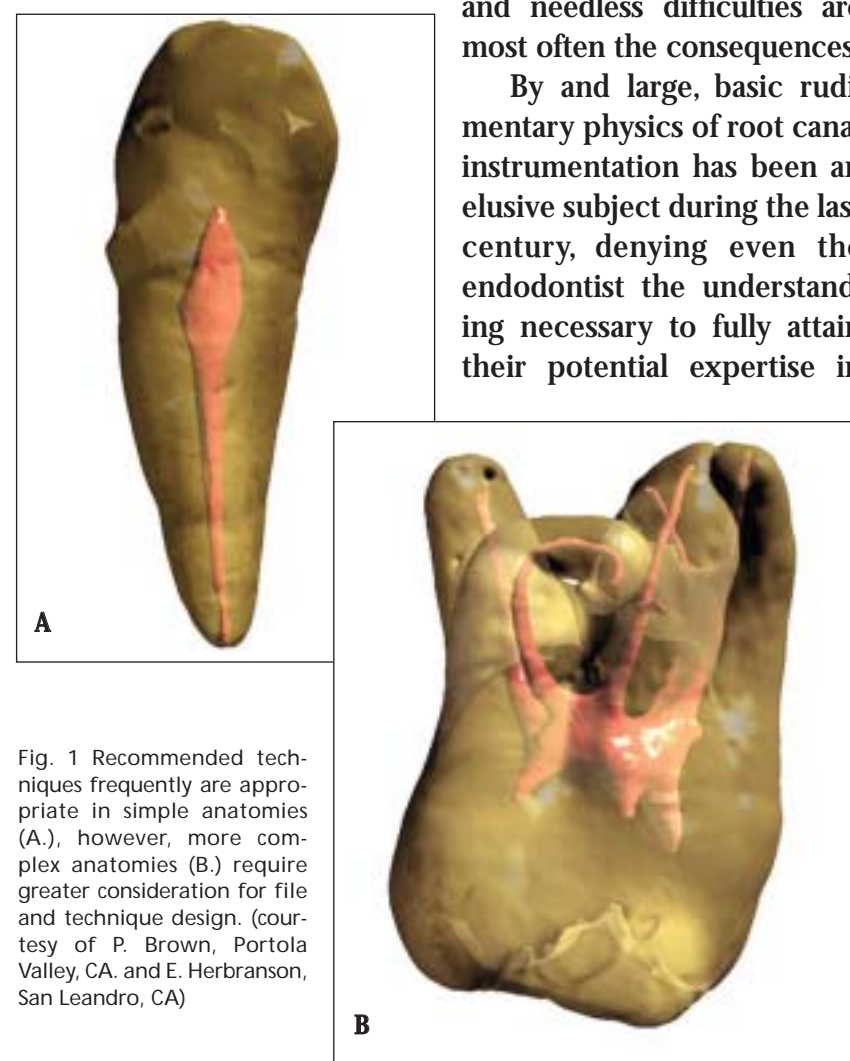
Understanding the ramifications of file and technique design relative to canal anatomy enables the dentist to consistently achieve the most expeditious and excellent treatment with the least risks. This is not a

new concept. Frank Weine described as early as 1975 in the *Journal of Endodontics* (Weine, F.S. The effect of preparation procedures on original canal shape and on foramen shape. *Journal of Endodontics* 1:8 August 1975.), a technique for modifying files in order to prevent transporting curved canals. He advocated using a diamond-surfaced fingernail file to remove the blades on one side of an endodontic file that would reciprocate against the outer canal wall between a curvature and apex to avoid zipping the canal, a design known today as the safe-sided file.

Often, techniques are designed to avoid a failure that has been experienced in one particular procedure, even though the application could be beneficial in other circumstances. For example, we are often instructed by some advocates never to rotate a file more than 350 rpm, yet in many circumstances 1200 rpm can be more than four times as effective with less threat of complications, and slowing the rotations can actually increase the threat. Consequently, without having the information needed to understand how to utilize the advantages while limiting the threat of failure, the practitioner frequently places limits on rotary instrumentation prematurely before expertise

and its most significant benefits are ever realized. The science for integrating anatomical canal complexities with instrumentation efficiency and effectiveness is the most often ignored technique consideration. Wasted time and needless difficulties are most often the consequences.

By and large, basic rudimentary physics of root canal instrumentation has been an elusive subject during the last century, denying even the endodontist the understanding necessary to fully attain their potential expertise in



performing the task that often requires the major portion of their time: root canal preparation. Rotary instrumentation is certainly not a new concept; it was introduced in the late 19th century, as were the rubber dam, rubber dam clamps, and even solid core carriers for gutta percha which were intro-

duced at the beginning of the 20th century.

The first manual and mechanical rotary files were formed from straight piano wire that had flats ground on its sides and twisted to result in the configuration of files still used today. Files were first mass-produced by Kerr Manufacturing Co. in the very early 1900's, hence the name K-type file or K-type reamer. Although the term file is commonly used generically to describe all ground or twisted endodontic instruments, more specifically the term file is used to describe an instrument used primarily during insertion and withdrawal motions for enlarging the root canal, whereas a reamer is used primarily during rotation. K-type files and reamers were both originally manufactured by the same process. Three or four equilateral flat surfaces were ground at increasing depths on the sides of wire to form a

tapered pyramidal shape that was stabilized on one end and rotated on its distal end to form the spiraled instrument. The number of sides and spirals determined if the instrument was best suited for filing or reaming. Generally, a three-sided configuration, with fewer spirals, was used for reaming or rotation; a three- or four-sided configuration with more spirals was used for filing or insertion and withdrawing. Even though the twisting method of file manufacturing has generally been considered an outdated means of fabricating files and has been replaced by computerized grinding processes for NiTi rotary files, new advances for manipulating shape memory alloys may offer economic and physical property advantages for reconsidering the twisting method of manufacturing for the future.



Fig. 2 A. A tapered pyramidal wire is used as a blank for forming a file.
B. Each end of the blank is stabilized and one end is rotated to twist a spiraled shape on the file's working surface.
C. Multiple rotations result in the familiar spiraled shape of the endodontic file.

A NiTi pyramidal wire can be twisted using a proprietary process.
Prototype by Sybron Dental Specialties



Fig. 3

Dating from the late 19th century, the earliest endodontic instruments used for extirpating the pulp and enlarging the canal were broaches or rasps. Still used today, these instruments are manufactured by hacking a round tapered wire with a blade device to form sharp barbs that project out from its side to form cutting or snagging surfaces. Although mostly used to engage and remove

soft tissue from the canal as manual instruments, these historic broach type instruments have the potential for becoming effective rotary instruments. The evolutionary development for endodontic instruments seems to have some cyclic peculiarities and is far from over. Even the tapered pyramidal design originally used as blanks as described above is now being used as rotary NiTi files.



The broach is formed by forcing a blade onto the surface of a tapered wire.

Fig. 4

1. What are the terms I need to know when comparing the physical properties of files?

The success of using instruments while preventing failure depends on how the material, design and technique relate to the forces exerted on the instruments. To fully understand how the file reacts to applied forces, terms have been defined to quantify the actions and reactions to these forces. Common terms related to forces exerted on files have the following definitions:

1. Stress—The deforming force measured across a given area.
2. Stress concentration point—An abrupt change in the geometric shape of a file, such as a notch, will result in a higher stress at that point than along the surface of the file where the shape is more continuous.
3. Strain—The amount of deformation a file undergoes.
4. Elastic limit—A set quantity which represents the maximal strain, which, when applied to a file, allows the file to return to its original dimensions. The residual internal forces after strain are removed and return to zero.
5. Elastic deformation—The reversible deformation that does not exceed the elastic limit.
6. Shape memory—The elastic limit is substantially higher than is typical of conventional metals.
7. Plastic deformation—Permanent bond displacement caused by exceeding the elas-

2. Why Nickel-Titanium?

Manual stainless steel files provide excellent manipulation control and sharp, long-lasting cutting surfaces. However, due to the inherent limited flexibility of stainless steel, preparation of curved canals is often a problem for manual files, and the mechanical use with conventional designs and grades of stainless steel poses the likely threat of file breakage or canal transportation.

The significant advantage of a file made of a nickel titanium alloy is its unique ability to negotiate curvatures during continuous rotation without undergoing the permanent plastic deformation or failure that traditional stainless steel files would incur. The first series of comparative tests demonstrating the potential advantages of endodontic files made of nickel titanium over stainless steel were conducted by Drs. Walia, Gerstein and Bryant. The results of the tests were published in an article entitled "An Initial Investigation of the Bending and the Torsional Properties of Nitinol Root Canal Files," (*Journal of Endodontics*, Volume 14, No.7, July 1988, at pages 346-351). In 1991, the first commercial nickel titanium manual and rotary files were introduced by NT Co. In 1994, NT Co. also introduced the first series of nickel titanium rotary files having multiple non-conventional tapers: the McXIM Series, which had six graduating tapers ranging from the conventional 0.02 taper to a 0.05 taper file in order to reduce stress by limiting the file's engagement during the serial enlargement of rotary instrumentation. Based upon the initial success and recognized advantages, the use of nickel titanium rotary files has proliferated and become

widely accepted by the profession.

Nickel titanium is termed an exotic metal because it does not conform to the normal rules of metallurgy. As a super-elastic metal, the application of stress does not result in the usual proportional strain other metals undergo. When stress is initially applied to nickel titanium the result is proportional strain. However, the strain remains essentially the same as the application of additional stress reaches a specific level forming what is termed *loading plateau*, during which the strain remains essentially constant as the stress is applied. Eventually, of course, excessive stress causes the file to fail.

This unusual property of changing from an anticipated response to an unanticipated response is the result of undergoing a *molecular crystalline phase transformation*. NiTi can have three different forms: martensite, stress-induced martensite (superelastic), and austenite. When the material is in its martensite form, it is relatively soft and can be easily deformed. Superelastic NiTi is highly elastic, while austenite NiTi is non-elastic and hard. External stresses transform the austenitic crystalline form of nickel titanium into the stress-induced martensitic crystalline structure that can accommodate greater stress without increasing the strain. Due to its unique crystalline structure, a nickel titanium file has shape memory or the ability to return to its original shape after being deformed. Simply restated, nickel titanium alloys were the first, and are currently the only readily available economically feasible materials that have the flexibility and toughness necessary for routine use as effective rotary endodontic files in curved canals. Other alternative materials are being investigated for the same purpose.

Comparison of Properties of NiTi and Conventional Stainless Steel

Property	NiTi	Stainless Steel
Recovered Elongation	8%	0.8%
Biocompatibility	Excellent	Fair
Effective Modulus	approx. 48 GigaPascal	193 GigaPascal
Torqueability	Excellent	Poor
Density	6.45 g/cm ³	8.03 g/cm ³
Magnetic	No	Yes
Ultimate Tensile Strength	approx. 1,240 MegaPascal	approx. 760 MegaPascal
Coefficient Thermal Expansion	6.6 to 11.0 x 10 ⁻⁶ cm/cm/deg.C	17 .3 x 10 ⁻⁶ cm/cm/deg.C
Resistivity	80 to 100 micro-ohm*cm	72 micro-ohm*cm

Table 5 (Breme HJ & Biehl V (1998) Metallic biomaterials. In: Black J & Hastings G (eds) Handbook of biomaterial properties, Chapman & Hall, London, p 135-213.)

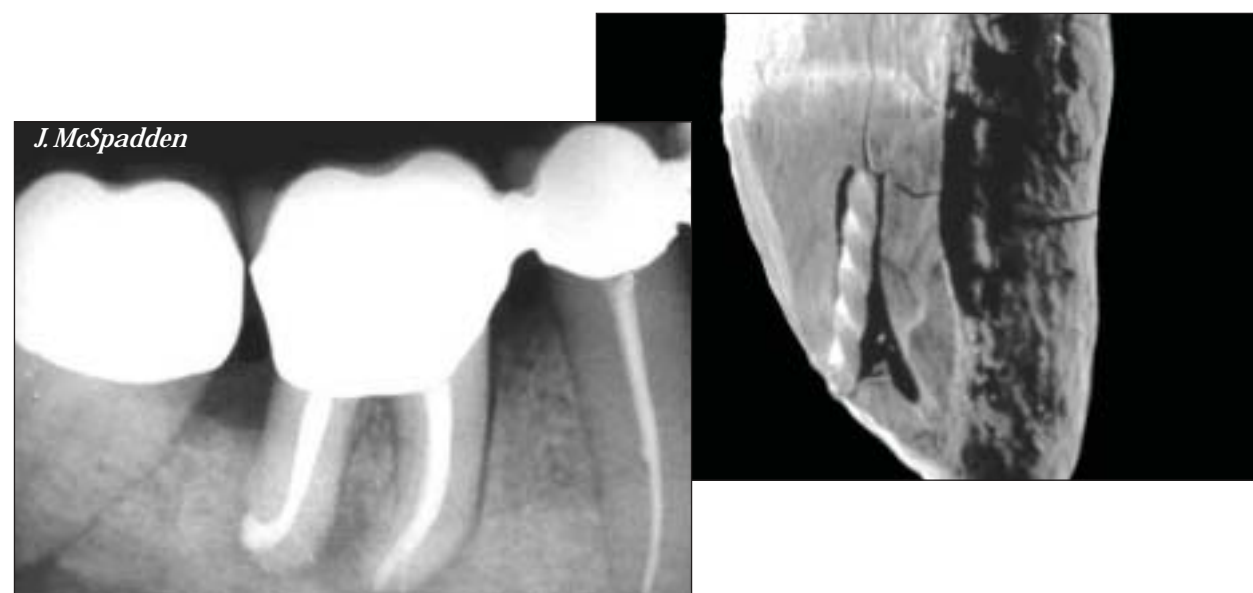


Fig. 6 Although stainless steel files could negotiate abrupt apical curvatures (left image), canal transportation could easily occur due to the file's lack of flexibility. Note the transportation that occurred in the apical curvature that occurred during instrumentation with stainless steel files. "Zipping" the apical foramen can be a consequence of file inflexibility.

3. Are nickel titanium files always advantageous over files of stainless steel during rotary instrumentation?

The function and physical property requirements of endodontic files are extremely important and need to be matched to manufacturing methods. Metallurgy of the specific material should be understood to achieve optimum properties for the application.

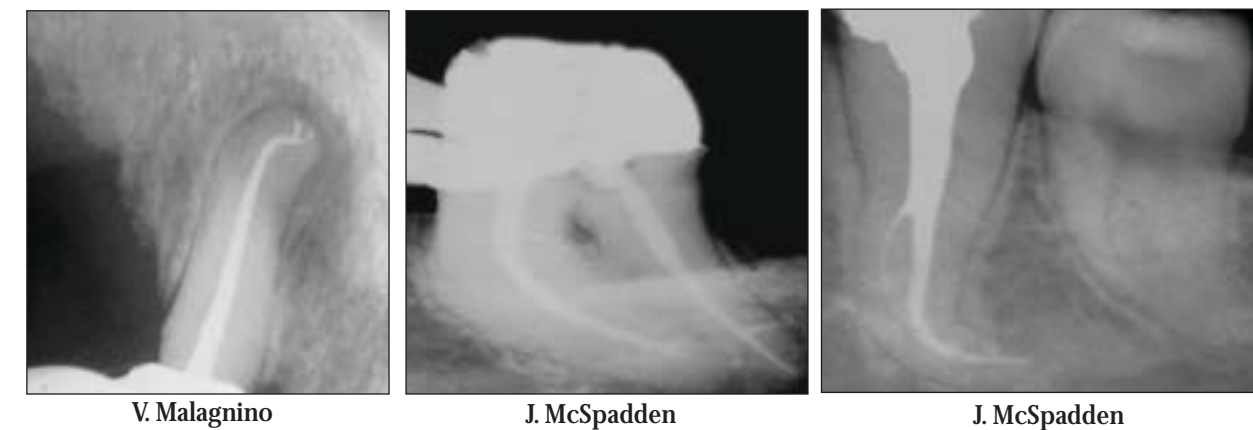


Fig. 7 Early cases for using nickel titanium rotary files demonstrated the ability of preparing canal curvatures while maintaining the central axis of the canals.

Stainless steels are a good case in point. Over 100 alloys, of which many have only recently been introduced, are included under the banner of stainless steel. Endodontics, unfortunately, has been lacking in its investigation of alloy selection and when we compare NiTi files with stainless steel files, we do so within the narrow framework of older stainless steel alloys that have been used for files. Comparisons between the two metals may change significantly in the future.

If all canals were straight, conventional stainless steel files would have results as good as, or better, than nickel titanium. Work hardened stainless steel files have more torsion strength and are able to maintain sharp edges longer. Of course, few canals are entirely straight and rarely can degree, radius, and direction of curvature be determined prior to treatment. The minor curvatures of most canal anatomies can cause excessive stresses on conventional stainless steel files and result in unwanted canal transportation or file failure. Nevertheless, the introduction of nickel titanium files seemed to ignore the fact that nickel titanium

offers no advantage for files having large diameters and tapers that lack any appreciable flexibility. Accordingly, these instruments have become an unnecessary expense, only because these larger files were a part of a series of instruments. The advantage of stainless steel rotary files of larger diameters and tapers to compliment the use of nickel titanium files is now recognized by many that have become familiar with the attributes and limitations of nickel titanium. Stainless steel rotary files are being introduced for use in lieu of nickel titanium files in larger sizes and tapers that lack the flexibility. More advanced design developments that reduce file stresses and modifications in the molecular structure of stainless steel are continuously causing reconsideration of stainless steel as a viable NiTi alternative.

4. Are there other alloys that offer advantages as rotary files?

Other alloys have been developed that are suitable for rotary files and might have properties that are advantageous over those of nickel titanium. One problem is economics.

