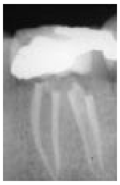

CLINICAL ARTICLE

The standardized-taper root canal preparation – Part 1. Concepts for variably tapered shaping instruments

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Abstract

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Aim To introduce the concept of variable taper instruments for predictable and ergonomic root canal preparation, and demonstrate the design features of Greater Taper files.

Summary Optimal root canal shaping is difficult to practice and teach with traditional instruments. Instrument sequences are complex, with up to 18 instruments and 63 procedural stages, providing almost limitless scope for poor results and iatrogenic error.

In the first of six articles, Dr Buchanan describes the Variable Taper concept, which grew from such frustrations, and represents a new concept in file design. Milled from NiTi alloys in tapers of 0.06, 0.08, 0.10 and 0.12 mm mm^{-1}, with accessory files for wide canals, their design embodies the key shaping features of adequate coronal enlargement, full deep shape, and predictable apical resistance form case after case. The ease and simplicity of their use is described, and enhanced cleaning and obturation outcomes discussed in relation to their unique design features.

Key learning points

- Canal preparation is difficult to practice and teach with traditional K-files and Gates Glidden drills.
- Variable Taper files are designed to offer the optimal preparation features of adequate (not excessive) coronal enlargement, full deep shape, and apical resistance form in a simple instrument sequence.
- Variable Taper technique is simple to master, and offers predictable cleaning and obturation outcomes, even in inexperienced hands.

Keywords: canal preparation, cleaning and shaping, NiTi, variable taper files.

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Figure 1 Mandibular molar with severe curvature of the mesial root. Note the lateral canals in the apical one third of the distal root.

Introduction

The birth of a concept

When I was an undergraduate dental student, I was taught the advantages of tapered root canal preparations and how to create them with serial step-back shaping routines using traditional K-files and Gates-Glidden burs. It took me 2 years of postgraduate training and a further 2 years of private practice to get proficient in using this technique, but the results were worth the steep learning curve and the considerable chairside time needed (Fig. 1).

What I did not fully take into account was the challenge of teaching a technique with 63 steps and 18 instruments for the next 20 years. That was hard! For me, the last straw came in 1986, when an attendee of one of my full-day lectures approached and said he now understood the advantages of tapered preparations, but was totally confused about the technique needed to accomplish this shaping objective. Then, in an honest moment, this young dentist said that he felt he now knew less about shaping root canals than he did before my lecture!

With that serious knock on the head, it occurred to me that these root canal shaping procedures were complex because we were using relatively nontapered instruments to create tapered root canal shapes. What would it be like, I thought, to use variably tapered files that possessed the final canal shape on a single instrument?

The logical answer seemed to be that variably tapered shaping instruments would allow ideal predefined canal shapes with fewer instruments, fewer procedural steps, and a shorter learning curve for clinicians. Most importantly, it would provide for the standardization of tapered root canal preparations.

The idea was simple, but little did I realize how difficult it would be to develop the technology. Surprisingly, it would take more than a decade to bring that concept to its full expression as a system-based collection of endodontic instruments, material, and techniques. Twelve years later, university-based research has revealed the efficacy of this significant departure in shaping concept and technique.

Problems with traditional preparations

Once a root canal has been negotiated to its terminus and its length determined, the only thing standing in the way of thoroughly cleaning and filling it is the need for ideal shape. Without adequate shape, the irrigation devices available at this time cannot adequately clean complex root canals to their full apical and lateral extents (Coffae & Brilliant 1975). Likewise, our obturation results, regardless of the filling technique used, are almost wholly dependent upon the shape into which the filling materials are placed (Schilder 1974).

Figure 2 Mandibular molar with a coronally positioned strip perforation in each root and an apical perforation in the mesial.

Unfortunately, however, shaping root canals has been the most dangerous, difficult, and time-consuming aspect of conventional endodontic treatment; the frequent occurrence of inadequate or iatrogenic shapes in root canals treated over the past 20 years provides us with ample evidence.

