# Current developments in rotary root canal instrument technology and clinical use: A review

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Rotary root canal instruments manufactured from nickel-titanium alloy have proved to be a valuable adjunct for root canal therapy. Over the past two decades, instrument design has been considerably modified; progress has been made in manufacturing, as well as alloy processing. Clinical procedures and ideal working parameters are still being refined as new instruments continue to be introduced to the market. This review is intended to summarize clinical and laboratory findings for several current instruments. Some guidelines and usage parameters are also detailed. *(Quintessence Int 2010;41:479–488)*

**Key words:** nickel-titanium, root canal anatomy, root canal preparation, shaping

The introduction of nickel-titanium (Ni-Ti) to endodontics almost two decades ago[1] has dramatically changed the way root canal preparation is performed, in both general and specialist practices. The perceived most significant advantage lies in the predictability with which a desired shape is achieved.[2] Possibly more important, the use of rotary instruments requires attention to detail, eg, regarding the efficacy of antimicrobial regimes that further contribute to successful endodontic therapy. Then, cases of varying degrees of difficulty can be successfully treated, with excellent long-term outcomes (Fig 1).

Not every instrument system is suitable for every clinician, and not all cases lend themselves to rotary preparation, mainly because of varying degrees of experience and complexity. Moreover, rotary instruments may break rather unexpectedly; if they are cleaned and sterilized for reuse, issues of corrosion and persistent contamination may come into play.[3] Therefore, knowledge of both clinical guidelines for and metallurgical properties of Ni-Ti rotary instruments is critical for their successful use.[2,4,5] A recent survey indicated that US-based endodontists are knowledgeable about Ni-Ti instrument usage but are still concerned about issues such as breakage and the quality of the canal shape.[6]

Therefore, this review is intended to summarize most recent trends in Ni-Ti technology, instrument design, and usage parameters. This is hoped to provide clinicians a knowledge base for evidence-based practice, thus maximizing the benefits from the selection of Ni-Ti rotary instruments for root canal treatments.

## NICKEL-TITANIUM METALLURGY AND MANUFACTURING

Nickel-titanium alloy, first developed for the US Navy,[7] is in principle highly resistant against corrosion, and, more important, it is superelastic and has a shape memory. The latter two properties stem from an atomic arrangement that is different from conventional alloys such as stainless steel. The atoms in steel can move against each other by a small specific amount before plastic deformation occurs (Fig 2); in contrast, Ni-Ti exists reversibly in two conformations, martensite and austenite, depending on ambient temperature (see Fig 2a) and external tension (see Figs 2b and 2c).

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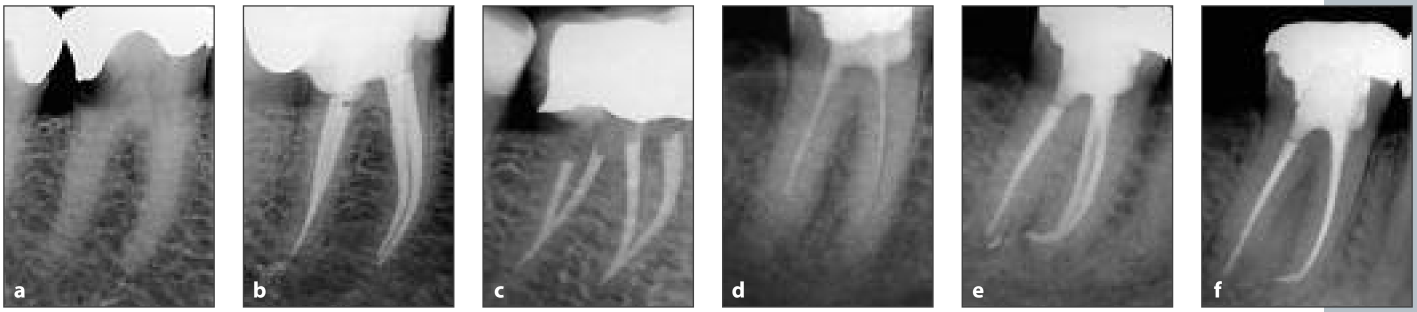


**Fig 1** Two clinical cases performed with Ni-Ti rotary instruments (by F.P.). *(a to c)* Primary root canal treatment of a mandibular molar with four canals. *(d to f)* Retreatment of a mandibular molar with three canals. The panels show preoperative radiographs, immediately postoperative films, and 4-year recall films, respectively.

