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REVIEW ARTICLE

Current Challenges and Concepts in the Preparation of Root Canal Systems: A Review

Ove A. Peters, PD Dr med dent, MS FICD

Nickel-titanium rotary instruments are important adjuncts in endodontic therapy. This review attempts to identify factors that influence shaping outcomes with these files, such as preoperative root-canal anatomy and instrument tip design. Other, less significant factors include operator experience, rotational speed, and specific instrument sequence. Implications of various working length definitions and desired apical widths are correlated with clinical results.

Despite the existence of one ever-present risk factor, dental anatomy, shaping outcomes with nickel-titanium rotary instruments are mostly predictable. Current evidence indicates that wider apical preparations are feasible. Nickel-titanium rotary instruments require a preclinical training period to minimize separation risks and should be used to case-related working lengths and apical widths. However, and despite superior in vitro results, randomized, clinical trials are required to evaluate outcomes when using nickel-titanium instruments.

Endodontic therapy involves treating vital and necrotic dental pulps so that patients can retain their natural teeth in function and esthetics. Although successful therapy depends on many factors, one of the most important steps in any root canal treatment is canal preparation. This is essential because preparation determines the efficacy of all subsequent procedures and includes mechanical debridement, creation of space for medicament delivery, and optimized canal geometries for adequate obturation. Unfortunately, canal preparation is adversely influenced by the highly variable root-canal anatomy (1–3) and the relative inability of the operator to visualize this anatomy from radiographs (4, 5). Hence, root-canal preparation is not only important but also demanding for the clinician.

Three main issues are presently considered most challenging and controversial in root canal shaping:

- Identification, accessing, and enlargement of the main canals without procedural errors
- Establishing and maintaining adequate working lengths throughout the shaping procedure
- Selection of preparation sizes and overall geometries that allow adequate disinfection and subsequent obturation.

This review attempts to describe current strategies to deal with these issues within the existing anatomical and technical framework.

The intricacies of dental anatomy (6) *per se* reveal themselves early in the procedure when canal orifices or entire canals may be overlooked (7). Furthermore, irregular canal cross-sections, accessory canals, and apical deltas (Fig. 1) are mostly inaccessible to mechanical preparation (8, 9). Moreover, canal curvature results in asymmetrical material removal during shaping, leading to canal transportation of varying degrees (Fig. 1, see movie clips in the online version of this article at http://www.jendodon.com/).

Most root canals are curved, whereas endodontic instruments are manufactured from straight metal blanks. This results in uneven force distribution in certain contact areas (10, 11) and a tendency of the instrument to straighten itself inside the root canal (12). Consequently, apical canal areas tend to be overprepared toward the outer curve or the convexity of the canal, whereas more coronal areas are transported toward the concavity or the furcation in multirooted teeth. This analysis is based on a primary curve (e.g., main palatal canal in Fig. 1A); however, in most cases, root canal anatomy is much more complicated, with curves in multiple positions and planes (5, 6, 13).

The fact that roots are curved was initially appreciated by simply stating the angle of the curve (14) and then categorizing roots as straight (5° and less), moderately (10 to 20°) or severely (>20°) curved. However, it has been pointed out that the radius of the curve has to be viewed together with its angle (15). It was later proposed that position and severity of canal curvature was important regarding a safe use of rotary instruments (16).

Later, advanced methods based on three-dimensional data acquisition became available for the description of canal geometry and possible changes during shaping procedures. One method