Coronal enlargement has often been excessive, resulting in short-term loss of teeth when strip perforations occurred. Almost any iatrogenic result in the apical third of a root can be repaired predictably, surgically or nonsurgically. This is not so in the cervical third of roots (Fig. 2). Even with the phenomenal new perforation repair material, mineral trioxide aggregate (MTA, Tulsa Dental Products, Tulsa, USA) strip perforation of a molar root dramatically lowers that tooth's long-term prognosis. This, in fact, is the worst possible outcome for conventional endodontic treatment and must be avoided at any cost.

The more common, but less noticed, failures are long-term losses due to vertical fracture when roots are not perforated but unduly weakened. I have heard endodontists say, 'The root is mine!' meaning that the shapes we create in root canals when we treat patients are our business. But the roots are not ours. They are the patients' roots, and they may have to function for 50 or 60 years. Aside from coronal leakage, root fractures are the competent endodontist's greatest threat to long-term clinical success.

Shapes achieved by the use of relatively nontapered coronal enlargement tools, such as Gates Glidden or Peezo burs, are at best, irregular. Whilst experienced clinicians can learn how to use these cutting instruments safely, neophytes are destined for painful learning experiences (Fig. 3).

A less disastrous but frequent outcome is the inadequate cleaning and filling that routinely results from ineffective shaping in the apical half of the canal. Two classic preparation deficits are seen in this region:

- 'Anaemic' enlargement in the middle third (not enough deep shape), and
- Over-enlargement of the apical preparation (Fig. 4).

Inadequate shape in the middle third of canals is a setup for poor cleaning, as irrigating solutions cannot be introduced to the full apical and lateral extents of root canal systems. Obturation results are also degraded, especially in the apical third. More than half of all cone-fitting and condensation problems may be caused by 'anaemic' deep shape due to premature binding of cones and condensation devices (including Thermafil carriers).

Apically, the classic error is to over-enlarge the terminal diameter of the canal. Taking successively larger files to the same length in a root canal is a setup for apical lacerations, even when using the Balanced Force technique (Roane *et al.* 1985). If the working length is too short (1–2 mm), the canal is often ledged, causing poor apical cleaning and a short fill. If the working length is even slightly in error beyond the terminus, all working length has been lost.

Figure 3 Maxillary molar with grossly over-enlarged canals. The student did not understand the step-back concept that each larger GG bur is to be used less deep in the root.

Figure 4 Maxillary incisor with severe apical laceration of the canal form. This can result from a length misdetermination as small as 0.5 mm when an apical ledge-form or 'stop' preparation is attempted.

We need just the opposite shaping outcome, a conservative shape at the orifice level, full deep shape at the junction of the middle and apical thirds, and a terminal canal diameter that is as small as is possible. In other words, a tapered canal preparation with controlled coronal enlargement (Fig. 5).

Advantages of tapered preparations

Research and clinical experience have demonstrated many advantages of tapered root canal preparations over the commonly taught 'apical stop preparation.' These advantages include improved cleansing ability (Ram 1977), dramatically enhanced apical control of instruments (Schilder 1974), less dependence on exact length determination, more dependable apical resistance form, greater confidence of cone fit (Buchanan 1991), and that these tapered preparation shapes are optimal for virtually all filling techniques (George *et al*. 1987).

A final strong argument for these tapered root canal shapes is that they are very similar to the morphology of root canals when they are first formed (Fig. 6). If clinicians can ideally clean and obturate root canal systems with these naturally tapered shapes, is not that shape an effective yet very simple preparation objective?

Problems with tapered preparations

Unfortunately, carving tapered root canal preparations with ISO-tapered instruments, regardless of whether they are used in a serial step-back or a serial crown-down procedure, presents several significant challenges to clinicians. Amongst these difficulties is the need for 15–18 instruments that are used in 47–63 procedural steps, if you want consistently ideal results. Just as difficult is the fact that each successively larger instrument must fit further back from terminal length by fairly exact 0.5–0.25 mm increments.