**Fig 2** *Important elements of Ni-Ti metallurgy.*

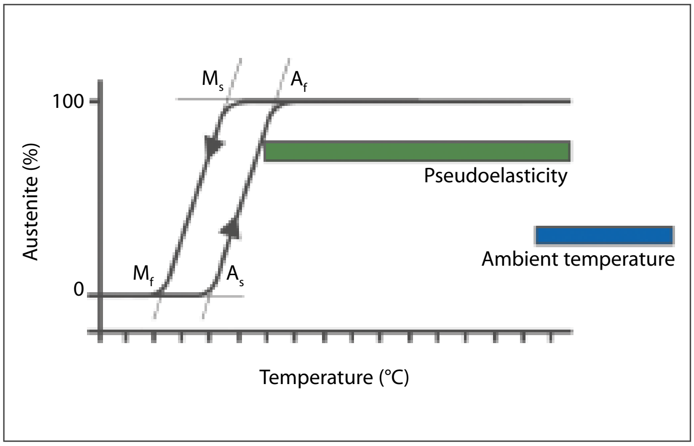


**Fig 2a** Temperature-dependent transition from austenitic (brittle, hard) to martensitic (soft) crystalline lattices. $M_f$, $M_s$, $A_f$, $A_s$ indicate martensitic and austenitic starting and finishing temperatures, respectively.

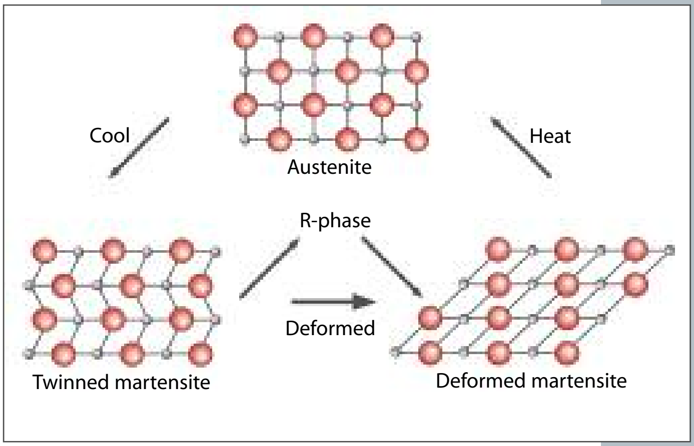


**Fig 2b** Force- and temperature-dependent transitions from austenite to martensite, including the intermediary R-phase. The proportion of alloy that is in R-phase depends on heat treatment of the raw wire.

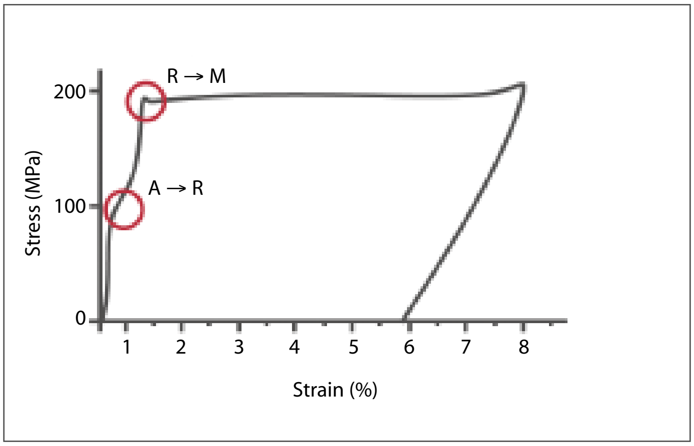


**Fig 2c** Stress-strain diagram (at 51°C) showing the presence of an R-phase (R) in the transition from austenitic (A) to martensitic (M) lattice. The shape of the stress-strain curve depends on ambient temperature and the heat treatment of the raw wire, among other factors.

While steel allows 3% elastic deformation, Ni-Ti can withstand deformations of up to 7% without permanent damage or plastic deformation.[8] This is critical for rotary endodontic instruments for two reasons: During preparation of curved canals, forces between the canal wall and abrading instruments are smaller with more elastic instruments; hence, fewer preparation errors will likely occur. Second, rotation in curved canals will bend instruments once per rotation, which will ultimately lead to work hardening and brittle fracture, also known as cyclic fatigue.

Steel can withstand up to 20 complete bending cycles, while Ni-Ti can be bent up to 1,000 times.[8] This difference is related to the different atomic structure of the two alloys, in particular the transition from austenite to martensite that occurs in Ni-Ti. The transformation characteristic depends on the ambient temperature and thermal pretreatment of the alloy[9] but usually takes place below temperatures in the dental setting so that the alloy is in the austenitic form (see Fig 2a). In addition to the transition from austenite to martensite under load, via twinned martensite, there is also a transition from the so-called R-phase (see Figs 2b and 2c), a temperature-dependent crystalline structure, to martensite. This transition further contributes to the ability of Ni-Ti to absorb stresses and thus to resist fatigue.