In order to be feasible, any other alloy usually must have applications in addition to rotary files that can help offset the cost of production. Otherwise the costs can be prohibitive. Another problem is ignorance. New materials and methods for altering the characteristics of existing materials are developing at such a rapid pace that our awareness simply does not keep up.

One alloy having considerable potential and economic feasibility is a nickel titanium niobium alloy having a substantially higher *loading plateau*, making it tougher than either stainless steel or nickel titanium. It has sharper, more durable cutting edges, and can

be more resistance to breakage. Somewhat stiffer than the conventional NiTi alloys, but more flexible than stainless steel, it is particularly advantageous for rotary activation of smaller files. The flexibility is sufficient to negotiate acute curvatures with minimum canal transportation, yet stiff enough to withstand the pressure desirable to feed it into small canals.

Other titanium alloys contain molybdenum and zirconium to increase stability, workability, or corrosion resistance. Only time will tell if the economic feasibility of these and other alloys will eventually provide a better endodontic rotary file.

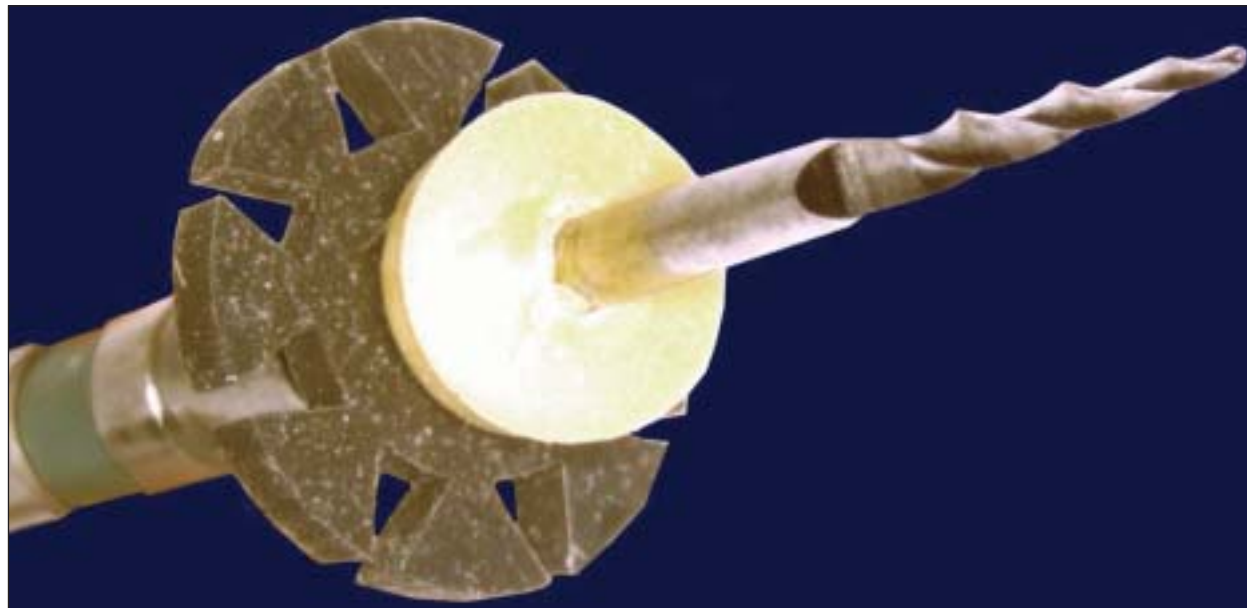


Fig. 8 The FKG stainless steel rotary files are examples of rotary files available in sizes that NiTi files would lack any appreciable flexibility or advantage.

5. Why Rotary Instrumentation?

One benefit of mechanical rotation is the enhanced ability to collect and remove debris from the canal system. Hand instrumentation can push debris laterally into the intricacies of the canal anatomy or even apically through the canal foramen when using techniques that commonly include insertions of files without rotation or rotations of files in a counter-clockwise direction. In contrast, continuous clockwise rotation will convey debris only in a coronal direction from the canal ramifications and apical foramen.

Mechanical rotation provides a more constant 360-degree engagement of the file tip in the canal that forces it to follow the canal and results in better control for maintaining the central axis of the canal, reducing the incidence of ledging or perforating. The flexibility for following the canal allows us to be more conservative in preserving tooth structure while effectively cleaning and shaping the canal. The most obvious benefit for continuous rotation is the reduction in the time required for instrumenting the canal. The fact that a file, constantly rotating from 200 to 2,000 rpm, produces results more rapidly than hand instrumentation that has significantly slower and intermittent rotations, should come as no surprise.

6. Why do we need to know anything about instrument design?

Although radiographs portraying desired canal shapes are often used to illustrate the capabilities of a particular type of file, the desired canal shape can be attained with virtually any set of files provided they are used properly. How efficiently the shape can be

attained is another matter. The capabilities of files made of the same material are entirely dependent on design and can mean success or failure. No one aspect of file design is indicative of the file's overall usefulness. Optimizing one design feature can compromise another benefit. Considerations for design effectiveness include the following: cutting ability, operational fatigue, stress concentration points, operational torque, torque at breakage, flexibility, screwing-in forces, ability to maintain the central axis of the canal, and tip mechanics. Successes of file design and, to a considerable extent, clinical success are determined by how efficiently these considerations address various canal anatomies.

Limitations of the initial nickel titanium file designs were largely due to an attempt to adapt the easily manufactured old hand file designs and technique concepts to these new rotary instruments. These old designs applied to a new modality comprised the first generation of NiTi rotary instrumentation. A second generation of designs, now particularly patterned for rotary instrumentation, is being introduced that can substantially advance treatment results. **In using any file design, understanding the rudimentary physics involved in its use is imperative for the practitioner to take full advantage of its benefits. Recognition of instrument features that improve usefulness or pose possible risks must also be achieved.** This need is especially important in employing a new file design. Regardless of the design and technique, there are certain considerations that provide the understanding for using rotary instrumentation to its fullest advantage. The practitioner must remember that although any new introduction of rotary files

can represent significant improvements, some designs without merit will continue to be introduced for marketing purposes and advocated by clinicians who lack the complete comprehension for the ramifications of use. Any significant treatment advancement will ultimately be predicated on each individual practitioner's understanding of design function. **The ultimate goal for anyone using rotary instrumentation is not only to be able to recognize that pivotal instant just before complications occur, but to recognize the most appropriate approach for achieving solutions. That goal can only be accomplished by thoroughly understanding the function of design.**

7. Is an appropriate technique important?

Canal anatomy, file design and file dimensions dictate the appropriate use of an instrument.

Often techniques for particular files are the result of subjective concepts recommended for the sake of simplicity. The capabilities of the files then become confused with the capabilities of the inappropriately recommended technique with which they have become associated. **How well a file performs, while following a specific technique, should not be the measure of the effectiveness of a file; rather, how well the capabilities of a file can address the requirements of the canal anatomy should be the measure of its usefulness.** Since canal anatomies vary, techniques to effectively clean and enlarge the canal may include modifications and may include different type instruments. Instrumentations involving more than one type instrument or technique are known as hybrid techniques.

8. What are the components of a file?

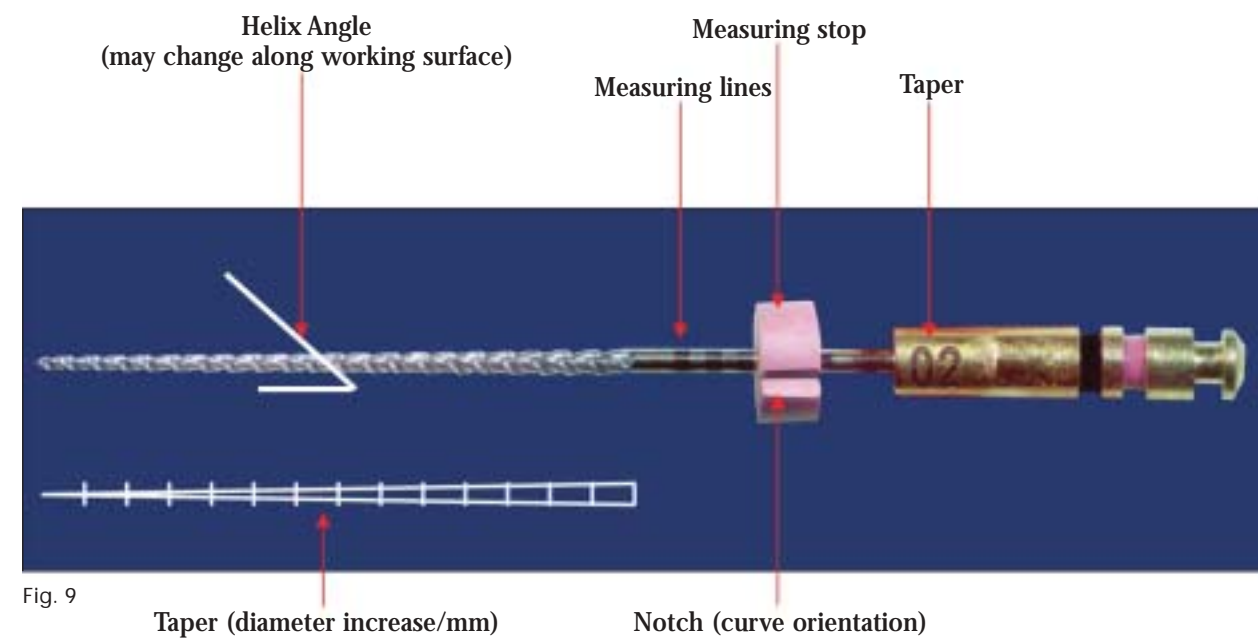
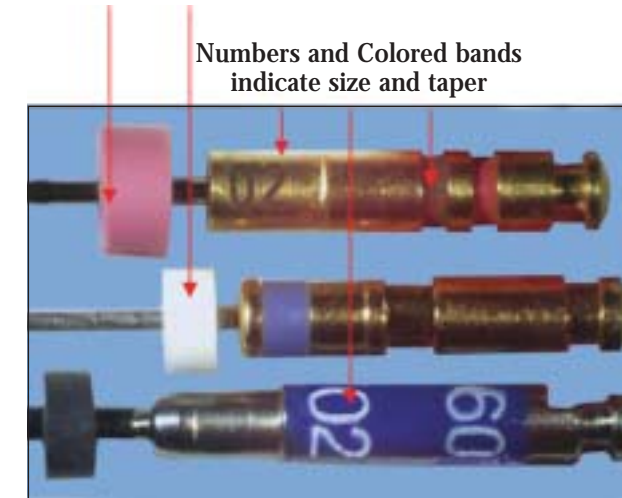


Fig. 9

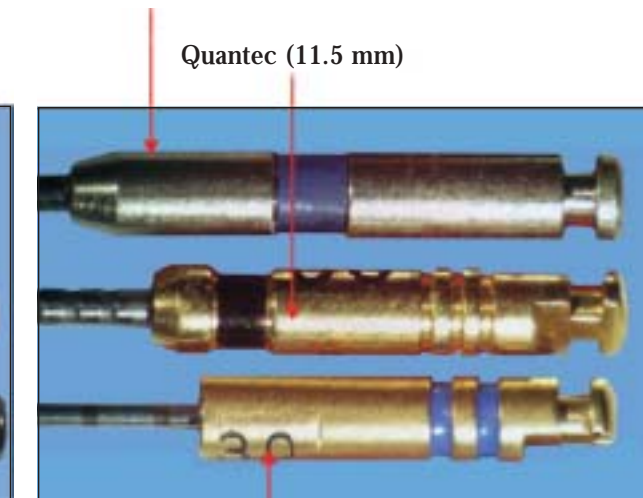
The *taper* is usually expressed as the amount the file diameter increases each millimeter along its working surface from the tip toward the file handle. For example, a size 25 file with a .02 taper would have a .27 mm diameter 1 mm from the tip, a .29 mm diameter 2 mm from the tip, and a .31 mm diameter

3 mm from the tip. Some manufacturers express the taper in terms of percentage in which case the .02 taper becomes a 2% taper. Historically, as an ISO standard, a file was fluted and tapered at 2% for 16 mm, but now files incorporate a wide variation of lengths and tapers of working surface.

Stops may indicate size or taper



Profile GT (13 mm)



K-3 Access handles can provide greater working and prevent undue stress caused file distortion outside the canal.