Furthermore, because of this indirect method of creating a tapered shape with relatively nontapered instruments, there is no precise way of knowing which cone to fit after shaping is completed. This is exemplified by the name given to the gutta percha cones

Figure 5 Mandibular molar with interesting anatomy and preparation shapes that closely relate to the geometry of natural canal forms.

Figure 6 Sagitally dissected distal root of a mandibular molar. Note the remarkable continuity of shape in this unprepared canal despite severe curvature. Great deep shape and a significant apical constricture.

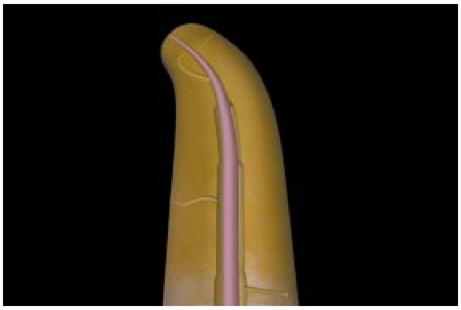

Figure 7 Canal with larger coronal shape than necessary due to irregularity of the preparation. Note how the low points of the preparation must be outside the profile of the gutta percha cone to be fitted in the canal.

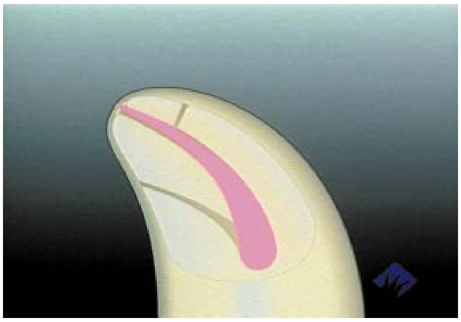

Figure 8 Cone-fit prematurity due to inadequate deep shape. Cone-binding short of its tip is a setup for overextended filling material during filling procedures. Conversely, a GP cone binding at its tip in a tapering preparation is nearly impossible to push through the terminus.

typically fitted in these preparations: 'nonstandardized'. Also attendant to this technique is the same problem seen with the apical stop preparation, the nightmare of uncontrolled coronal enlargement with Peezo and Gates Glidden burs.

Not surprisingly, the learning curve to competence when creating tapered canal shapes with relatively nontapered instruments is large. Most clinicians need between 150 and 250 shaping experiences before they achieve predictable results, and between 500 and 1000 cases before they are unconsciously competent. For me, spending the time to learn it was okay because the results were so nice, but it tired me to think about spending the rest of my career teaching other clinicians such a challenging technique.

The variably tapered file concept and its advantages

The power of the variably tapered file concept is in its total control of the root canal shape, from orifice to terminus. For the first time in endodontics since the single-cone era, dentists can predictably create a predefined specific shape throughout the full length of a root canal. This provides many advantages – some of them obvious, some not so obvious.

Perfectly adequate coronal enlargement

The first advantage is safety, because we can now dictate exactly how much coronal enlargement we want. As it turns out, we only need a certain amount of shape in a root canal, not endless shape. Creating just enough shape – skirting the fine line – is very difficult to do with serial step-back shaping and Gates Glidden burs. With these techniques, most of us prepared canals to slightly larger diameters than was necessary.

The inherent irregularity of our tapered preparations required more enlargement than would be needed if the shapes were more ideal, if they had more uniform tapers. In other words, if the prepared shape is somewhat irregular, the canal must be enlarged to an extent that ensures that the low spots in the preparation are still outside the profile of the gutta percha cone and condensation device to be fit in it (Fig. 7). When things go wrong, this need for larger coronal shapes can be a setup for disaster.

So perhaps the greatest accomplishment of the variably tapered file concept is its resolution of this serious problem, as it eliminates the need for coronal enlargement burs. Furthermore, the files in the standard set have a maximum flute diameter (MFD) of 1 mm, regardless of the file's degree of taper. Limiting coronal enlargement to 1 mm may initially seem a bit small because many clinicians have come to equate wide coronal shapes with high levels of apical control. The reality is that we only need *adequate* coronal shape.