Most of the instruments described in this section are manufactured by a grinding process, although some are produced by laser etching and others by plastic deformation under heating. Surface quality is an important detail, because cracks can arise from superficial defects and may play a role in instrument fracture[10]; milled files show characteristic marks (Fig 3). More dramatic defects such as metal flash and rollover were common in unused Ni-Ti instruments in the past.[11–13]

Attempts have been made to improve surface quality by a process known as electropolishing the surface. Electropolishing is an electrochemical process that reduces surface irregularities such as flash and milling marks (see Fig 3, compare Sequence and GTX files); it is believed to improve material properties, specifically fatigue and corrosion resistance; however, the evidence for both these claims is mixed. Some authors[14,15] found an extension of fatigue life for electropolished instruments, while most did not.[16–20] Moreover, Boessler et al[21] suggested a change in cutting behavior with an increase of torsional load after electropolishing. One possible reason for these variable outcomes is the different testing environments used in vitro[22]; clinically, even greater outcome variability may be expected.

Corrosion resistance of electropolished NiTi rotaries is also controversial. Bonaccorso et al[23] found superior corrosion resistance for electropolished RaCe instruments (FKG), while Peters et al[24] found similar corrosion susceptibility for RaCe and nonelectropolished ProFile (Dentsply Maillefer) instruments.

In contrast to electropolishing, physical vapor deposition is a process that allows coating of Ni-Ti instruments with a layer of titanium nitride.[25,26] The resulting instruments appear to have better cutting efficiency[26] and corrosion resistance.[23] However, the only instrument manufactured with this technology (Alpha, Brasseler-Komet) has not gained a significant market share.

Finally, modifications of the alloy itself have been introduced with the aim to make the alloy more resistant to cyclic fatigue. A process based on the changes in alloy composition along a temperature gradient (see Fig 2a) leads to novel Ni-Ti alloy M-Wire (SportsWire). Early investigations hinted that M-Wire has increased fatigue resistance.[27] However, Kramkowski and Bahcall[28] could not confirm these findings comparing two similar instrument designs, ProFile GT and GTX. Moreover, Kell et al[29] did not find GTX to perform better than ProFile GT manufactured conventionally.

## ROTARY INSTRUMENT DESIGN

The specific design characteristics vary, such as tip sizing, taper, cross section, helical angle, and pitch (see Fig 3). Some of the early systems have been removed from the market or play only minor roles today; others, such as

ProFile, are still widely used. However, a redesigned version, called ProFile Vortex, has been recently introduced. This signifies a trend in which new and often only slightly modified instrument designs are marketed for improved in vitro characteristics; however, the extent to which clinical outcomes, if any, will improve depends on design characteristics and is difficult to forecast.[6,30] Three instruments described below illustrate several of the latest modifications.

## EndoSequence

The EndoSequence rotary instrument is produced by FKG in Switzerland and marketed in the United States by Brasseler (see Fig 3). This is an instrument that adheres to the conventional length of the cutting flutes, 16 mm, and to larger tapers, .04 and .06, to be used in a crown-down approach. While the overall design, including the available tapers and cross-sections, is thus similar to many other files, the manufacturer claims that a unique longitudinal design called *alternating wall contact points* (ACP) reduces torque requirements and keeps the file centered in the canal. Another feature of the EndoSequence design is an electrochemical treatment (electropolishing) after manufacturing, similar to RaCe files, that results in a smooth polished surface. This is believed to promote better fatigue resistance, and a rotational speed of 600 rpm is therefore recommended for EndoSequence.[31] However, other studies did not find better fatigue resistance for EndoSequence files compared to nonelectropolished files.[16,19]

## ProFile GT and GTX

The Greater Taper, or GT, file was originally introduced in 1994. This instrument incorporated the U-file design and was marketed as ProFile GT. The instruments had a variable pitch and an increasing number of flutes in progression to the tip; the apical instrument diameter was 0.2 mm. Instrument tips were noncutting and rounded; these design principles are mostly still present in the current incarnation, the ProFile GTX, or GTX for short, instrument. The main differences are use of M-Wire for GTX, subtle changes in the longitudinal design, and a different approach to instrument usage, emphasizing the use of the no. 20 .06 rotary.

The GTX set currently includes tip sizes 20, 30, and 40, in tapers ranging from .04 to .010. The recommended rotational speed for GT and GTX files is 300 rpm, and the instrument should be used with minimal apical force and a slight pecking action.