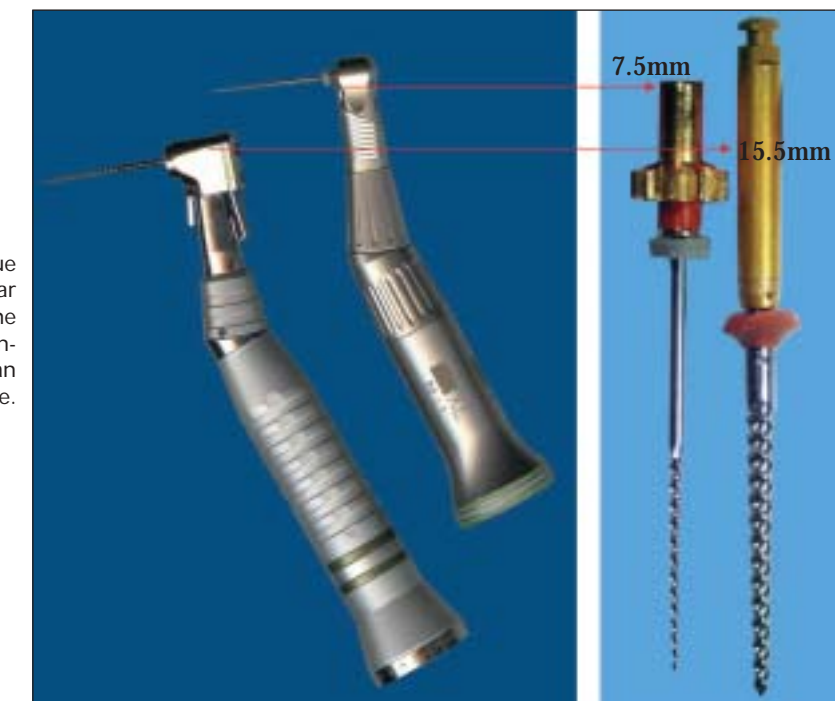
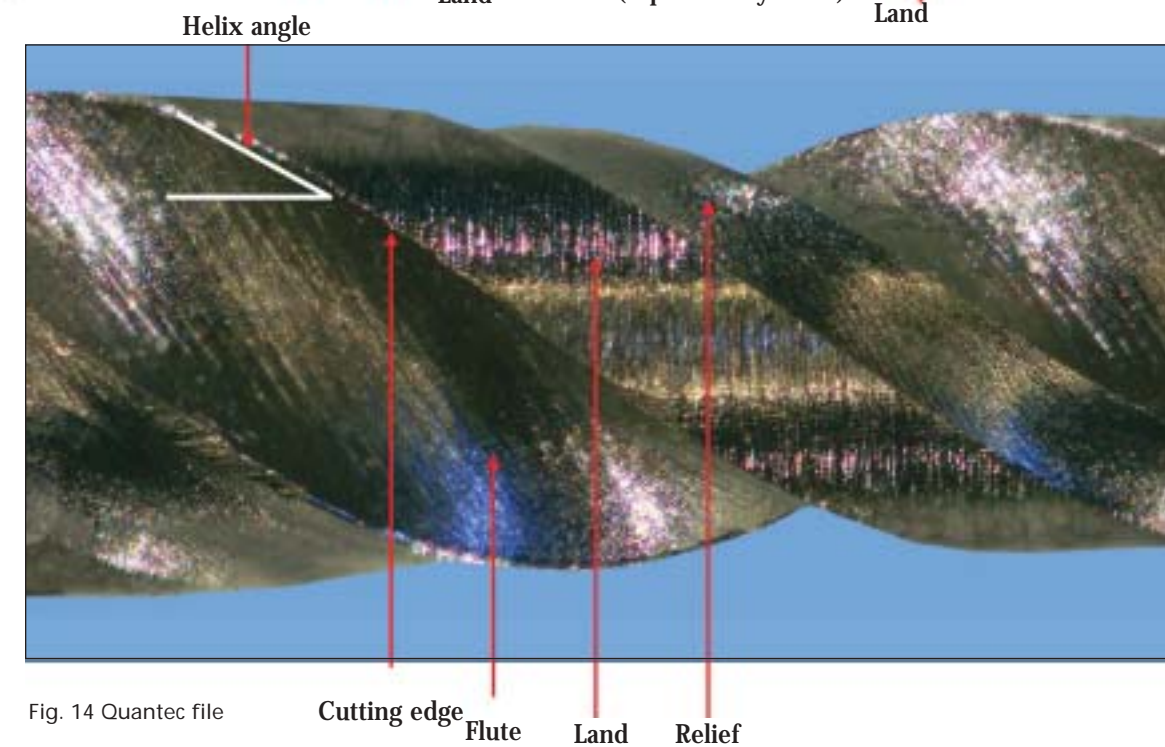
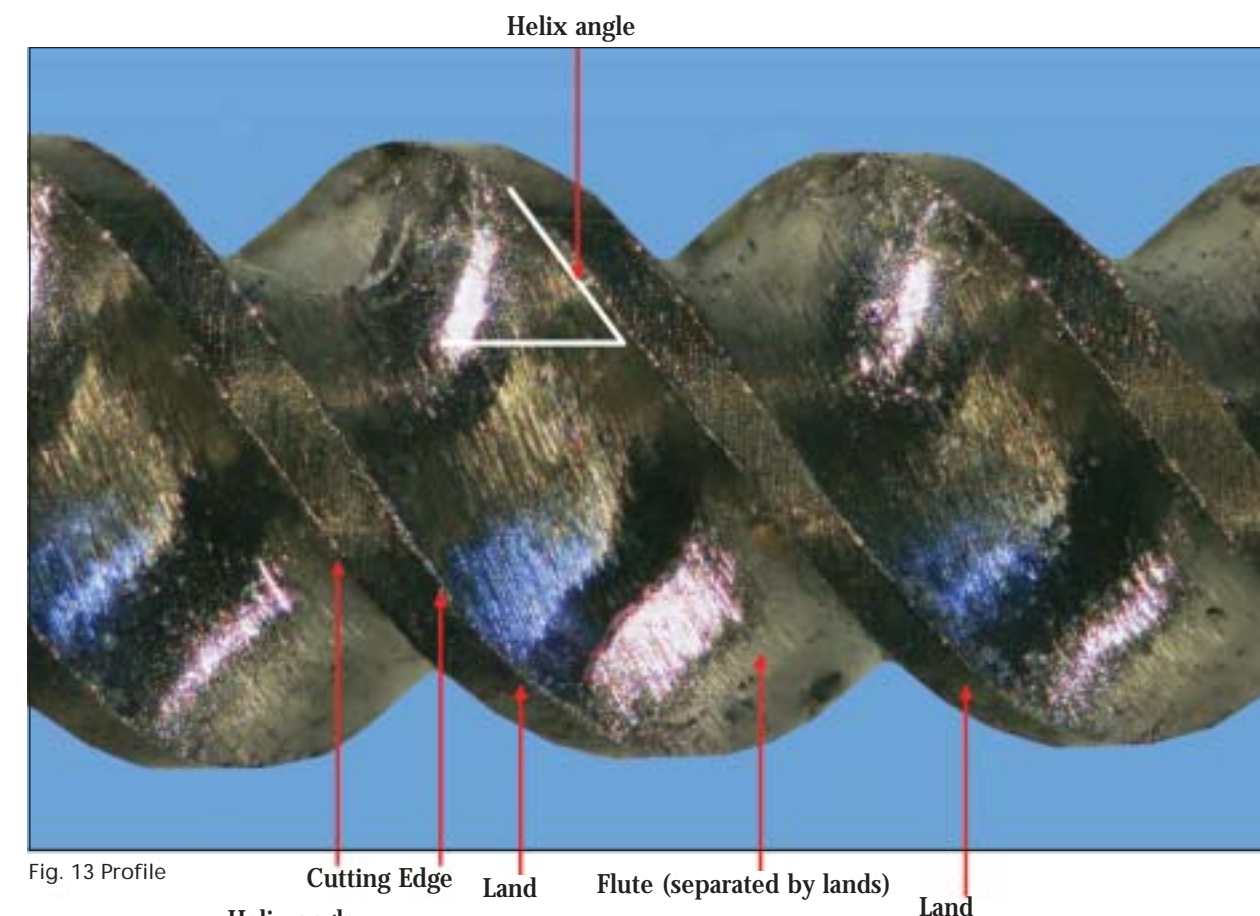
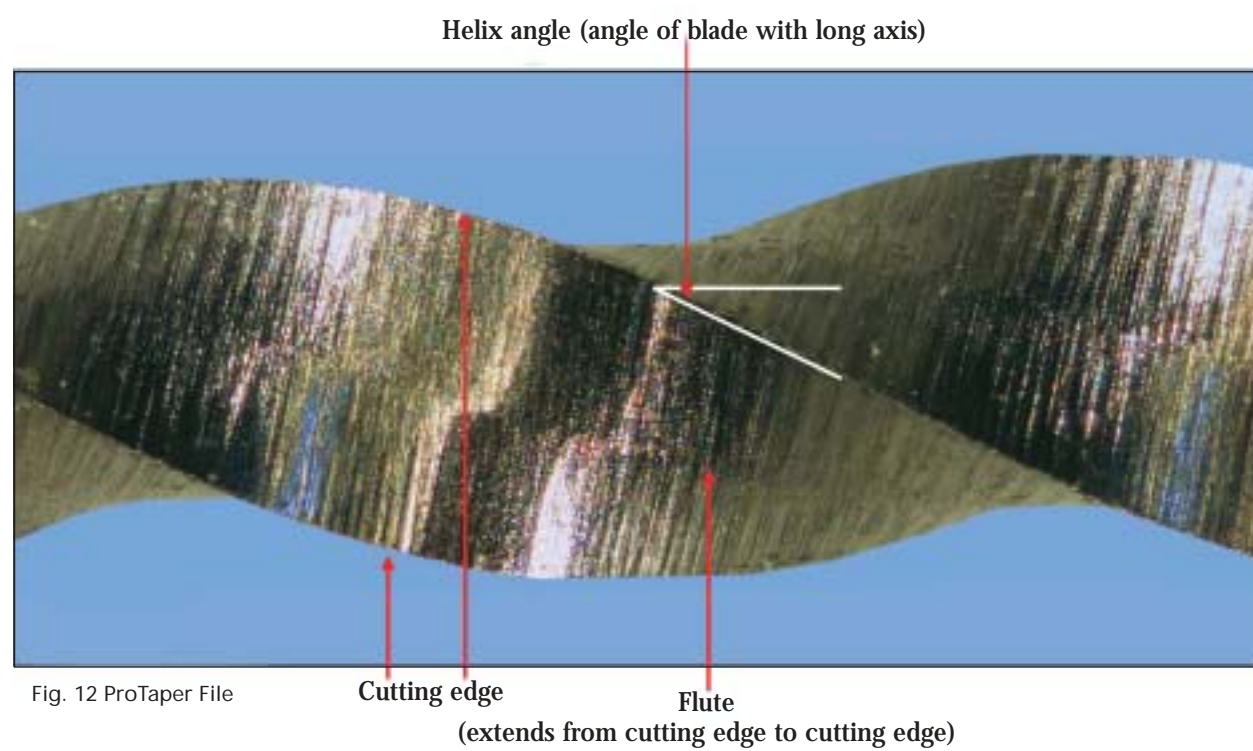


Fig. 11 MicroMega has used the unique approach of combining the pinion gear of the hand-piece and the handle of the file to increase access. The result is a handle that is 7.25 mm in length or less than one half the length of a standard handle.

Standardized dimensions played an important role at the time they were instituted for providing the needed consistency for hand instruments, but were soon seen as limitations for rotary instrumentation. As different dimensions of rotary files are introduced, the complexities of identification cause confusion. Hopefully, the common components of rotary files can eventually have standardized identifications for easier recognition.

The **flute** of the file is the groove in the working surface used to collect soft tissue and dentine chips removed from the wall of the canal. (Figs. 12, 13 and 14) The effectiveness of the flute depends on its depth, width, configuration and surface finish. The surface having the greatest diameter that follows the groove (defined as where the flute and land intersect), as it rotates, forms the leading (cutting) edge, (Figs. 12, 13 and 14) or the blade of the file that forms and deflects chips from the wall of the canal and severs or

snags soft tissue. Its effectiveness depends on its angle of incidence and sharpness. If there is a surface that projects axially from the central axis as far as the cutting edge, between flutes, this surface is called the land (Figs. 13 and 14) (sometimes called the marginal width). The land reduces the screwing-in tendency of the file, reduces transportation of the canal, decreases the propagation of micro-cracks on its circumference, gives support to the cutting edge, and limits the depth of cut. Its position relative to the opposing cutting edge and its width determine its effectiveness. In order to alleviate frictional resistance or abrasion resulting from a land, some of the surface area of the land that rotates against the canal wall may be reduced to form the relief (Fig. 14). The angle that the cutting edge makes with the long axis of the file is called the helix angle (Figs. 12, 13, and 14) and serves to auger debris collected in the flute from the canal.



9. What is the core of a file?

The **core** (Fig. 15) is the cylindrical center part of the file having its circumference outlined and bordered by the depth of the flutes. The flexibility and resistance to torsion is partially determined by the core diameter. The core taper and total external taper can be different and the relative diameter of

the core, compared to the file's total diameter, may vary along its working portion in order to change the flexibility and resistance to torsion. The importance of the ratio of core diameter to total diameter is often overlooked in predicting a file's susceptibility to failure and can be different for each file size of the same series.

Fig.15 The central core circumference shown in cross-section of the K-3 file is determined by the boundaries of the depths of the flutes or is described as the largest diameter of the cross-section that has not been ground. The core taper may be less than the file taper in order to proportionately increase the file's flexibility toward the handle. A .04 tapered file can have a .02 tapered core, and the file would have proportionally less cross-sectional mass toward the handle and greater flexibility toward the handle than if the core taper and file taper were the same.

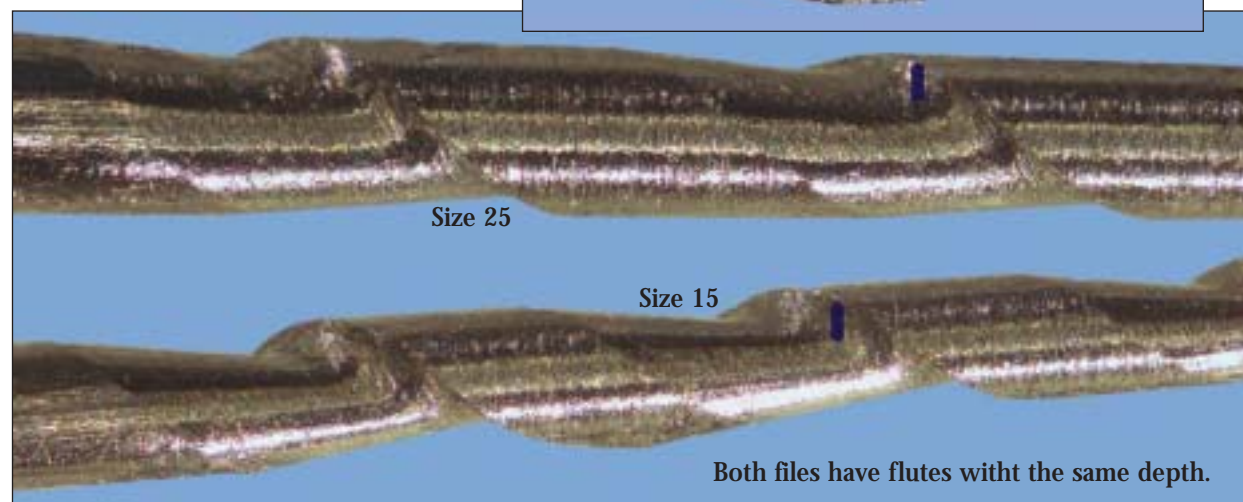
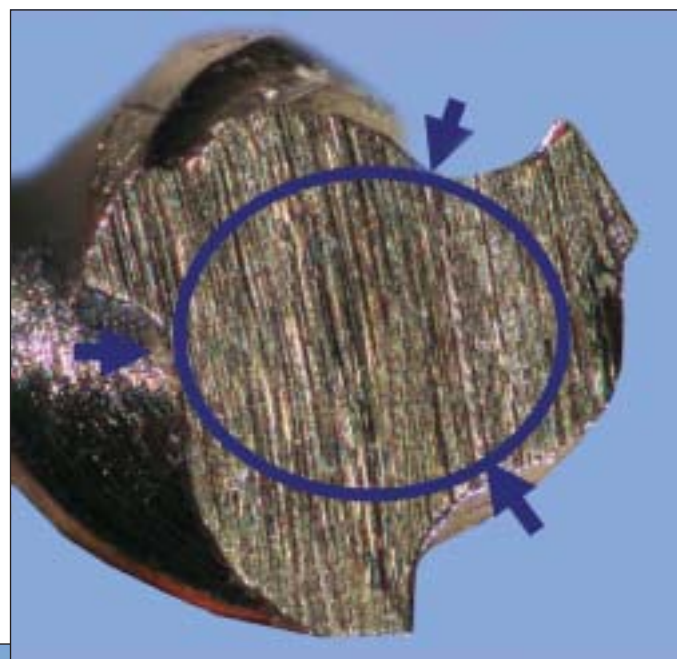


Fig. 16 Although the two files above have the same basic design and are of the same series, the ratio of the depth of the flute to the external diameter differs significantly. The depth of flute of the small instrument is approximately the same as for the larger instrument resulting in excess susceptibility to failure, whereas the larger instrument has adequate flexibility and adequate resistance to torsion failure.

10. What is the difference between the rake angle and cutting angle?

If the file is sectioned *perpendicular to its long axis*, the **rake angle** (Fig. 17-29) is the angle formed by the leading edge and the radius of the file. If the angle formed by the leading edge and the surface to be cut (its tangent) is obtuse, the rake angle is said to be **positive or cutting**. If the angle formed by the leading edge and the surface to be cut is acute, the rake angle is said to be **negative or scraping**. However, the rake angle may not be the same as the **cutting angle** (Figs. 17-29). The cutting angle, **effective rake angle**, is a better indication of the cutting ability of a file and is obtained by measuring the angle formed by the cutting

(leading) edge and the radius when the file is sectioned *perpendicular to the cutting edge*. In some instances, as with some Quantec files, a file may have a blade with a negative rake angle and a positive cutting angle. If the flutes of the file are symmetrical, the rake angle and cutting angle will be essentially the same. Only when the flutes are asymmetrical are the cutting angle and rake angle different. Both angles may change as the file diameters change and may be different for file sizes.

The **pitch** of the file is the distance between a point on the leading edge and the corresponding point on the adjacent leading edge along the working surface, or it may be the distance between points within which the pattern is not repeated. The smaller the pitch or the shorter the distance between corresponding points, the more spirals the file will have and the greater the helix angle will be. Most files have a variable pitch, one that changes along the working surface, because the diameter increases from the file tip towards the handle and the flute becomes proportionately deeper resulting in a the core taper that is different from the external taper. Some

Direction and Action of the Leading Edge (angle of incidence)

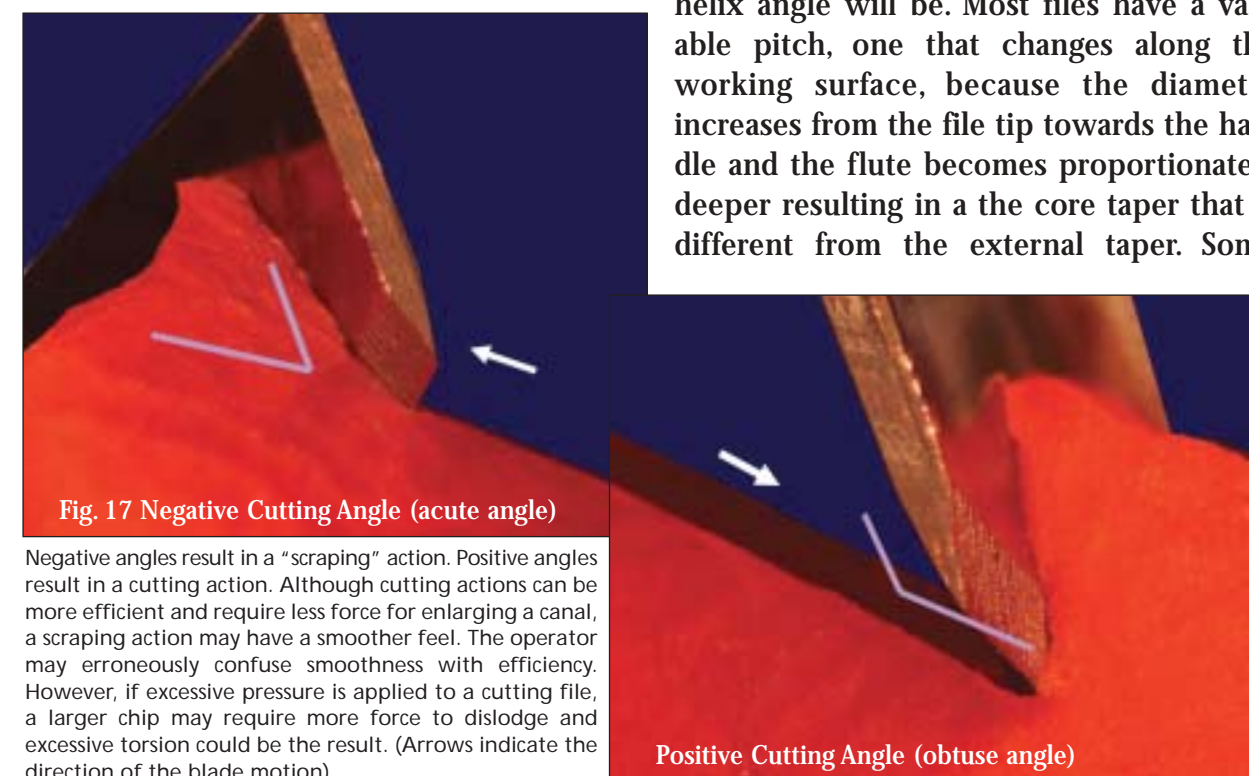


Fig. 17 Negative Cutting Angle (acute angle)

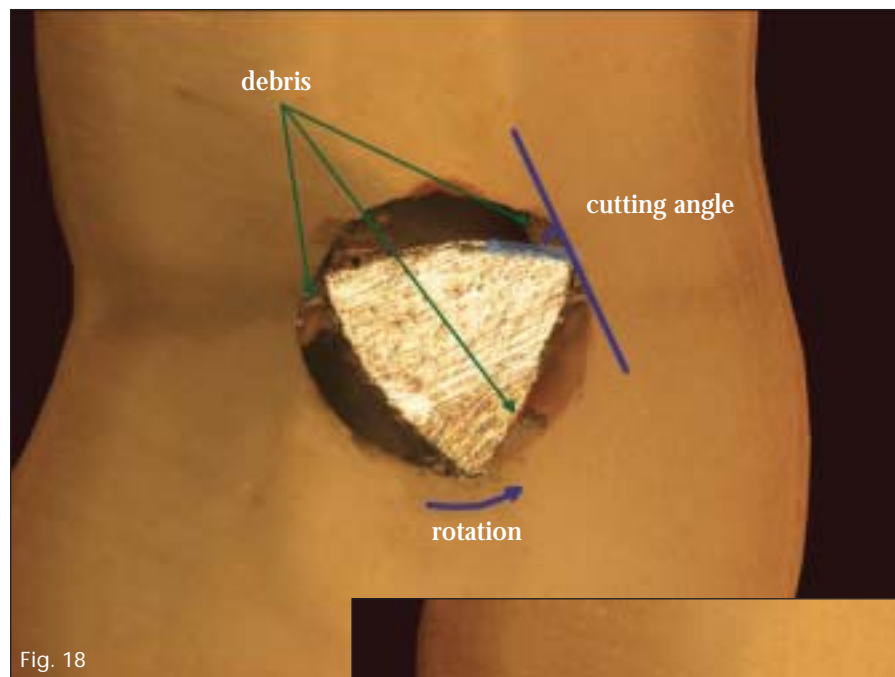
Negative angles result in a "scraping" action. Positive angles result in a cutting action. Although cutting actions can be more efficient and require less force for enlarging a canal, a scraping action may have a smoother feel. The operator may erroneously confuse smoothness with efficiency. However, if excessive pressure is applied to a cutting file, a larger chip may require more force to dislodge and excessive torsion could be the result. (Arrows indicate the direction of the blade motion).