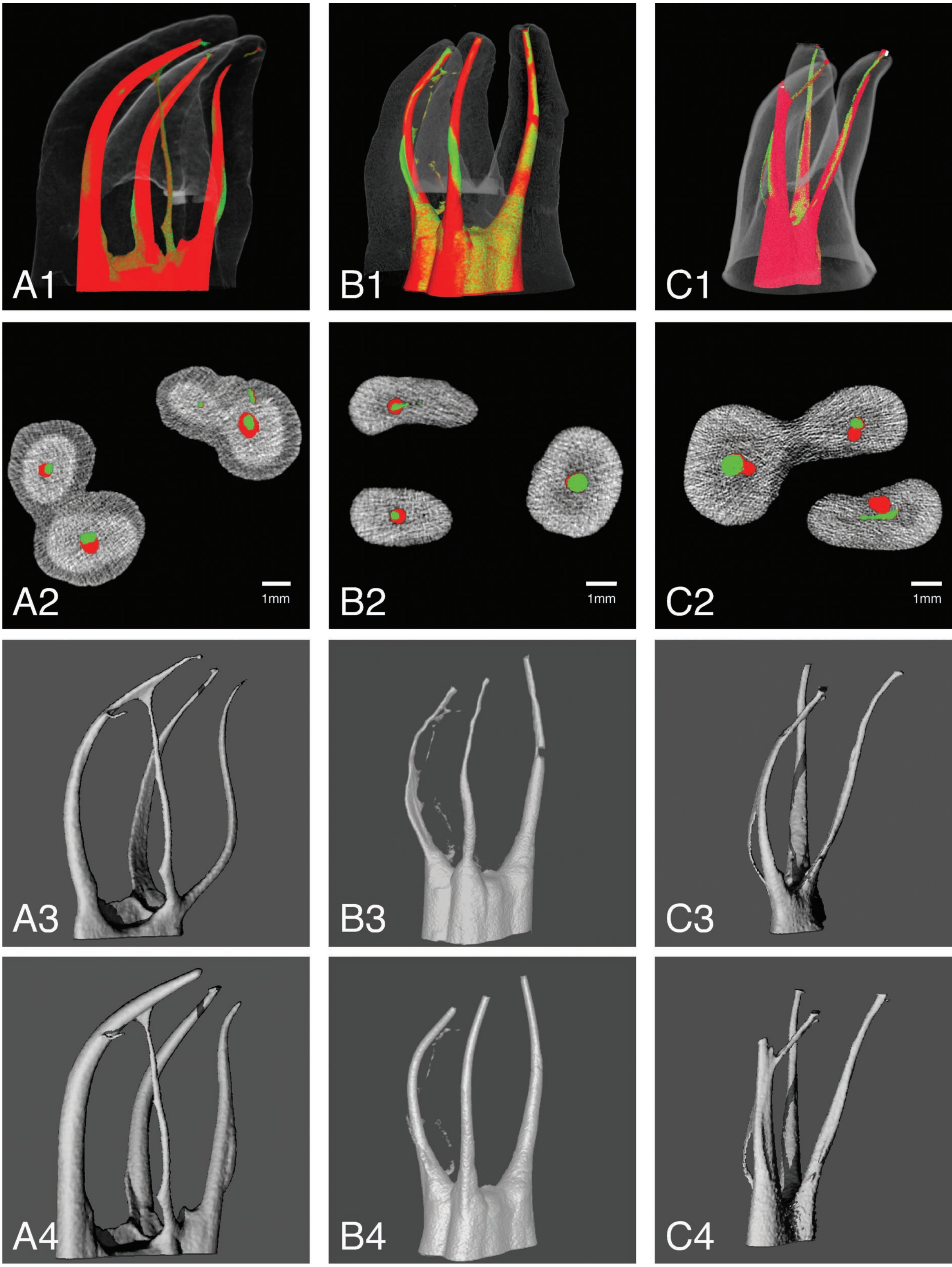

FIG 1. Root canal anatomy and effects of canal shaping illustrated by microcomputed tomography. Mpeg-4 movie clips showing 360-degree views of A1 to C1 are available as part of the on-line version of this article at http://www.jendodon.com/. (*A*) Preparation with variably tapered instruments, (*B*) .04 & .06 instruments, and (*C*) oscillating tapered instruments. (*Row 1*) color-coded compound figures: (*red*) postoperative shapes, (*green*) preoperative canal systems. Mixed colors indicate summation, i.e., no changes during shaping. (*Row 2*) representative postoperative cross-sections (*red*) superimposed with preoperative canal shapes (*green*) (magnification indicated by white bars). (*Rows 3 and 4*) three-dimensional renderings of preoperative and postoperative canal systems, respectively. Note bright white spots in C1 denoting separated instruments and a ledge with perforation in the main mesiobuccal canal. (*A3 and A4*) reprinted with permission from Peters et al. ProTaper rotary root canal preparation: effects of canal anatomy on final shape analysed by micro CT. Int Endod J 2003;36:86–92. (*B1, B3, and B4*) reprinted with permission from Hübscher et al. Root canal preparation with FlexMaster: canal shapes analysed by micro-computed tomography. Int Endod J 2003;36:740–7.