Studies on GT files found that the prepared shape stayed centered and was achieved with few procedural errors.[32–36] Shaping assessments using microcomputed tomography (μCT) showed that GT files machined statistically similar canal wall areas compared with ProFile and LightSpeed (Discus Dental) preparations[34] but tended to underprepare apical canal sections.[37] The walls were homogeneously machined and smooth.[36,38]

## Twisted File

In 2008, Sybron Endo presented the first fluted Ni-Ti file manufactured by plastic deformation, similar to the twisting process that is used to produce stainless steel K-files. According to the manufacturer, a thermal process allows twisting during a phase transformation into the so-called R-phase of Ni-Ti. The instrument is available with only no. 25 tip sizes, in taper .04 up to .12. However, instruments with tip sizes no. 30, 35, and 40 were recently added.

The unique production process is believed to result in superior physical properties; indeed, early studies suggested significantly better fatigue resistance of size no. 25 .06 taper Twisted File compared to K3 (Sybron Endo) instruments of the same size and size no. 20 .06 GTX.[39] Moreover, as determined by bending tests according to the norm for hand instruments, ANSI/ADA No. 28 (ISO 3630-1), Twisted Files size no. 25 .06 taper were more flexible than ProFiles of the same size.[40] However, Larsen et al[16] showed similar fatigue resistance by Twisted Files compared to conventionally manufactured ProFiles. Again, shaping data are not available at this point in time.

The preceding descriptions covered only a limited selection, the most popular and widely used rotary instruments on the market. Older systems are updated, and new files are continually added to the armamentarium, for