Positive Cutting Angle (obtuse angle)

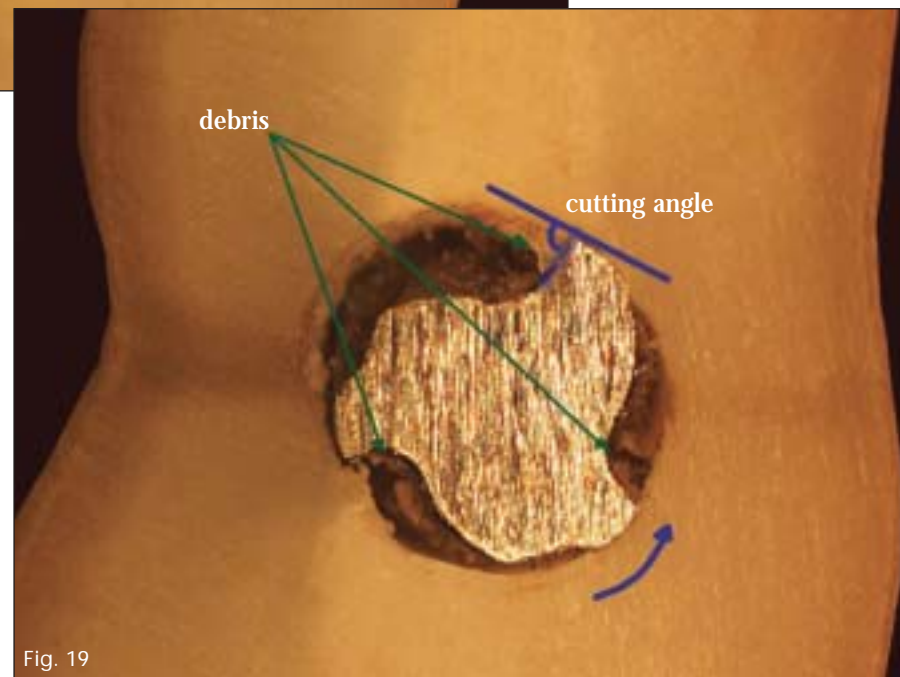
instruments, such as the Quantec and K-3 files, have asymmetrical cross-sectional designs in which case the pitch may be considered to be the distance between points that the pattern is not repeated.

The cutting angles, helix angles, external and core taper may vary along the working surface of the file and the ratios of these

quantities can vary between instruments of the same series. Any change of any of these features can influence the file's effectiveness or its propensity for breakage as it progresses into the canal space and can account for some files to act uncharacteristically when compared to files that have different dimensions in the same series.



The ProTaper file utilizes a negative angle of incidence to enlarge the canal. The surface of the file blade meets the canal wall with an acute angle resulting in a scraping action. More pressure is required when enlarging the canal in this manner.



The K-3 file utilizes a slightly positive angle of incidence to enlarge the canal. The file blade meets the canal wall with an obtuse angle resulting in a cutting action. Less pressure is usually required when enlarging the canal in this manner. Excessive pressure can cause excessive torsion by forming chips too large to be dislodged.

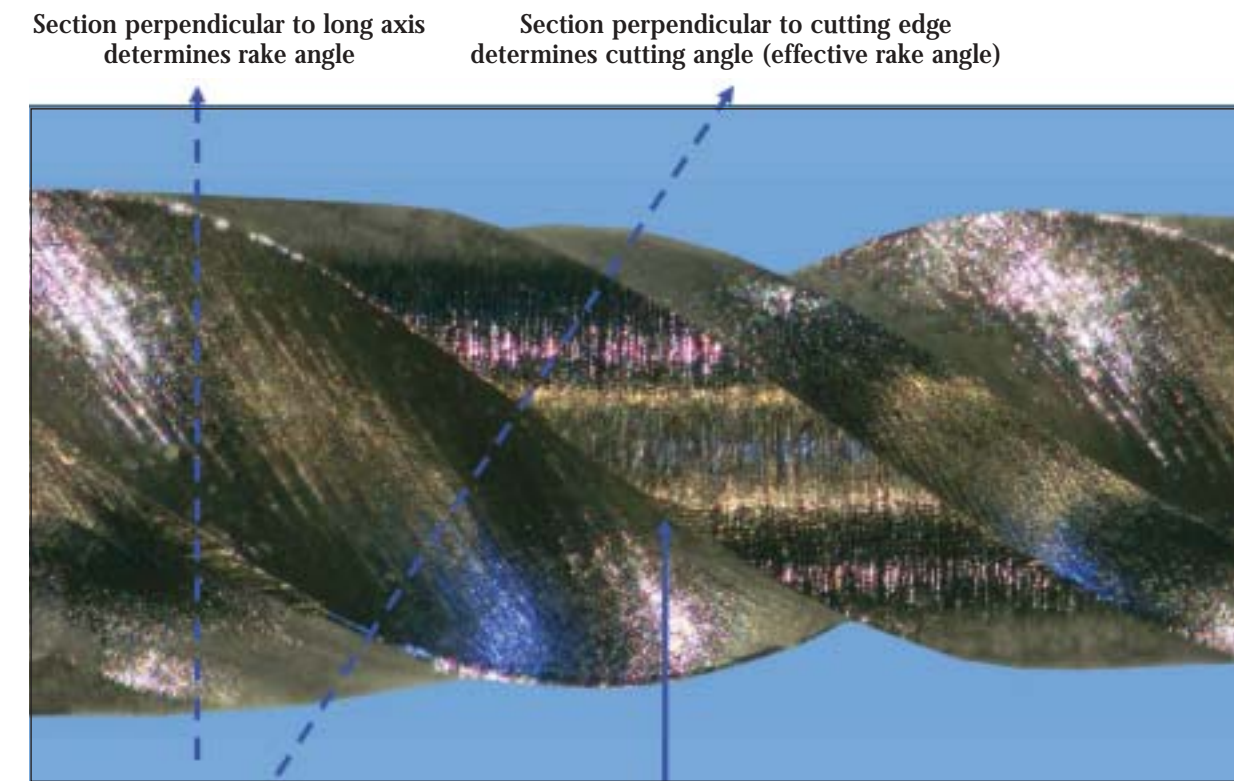


Fig. 20 Quantec File.

The cutting angle, effective rake angle, is a better indication for determining the cutting ability of a file than the rake angle, because it shows the actual angle of incidence.

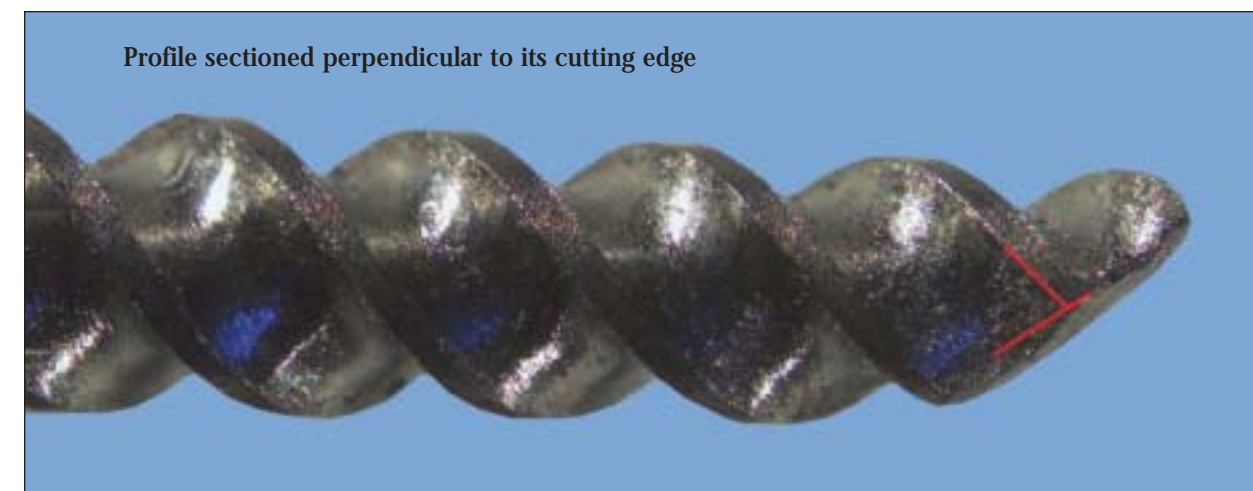


Fig. 21

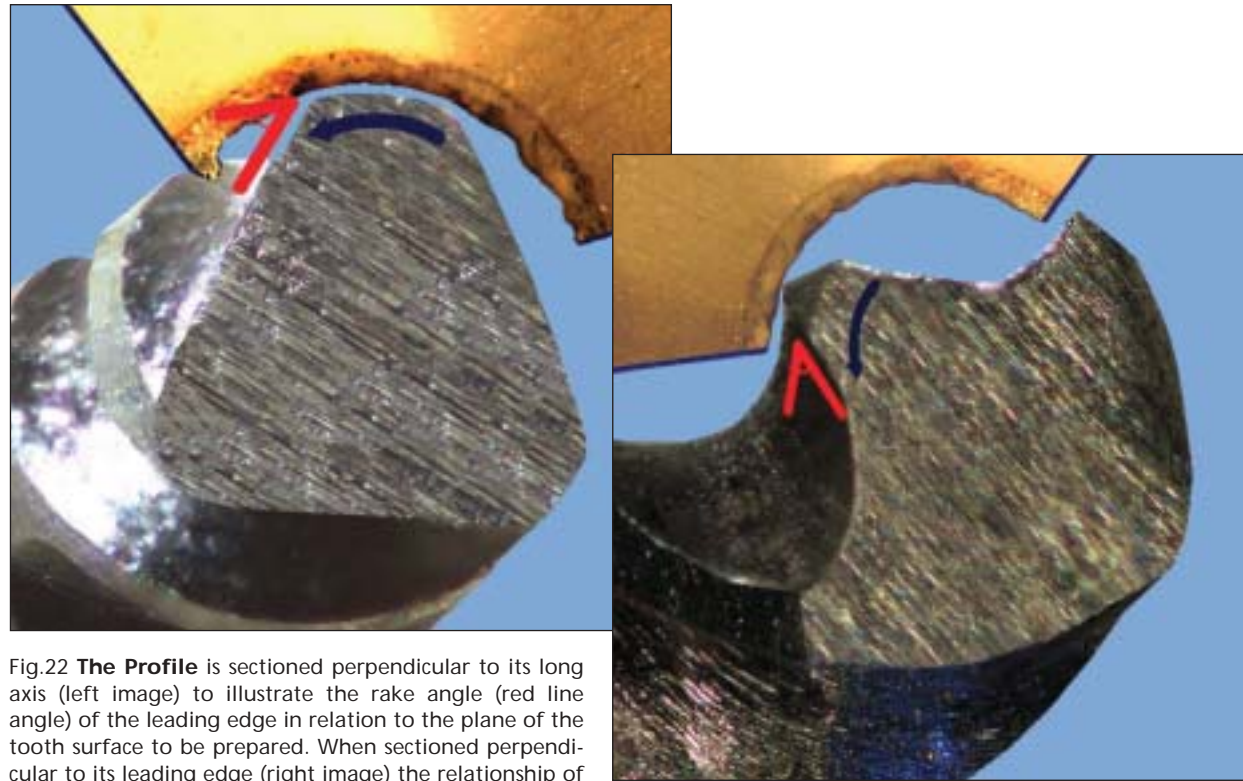


Fig.22 **The Profile** is sectioned perpendicular to its long axis (left image) to illustrate the rake angle (red line angle) of the leading edge in relation to the plane of the tooth surface to be prepared. When sectioned perpendicular to its leading edge (right image) the relationship of the cutting angle (red line angle) and the tooth surface to be prepared have the same relationship as in the perpendicular to the long axis section. The rake angle and cutting angle are the same because the flutes are symmetrical on the Profile.

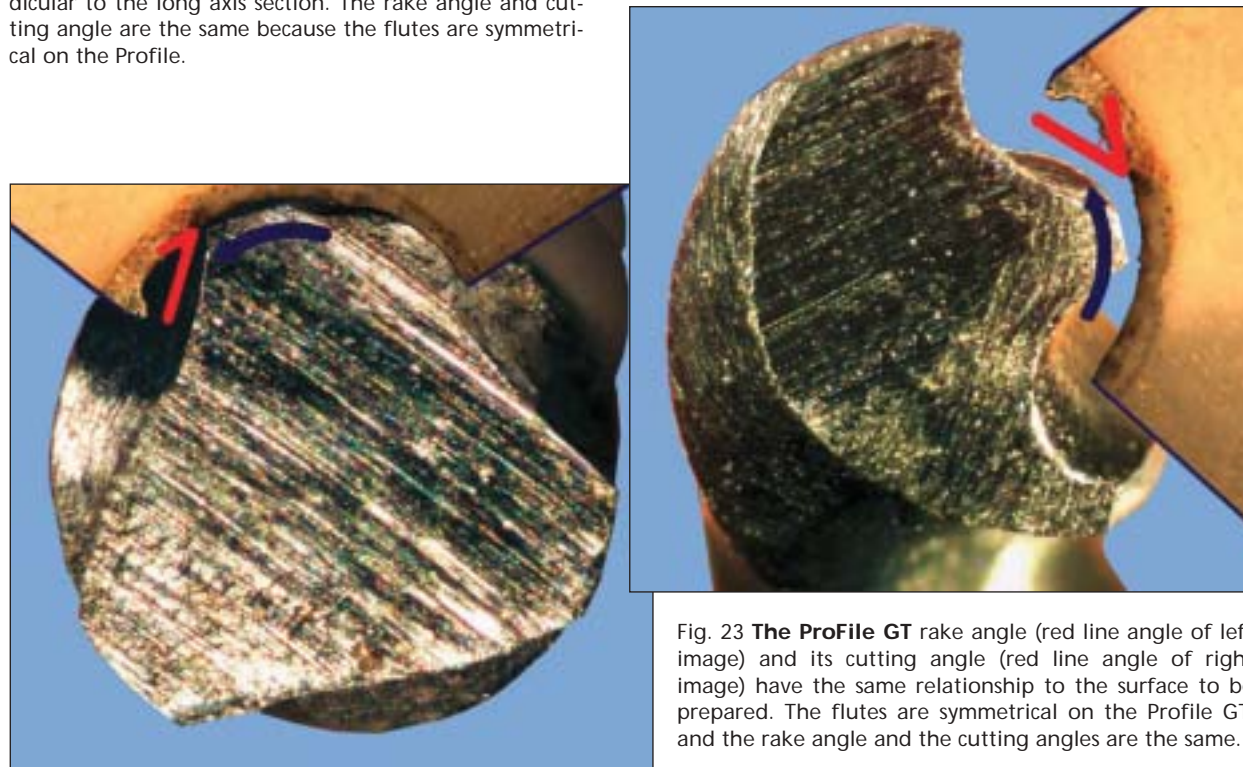


Fig. 23 **The Profile GT** rake angle (red line angle of left image) and its cutting angle (red line angle of right image) have the same relationship to the surface to be prepared. The flutes are symmetrical on the Profile GT, and the rake angle and the cutting angles are the same.

