Fifth-generation technology in endodontics: The shaping movement

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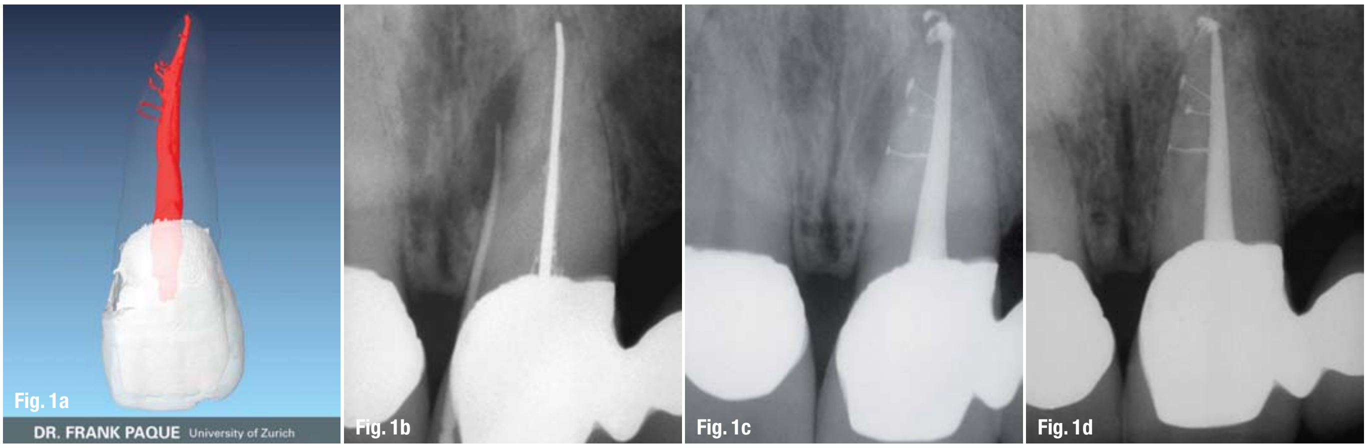


Fig. 1a_A µCT image of a maxillary central incisor demonstrating a root-canal system with multiple portals of exit.
Fig. 1b_A pre-op radiograph revealing an endodontically failing anterior bridge abutment with a draining fistula.
Fig. 1c_This post-op retreatment image emphasises that shaping canals promotes 3-D cleaning and filling of root-canal systems.
Fig. 1d_A 25-year recall radiograph demonstrating osseous healing.

_Since the beginning of modern-day endodontics, there have been numerous concepts, strategies, and techniques for preparing canals. Over the decades, a staggering array of files have emerged for negotiating and shaping them. In spite of the design of the file, the number of instruments required and the surprising multitude of techniques advocated, endodontic treatment has typically been approached with optimism for probable success.

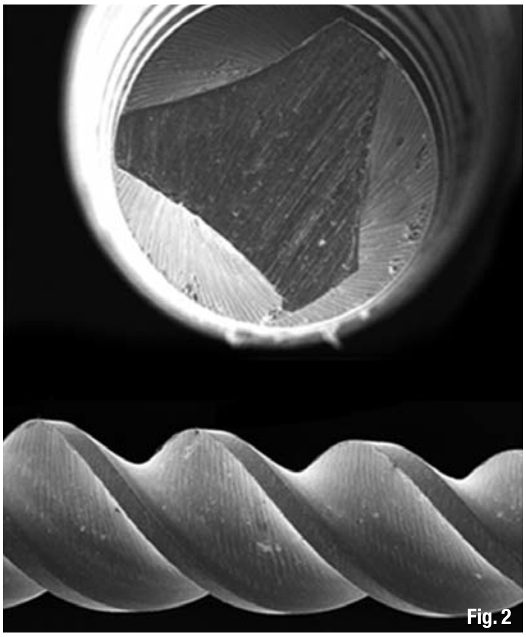
The breakthrough in clinical endodontics progressed from utilising a long series of stainless-steel (SS) hand files and several rotary Gates-Glidden drills to the integration of nickel-titanium (NiTi) files for shaping canals. Regardless of the methods, the mechanical objectives were brilliantly outlined by Dr Herbert Schilder almost 40 years ago.[1] When performed properly, they promote the biological objectives for shaping canals, 3-D disinfection, and filling root-canal systems (Figs. 1a–d). The purpose of this article is to identify and compare how each new generation of endodontic NiTi shaping files has helped to advance canal preparation methods. More importantly, it will discuss a new file system and describe a clinical technique that combines the most successful design features from the past with today's innovations.