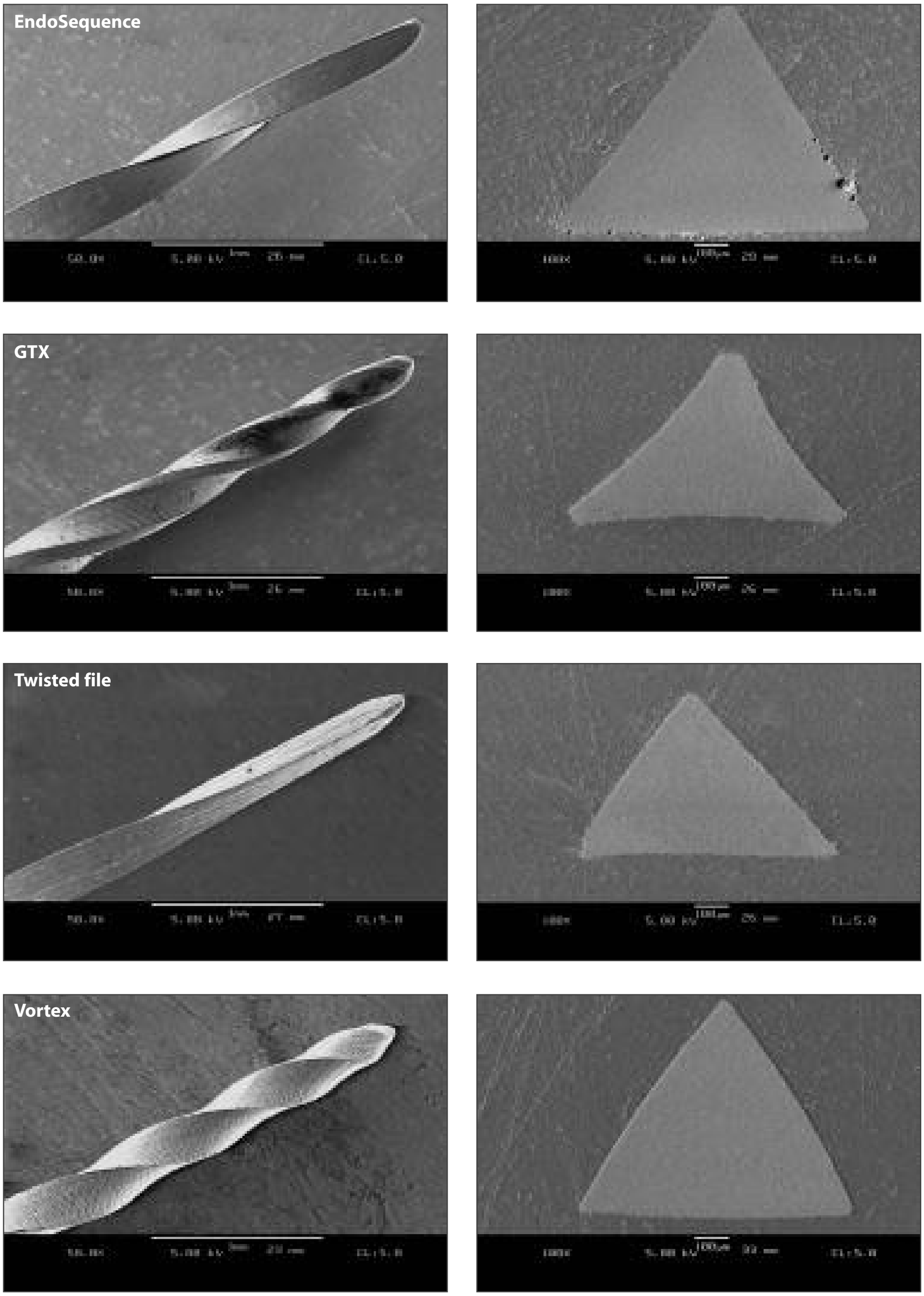


**Fig 3** SEM images of current rotary Ni-Ti files, detailing lateral and cross-sectional views.

example, the ProFile Vortex (Dentsply Tulsa Dental) that incorporates a more actively cutting triangular cross section along with a presumably more fatigue-resistant alloy. The rapid succession of new development is at least partly the reason for the scarcity of clinical outcome studies at this point.

To summarize, most systems include files with tapers greater than the .02 stipulated by the ISO norm. The LightSpeed LS1 and LSX (distributed by Discus Dental) are different from all other systems in that they have no taper at all; other new systems such as GTX, EndoSequence, and Twisted File also have some unique features.

Minor differences exist in tip designs, cross sections, and manufacturing processes, but the clinical effects of these modifications currently are unknown. Even in vitro tests have only begun to identify the effect of specific designs on shaping capabilities,[2,4,5] and differences in clinical outcomes in regard to these design variations appear to be minimal.[30,41,42]

## PREPARATION QUALITY WITH ROTARY INSTRUMENTS

Experimental and clinical evidence suggests that the use of Ni-Ti instruments in particular with rotary movement results in improved preparation quality (Fig 4). Specifically, the incidence of gross preparation errors is greatly reduced.[43,44] However, at this point in time, there is no published evidence of the shaping performance of the three instruments detailed above (GTX, EndoSequence, Twisted File).

Figure 4 shows three-dimensional reconstructions of canal shapes with rotary instruments that, despite some canal straightening, are virtually free of preparation errors. Canals with wide oval or ribbon-shaped cross sections present difficulties for rotary instruments, and strategies such as circumferential filing are recommended.[45] Canal transportation with Ni-Ti rotaries, measured, for example, as undesirable changes of the canal center seen in cross sections of natural teeth or the canal path in transparent plastic blocks, is usually in the range of 0.10 to 0.15 mm.[2]

However, preparation usually removes dentin somewhat preferentially toward the outside of the curvature[46]; overall, 50% or less of canal surface is mechanically prepared.[44] Rotary instruments with a radial-landed design (see Fig 3, GTX) prepare canals in a planing action and should be advanced with light pressure (approximately 1 to 3 N) to engage the perimeter of the canal and then cut dentin there.[47] Usually, these instruments enlarge the canal path safely without creating procedural errors.

Nonlanded instruments (eg, EndoSequence, Twisted File, Vortex; see Fig 3) prepare canals more in a cutting action; the active blades arising from a triangular cross section can be used with lateral force toward a specific point on the perimeter. This brushing action allows the clinician to change canal paths away from the furcation in the coronal and middle root canal thirds[48] but may reduce fatigue life in larger instruments.[49] However, circumferential engagement of canal walls by active instruments may lead to a threading-in effect. Rotaries are designed (eg, with variable pitch and helical angle or with alternating cutting edges) to counteract this tendency.

One possible outcome of dentin removal during shaping is the accumulation of dentinal debris in irregularities of the root canal system, eg, isthmuses, fins, and accessory canals.[50] Theoretically such debris accumulation may shelter microorganisms from the attack by disinfection solutions. Moreover, it has been demonstrated that different rotary instruments produce various types of smear layer,[51] which consists of dentinal debris, organic tissue remnants, and microorganisms. The potential clinical impact of these preparation effects is at present unknown.

An important design element is a passive, noncutting tip that guides the cutting planes so that more evenly distributed dentin removal may take place. Radial-landed instruments, even when accidentally taken beyond the apical foramen, will not engage and create an apical zip formation due to the passive reaming action. However, actively cutting instruments should not be taken beyond the apical constriction, nor should they be allowed to linger apically, to avoid the occurrence of canal transportation.