Confirmed full deep shape

A little recognized, but frequent problem is the under-shaping of canal preparations near the junction of the middle and apical thirds. Whilst the most common shaping error is to over-shape coronally and under-shape the canal beyond mid-root, the opposite outcome is needed; more conservative coronal enlargement and fuller deep shape. 'Anaemic' deep shape significantly limits irrigation efficacy in the apical third and causes conefit prematurities (Fig. 8), a setup for overextended filling material. One of the unique advantages of variably tapered files (also known as files of greater taper or GT files) is that, whether in hand or mechanized rotary form, they guarantee full deep shape. Most important of all, GT files predictably create full deep shape through remarkably conservative coronal shapes (Fig. 9).

Testament to that fact is the common use of GT files by clinicians as a finishing instrument

Figure 9 Mandibular molar with long, curved roots and more severely curved root canals. Note the significant deep shape that was carved and the lateral canals that were filled despite the relatively conservative coronal enlargement.

after going through their usual shaping technique with conventionally tapered files and Gates Glidden burs. This works well because, in this situation, it only takes a single file a minute or two to confirm (and often to carve) full deep shape in the preparation, thereby ensuring predictable cone-fitting. After a couple of positive experiences in using GT files as finishing instruments, operators can easily understand how full shape in a root canal could be accomplished with only three variably tapered GT files.

Dentists should not misunderstand a request for full deep shape to mean over-enlargement of the apical regions of canals. As necessary as deep shape is, it is critical that the narrowest apical canal diameters be maintained for resistance form. This can be difficult when using files of similar taper in a step-back shaping technique, where a length determination error of 0.75 mm can cause an apical rip.

Predictable apical resistance form

A more subtle safety feature of this concept is expressed in the apical regions of the preparation. With relatively untapered files (conventional files with 0.02 mm mm^{-1} tapers), there is a great chance of apical iatrogenesis if the working length is even fractionally incorrect (Fig. 10). If 12 file sizes are stepped back from an erroneously long working length, then perhaps six of the files have blundered through the apical constriction, destroying any apical resistance form that may have been present preoperatively.

Conversely, if a file of greater taper is mistakenly taken 1 or even 2 mm beyond the root canal terminus (Fig. 11), there is still linear, tapered resistance form present because even the most tapered file size has a 0.2 mm tip diameter. In fact (as will be described in part 4 of this series), in cases with slightly larger terminal diameter (0.25–0.30 mm) the shaping strategy is to intentionally overextend these files, so that the segment of the file that is that diameter is taken to the terminus of the canal, ensuring a continuous apical taper-form.

Standardized predefined tapers

Aside from safety, the most striking advantage of these files is that they enable clinicians to control the canal shape from orifice to terminus. Clinicians who are using GT files for the first time can most easily incorporate them into their existing shaping routine by bringing them in at the end of the procedure as a finishing file. This is very effective

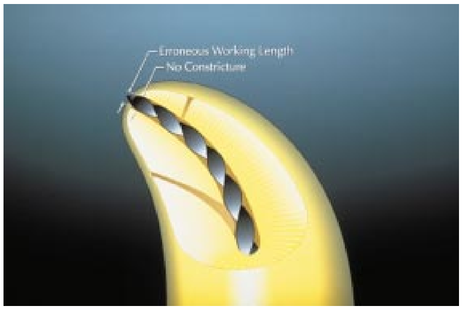

Figure 10 #35 K-file placed fractionally long destroys all apical resistance form.

Figure 11 0.06 taper GT file taken 1.0 mm beyond the terminus, with apical resistance form still present at the canal terminus. Perhaps the apical diameter is now a bit larger than desired, but apical control of filling material will not be problematic.

because it ensures that the preparation has adequate deep shape, an accomplishment that will ensure ideal cone-fitting and apically controlled obturation.

Beyond controlling coronal enlargement and ensuring the presence of deep shape, it is very advantageous to know, with certainty, exactly which taper exists in a root canal preparation when shaping procedures are completed. This standardization of tapered root canal preparations ensures that filling materials, condensation devices, and even restorative posts are easily chosen (the GT file also functions as the post-preparation bur) and that they fit the canal precisely. The term 'nonstandardized' no longer needs to be associated with tapered root canal preparations.