_NiTi shaping movement

In 1988, Walia proposed nitinol, a NiTi alloy for shaping canals, which is two to three times more flexible than SS.[2] A game-changing feature of files manufactured from NiTi was that curved canals could be mechanically prepared through continuous rotary motion. By the mid-1990s, the first commercially available NiTi rotary files were launched to the market.[3] The following overview is a mechanical classification of each generation of file systems. Rather than identify the myriad of available cross-sections, files will be characterised as having either a passive or an active cutting action.

First generation

In order to appreciate the evolution of NiTi mechanical instruments, it is useful to know that first-generation NiTi files in general have passive cutting radial lands and fixed tapers of 4 and 6 per cent over the length of their active blades (Fig. 2).[4] This generation of technology required numerous files for achieving the preparation objectives. From the mid to late 1990s, GT files (DENTSPLY Tulsa Dental Spe-



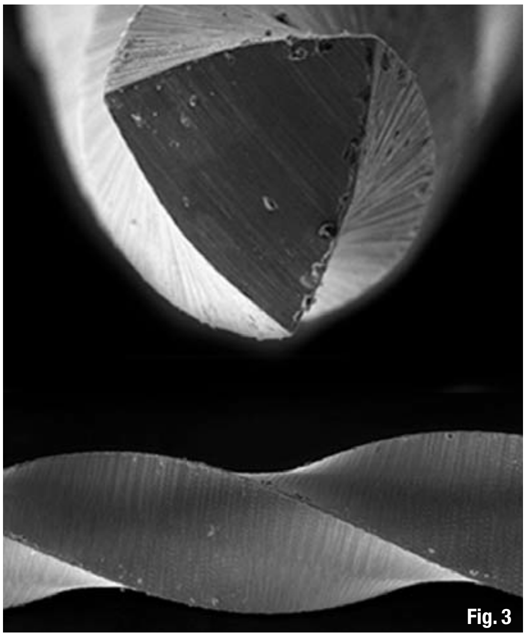


Fig. 2_Two scanning electron microscope images showing the cross-sectional and lateral views of a passively cutting radial-landed file.

Fig. 3_Two scanning electron microscope images showing the cross-sectional and lateral views of an active file with sharp cutting edges.

cialties) became available that provided a fixed taper on a single file of 6, 8, 10, and 12 per cent.[5] The most important design feature of first-generation NiTi rotary files was passive radial lands, which helped a file to stay centred in canal curvatures during work.

Second generation

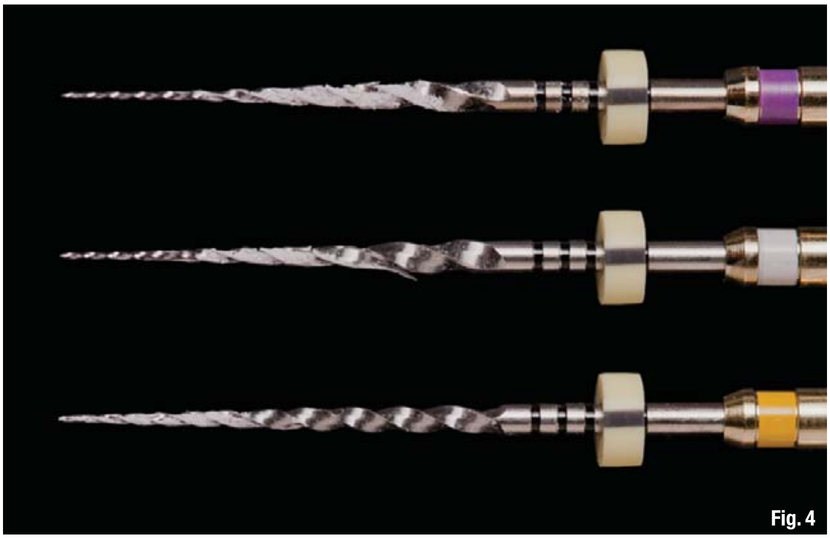
The second generation of NiTi rotary files reached dental markets in 2001.[6] The one feature that distinguished this generation of instruments from previous ones is that they have active cutting edges and thus require fewer instruments to prepare a canal fully (Fig. 3).