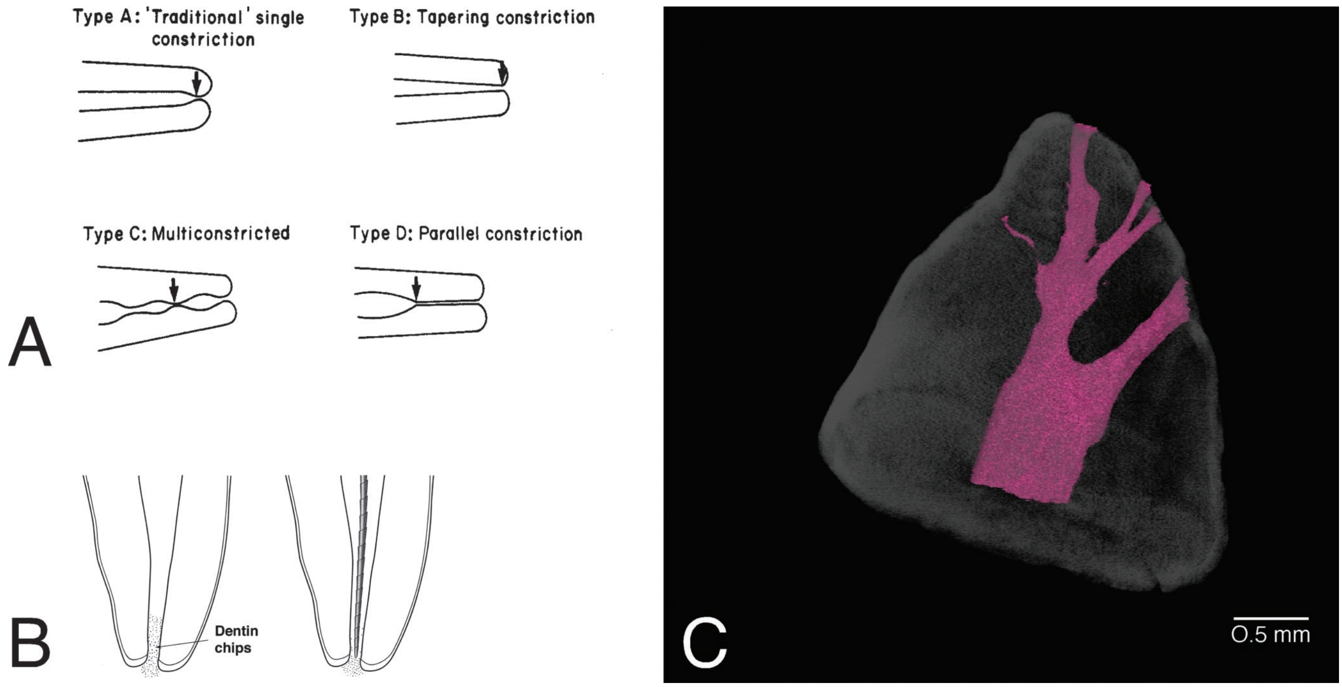

FIG 2. Apical anatomy and relation to instrumentation. (*A*) Possible formations seen in the apical root canal third. Redrawn from histological slides; modified and reprinted with permission from Dummer et al. The position and topography of the apical canal constriction and apical foramen. Int Endod J 1984;17:192–8. (*B*) Dentin chips packed into the portal of exit by filing actions. Note the nonexisting apical stop or constriction. Modified and reprinted with permission from Wu et al. Apical terminus location of root canal treatment procedures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:99–103. (*C*) Three-dimensional rendering of an apical section of a mesiobuccal root of a maxillary molar at a resolution of 8 μm. Note multiple portals of exit with no obvious apical constriction in either of them (magnification indicated by white bar).

relied on multiple conventional radiographs (17), and this method was later modified to assess root curvature three-dimensionally (18). In the former study, 433 roots were radiographed and from mathematical calculations, canals were described as presenting with I-, J-, C-, or S-form (17). Bjørndal et al. (19) described another advanced technique, which compared cross-sections of outer root contours with canal outlines. They found high correlations between contours of mesiobuccal and distobuccal root components and canal outlines.

Recently, microcomputed tomography (μCT) has emerged as a powerful tool for evaluation of root-canal morphology (20–29). This technology (Fig. 1 and also mpeg files in the online version of this article at JOE online at http://www.jendodon.com/) allows more complete descriptions of three-dimensional effects that canal preparation exert on anatomy. However, at this time, such detailed analyses cannot be performed in clinical practice but may become available in the near future (30).

Another anatomical area that is not fully appreciated from clinical radiographs is the apical region (Figs. 1 and 2). The action of rotary instruments with actively cutting blades in this region needs to be further evaluated, but it can be surmised that such an instrument taken long and outside the canal space would create a preparation error known as apical zip with perforation (31). The occurrence of such apical preparation errors has previously been linked to hand and rotary instruments with sharp tips (32–34).