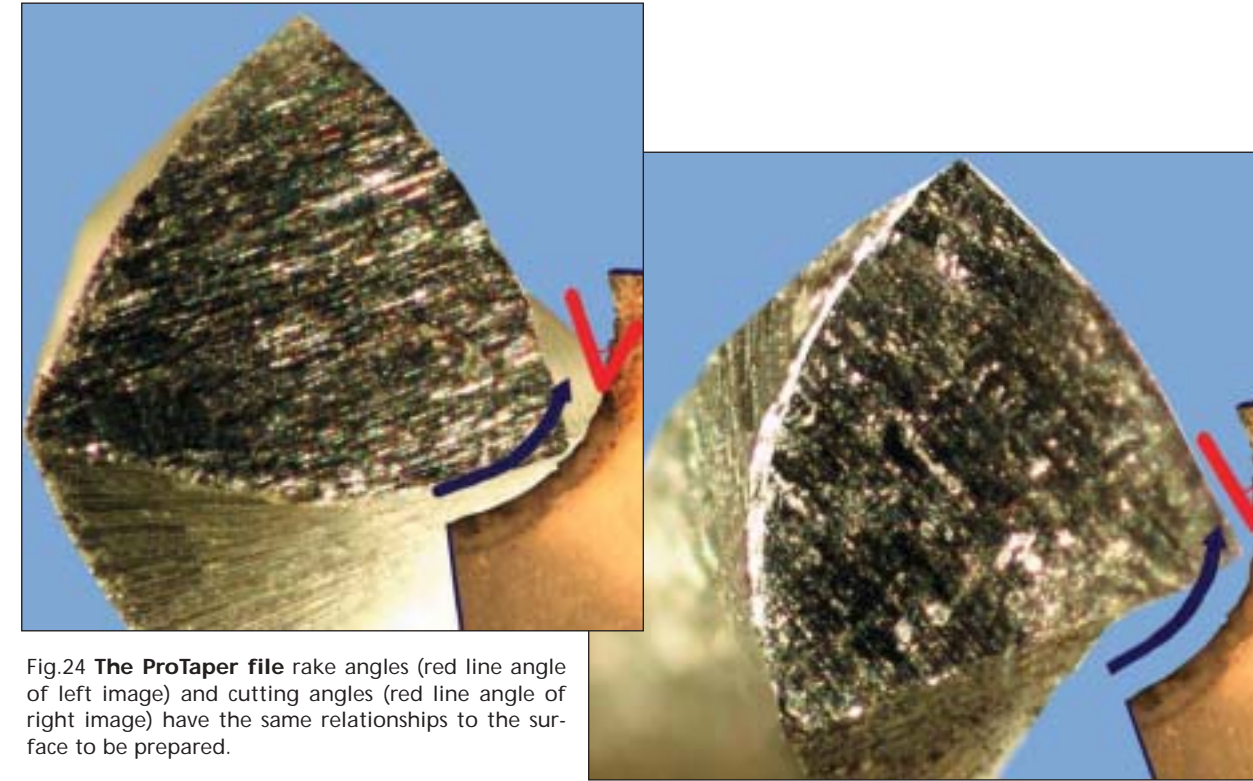


Fig.24 **The ProTaper file** rake angles (red line angle of left image) and cutting angles (red line angle of right image) have the same relationships to the surface to be prepared.

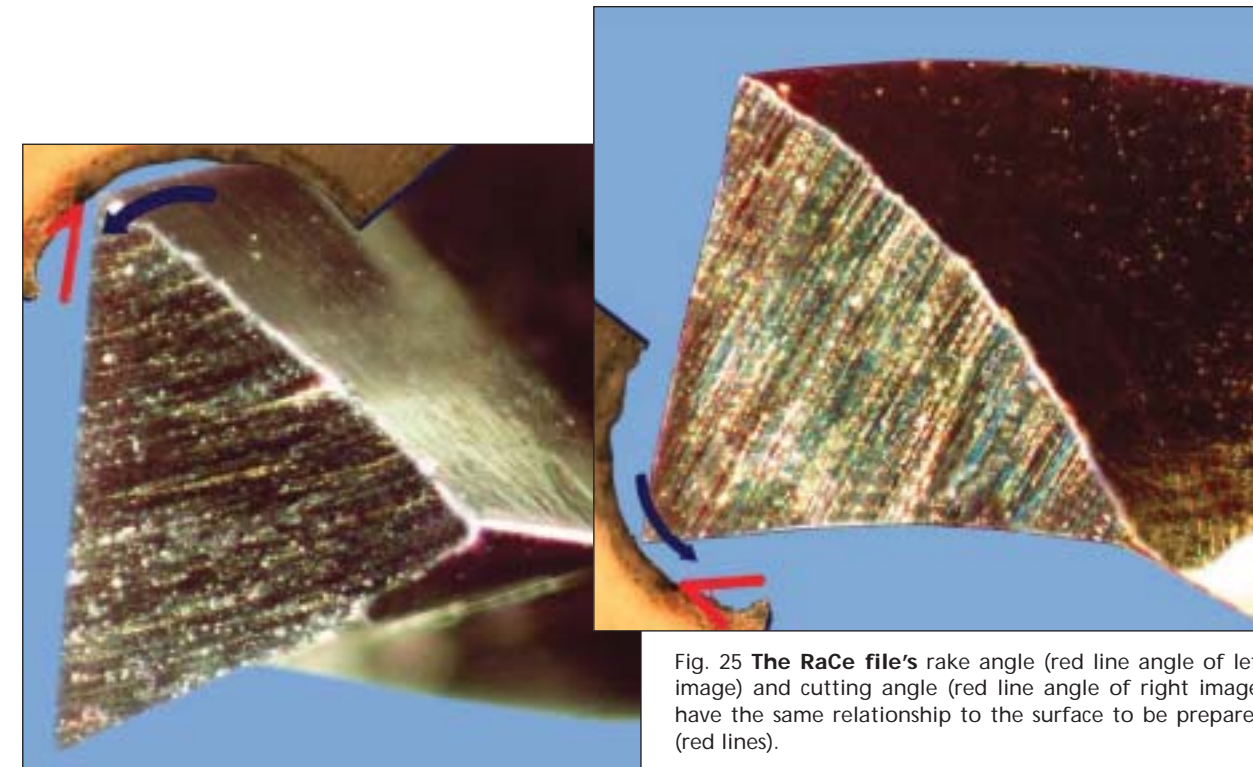


Fig. 25 **The RaCe file's** rake angle (red line angle of left image) and cutting angle (red line angle of right image) have the same relationship to the surface to be prepared (red lines).

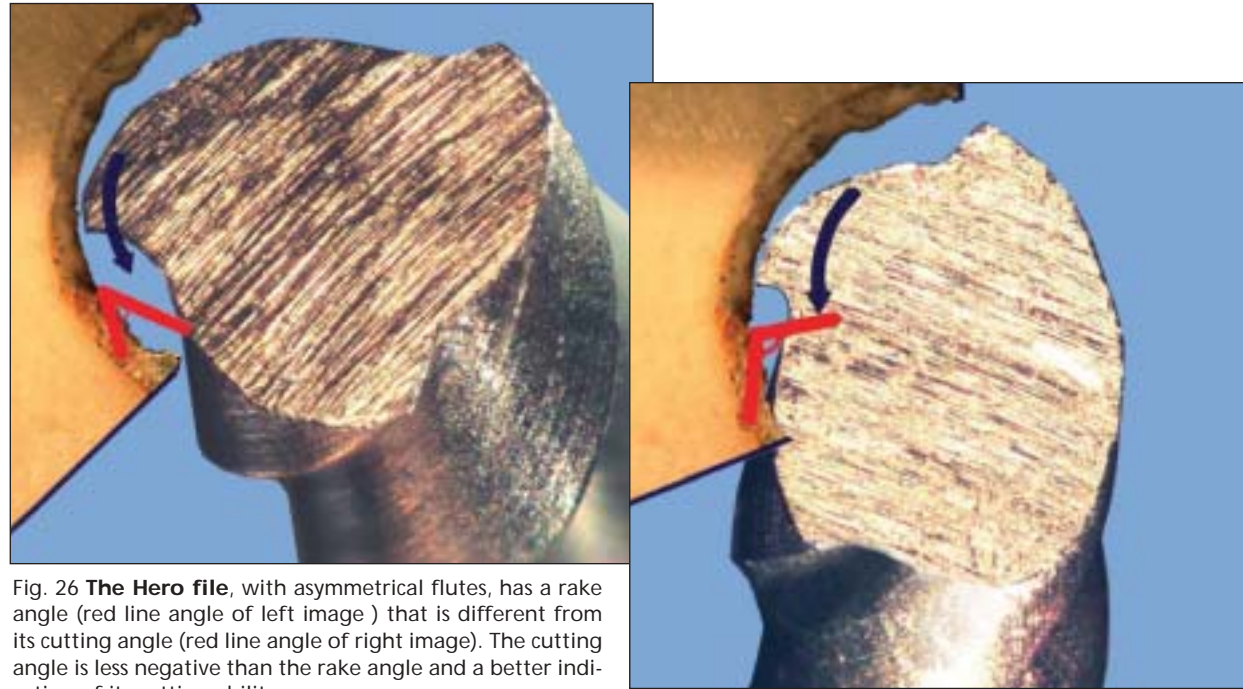


Fig. 26 **The Hero file**, with asymmetrical flutes, has a rake angle (red line angle of left image) that is different from its cutting angle (red line angle of right image). The cutting angle is less negative than the rake angle and a better indication of its cutting ability.

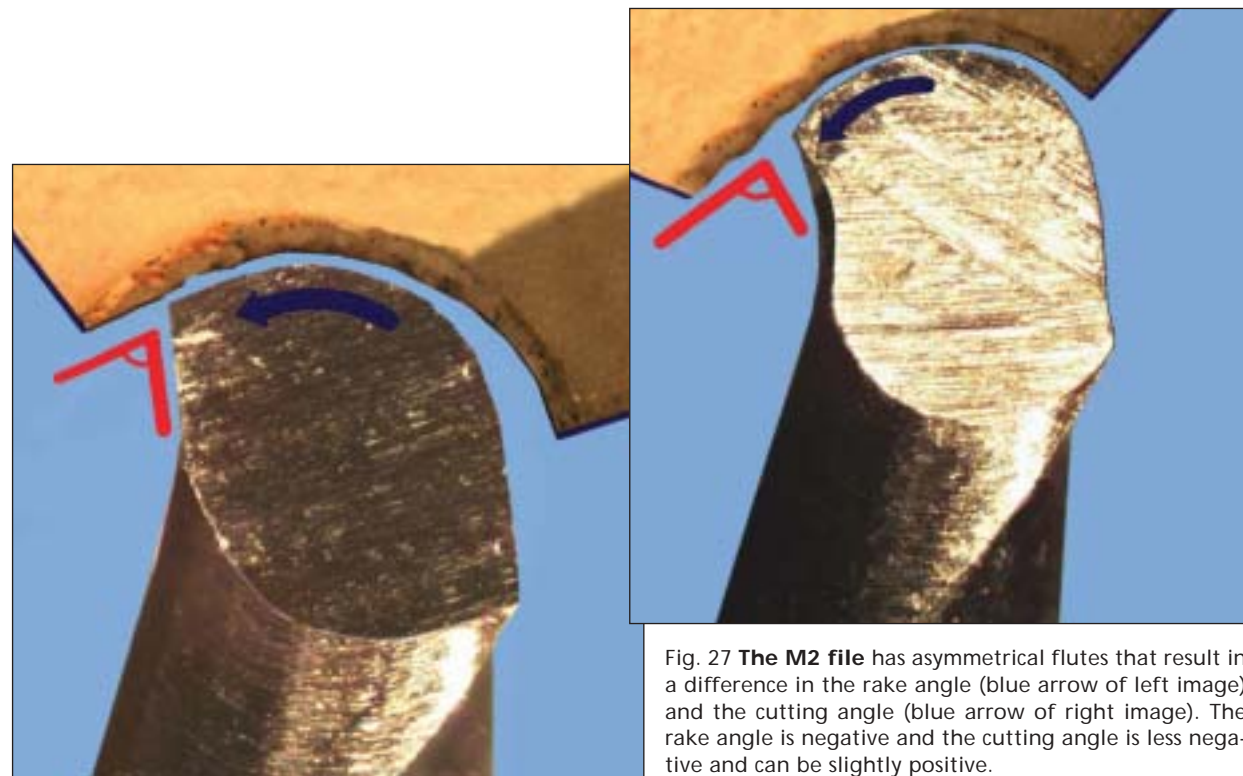


Fig. 27 **The M2 file** has asymmetrical flutes that result in a difference in the rake angle (blue arrow of left image) and the cutting angle (blue arrow of right image). The rake angle is negative and the cutting angle is less negative and can be slightly positive.

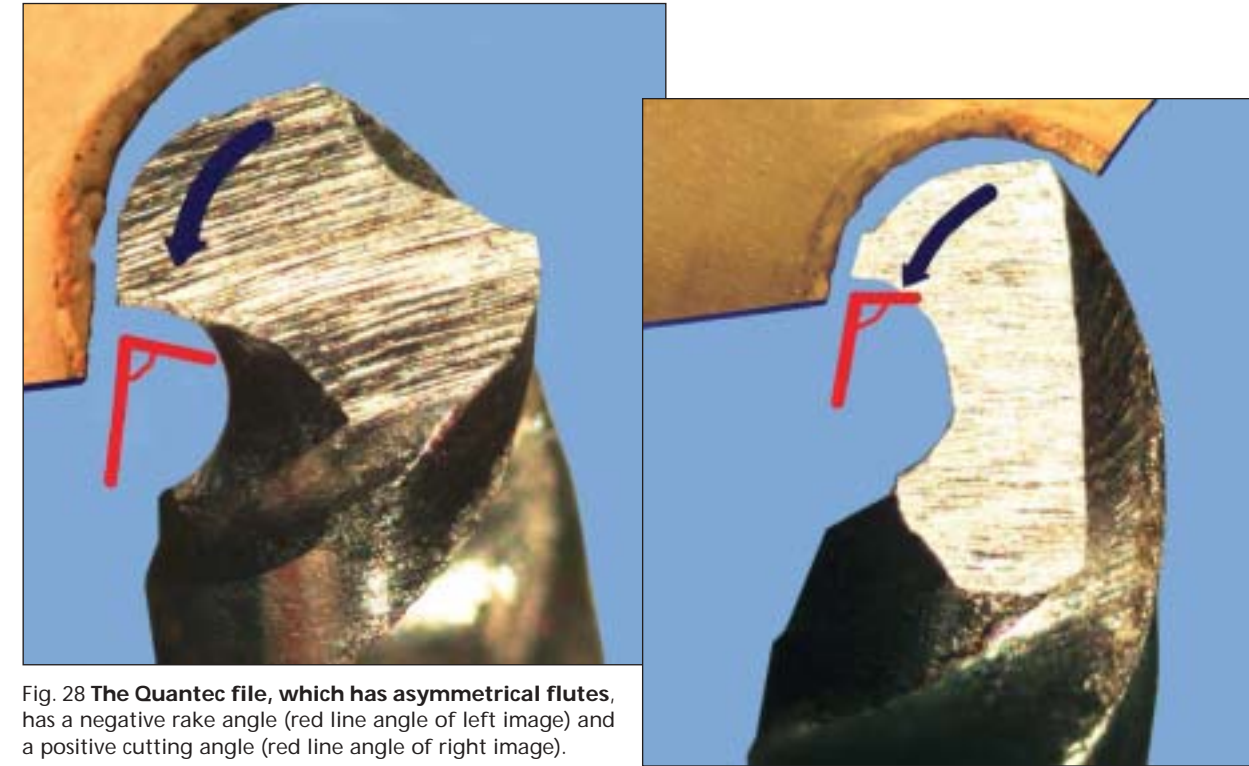


Fig. 28 **The Quantec file**, which has asymmetrical flutes, has a negative rake angle (red line angle of left image) and a positive cutting angle (red line angle of right image).