In order to prevent taper lock and the resultant screw effect associated with both passive and active fixed-taper NiTi cutting instruments, EndoSequence (Brasseler) and BioRaCe (FKG Dentaire) provided file lines with alternating contact points.[7] Although this feature is intended to mitigate taper lock, these file lines still have a fixed-taper design over their active portions. The clinical breakthrough occurred when ProTaper Universal (DENTSPLY Tulsa Dental Specialties) utilised multiple tapers of an increasing or decreasing percentage on a single file. This revolutionary, progressively tapered design limits each file's cutting action to a specific region of the canal and affords a shorter sequence of files to produce deep Schilderian shapes safely (Fig. 4).[8] During this time, manufacturers began to focus on other methods that could increase the resistance to file separation. Some manufacturers, for example, electropolished their files to remove surface irregularities caused by the traditional grinding process. However, it has been observed clinically and reported scientifically that electropolishing dulls the sharp cutting edges. As such, the perceived advantages of electropolishing were offset by the undesirable inward pressure required to advance a file to length. Excessive inward pressure, especially when utilising fixed-taper files, promotes taper lock, the screw effect and excessive torque on a rotary file during work.[9] In order to offset deficiencies in general, or inefficiencies resulting from electropolishing, cross-sectional designs have increased and rotational but dangerous speeds are advocated.

Third generation

Improvements in NiTi metallurgy became the hallmark of what may be considered the third generation of mechanical shaping files. In 2007, some manufacturers began to focus on using heating and cooling methods for the purpose of reducing cyclic fatigue in and improving safety with rotary NiTi instruments

Fig. 4_The ProTaper shaping files cut dominantly in their coronal and middle one-thirds, whereas the finishing files cut primarily in their apical one-thirds.



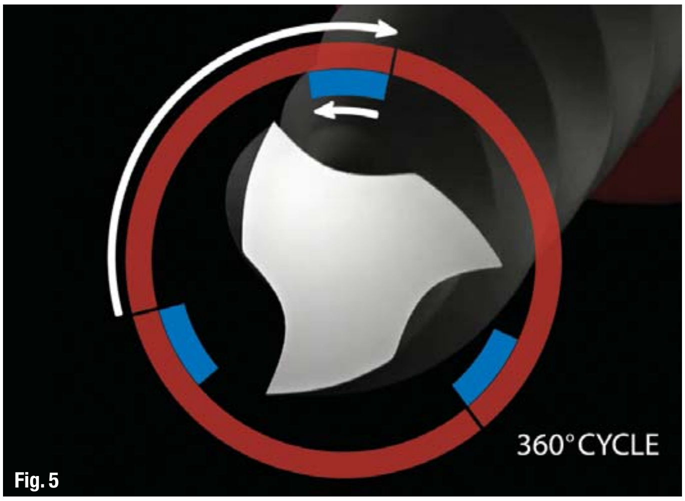


Fig. 5

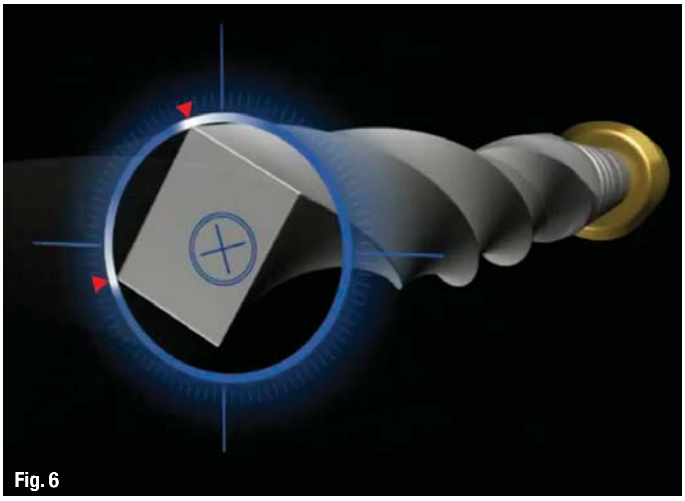


Fig. 6

Fig. 5_A WaveOne reciprocating file utilises unequal CCW and CW angles to improve efficiency, inward progression and removal of debris from the canal.

Fig. 6_A cross-section of a ProTaper Next file. Note that an offset mass of rotation desirably reduces file engagement, provides greater space debris, and improves flexibility.

used in canals that are more curved.[10] The intended phase-transition point between martensite and austenite was identified as producing a more clinically optimal metal than NiTi. This third generation of NiTi instruments significantly reduced cyclic fatigue and, hence, broken files. Some examples of brands that offer heat treatment technology are Twisted Files (SybronEndo), HyFlex (Coltène/Whaledent), and GT, Vortex, and WaveOne (all DENTSPLY Tulsa Dental Specialties).