Zip-and-elbow formation and other well-described preparation outcomes such as ledges, strip-perforations, or excessive thinning of canal walls have in common that they are possible results of canal transportation. The latter term has been defined, and calculated, in various ways (2, 20, 25, 35, 36) to account for canal diameters and instrument sizes; it can be more simply defined as any undesirable deviation from natural canal paths. From a clinical perspective and according to guidelines set forth by the European Society of Endodontology (37), it is envisaged that a prepared root canal encircles the entire circumference of the unprepared canal indicating that a given canal is thoroughly debrided.

The impact of procedural errors or instrument separations on clinical outcomes has been discussed in some detail in the past (38, 39). In principle, canal transportation could result in inadequately cleaned canals with the possible outcome of persistent apical lesions or in thinned canal walls with the possible outcome of perforations or vertical fractures. Unfortunately, only sparse information exists from studies in the nickel-titanium (NiTi) era (40, 41), and at present, no evidence links improved canals shapes through NiTi instrumentation to higher success rates (42).

It should be cautioned that another way for some preparation errors, e.g., apical perforations, to occur is canal blockage with dentin mud and subsequent overzealous enlargement with inflexible files (Fig. 2). Considering a high prevalence of preparation errors and their potential clinical effects (43), a noninstrumental technique (NIT), relying exclusively on activated disinfecting and tissue-dissolving solutions, may be preferred (44). Unfortunately, a recent clinical evaluation revealed that only 21% of the tested roots were sufficiently cleaned with this method, indicating a need for further modifications before this technique can be used in routine clinical practice (45).

For now, endodontic therapy will include mechanical preparation; a simple way of comparing canal paths before and after shaping is to superimpose radiographs of both stages, using a double exposure system (46–48). This system has recently been refined by using scanned images instead of original radiographs (49) but still allows measurements only from two-dimensional projections of the canals. Bramante et al. (50) described a technique to analyze the effects of instrumentation on cross-sections of root canals that was later modified (51–53). Briefly summarized, roots are embedded in a muffle system, cut and the cross sections evaluated before and after canal preparation (similar to Fig. 1, A2–C2). Center points of the canals may then be calculated before and after preparation; scores indicate the ability of a specific instrument to remain centered within the canal. For research purposes, movements of the canals' centers of gravity were calculated directly from the Pythagorean theorem (54–57) or from modified formulas (35, 58–60). Numerous studies evaluated shaping capabilities of specific instruments using canals of varying geometry in plastic blocks and extracted teeth. Some possible factors for canal transportation have been discussed, such as canal anatomy, instrument type, cross-sectional and tip design, instrument taper, sequence, operator experience, rotational speed (rpm), and the use of an irrigant or lubricant.

As indicated above, the effect of canal anatomy on shaping outcome is well documented for Lightspeed (Lightspeed Inc., San Antonio TX), ProFile .04 & .06 (Dentsply-Maillefer, Ballaigues, Switzerland), Quantec LX & SC (Analytic Endodontics, Glendora CA) and Hero 642 (Micro-Mega, Besancon, France), in particular by experiments from Dummer's group using plastic blocks (34, 61–68). Taken together, these studies demonstrated an impact of canal geometry on outcome: the more severe the angle and radius of the curve, the more severe canal transportation. On the other hand, there was no significant effect of canal shape on preparation times.

Furthermore, file design was essential in avoiding preparation errors: actively cutting tips such as with Quantec SC (68) and to a lesser extent Quantec LX (34) produced more apical zips and perforations than instruments with noncutting tips such as ProFile .04 and .06 (63–65, 69) and Lightspeed (61, 62). Further observations indicated deficient secondary shaping characteristics such as insufficient taper for Hero 642 (67) and poor flow for Lightspeed instruments (61) as well as cases of "outer widening" (65) with instruments with tapers $>$ .04 (66). The direction of apical canal transportation varied but occurred mainly outwards in relation to the canals' curve; the total amount of canal transportation varied significantly, again in relation to canal geometry, and ranged in most cases between 0.01 and 0.15 mm (34, 61–68).