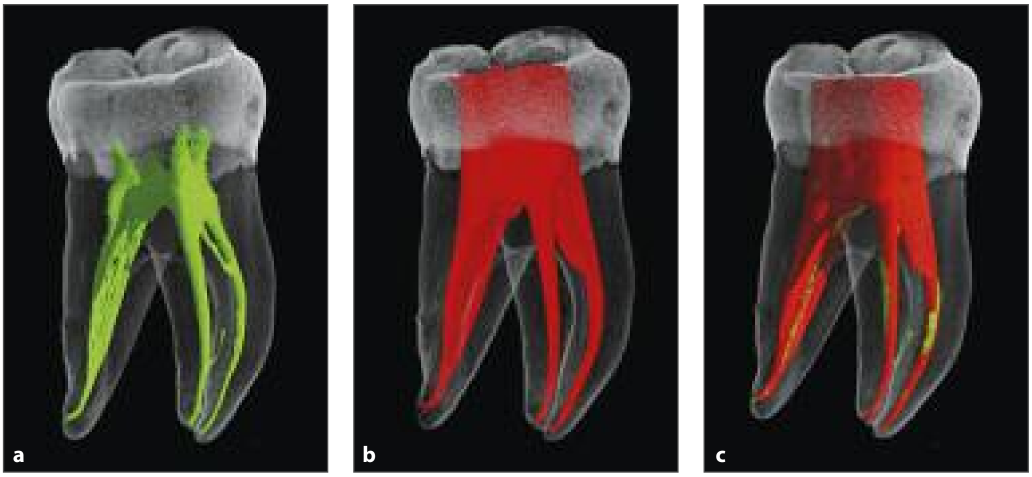

**Fig 4** Microcomputed tomographic reconstructions of root canals treated with rotary instruments. The preoperative canal system is shown in green *(a)*, the postoperative canal shape in red *(b)*. The superimposition *(c)* reveals few areas that have not been instrumented. Extra care was taken to fully instrument this mandibular molar. This resulted in nearly optimal canal shaping, as indicated by absence of transportation and limited untreated area.

## NI-TI INSTRUMENT USAGE AND FRACTURE PREVENTION

According to Spili et al,[52] rotary instruments fractured in a specialist practice only slightly more frequently than stainless steel files. However, any case with a file fragment lodged in a root canal presents a potential problem, and as such, fracture prevention is of prime importance. It has been conclusively shown that success with NiTi rotaries depends on the clinician's level of expertise.[53–55] Experience will aid in case selection and, in particular, applying adequate hand movements during canal preparations to optimize canal shape and to avoid file separation.

Two distinct fracture mechanisms have been described[56]: torsional load and cyclic fatigue. Torsional load is transferred into the instrument through friction against the canal wall, while cyclic fatigue occurs with rotation in curved canals. These factors work in concert to weaken the instrument.[57,58]

Torsional overload and fracture typically happen when an instrument tip is forced into a canal that is smaller than the tip diameter; depending on the contacting canal area and the apical pressure exerted by the clinician, the tip locks into the canal, does not follow the speed of rotation of the instrument shank, and breaks. In such a situation, the coronal fragment often shows plastic deformation. In contrast, fracture due to cyclic fatigue leaves inconspicuous traces, mostly on the cross-sectional surface.

As a general rule, flexible instruments are not very resistant to torsional load but are resistant to cyclic fatigue. Conversely, more rigid files can withstand more torque but are susceptible to fatigue. The greater the amount and the more peripheral the distribution of metal in cross section, the stiffer a file.[59,60] Therefore, a file with greater taper and larger diameter is more susceptible to fatigue failure; moreover, an acute canal curvature more coronally is more likely to lead to an instrument fracture than is a gradual apical curve.

Instrument handling has been shown to be associated with file fracture; for example, a lower rotational speed (~250 rpm) results in delayed buildup of fatigue.[61–63] Lower speed also reduced the incidence of taper lock with ProFile instruments[53]; however, this relationship was not observed with experienced clinicians in that study. The term *taper lock* describes a situation in which the instrument dimension closely approaches the canal's size and taper; this may lead to instrument fracture. Handling parameters for the successful use of Ni-Ti rotaries are summarized in Table 1.

**Table 1 Summary of basic rules for rotary instrumentation**

| | Do | Do not |
|---|---|---|
| Case selection | Gradual curves, glide path confirmed with straight size no. 20 K-file | Acute coronal curves and other anatomical variations |
| Glide path | Confirm a patent canal to the level the rotary should follow | Unknown canal conditions ahead of the rotary instrument |
| Speed* | Low (~ 250 rmp) | High (> 350) |
| Torque | Dependent on file; low for small-diameter taper; governed by motor or tactile feedback | Uniformly low or always high; reliance on torque-controlled motor |
| Hand movement | Pecking for radial-landed files, brushing for nonlanded files | Forcing the file apically |

*Manufacturer recommendations and instrument sequence should be taken into account for the actual speed used.