Fourth generation

Another advancement in canal preparation procedures was achieved with reciprocation, a process that may be defined as any repetitive up-and-down or back-and-forth motion. This technology was first introduced in the late 1950s by a French dentist. Recent brands that use equal clockwise (CW) and counterclockwise (CCW) degrees of rotation in their movement are M4 (SybronEndo), Endo-Express (Essential Dental Systems), and Endo-Eze (Ultradent). Compared with full rotation, a reciprocating file requires more inward pressure to progress and will not cut as efficiently as a rotary file of the same size. It is also more limited in removing debris from the canal. Based on these experiences, innovation in reciprocation technology led to a fourth generation of instruments for shaping canals. This generation of instruments and its related technology have fuelled the hope again for a single-file technique.

ReDent Nova introduced the Self Adjusting File. This has a compressible open-tube design that is purported to exert uniform pressure on the dentinal walls, regardless of the cross-sectional configuration of the canal. It is mechanically driven by a handpiece that produces both a short 0.4 mm vertical amplitude stroke and vibrating movement with constant irrigation.[11] Another emerging single-file technique is One

Fig. 7_The five ProTaper Next files. Most canals in posterior teeth can be optimally shaped using two or three instruments.

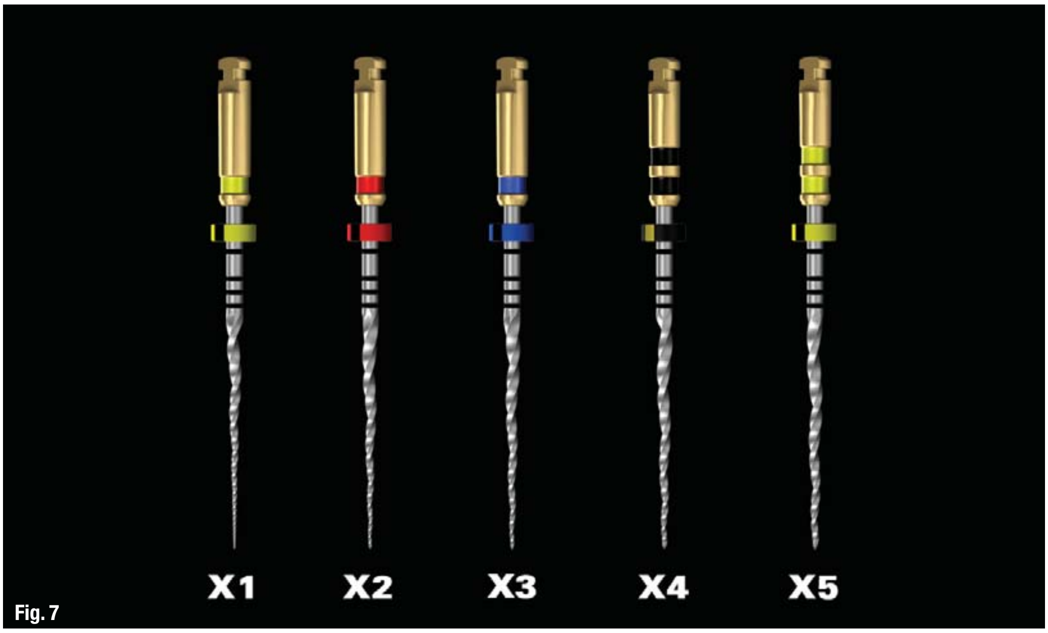


Fig. 7

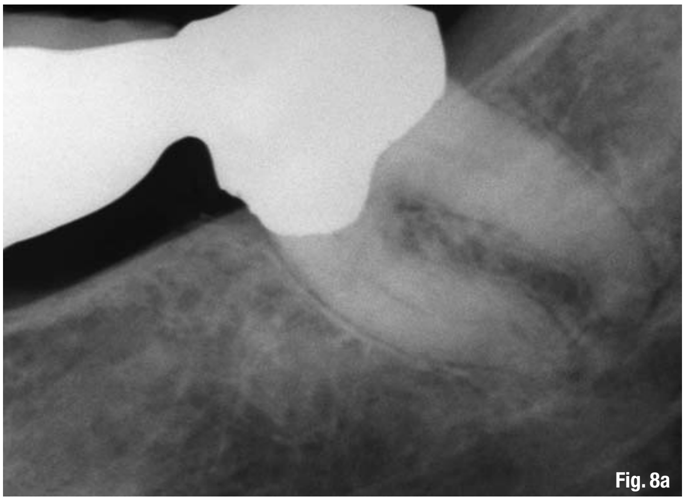


Fig. 8a

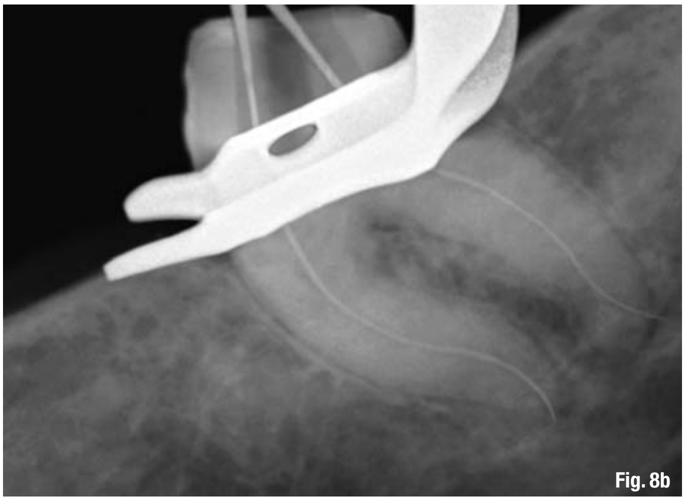


Fig. 8b

Fig. 8a_A radiograph showing an endodontically involved posterior bridge abutment. Note the orientation of the prosthesis to the underlying roots.

Fig. 8b_A working image showing coronal disassembly, isolation and #10 files traversing through canals that exhibit curvatures and recurvatures.

Shape (MICRO-MEGA), which will be mentioned again in the section on the fifth generation of instruments.

By far the most popular single-file concepts are DENTSPLY's WaveOne and RECIPROC (VDW). WaveOne combines the best design features of the second and third generation of files, complemented by a reciprocating motor that drives any given file in unequal bidirectional angles. The CCW engaging angle is five times the CW disengaging angle and was designed to be lower than the elastic limit of the file. After three CCW and CW cutting cycles, the file will have rotated 360 degrees, or one full circle (Fig. 5). The reciprocating movement allows a file to progress more readily, cut efficiently, and remove debris from the canal effectively.[12]

Fifth generation