Less obvious but no less important is how predefined root canal shapes allow, for the first time, serious refinement of our cleaning and filling techniques. It is a truism that only by standardizing tapered root canal preparations can we figure out how to optimize our work in those tiny spaces. When every canal shape is different, every treatment result is different. When every canal shape is the same, we can push the envelope of possibility to consistently achieve the best results in the least amount of time.

Enhanced cleaning efficacy

The challenge of thoroughly cleaning complex root canal spaces continues to yield to studies of different irrigation techniques and devices. We know that apical irrigant exchange occurs when the inactivated irrigant is displaced by patency files, so it follows that irrigating cannulas with tapers matching the shaping files could more effectively freshen solutions in that tiny, complex, apical region. In fact, the velocities of irrigants

Figure 12 Maxillary incisor with internal resorption filled in a 2-s downpack with the Continuous Wave of Condensation technique.

streaming by the orifices of lateral and accessory canals would be greatly accelerated by an irrigating cannula with similar shape and dimensions as the root canal preparation.

Enhanced obturation efficacy

In considering 3D obturation of root canal systems, it is obvious that warm gutta percha techniques can gain advantage in predefined canal shapes. Predefined canal shapes allow for a simple but accurate size selection of gutta percha points, paper points, obturation carriers, and Continuous Wave electric heat pluggers, which will work optimally in the preparation. When a 0.08 mm mm^{-1} tapered GT file has been used, materials and instruments identified as size 0.08 function optimally in those predefined root canal shapes.

It is also easier to predict the behaviour of materials being condensed into a predefined root canal shape, allowing optimization of gutta percha point and electric heat plugger shapes, and the dialling in of the most effective plugger temperatures and condensation techniques.

In a predetermined canal shape, an electric heat plugger (System-B Heat Source, Analytic Endodontics, Orange, CA, USA) with the same taper can optimally condense thermoplastic materials into the most bizarre canal-forms in seconds (Fig. 12). As the taper of an electric heat plugger more closely matches the taper of the root canal preparation, the hydraulic forces on the softened gutta percha approach their optimal function in the Continuous Wave of Condensation root canal obturation technique.

Research

To find out how well this concept works in the clinical environment, we instituted a hitherto unpublished study at the University of the Pacific School of Dentistry, San Francisco, USA. Briefly, the study participants were 150 dental students who had each taken a 2-week preclinical lab course on the use of traditional instruments, and had done fewer than three root canals in the clinic. We chose these participants to truly reflect the results of a first-time use by a neophyte dentist.

Twenty-five students were given one mesial root of an extracted mandibular molar and 125 other students were each given two large single-rooted teeth. The students

Figure 13 Computer reconstruction of CT-scanned mesial root of an extracted mandibular molar shows the GT file shape on the right. On the left is a typical result achieved by students with traditional instruments.

created a tapered canal preparation in one of the two canals using K-files and Gates Glidden burs. The students were given a 1-h training session in the use of GT files, and they then used those instruments to shape the adjacent canals in the same roots.

The 25 mesial roots of mandibular molars were CT scanned before and after students shaped those canals (Fig. 13). The other 250 teeth were radiographically imaged post-operatively with contrast medium in their shaped canals. The results were amazing. Students completed shapes in 75% less time with the GT files. Resulting canal shapes were rounder throughout their length. Coronal canal shapes were more conservative, and shapes in the middle third were more robust.

In summary, the GT files delivered consistently more ideal canal shapes, with a shorter learning curve to competence, and dramatically reduced procedural times.

GT file design

It took more than 26 rounds of prototyping before the GT files could consistently achieve our functional objectives, but through each round something important was learned. For instance, we made them with 10 different taper sizes and then found out we only needed four to treat the same full range of anatomy.

One of the most important discoveries to come out of this development process was the variable-pitch GT flute design. We made GT files with reamer flute angles (30%) and they cut very fast but they all broke. Then we made them with K-file flute angles (45%) and they did not break, but they did not cut well either. Finally, I realized that we need both K-file and reamer flute angles on the same instrument.

