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 could

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.

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, 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 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 continuous 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.

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.

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 complicated 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 provide 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

A

B

Fig. 1 Recommended techniques frequently are appropriate in simple anatomies (A.), however, more complex anatomies (B.) require greater consideration for file and technique design. (courtesy of P. Brown, Portola Valley, CA. and E. Herbranson, San Leandro, CA) were introduced 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.

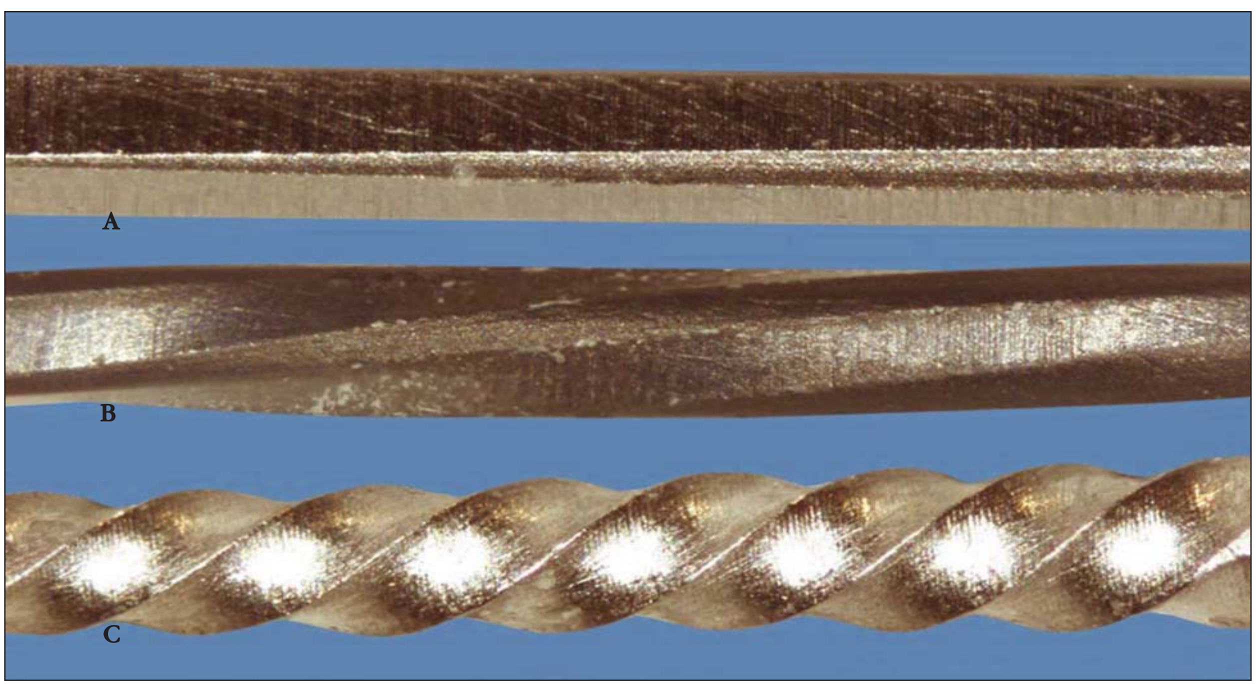
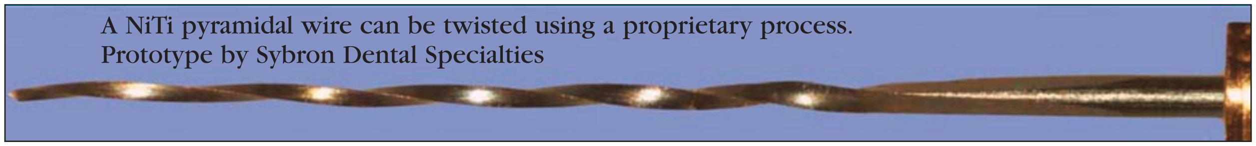


Fig. 2 A. A tapered pyramidal wire is used as a blank for forming a file.
B. Each end of the blank is stabilized and one end is rotated to twist a spiraled shape on the file's working surface.
C. Multiple rotations result in the familiar spiraled shape of the endodontic file.



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 elastic limit.**
8. **Plastic limit—The point at which the plastic deformed file breaks.**

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, 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/cm3	8.03 g/cm3
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.)

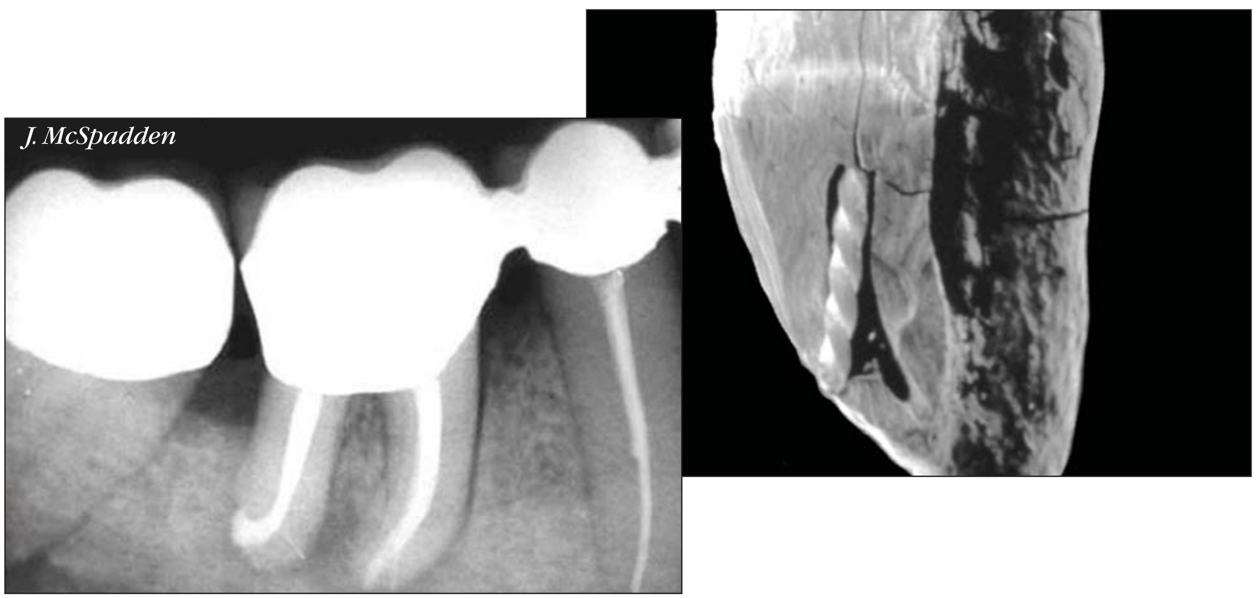


Fig. 6 Although stainless steel files could negotiate abrupt apical curvatures (left image), canal transportation could easily occur due to the file's lack of flexibility. Note the transportation that occurred in the apical curvature that occurred during instrumentation with stainless steel files. "Zipping"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