The latest generation of shaping files have been designed in such a way that the centre of mass or the centre of rotation, or both, are offset (Fig. 6). When in rotation, files that have an offset design produce a mechanical wave of motion that travels along the active length of the file. Like the progressively percentage tapered design of ProTaper files, this design minimises the engagement between the file and dentine.[13] In addition, it enhances the removal of debris from a canal and improves flexibility along the active portion of the file. The advantages of an offset design will be discussed later in this article. Commercial examples of file brands that offer variations of this technology are Revo-S, One Shape (both MICRO-MEGA) and ProTaper Next (DENTSPLY Tulsa Dental Specialties/ DENTSPLY Maillefer). Currently, the simplest, safest, and most efficient file systems combine the most proven design features with the most recent technological advancements. The following will offer a brief technical overview of the ProTaper Next rotary file system.

_ProTaper Next

There are five ProTaper Next (PTN) files in different lengths available for shaping canals: X1, X2, X3, X4 and X5 (Fig. 7). These files have yellow, red, blue, double black, and double yellow identification rings on their handles, corresponding to sizes 17.04, 25.06, 30.07, 40.06, and 50.06. The tapers are not fixed over the active portion of the files. Both the X1 and X2 files have an increasing and decreasing percentage taper on a single file, whereas the X3, X4, and X5 files have a fixed taper from D1 to D3, then a decreasing percentage taper over the rest of their active portions.

PTN files are the convergence of three significant design features, which include a progressive percentage taper on a single file, M-Wire technology, and the fifth generation of continuous improvement, the offset design. As an example, the X1 file has a centred mass and axis of rotation from D1 to D3, whereas it has an offset mass of rotation from D4 to D16. Starting at 4 per cent, the X1 file has ten increasing percentage tapers from D1 to D11, whereas there are decreasing percentage tapers from D12 to D16 to enhance flexibility and conserve radicular dentine during shaping.

PTN files are used at 300 rpm and a torque of 2–5.2 Ncm, based on the method used. However, the authors prefer a torque of 5.2 Ncm, as this level of torque has been validated as profoundly safe if clinicians perform meticulous glide path management procedures and utilise a deliberate outward brushing motion as they progressively shape canals.[14]

_ProTaper Next shaping technique

In the PTN shaping technique, all files are used in exactly the same way, and the sequence always follows the ISO colour progression and is always the same regardless of the length, diameter, or curvature of a canal. The PTN shaping technique is extraordi-