GT flute geometry

These Standard and Accessory Series instruments come in hand and rotary (handpiece-driven) styles, the hand files having reverse-cut triangular flutes (Fig. 14a) and the rotary files having clockwise 'U-blade' flutes (Fig. 14b). Both types of GT files have variably pitched flute angles, which deliver several advantages over conventional fluting patterns. All these instruments are available in lengths of 17, 21, 25 and 30 mm.

Most ground-flute files have blade angles that are relatively open (reamer-like) at their tips and are more closed (K-type) near their shanks. This is the easiest flute arrangement for CNC (computer numerically controlled) fluting machines to create. GT files (hand and

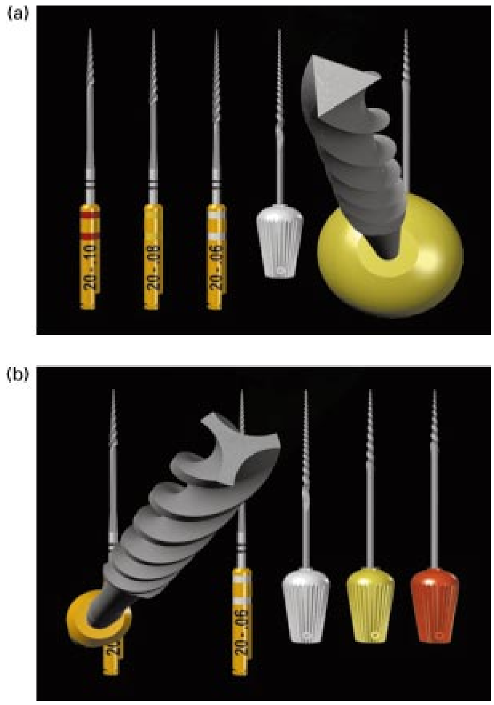

Figure 14 (a) Triangular cross-section of the GT hand file. (b) 'U' blade cross-section of the rotary GT file.

Figure 15 0.06 taper GT file with variable-pitch flute angles. Note the open, reamer-like flute angles at the shank end of the file, and the closed K-type flute angles near the file tip.

rotary) have the opposite flute angulation (K-type) flute angles at their tips, and more open reamer-like flute angles at their shank ends (Fig. 15).

This design maximizes strength at the file tip, where it is weakest and where the less aggressive flute angles are acceptable since less dentine removal is needed. It also creates an open aggressive reamer blade at the fatter, shank end of the file where the diameter of the file adds strength and also where the canal needs the most aggressive dentinal cutting action. In the rotary version of the GT file, the 'grabbiness' that is so common with other handpiece-driven files is significantly lacking, another important advantage of this variable-pitch flute design. When the shank-end flutes are closed (K-type), they literally act like screw threads, pulling the files into the canal. Shank-end flute angles, which are more open, present less of an inclined plane to the canal wall being cut, and therefore are demonstrably less likely to thread into a canal. As an aside, limiting the maximum flute diameters also greatly contributes to the GT rotary files.

The GT Hand File has a unique pear-shaped handle (Fig. 16). At the shank end it is 50% larger in diameter than most file handles to provide more torque during rotational cutting. It has a smaller than usual diameter at the dentist's end of the handle, both to maximize the application of apically directed cutting forces, as well as to minimize the discomfort felt when pinching a file handle between thumb and forefinger.

Standard GT file features

The standard set contains three taper sizes (0.06, 0.08, and 0.10 mm mm^{-1}). All three files have the same tip diameters (0.20 mm), the same 1 mm maximum flute diameters (MFDs), and the same variable-pitch flute patterns (Fig. 17). All of these files, hand or rotary, standard or accessory, are made of hyper-flexible nickel titanium, as stainless steel is not strong enough or flexible enough in these greater taper configurations.

Because they vary by taper, but have the same tip diameters and MFDs, the flute lengths become shorter as the tapers increase. This results in canal shapes for large long roots that have dramatic, but relatively short, apical tapers (5–7 mm) and coronally parallel walls.