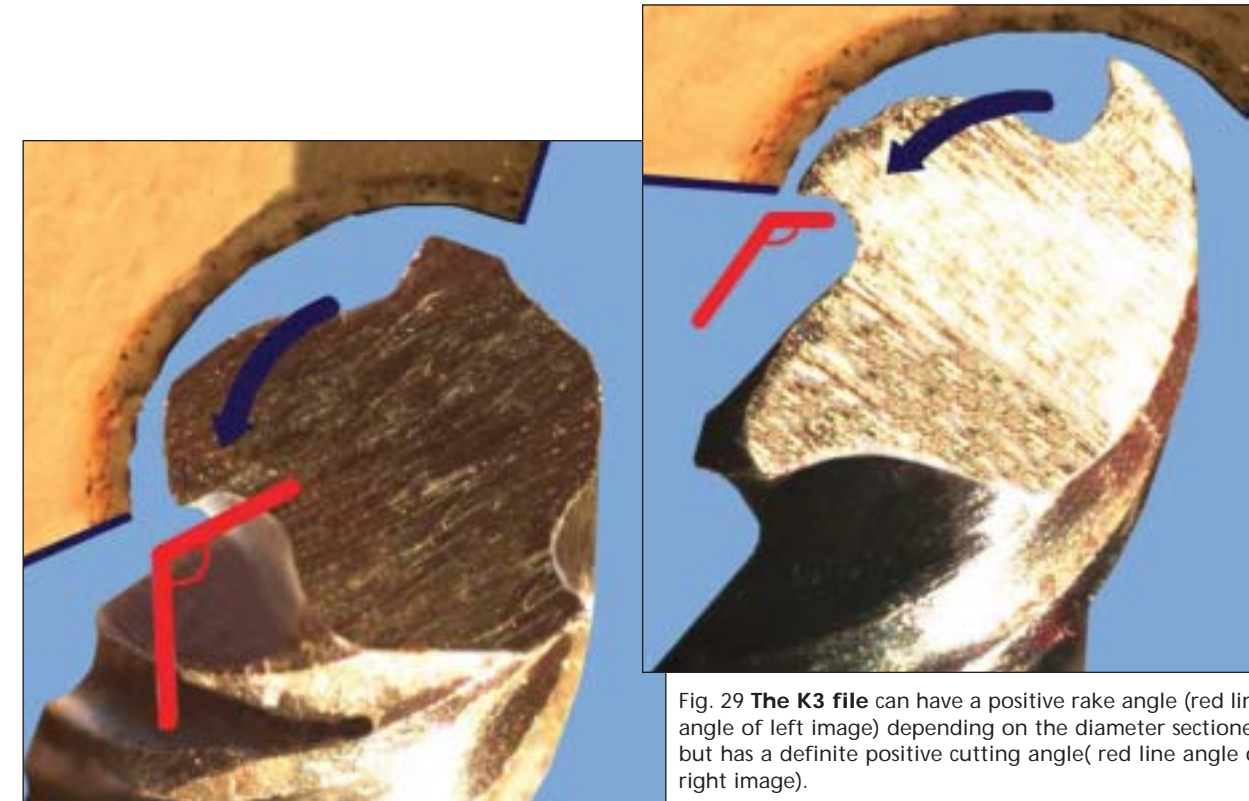


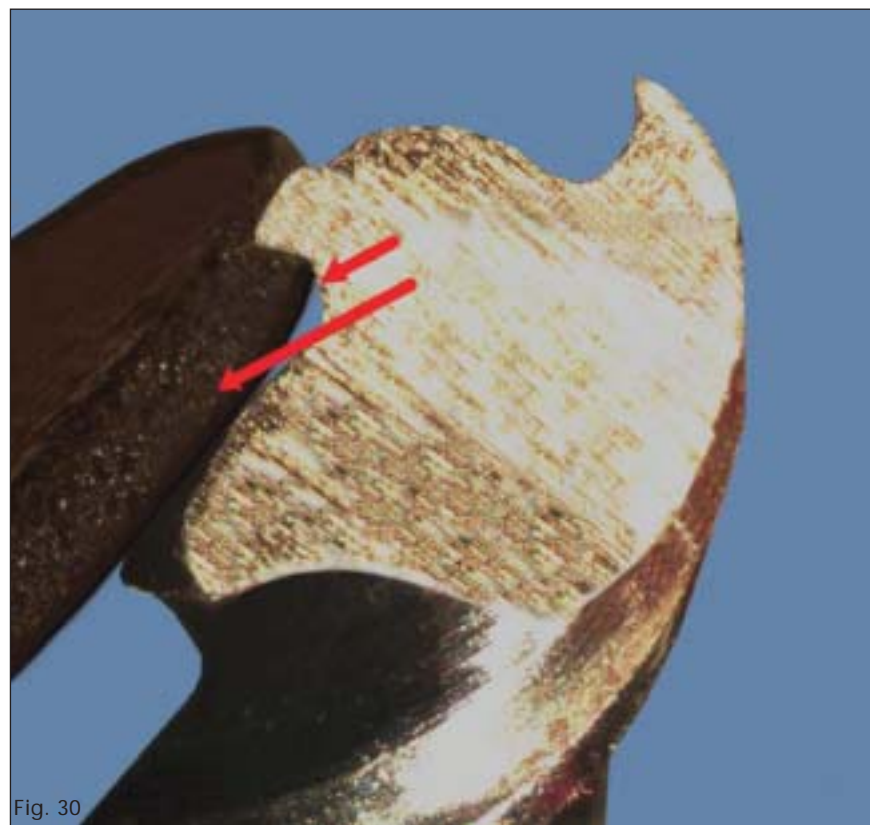
Fig. 29 **The K3 file** can have a positive rake angle (red line angle of left image) depending on the diameter sectioned but has a definite positive cutting angle (red line angle of right image).

11. Why are the rake angles and cutting angles the same on some files and not on others?

All nickel-titanium files begin as round wires. When files are manufactured with conventional grinding processes, the wire transverses a grinding wheel to form a flute (groove) in the side of the wire. If the wire is rotated, as it is fed across the grinding wheel, a spiraled flute is formed having a helix angle (the angle of the flute with the long axis of the file), and the shape of the flute is formed by the shape and angulations of the grinding wheel. Positive rake angles are difficult to accomplish due to the size of the grinding wheel relative to the file diameter. However, by adjusting angulations of the grinding wheel, positive cutting

angles are more easily accomplished. Of all the current spiraled instruments, positive rake angles, of at least one blade, exist only on the larger diameters of K3 files. However, it is conceivable that other H-type (Hedstrom) instruments could incorporate positive rake angles.

Files that have **symmetrical** flutes will not have positive rake or cutting angles and both of these angles will be essentially the same. Any positive cutting angle is the result of the flute having a smaller radius (**asymmetrical**) adjacent to its cutting edge as compared to the radius of the remaining portion of the flute. By varying the depth and/or asymmetry of the flute, the cutting edge of the file can be adjusted to become more or less positive along its working length, in order to enhance its effectiveness.



Grinding angle for asymmetrical flute (sectioned perpendicular to the cutting blade)

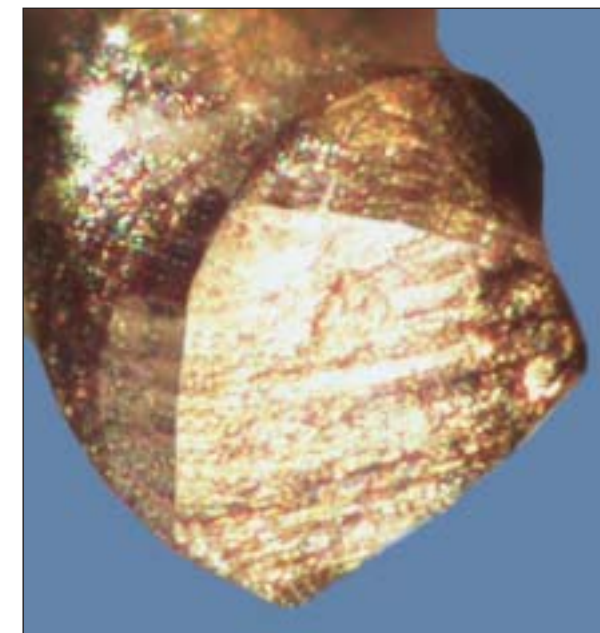
The grinding wheel during fabrication of the K-3 file forms a positive cutting angle by grinding a smaller radius on one side of the flute (asymmetrical).

Fig. 30

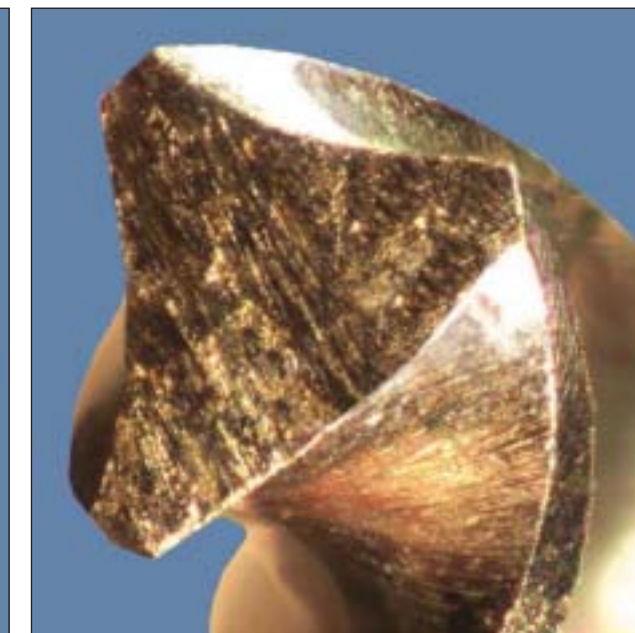
12. Do cutting angles change along the working surface of a file?

If the flute design of a file has no radius (the flute is a flat surface) when viewed in its cross-section, the cutting angle will remain the same along its working surface from D1 to D max. Without a radius, the depth of the flute in its cross-section will be outlined as a straight line. The only files having that design are the K-type file and reamer, the RaCe file, the Sequence file, and the Liberator file. Although there are exceptions, as is the Hero file, any file that has a cross-sectional design with an asymmetrical radius may likely have a cutting angle that changes along its working

surface. The flutes of these files usually occupy proportionately less of the cross-sectional area at their tips than at their largest diameters for two reasons. One reason is the intentional design to provide a more rigid tip and the other reason is the limitation of manufacturing capabilities. Consequently, the cutting angles near the tips would be less positive than at their larger diameters and the tips of these files have comparatively less flexibility but more resistance to torsion stress. If one attempts to mentally determine the cutting action of a file by viewing its cross-section, it is important to keep in mind that the cross-section design may change along the working surface and may be substantially different from the manufacturer's representations.



Profile GT sectioned at .35 mm. diameter



Profile GT sectioned at .90 mm diameter

Fig. 31

Although the ProFile and ProFile GT series of files are usually portrayed as having a U-file having a flute with a radius with neutral rake angles, diameters smaller than .6 mm have flutes that are essentially straight in cross section. The radius of the flute is limited by the radius of the grinding wheel during the manufacturing process

13. What is an aggressive file?

Efficiency is defined as the ratio of the work done to the work equivalent of the energy supplied to it. An efficient file, a file having greater cutting ability, requires less time, torque and/or pressure to accomplish canal preparation. The less pressure, torque and time required, the more likely file failure can be prevented. The *concept* is often confused, however, by describing a more efficient file as a more aggressive file, a term that seems to be used with a negative connotation. Aggressive forces of the operator on an efficient file are unnecessary and can be counter-productive. For example, if one pushes with excessive pressure on an efficient file the chips that are formed on the wall of the canal can be larger than can be removed without requiring significantly more torque than would have been required for forming and removing smaller chips with less pressure. Clinicians who change file systems and

begin working with more efficient files often have a tendency to apply the same time or force as was required with less efficient files. The excessive (aggressive) force on the more efficient file should be avoided and the clinician will enhance the quality of preparation and reduce the threat of failure by learning to match the file's efficiency with the level of force required. Without the benefit of efficiency data, clinicians often choose less efficient files because of the tactile sensations perceived. A file that enlarges a canal with inefficient scraping actions, for instance, can "feel" smoother than a file that uses cutting actions. **How an instrument feels during use is not a reliable indication of its efficiency.**

The major concern for an efficient instrument is its ability to transport the canal. It should be remembered that **time** as well as **force** are functions of efficiency and less time will be required to transport as well as

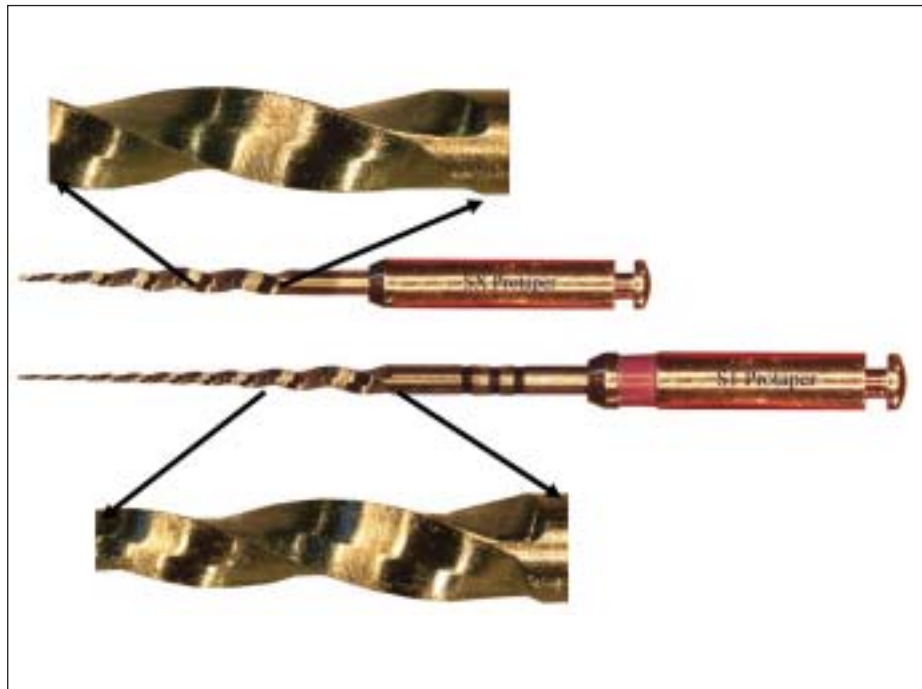


Fig. 32 The S1 and the SX ProTaper files have the same cross-section design and maximum diameter. However, slight dimensional differences of the S1 enable it to have greater cutting efficiency (generating less torsion) when engagement is limited to the maximum diameters. (Refer to Chart 50)

to enlarge a canal with an efficient file. On the other hand, the less efficient file requires more time that results in more rotations and greater fatigue, and/or more force that results in greater torsion. The additional fatigue and torsion, of course, increase the possibilities of breakage.

One should also keep in mind that a file cannot transport unless it was at first where it should be, and only the excessive time it remains in that position results in transportation. **Once a file has rotated one time in one position, the canal will be enlarged to the file's diameter and to avoid transportation the file should not remain in that position once the canal is enlarged.** Even very minor differences in file design dimensions can affect the cutting efficiency of files and their propensity for transporting canals.

14. What are the functions of lands?

Lands are the surfaces of files that extend as far axially from the center as the cutting edges that define the file's circumference. Lands are used to reduce screwing-in forces, support

the cutting edge, reduce transportation, and limit the depth of cut in much the same manner that a safety razor functions. The surface of a land reduces the tendency of faults caused by stress or manufacturing imperfections in the metal to propagate along its cutting edge or circumference. Lands need not be very wide to function.

The force of abrasion is a direct result of the surface area of a land that rotates against the wall of the canal. Wide lands can result in excessive abrasion forces that increase the torque requirements for rotation. In addition, faster rotations of a file cause the lands to further limit the depth of cut, and wide lands on larger files can prevent the blades from engaging an adequate depth into the canal. Wide lands can be very useful in small diameter files by adding rigidity and by enabling the file to negotiate curvatures when canal enlargement is minimal. When lands are too wide for effective canal enlargement, the files can be used very effectively for removing gutta percha from the canal and for circulating irrigation in the canal.

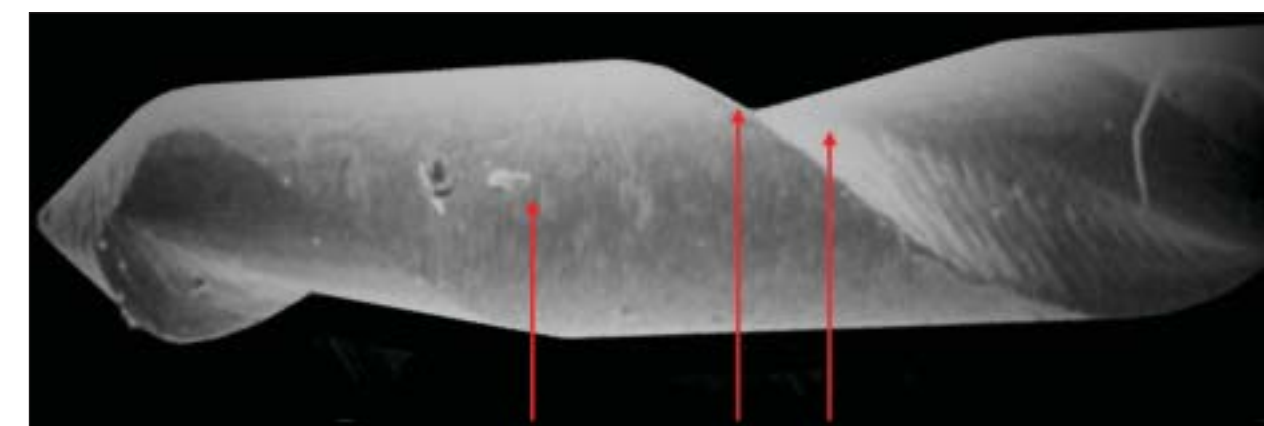
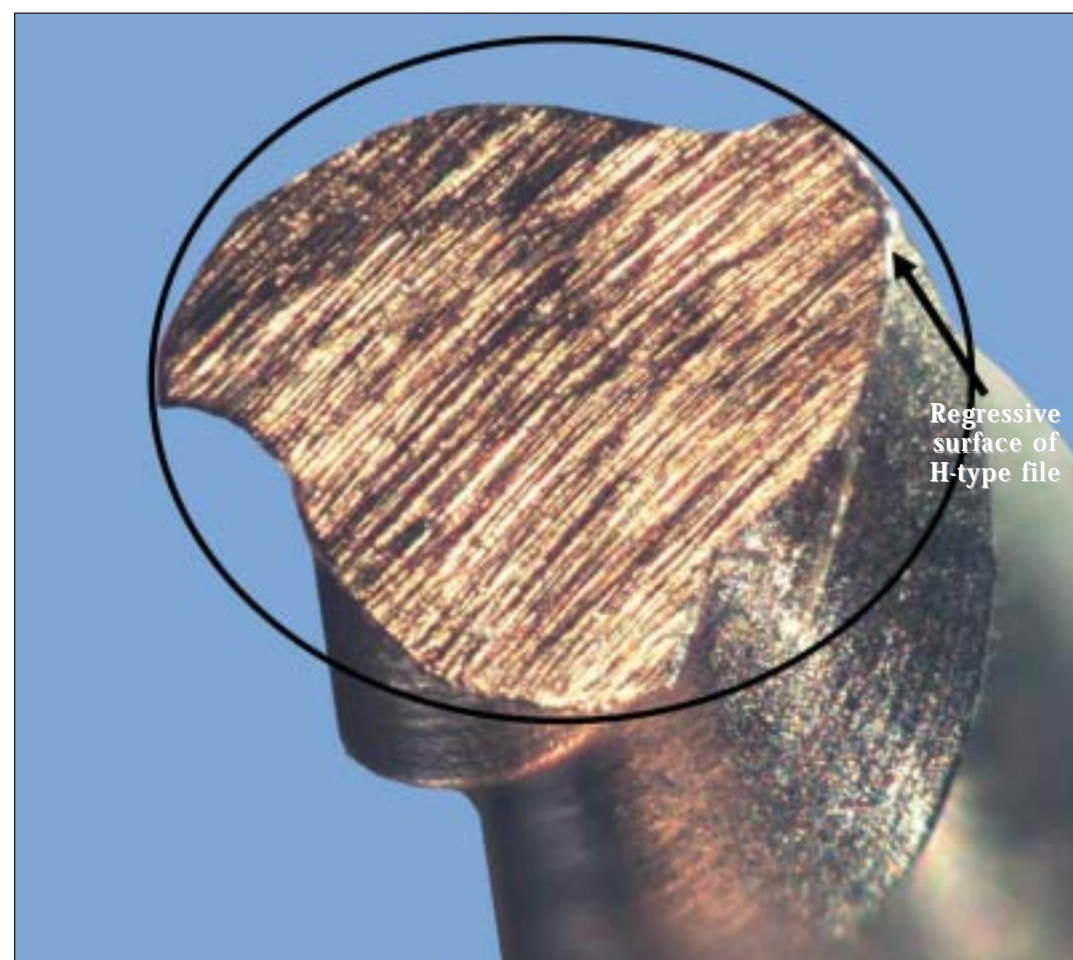


Fig. 33 The GPX instrument, Brasseler USA, is used for removing gutta percha from the canal. The friction of the wide land rotating against gutta percha causes it to plasticize while the spirals auger it from the canal. The instrument is very effective for removing gutta percha but is ineffective as a larger size file because the land occupies most of the working surface and keeps the leading edge from engaging into the canal surface.