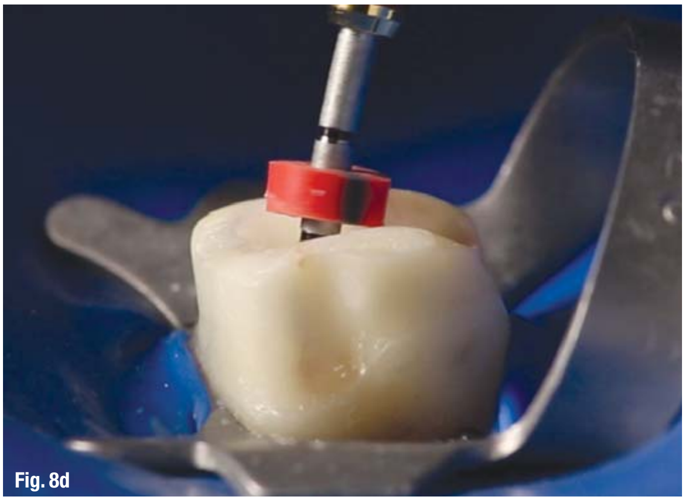


Fig. 8c_A video grab image showing a mechanical wave of motion travelling along the active portion of a PTN X1 shaping file.
Fig. 8d_A video grab image showing a PTN X2 file at length in the mesiobuccal root-canal system.

narily safe, efficient and simplistic when attention is focused on access preparation and glide path management. As required for any shaping technique, straight-line access to each orifice is emphasised. Attention is directed to flaring, flattening, and finishing the internal axial walls. For radicular access, the original ProTaper system offers the auxiliary shaping file SX, which is used in a brushing motion on the outstroke to pre-flare the orifice, eliminate triangles of dentine, relocate the coronal-most aspect of a canal away from external root concavities, or produce more curvature if desired.

Perhaps the greatest challenge in performing endodontic treatment is to find, follow, and predictably secure any given canal to its terminus. Negotiating and securing canals with small manual files requires a mechanical strategy, skilful touch, patience and dedication.

A small hand file is used initially to scout, expand, and refine the internal walls of the canal. Once the canal can be reproduced manually, a dedicated mechanical glide path file may be used to expand the working width in preparation for shaping procedures.[15] For clarification, a canal is secured when it is empty and has a confirmed, smooth, and reproducible glide path. With an estimated working length and in the presence of a viscous chelator, a #10 file is inserted into the orifice. Then it is determined whether the file moves towards the terminus of the canal easily. In shorter, wider, and straighter canals, a #10 file can usually be inserted to the desired working length. Once a #10 file has been confirmed to be loose at length, the glide path may be further enlarged with either a #15 hand file or dedicated mechanical glide path files, such as PathFiles (DENTSPLY Tulsa Dental Specialties). The glide path just described confirms that sufficient existing space is available to initiate mechanical shaping procedures with the PTN X1 file.

In other instances, certain endodontically involved teeth have roots with canals that are longer, narrower and more curved (Fig. 8a). In these situations, often a #10 file will not go to length initially. Generally, there is no need to use #6 and/or #8 hand files in an effort to reach the terminus of the canal immediately. Rather, the size #10 hand file simply has to be worked gently within any region of the canal until it is completely loose. PTN files can be used to shape any region of a canal that has a smooth and reproducible glide path. Regardless of the glide path and shaping sequence, the objective is to negotiate the entire length of the canal, establish working length, and confirm apical patency (Fig. 8b). The canal is secured and a glide path is verified when a #10 file is loose at length and can reproducibly slip, slide and glide over the apical one-third of the canal.

Once the canal has been secured, the access cavity is flushed voluminously with a 6% solution of NaOCl. Shaping can then commence, starting with the PTN X1 file. It should be noted that PTN files are never used with an inward pumping or pecking motion. Rather, they are used with an outward brushing motion. This method will enable any PTN file to move inward passively, follow the glide path and progress towards the working length. The X1 file is carried through the access and inserted passively into a pre-flared orifice and secured canal. Before encountering resistance, deliberate brushing on the outstroke has to begin immediately (Fig. 8c). Brushing creates lateral space and enables this file to progress a few millimetres inward. A brushing action serves to improve contact between the file and dentine, especially in canals that exhibit irregular cross-sections or deviations off their rounder parts.

Progression with the PTN X1 file through the body of the canal has to be continued. After every few millimetres of file progression, the mechanical shaping file has to be removed to inspect and clean its flutes.