In large long roots, this does require custom rolling of conventional nonstandardized gutta percha cones to make their shank ends parallel in diameter. Using the GT-tapered gutta percha cones, paper points, and condensation devices (Autofit by Analytic Endodontics, Orange, CA, USA) obviates the need for this irritating subroutine.

The three files in the standard set each have the same tip diameter, a great departure from ISO-tapered files, which come in 21 tip sizes. These instruments will ideally shape 90% to 95% of the roots you will encounter in practice, because most root canal termini are 0.15–0.25 mm in diameter. Remarkably, it takes just one of the three files in the 0.12 GT Accessory Series to manage canals with large apical diameters.

We only needed all of those ISO sizes because serial instrumentation requires file tip diameters stepping back through much of the canal. GT files, due to their tapers ranging between the common 0.2 mm tip diameters and their common 1.0 mm MFDs, contain 13 ISO file diameters along each of their lengths (or 26 if using half sizes). In fact, variably tapered files have an infinite number of diameters, between 0.2 and 1.0 mm, along their lengths.

0.12 accessory GT file features

A set of three accessory GT files (Fig. 18) is available for those relatively unusual large root canals that have apical diameters of greater than 0.3 mm. These instruments have common tapers (0.12 mm mm^{-1}) and the same larger MFDs (1.5 mm), but they vary by their tip diameters (0.35, 0.5, and 0.7 mm). When used in canals with large apical diameters, they are typically able to complete the whole shape with just one file. More important, the resistance form created is of enough taper to really lock the master cone in tightly, to ensure apical control during obturation of these previously challenging cases.

No panacea for bad technique

Really, the only 'bug' in this whole system of instruments and technique is the potential breakage of GT files, particularly the rotary GT files. Whilst they are less prone to breakage than most rotary files, due to their variably pitched flute pattern, like all rotary files, GT files can be quickly separated when they are misused.

After 5 years of designing and teaching the use of rotary files, breakage parameters are well known and can be easily and consistently avoided. But you must obey those

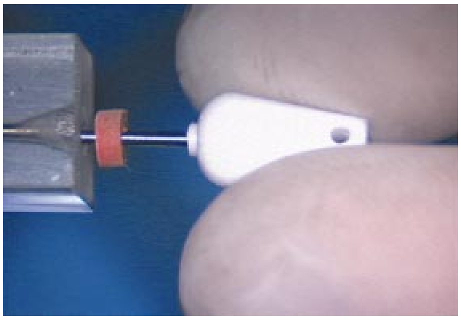

Figure 16 Pear-shaped handle of the GT hand files, with 50% larger diameter than conventional files to improve rotational torque for ease of cutting.

Figure 17 Standard set of GT files, 0.06, 0.08, and 0.10 tapers. Note their similar tip (#20) and maximum flute diameters (#100) which dictate the variable flute lengths between the tapers.

Figure 18 0.12 accessory GT files, sizes 35, 50 and 70.

rules or you should stick with K-files operated by hand (and probably lose the Gates Glidden burs).

Knock on wood, I have only broken one file a year in the 7 years I have used GT files, and in every case it was my fault. My GT file separations were from two causes. I pushed harder on a file that would not go to length, instead of recapitulating the crown-down series of files, or I used a file too long. I have learned the hard way that sometimes it is wise to replace a new-to-this-case 0.06 GT instrument before cutting the last 1 or 2 mm through a wildly bent canal with multiplanar curvature.

The payoff, if you can discipline yourself in a new mode of file use, is that these instruments can create ideal root canal shapes in some roots in less than 2 min with a single

Figure 19 Maxillary molar with four canals, shaped in less than 13 min using 3 rotary GT files.

file. Even canals with severe curvatures (Fig. 19) can usually be shaped in less than 5 min with three instruments and seven steps.

Conclusions

The Variable Taper concept offers the potential to achieve optimal root canal shapes quickly and safely. In the next article, guidelines will be presented on Variable Taper file selection, and their safe use in the handpiece.

Acknowledgement

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