Fig. 34 The **Endomagic** file (size 15) utilizes wide lands for smaller size files to facilitate negotiating curvatures.



Hero file cross section

Fig.35 Although not technically lands, since the surface does not extend axially from the center of the file as far as the cutting edge, H-type files have surfaces that follow the blades that gradually retreat from the file's circumference.

A recessive surface that follows the blade on H-type files gradually recedes from the file's outside diameter, provides support of the blade, and reduces propagation of cracks along the blade in the same manner as lands, but lacks some of the effectiveness in avoiding canal transportation. However, the force of abrasion is reduced. Rotary files having this design include the three-fluted Hero file (MicroMega) and the newly introduced two-fluted M2 file (Sweden Martina). The M2 file is essentially a modification of

the Dynatrac file and NT file design, having positive cutting angles but having fewer spirals. This modification is attributed to Dr. Vinio Malignino of Italy. Another modification is the LA Access file, which has a surface that at first gradually retreats from the blade, but becomes a flat recess or relief. This file is used primarily to intentionally transport the canal orifice and utilizes the piloted tip like the Dynatrac to minimize canal transportation at the tip. This design is attributed to Dr. Steve Buchanan.



Fig. 36 **Dynatrac** file. This file was the first multi-fluted H-type file to have a non-cutting pilot. Made of stainless steel, it was used in a reciprocating handpiece to avoid fatigue. (Designed by J. McSpadden, 1977)



Fig. 37 **Hero** file. Even though this file has about the same pitch as the Dynatrac file, its three flutes result in a helix angle for less screwing-in forces during rotation. (Micro-Mega)



Fig. 38 **M2** file. This 2-fluted H-type file has the same cross-section design as the Dynatrac file but has a longer pitch that is more suitable for rotation.



Fig. 39 **LA Access** file. Designed for preparing the canal access, this stainless steel file has much the same design as the Quantec file except it has no land following its cutting edge since it is not meant to negotiate curvatures.

15. Do the designs of files have to be limited to a grinding process during manufacturing?

The capabilities for fabricating complex file designs have increased dramatically with computerized multi-axis grinding processes. However, any process of grinding limits the shape and strength of files. The size of the grinding wheel limits the file's shape, and cutting across the grain of the crystalline structure of the wire limits its strength. The process of **electrical discharge machining, EDM**, is a promising alternative means of manufacturing endodontic files. The shape of the file is formed by electric spark erosion of a wire. EDM manufacturing alters the molecular structure on the file's surface potentially strengthening the file without affecting its flexibility.

Another promising method for manufacturing nickel titanium files is using the **process of twisting** that was used for fabricating steel files for decades but was initially thought to be an impractical method for nickel titanium. Residual stress and the problem of shape memory for nickel titanium can be avoided during this process by heat-treating before, during or after twisting. The helix angle can be varied along the working surface by using a computerized twisting process. The rationale for using this manufacturing technique is that

work hardening the metal by twisting might occur as it does during the twisting process of stainless steel files, and enhance its strength while maintaining greater integrity of the crystalline structure. Alternative manufacturing also includes flute formation by forcibly pushing a blade into a tapered wire. A **furrowing process** forms the flute rather than being ground and the blade becomes projected from the shaft either with a continuous furrow or intermittently to form barbs. Barbed broaches are manufactured by this process. The file shape can actually result from being pressed or impacted into the NiTi wire.

The molecular structure of conventional metals is organized into grains or crystals. The boundaries between the crystals are the areas of weakness where failure occurs when undergoing excessive stress. Scientists have discovered that if some alloys are cooled very quickly during the process of casting, crystallization can be avoided. One of the most unique developments for the potential for fabricating complicated file designs incorporates this **process of casting** and avoids many of the limitations of grinding altogether. The resulting metal has an amorphous non-crystalline structure, the properties for accommodating stress are enhanced, and the microscopic irregularities caused by the grinding wheel that result in stress concentration points are eliminated.



Fig. 40 **Liquidmetal** cast file (the handle and shaft are cast as one piece). Casting allows the blades to be designed to spiral only 180 degrees around the shaft in order to reduce canal wall engagement. It also allows each blade to have a different helix angle to avoid screwing-in forces. Continuous advancements in casting techniques can make it a viable manufacturing process in the near future.

16. Does the quality of manufacturing make much difference?

Before different types of files are studied, it should be stressed that the quality of manufacturing is the most basic consideration for determining the success or failure of files independent of its composition or design. Less than ideal manufacturing quality controls result in the formation of micro-cracks and defects along the surface of a file.

Cracks can propagate to failure at a stress level lower than the stress ordinarily encountered during instrumentation and other defects can cause stress concentration points that

lead to file failure and jeopardize endodontic success. It should be pointed out that considerably less force is required to propagate a crack than is required to form it. It is not surprising to find that fatigue cracks in files usually start at geometrical irregularities on a macro- and micro-scale. If the defects are in a position of high stress, failure can occur quickly. The area of highest stress is along the blade or leading edge. Failure is the result of stress per unit area so a blade that is unsupported by a land, such as a file having a triangular cross-section, will have greater forces for failure than a blade supported by a land or regressing circumference.

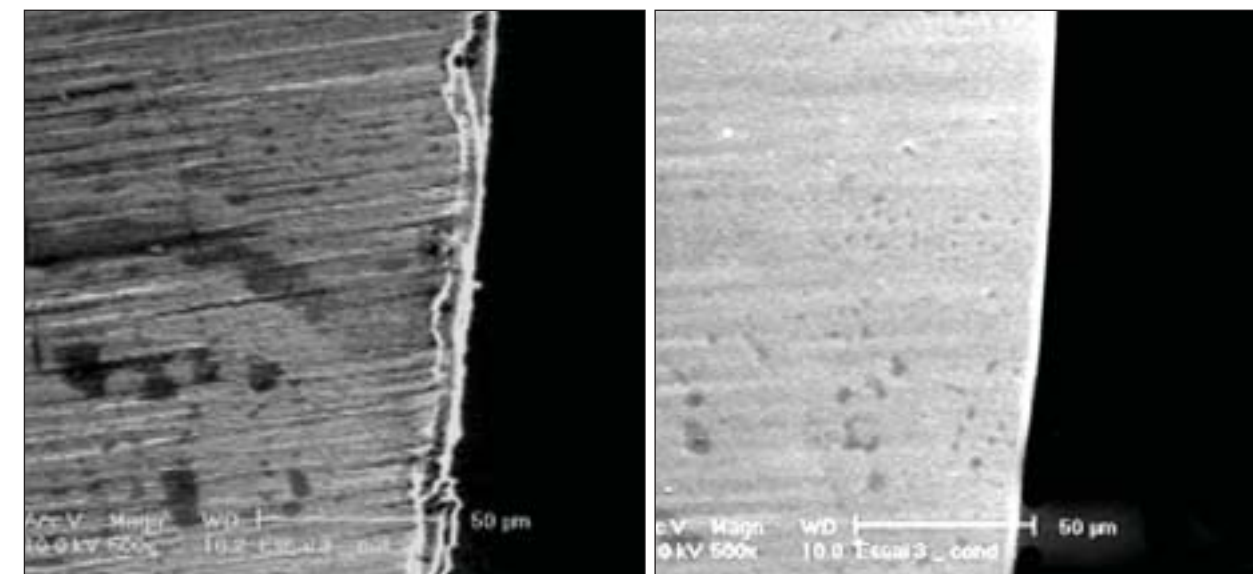


Fig. 41 Before and after surface treatment during manufacturing.

The formation of micro-cracks (shown on the file's cutting edge in the left photograph) during initial production of files by FKG Dentaire SA was later eliminated by a special surface treatment process. (shown in the right photograph) and resulted in increasing the resistance to torque failure by as much as 1000% in some samples. Files were compared rotating in a glass tube (inside diameter 2 mm, 90 degree curvature and 8 mm radius) at a speed of 350 rpm until failure.

Design Considerations:**17. What are the most important relationships of the components of file designs and canal anatomies that enable us to improve our technique?**

Careful examination of technique and design considerations identifies the limitations and usefulness of existing instruments and facilitates the development of a new generation of rotary instruments and techniques, one unencumbered by traditional concepts. A few all-important consequential relationships of different file designs and tooth anatomies are useful in understanding how files function. Although research on endodontic instruments cannot determine with absolute certainty how files will react under all circumstances, research can result in inferences having significant predictability that can be used as considerations for instrument and technique design. The following are some of the considerations and ramifications of designs that are most important in formulating techniques in approaching difficult cases:

1. A file with a more efficient cutting design requires less torque, pressure or time to accomplish root canal enlargement.
2. In a straight canal, the ability of a file to withstand torsion is related to the square of its diameter.
3. In a curved canal, the ability of a file to resist fatigue has an inverse relationship with the square of its diameter.
4. The torque required to rotate a file varies directly with the surface area of the file's engagement in the canal.

5. Fatigue of a file increases with the number of rotations of the file in a curvature.
6. Fatigue of a file increases with the degree of curvature of the canal.
7. To improve efficiency, the smaller the surface area of a file engaged in the canal, the greater the rotation speed should be.
8. The more spirals a flute has per unit length around the shaft of a ground file, the less resistance to torsion deformation there is, but the more flexible the file is.
9. The fewer spirals a flute has per unit length around the shaft of a ground file, the more it resists torsion deformation, but the more rigid it is.
10. The sharper the cutting blade of a file, the fewer spirals per unit length the file should have.
11. The greater the number of flutes with similar helix angles, the greater tendency a file has to screw into the canal and become bound.
12. Maximum engagement of a file occurs when it progresses into the canal at a rate that is equal to its feed rate, the rate the file progresses into the canal without the application of positive or negative pressure.
13. Less canal transportation occurs with a file having greater flexibility, an asymmetrical cross-section design, and/or a land.

Section II.

Mastering Instrument Designs

18. How do we test designs?

To test the validity of claims for file designs, a computerized clinical simulator was constructed to simultaneously measure torque, pressure and time, during the prescribed use of instruments, to determine efficiency and the threat of file failure. The simulator computer provides the means for precisely duplicating motions (US Robotics) designed to simulate clinical applications for comparing different instruments. While eliminating operator variability and conforming to operation recommendations, computer programming can control the preparation parameters for the depth and the speed of file insertion and withdrawal, as well as the speed of file rotation. Not only can the stress of the force of insertion and torsion of each individual file size and taper be measured under different circumstances, but also the stresses, using different file sequences, can be recorded in order to determine the least stressful and most expeditious technique approaches. All measurements are plotted over time to illustrate when and how stress occurs.

Rather than measuring the over-all flexibility of the file, the simulator device can be used to measure dynamic flexibility, recording the resistance to bending as a rotating file progresses onto an inclined plane or simulated curved canal. The measurement occurs over time as different diameters and cross-section configurations of the file transverse a curvature.

The logged data help determine the methods for which each instrument may be used most effectively while minimizing the threat of failure. The simulations can be applied to different anatomies and technique solutions quickly become apparent, rather than having to rely on subjective and time-consuming trial and error experience that lack the benefit of controls. An examination of the results puts the manufacturer's technique recommendations in perspective, validating or invalidating their claims. Identifying technique enhancements and file design improvements become more feasible. The results can be used to substantially enhance efficiency and may be surprisingly different from what has been recommended.

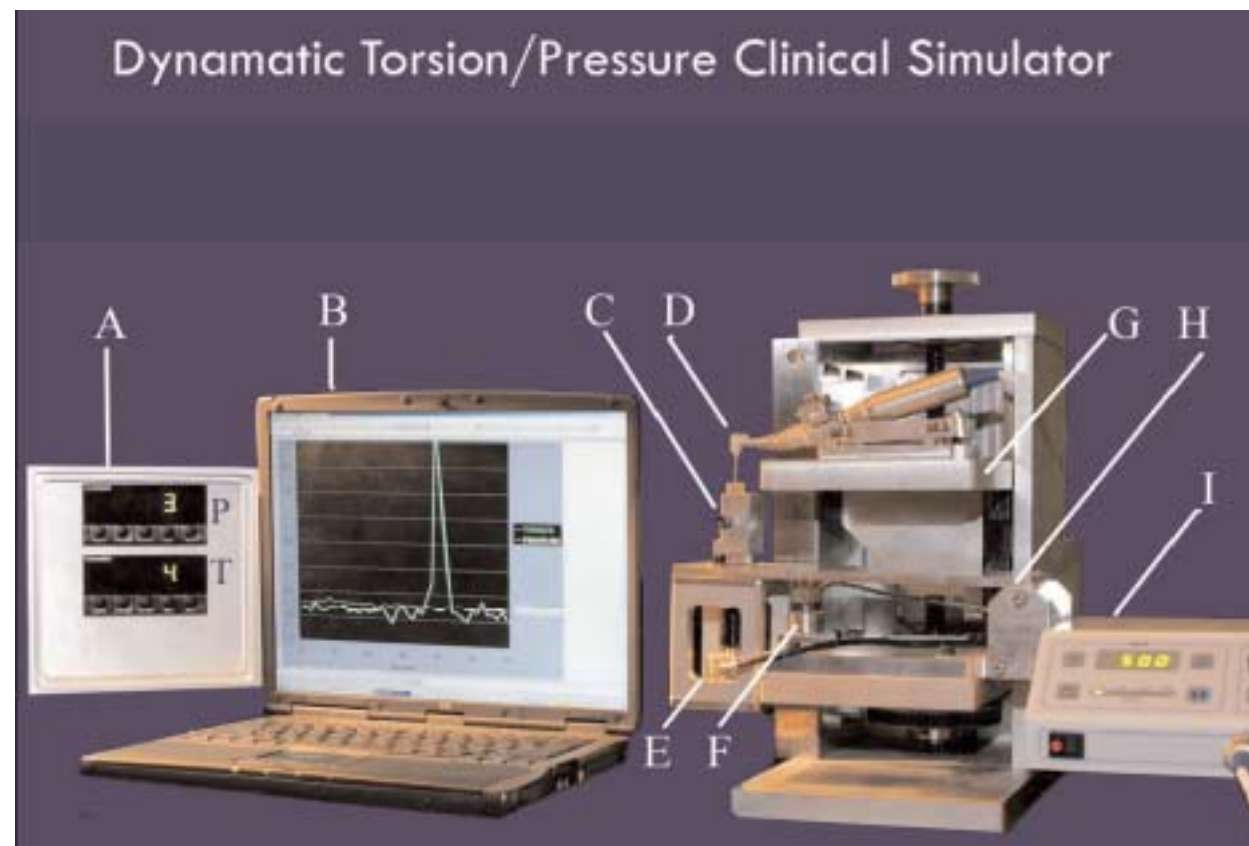


Fig. 42 The clinical simulator computer (B) includes two software programs. One program executes the motions of the rotary handpiece and the other is fully integrated with the hardware for the custom acquisition of data. The desired rotation speed of the file is adjusted by the handpiece control box (I). The handpiece is mounted on a stage (G) that is raised and lowered at rates and distances determined by the parameters of the particular program used to precisely reproduce selected clinical insertion-withdrawal movements of the rotating endodontic file. The file is inserted-withdrawn into, or from, a root canal or plastic practice block mounted on a bracket (C). The bracket is supported by a hinged stage (H) that is free to travel in the same plane as the file to simulate the clinician's resistance to any screwing-in forces that might result from the rotation of the file. The torsion exerted by the rotating file is measured by a torque transducer (E) and the pressure is measured by a pressure transducer (F). The pressure and torque are simultaneously viewed on a screen display (A). The resulting measurements in real time are based on graphical programming (B).

The most important information afforded by the simulator is not the means to just avoid breakage, but to minimize stress on the file, data that can distance the clinician from the possibility of failure while maximizing efficiency. Although the simulator can facilitate the formulation of technique design, it does not eliminate the need to understand the causes of file failure and the means for avoiding it.

19. What causes breakage?

In the most basic terms, the strength of a file is due to the cohesive forces between atoms. As forces that tend to deform a file are increasingly applied, the forces to separate atoms increase and their attractions decrease. Breakage occurs when the force of separation of the atoms exceeds the force of attraction.