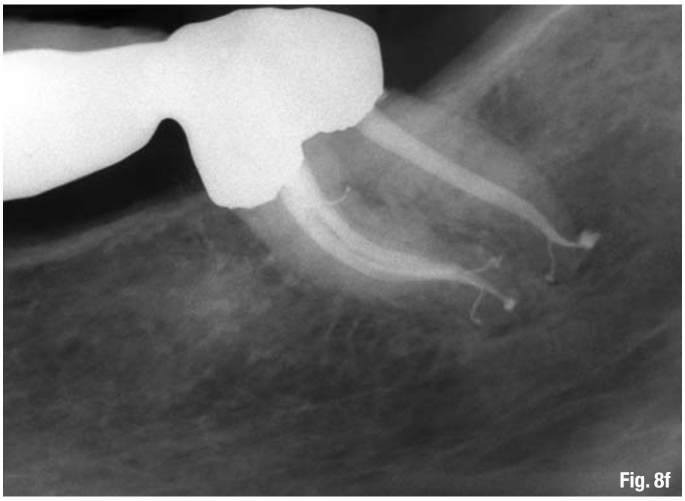


Fig. 8e_A video grab image showing a PTN X3 file at length in the distal root-canal system.
Fig. 8f_A radiograph showing the provisional bridge, flowing shapes, and the importance of treating root-canal systems.

Before reinserting the X1 file, it is critical to irrigate and flush out gross debris, recapitulate with a #10 file to break up residual debris and move the debris into solution, then re-irrigate to liberate this debris.

In one or more passes, progression with the X1 file should be continued until the working length is reached. In order to promote the mechanical objectives, clinicians are advised to always irrigate, recapitulate and then re-irrigate after removing any mechanical shaping file. The PTN X2 file then has to be selected and used to begin to advance inward. Before encountering resistance, it has to be brushed against the dentinal walls, which will enable the X2 file to advance inward passively and progressively. The X2 file will follow the path of the X1 file easily, shape progressively, and advance incrementally towards the working length. If this file becomes stuck and ceases to move inward, it has to be removed and cleaned. Flutes have to be inspected as well before irrigation, recapitulation and re-irrigation. Progression with the X2 file is continued until the working length is reached. It may take one or more passes, depending on the length, width, and curvature of the canal (Fig. 8d).

Once the PTN X2 file has reached the working length, it is removed. The shape may be confirmed as finished when the apical flutes of this file are visibly loaded with dentine. Alternatively, the size of the foramen may be gauged with a 25.02 NiTi hand file. When the #25 hand file is snug at length, the shape is finished. If the 25.02 hand file is loose at length, it simply means that the foramen is larger than 0.25 mm. In this instance, the foramen may be gauged with a 30.02 NiTi hand file.

If the #30 hand file is snug at length, the shape is finished. However, if the #30 hand file is short of the working length, proceed to the PTN X3 file, following the method just described for the PTN X1 and X2 files.

The vast majority of canals will be optimally shaped after using either the PTN X2 or X3 files (Fig. 8e). The PTN X4 and X5 files are primarily used to prepare and finish larger-diameter canals. When the apical foramen is determined to be larger than a 50.06 X5 file, other recognised shaping methods may be utilised to finish these larger canals, which are typically less curved and more straightforward to prepare. It is important to appreciate that meticulously secured canals promote shaping, 3-D cleaning, and filling of root-canal systems (Fig. 8f).

_Discussion

From a clinical standpoint, the PTN rotary system is a convergence of the most proven and successful generational designs, coupled with the most recent advances in critical path technology. This brief discussion will consider the influence of design on performance.

The most successful generational design is the mechanical concept of utilising a progressive percentage taper on a single file. The patent-protected ProTaper Universal NiTi rotary file system utilises an increasing or decreasing percentage taper on a single file. This design feature serves to minimise the contact between a file and dentine, which decreases the risk of taper lock and the screw effect while increasing efficiency.[8] Compared with a fixed-taper file of similar size, a decreasing percentage taper design, strategically improves flexibility, limits the shaping in the body of the canal, and conserves two-thirds of coronal dentine.

Following this mechanical design, PTN also features progressive tapers on a single file. This design has contributed to the ProTaper system becoming the top-selling file in the world, the file choice of endodontists, and the leading system taught to undergraduate students in dental schools internationally.[16]