As stated before, material imperfections such as microfractures and milling marks are suspected to act as fracture initiation sites.[20,64] Such surface imperfections after manufacturing can be removed by electropolishing, but it is unclear if this process extends fatigue life.[19,20] Manufacturers' recommendations stress that rotaries should be advanced with very light pressure; the recommendations differ with regard to the way the instruments are moved. Most instruments are used with a gentle pecking motion; some rotaries are recommended to be continuously advanced, while others should be used in a lateral brushing motion. None of these procedures have been linked to significantly better clinical performance, but the intermittent or pecking movements may reduce the incidence of taper lock and may at least theoretically be helpful in distributing fatigue over a larger distance.[63]

It is difficult to exactly determine the apically exerted force in the clinical setting; experiments have suggested that forces start at about 1 N and range up to 5 N.[56,65,66] However, precise torque limits have been discussed as a means to reduce failure. In fact, torque-controlled motors are today used by a significant proportion of clinicians. Most torque-limiting motors are based on presetting a maximum current for a direct current (DC) electric motor, the use of which per se is an improvement over air-driven low-speed motors because of more precise rpm control.

Torque limits are one way to decrease torsional fractures, particularly if torque settings are accurate and low. Moreover, Gambarini[67] indicated that preparation with low torque could extend the fatigue life of rotary instruments. However, one has to consider that these low torque settings may not allow efficient preparation, in particular for more tapered instruments that require relatively high working torques.[47,66] In fact, Yared et al[68] suggested that torque-limiting motors may be of greater importance for the learning phase and practitioners with less experience than for highly trained clinicians.

To reduce friction, manufacturers often recommend the use of gel-based lubricants such as RCPrep (Premier); in dentin, such lubricants have not been shown to be beneficial and did actually increase torque for radial-landed ProFile instruments.[69,70] Taken with the importance to maximize sodium hypochlorite (NaOCl) contact time, it is recommended to flood the canal system with NaOCl during the use of rotaries.

Corrosion has been shown to potentially occur when Ni-Ti rotaries are fully immersed in NaOCl[3,71,72]; however, in the clinical setting usually only the cutting flutes are in contact with NaOCl, and it is the shank part that is required to act as anode in corrosion processes.[73,74] Thermal sterilization processes do not extend fatigue life[64] and do not reduce torsional resistance.[75] However, the reuse of rotary instruments has to be closely monitored to avoid buildup of fatigue and NaOCl-related corrosion. Several governing bodies and many clinicians recommend single-patient use of a set of rotary instruments.[3]

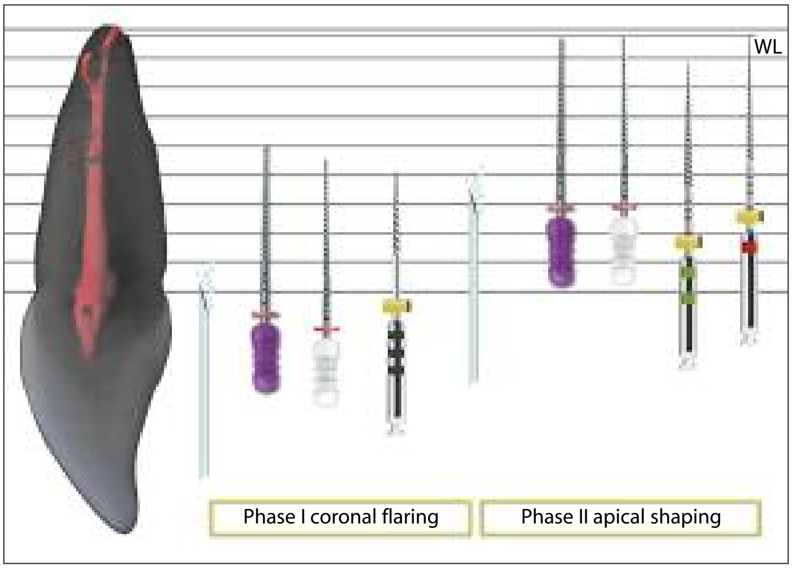


**Fig 5** Basic shaping strategy for root canal preparation with Ni-Ti rotary instruments, consisting of coronal flaring and apical shaping phases. During both phases, scouting with hand files verifies a patent glide path for subsequent rotary preparation. The flaring phase not only removes coronal obstructions and creates space for irrigation, but also provides tactile feedback aiding in case selection. (WL) Working length.

## USAGE PARAMETERS AND STRATEGIES

First and foremost, good diagnostics are important for successful rotary canal preparation, including the exposure and analysis of adequate radiographs. Clinicians need to carefully determine, besides overall root anatomy, the existence, extent, and position of canal curvatures.[76] Radiographs and findings during the treatment phase usually help to determine merging points and canal dimensions. Based on these findings, two general strategic rules help the practitioner to safely and successfully use rotary instruments (Fig 5): first, to ascertain a glide path, which may be defined as a patent canal section that allows the tip of the instrument to rotate freely and to act as a guide; and second, to have a direct straight line of access deep into the middle root canal third, which will reduce cyclic fatigue and allow the instrument to shape canals with little or no canal transportation. This can be more readily accomplished in a crown-down method than in a step-back pattern; this sequence also helps to reduce friction and consequently, torque.[77] More research is needed to determine optimized instrument sequences for various canal anatomies and instrument designs.