On a larger scale, the molecules of a metal are arranged in patterns denoting its crystalline structure or grain, and the fracture of files usually can be characterized in

two ways. 1. One cause of fracture is accompanied by an apparent deformation of a file and the separation occurs as a result of *slippage between the planes* of its crystalline boundaries, most often due to the excessive forces of **torsion**. 2. Another fracture may occur *across the grain* of the metal with little or no apparent deformation. This type of fracture can be seen as a result of **fatigue** most often caused from the excessive stresses of the repetitive compression and tension that occurs during rotation of a file around a curvature. Of course, most fractures are a *combination* of different forces of separation.

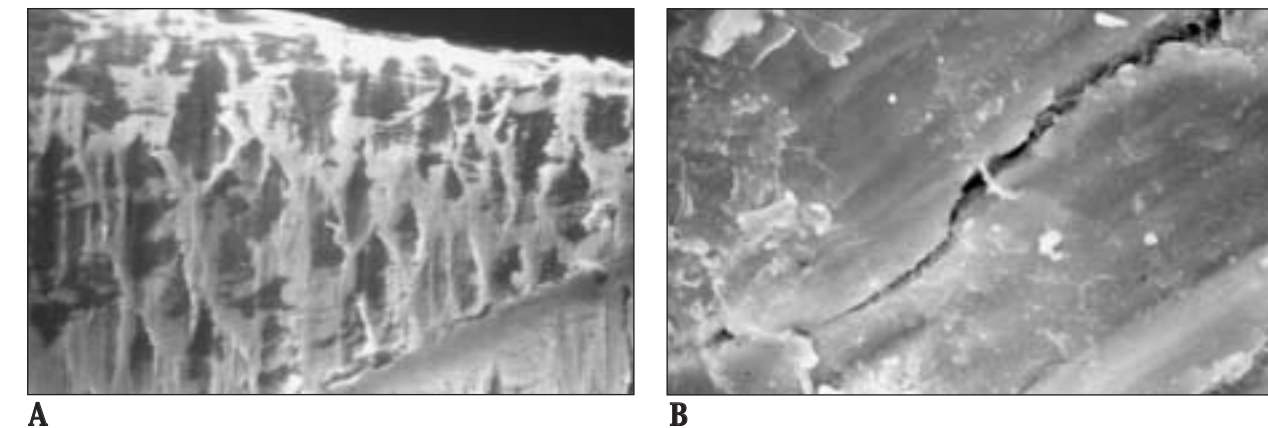


Fig. 43 Irregularities in the surface of the leading edge of a file shown in image (A) act as stress concentration points for potential torque or fatigue failure. The force to propagate the crack, shown in image (B), can be less than one half the amount of force that was required to form it. Examining the SEM images of the quality of manufacturing can provide valuable information for the probability for breakage.

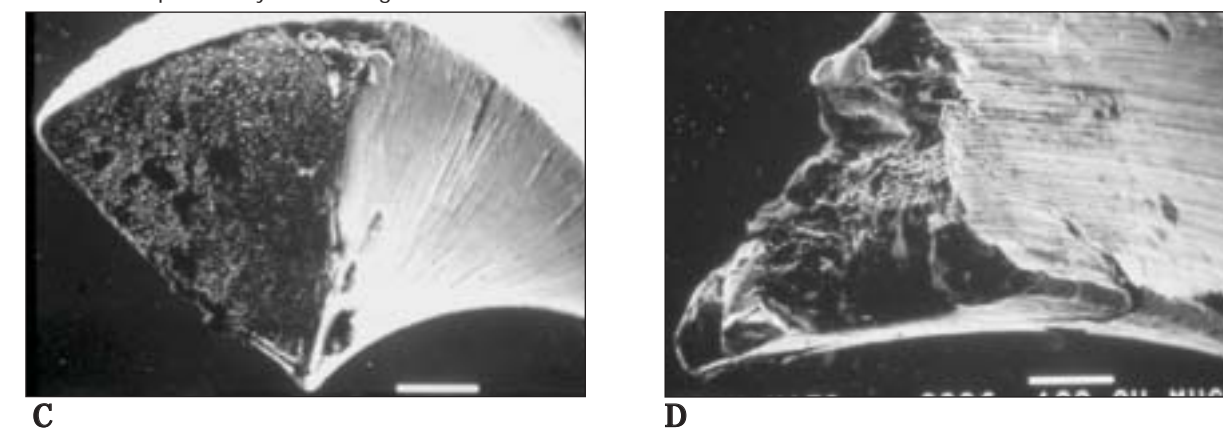


Fig. 44 The fracture across the grain of the metal of file (C) was probably the result of fatigue. Note the faults along the blade that are particularly susceptible to stress concentration. The fracture resulting from slippage between the crystalline boundaries in file (D) was probably the result of excessive twisting.

20. What is torsion?

Torsion is the axial force of being twisted when one part of a file rotates at a different rate than another part. Any distortion of a file that results from twisting, such as un-winding, is caused by stress of torsion. When a file resists rotation during hand instrumentation with conventional .02 tapered files, excessive torque can usually be tactilely perceived and file breakage can usually be avoided. On the other hand, even the use of torque limiting handpieces during rotary instrumentation does not provide the means for adjusting to varying circumstances, such as curvatures, the amount of file engagement, nor the diameters of the file that are engaged. Any excessive torque, as a result of these circumstances, is not always avoided by preset torque limitations. On the other hand, the torque limits can be set so low that file failure would be difficult, but effective canal enlargement would also be limited. Understanding the factors that cause exces-



Fig. 45 Abrasion of rotating accumulated debris against the canal wall increases torsion stress. The file efficiency is decreased when the debris prevents the cutting edge from engaging the canal wall. Limiting file engagement by using different file tapers, restricting the depth of file insertion, and frequent irrigation can minimize debris accumulation.

A file with a larger diameter can resist more torsion stress than one with a smaller diameter. The relationship varies very closely with the square of the file radius. Therefore, a size .25 mm diameter can resist as much as 50% more torque than a size .20 mm diameter having the same design, even though the difference in diameters is only .05 mm. The reason that the description direct relation between torque and radius squared is not used, is because the complicated variables in the crystalline structure of nickel titanium cause variations in the patterns of breakage.

sive torque is the most reliable means for avoiding torsion failure.

21. What causes torsion stress?

Torsion stress on a file is primarily the result of: (1) the force of cutting, specifically, how effectively a chip is formed and deflected from the wall of the canal, (2) the force of screwing-in due to the spiraled blades that become engaged in the wall of the canal without deflecting the chips that are formed, (3) the force of abrasion of the non-cutting surface of the file against the wall of the canal, (4) the force of distortion resulting from rotating in curvatures, and (5) the force the debris exerts on the wall of the canal as it accumulates in the flutes. Incorporating designs to reduce any of these forces increases the file's efficiency and is one approach to advance instrument design. Another approach is to provide designs that can accommodate greater forces, although the efficiency may remain unchanged.

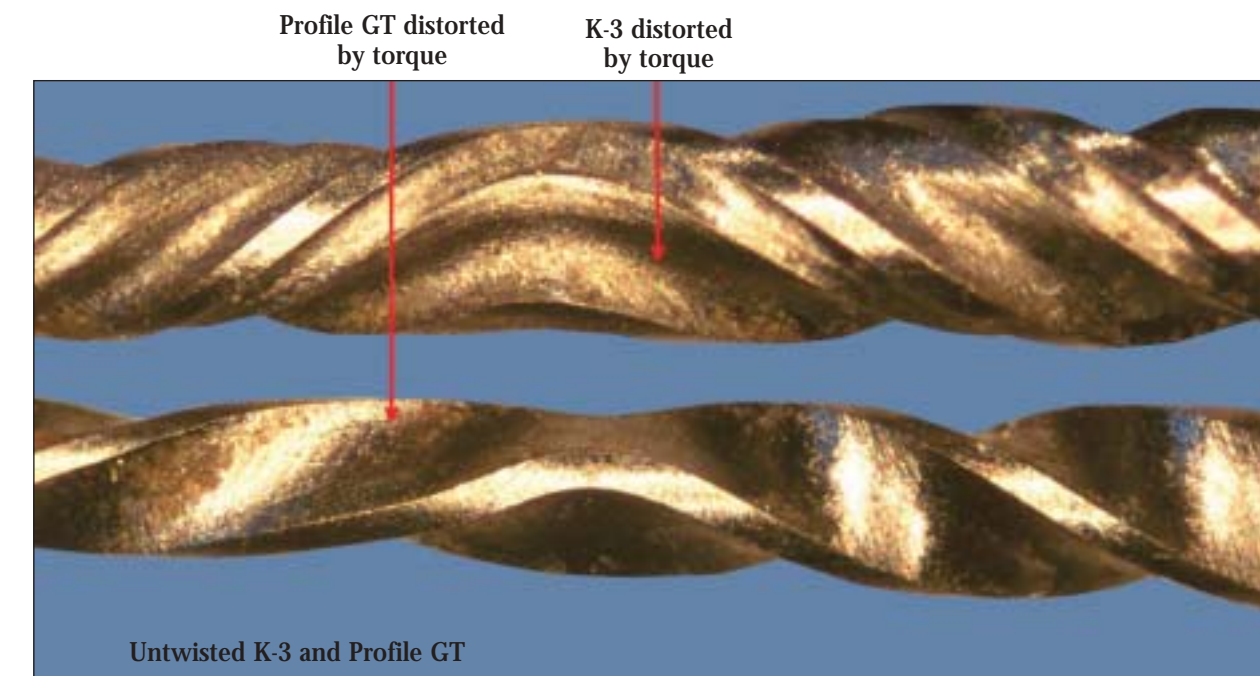


Fig. 46 Stainless steel has an effective modulus greater than that of Nickel Titanium (Table 5). The significant advantage of NiTi is its flexibility. Although NiTi's super-elastic ability to be distorted without permanent deformation is often cited as an attribute, this quality is of little consequence for a file rotating over 200 rpm. Some NiTi files may continue to twist for three complete revolutions after becoming bound in the canal without failing, compared to less than one revolution for stainless steel files, but without warning, this may mean less than one second of reaction time for the operator. A more meaningful relationship may be the torsion force required to fracture the file relative to its flexibility. Most files having the same size and taper usually distort in similar manners, however the force for distortion varies with file design.

22. How do torque requirements vary with the file diameters that we are likely to encounter in canals?

Smaller diameters of files are more likely to break with the application of torsion. However, binding of a small diameter can usually be detected and prevented if that part of the instrument that is likely to become bound is the only part that is engaged in the canal. When the difference between the largest and smallest diameters engaged is minimal, increases in torque are usually the result of increased applied pressure. **If the torque and pressure required for rotating the larger diameter portion of a file exceeds the torque required to break the**

smaller diameter portion, the file is particularly vulnerable when engaging the larger diameter since the stress on the smaller diameter cannot be detected.

Even establishing glide paths (canals or segments of canals enlarged to a diameter larger than the tip of a subsequent file to allow its passive entrance into that portion of the canal) is no assurance that a small tip size cannot be unknowingly pushed into, and become bound in, canal aberrations such as a fin, an anastomosis, a bifurcation, or auxiliary canal while the force necessary for engaging the larger diameter is applied. Glide paths are usually established with smaller more flexible files that follow the pathways of least resistance, usually that portion of the canal having the largest diam-

eter along its path. As larger tapered, less flexible files that have smaller tip sizes than the established glide path are used, the files can have a tendency to deviate from the glide path and can become bound in the

smaller canal aberrations. The file that is most likely to follow the canal is one that remains 360 degrees engaged, but that is assuming it has adequate flexibility and excessive torsion is avoided.

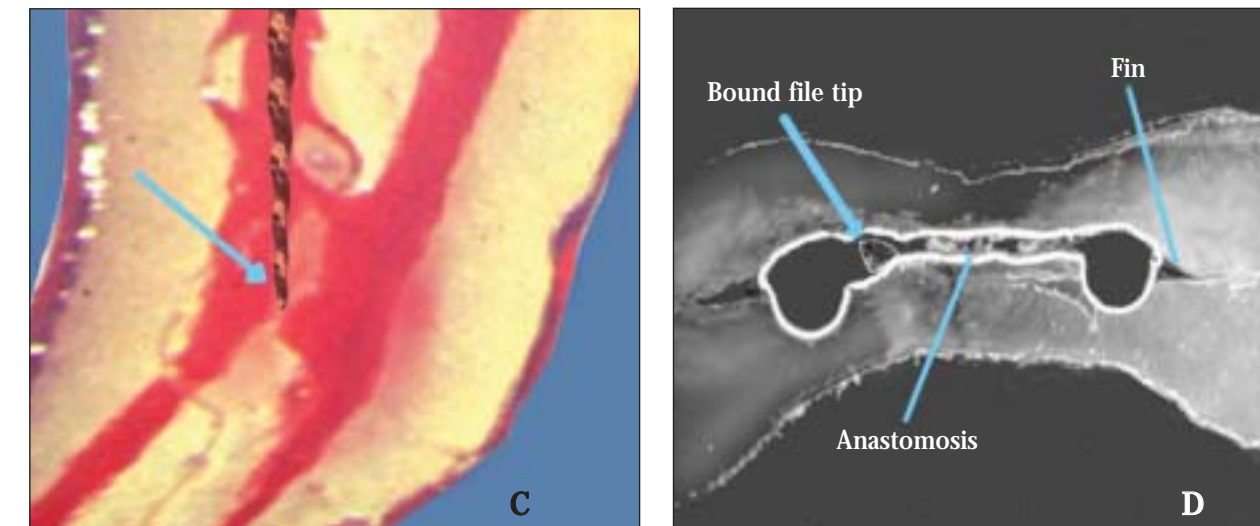
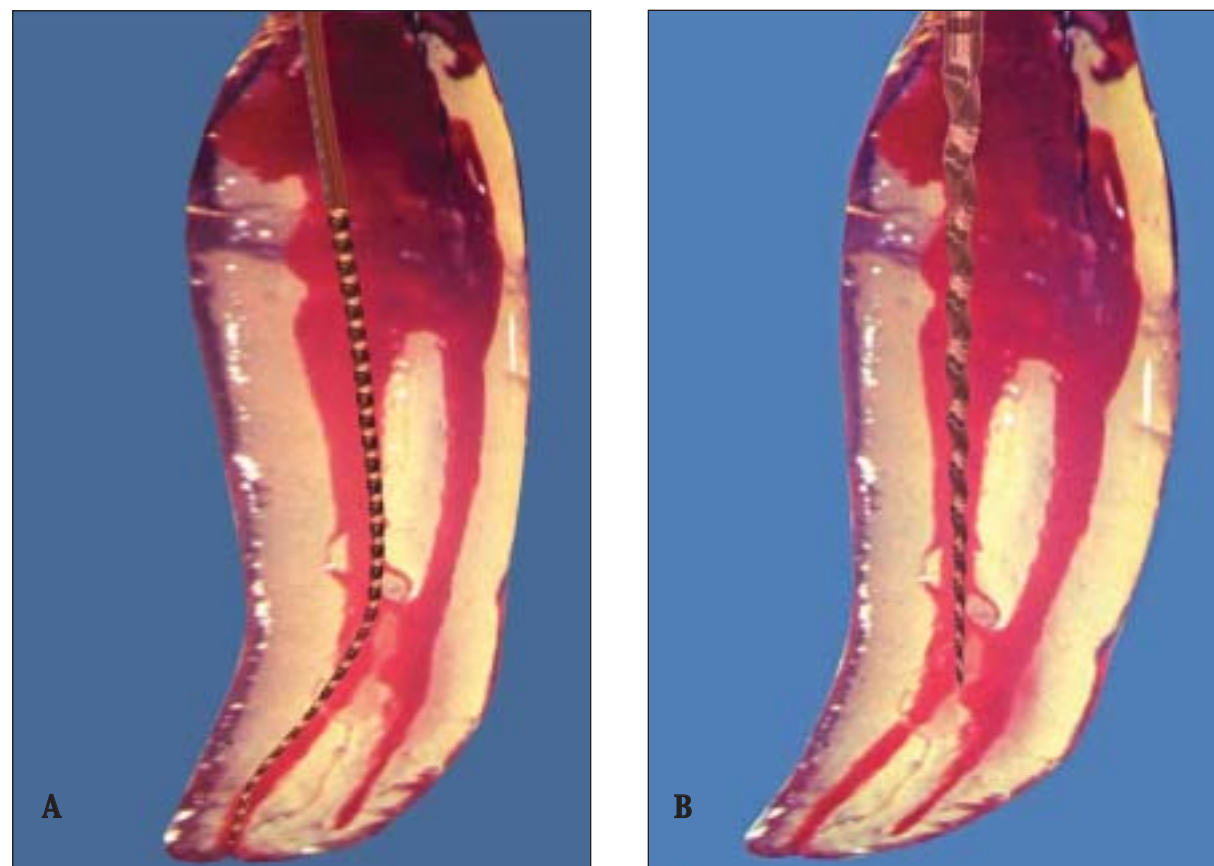


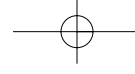
Fig. 47 A glide path, a minimally enlarged pathway for subsequent files to follow (A), is established with a small flexible file. However, as a larger tapered file with small tip size (B) is used, its greater rigidity can force its tip into a fin or anastomosis in a curvature (C & D) and can become bound. The torque required for the larger diameter part of the file to function could be sufficient to cause the bound tip to separate.



Fig. 48

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Establishing a pathway might not preclude a file of a different size and taper from following a different path than expected. The result can be a tip that becomes bound when the necessary torque and pressure is applied for a larger diameter and taper to function. The example at the left illustrates several aberration of the canal system in which a small file tip could have become bound.



Mastering Endodontic Instrumentation

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