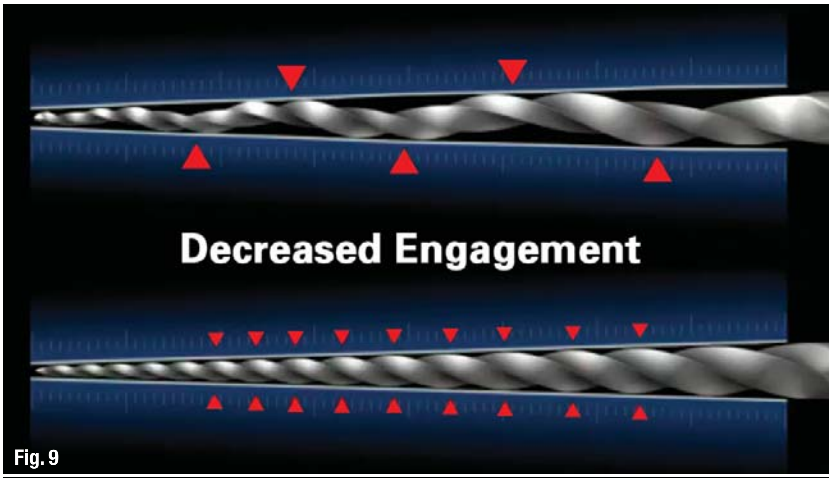


Fig. 9

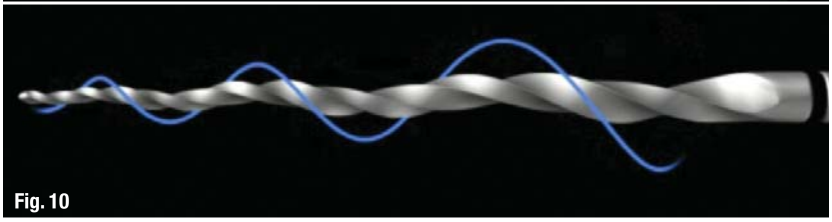


Fig. 10

Fig. 9_A PTN file has a progressively tapered and offset design. These features minimise engagement, maximise debris removal and improve flexibility. In contrast, the bottom image shows a fixed-taper file with a centred mass and axis of rotation.

Fig. 10_Similar to a sinusoidal wave, a rotating PTN file produces a mechanical wave of motion, or a swaggering effect, along its active portion.

Another critical design feature that is intended to benefit certain brand lines of mechanical shaping files is metallurgy. Although NiTi files have been shown to be two to three times more flexible than SS files of the same size, additional metallurgical benefits using heat treatment have been identified. Research and development has focused on heating and cooling traditional NiTi, either pre- or post-machining. Heat treatment aims to create a more optimal phase-transition point between martensite and austenite.

It should be appreciated that the best transition point is dependent on the cross-section of the file. Research has shown that M-Wire, a metallurgically improved version of NiTi, reduces cyclic fatigue by 400 per cent when comparing files of the same D0 diameter, cross-section, and taper.[17] This third-generational advancement is a strategic improvement to the overall clinical safety and performance of the PTN rotary file system. The third design feature of PTN is related to its offset cross-sectional design. There are three major advantages when the mass of rotation of a continuously rotating file is offset:[13]

1. An offset design generates a travelling mechanical wave of motion along the active portion of a file. This swaggering effect minimises the engagement between the file and dentine compared with the action of a fixed-taper file with a centred mass of rotation (Fig. 9). Reduced engagement limits taper lock, the screw effect, and torque with any given file.
2. A file with an offset design affords more cross-sectional space for enhanced cutting, loading and removal of debris from a canal compared with a file with a centred mass and axis of rotation (Fig. 10). Many instruments break as a result of excessive debris packed between the cutting flutes over the active portion of a file. More importantly, an offset file design decreases the probability of laterally compacting debris and blocking the root-canal system (Fig. 6).
3. A shaping file with an offset mass of rotation will generate a mechanical wave of motion analogous to the oscillation along a sinusoidal wave (Fig. 10). Owing to this design, any PTN file can cut a larger envelope of motion compared with a file of similar size with a symmetrical mass and axis of rotation (Fig. 6). The clinical advantage of this is a smaller and more flexible PTN file that can prepare the canal to the same size as a larger and stiffer file with a centred mass and axis of rotation can (Fig. 9).

_Conclusion

Each new generation of shaping files was intended to offer improvements on previous generations. Being a fifth-generation system, PTN was designed to bring together the most proven performance features and the most recent technological advancements. The system should simplify rotary shaping procedures by eliminating the number of files typically used to shape canals and through the so-called hybrid techniques. Clinically, PTN files fulfil the three sacred tenets for shaping canals, which are safety, efficiency and simplicity. Scientifically, further evidence-based research is needed to validate the benefits of this system.

_Acknowledgement

The authors would like to recognise Dr Michael J. Scianamblo for his work in the field of critical path technology, which led to the development of ProTaper Next._

Editorial note: This article originally appeared in Dentistry Today in April 2013. A list of references is available from the publisher. Drs Ruddle, Machtou, and West have a financial interest in the products they design and develop, which includes the ProTaper Universal system.

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