Also, clinicians must master hand movements[78] that match the design of the instrument they are using. Radial-landed instruments, specifically smaller ones, require circumferential wall contact, while more actively cutting files are preferably directed against a specific area of the canal circumference, potentially in a so-called brushing motion.[47]

This reasoning led to an approach that is schematically shown in Fig 5. After preparation of an optimized access cavity with high-speed burs and localization of the canal orifices, the coronal canal portions are carefully explored with small (eg, no. 10, 15) K-files without attempting to immediately reach the expected working length, previously determined from preoperative radiographs. The explored canal portion may be safely prepared with a stiffer and actively cutting rotary instrument (eg, PreRace [FKG], LightSpeed MSX [Discus Dental], Quantec LX Flare [Sybron Endo]) almost to the length the K-file passed to but not into a determined curvature.

Coronal flaring[79–81] facilitates direct access into the middle and sometimes even into the apical canal third. It promotes access of irrigants and allows rotary instruments to prepare the apical canal third with less wall contact and hence friction. Subsequently, the remainder of the canal portion is explored again with small K-files up to electrometrically determined working length. Here, it is recommended to prepare with straight, not precurved, hand files up to a size no. 20 or at least no. 15 to the previously determined working length, using a watch-winding or possibly a balance force motion.[82] This procedure is important, as it secures an open glide path,[48,83] allowing a subsequent rotary instrument to predictably reach working length.

The extent and position of the curvature determines the strain and fatigue to which a rotary instrument of a given design is subjected: A more coronally located and/or more acute curvature precludes an instrument of larger taper and/or larger tip diameter to safely work at working length.

Individual clinicians may vary in their decision as to how large an apical preparation to create. While no definite guidelines exist, information can be gathered from anatomical dimensions of apical foramina, assessed with light microscopy[84,85] and by tactile methods.[86] Weiger et al[87] proposed a clinical method for apical size determination that relied on nontapered noncutting instruments. The authors concluded that for maximal mechanical preparation of canal walls, root canals should be prepared to larger sizes than usually recommended.[87]

Obviously, insufficient enlargement does not permit disinfecting NaOCl to penetrate deeply enough to clean the root canal system properly; instrument tip size and taper play a role,[88,89] but in routine cases a minimum apical size of no. 30 has been suggested.[90] Nevertheless, every canal needs to be evaluated in its own merits regarding length, width, and curvature. It is only then that an educated decision about the strategy for rotary root canal preparation can be made. If the basic rules outlined above are followed, clinicians will be able to successfully prepare most root canals using rotary Ni-Ti instruments.

## CLINICAL OUTCOMES

While results from in vitro studies on rotary systems are abundant, clinical studies on these instruments are sparse. Comparing Ni-Ti and stainless steel K-files in cases with periapical radiolucencies done by undergraduate students, Pettiette et al[43] found less canal transportation and fewer gross preparation errors such as strip perforations when Ni-Ti hand files were used. Subsequently, using radiographic evaluation of the same patient group, they demonstrated better healing in the Ni-Ti group.[91] However, when cases with gross preparation errors in the stainless steel group were eliminated, the difference between the two groups was much reduced. Schäfer et al[41] demonstrated radiographically less canal straightening using FlexMaster NiTi instruments (VDW) compared to stainless steel hand files.

A recent prospective study with undergraduate dental students indicated that improved preparation with FlexMaster instruments leads to better obturation results compared to stainless steel K-files (Sonntag et al, unpublished data). Similarly, Cheung and Liu[92] found a higher apical healing rate with Ni-Ti rotary instruments (77%) compared to K-file preparation (60%) in a retrospective study with dental students as providers. An earlier outcome study with three rotary preparation paradigms had failed to show any difference between the three systems, with an overall favorable outcome rate of 86.7%.[30] More recently, Spili et al[52] found similar healing rates (91.8% and 94.5%, respectively) for teeth diagnosed with periapical periodontitis with a retained instrument fragment and matched control teeth after uncomplicated treatment.

Taken with the in vitro experiments, the available clinical studies suggest that the use of Ni-Ti rotaries does lead to a reduced incidence of gross preparation errors and possibly to improved clinical outcomes, in particular for clinicians with less expertise. However, for less experience clinicians, adequate clinical handling needs to be emphasized.

## REFERENCES

A full list of references is included in the online version of this article, which is available at www.quintpub.com.