Comparisons with earlier experiments by the same group indicated that NiTi instruments are superior to stainless-steel ones with regard to their shaping ability (70, 71). Schäfer et al. reported that Hero 642 (72), FlexMaster (VDW, Munich, Germany) (73) and K3 instruments (SybronEndo, West Collins, CA) (74) maintained the original canal path in curved plastic blocks better compared with stainless-steel hand instruments. They found little incidence of canal aberrations and material removal in excess of 0.15 mm in $<$ 50% of the levels analyzed for Hero, FlexMaster, and K3 (72–74), whereas hand instrumentation resulted in material removal of up to 0.69 mm (74).

ProTaper instruments (Dentsply-Maillefer) prepared curved canals in plastic blocks in less time (mean, 34 $\pm$ 5 s) and with no definite canal aberrations, but with a larger amount of material removal, compared with GT Rotary, Quantec, and ProFile .04 and .06 instruments (75). In a study using another brand of plastic blocks, Hata et al. found overall long preparation times ($>$250 s) for ProFile .04, ProFile .04 and .06, GT Rotary, and, in particular, balanced force instrumentation (76). They further demonstrated material removal below 0.15 mm in 93% of the canal levels analyzed (76). However, although simulated canals in plastic blocks allow comparisons between instrument types and sequences under identical conditions, there are certain disadvantages as their surface texture and hardness as well as cross-sections differ from those in natural teeth.

Studies on extracted teeth using cross-sections (35, 55, 59, 60, 77–79) fully confirmed observations made on plastic blocks. Moreover, it was evident from root cross-sections that canals were usually circumferentially prepared to 60% to 80% or less of the canal outlines (80–84).

These studies were validated by three-dimensional analyses (Fig. 1) using microcomputed tomography (3, 21, 24, 27, 85, 86). Although the amount of prepared canal surface seems to be independent of instrument type, it was significantly affected by preoperative canal anatomy (3, 21, 24).

Besides canal anatomy, instrument tip design has been identified as a potential factor for preparation outcomes (32, 33, 68, 87–90). In particular, a high incidence of zips that occurred in acute apical curves was noted for instruments with actively cutting tips (68).

Instrument shaft design did not significantly modify shapes of similar apical sizes in one series of studies (85, 86), although it is generally held that a thin, flexible shaft will allow larger apical shapes with less aberrations (35, 91). In contrast, ProFile .04 instruments alone removed more material compared with a combination of ProFile .04 and .06 (76).

Cutting blade design was modified lately from passive, so-called, U-file designs to more actively cutting triangular ones in instruments such as ProTaper, FlexMaster, K3, Hero 642, and RaCe (FKG, La Chaux-de-Fonds, Switzerland). However, although there is only limited evidence for each individual file (3, 24, 72, 73, 86, 92, 93), the introduction of actively cutting cross-sections does not seem to negatively affect centering abilities.

It may be inferred, however, that care should be taken not to instrument the apical foramen with more actively cutting blades to avoid zipping with perforation (94). Furthermore, actively cutting instruments such as ProTaper should not be used with an extended pecking motion, which was recommended for U-file designs such as Lightspeed and ProFile to avoid canal transportation (3, 16). In the past, rotary instrument design has been linked to operational safety and fracture resistance during shaping procedures more than to shaping outcomes.

Physical parameters such as torque and force present when shaping root canals with rotary instruments have been assessed in straight (95, 96) and curved canals (3, 97, 98). A detailed discussion of nickel-titanium metallurgy and manufacturing processes is beyond the scope of this article [for review see (99)]; however, safe clinical usage of NiTi instruments requires an understanding of basic fracture mechanisms and their correlation to canal anatomy.

Instruments used in rotary motion separate in two distinct modes: torsional and flexural (100). Torsional fracture occurs when an instrument tip is locked in a canal while the shank continues to rotate, thereby exerting sufficient torque to fracture the tip. This also may happen when the instrument rotation at the tip is slowed substantially in relation to cross-sectional diameters. In contrast, flexural fractures occur after repeated subthreshold loads have led to metal fatigue. In fact, the latter problem impacts the production of rotary endodontic instruments from stainless steel, because steel develops fatal fatigue after only a small number of cycles in severe curves (99). In contrast, NiTi instruments may withstand several hundreds of flexural cycles before they fracture (98, 101).

Resistance of rotary instruments to cyclic fatigue decreases with increasing instrument diameters, specifically with core dimensions

(101). Moreover, increased severity of angle and radius of the curve, around which the instrument rotates, decreases instrument lifespans in vitro and clinically (15, 98, 101, 102).

Likewise, a greater and more acute curve subjects an instrument to greater restoring forces (11). Consequently, canals with more severe curves (e.g., main palatal canal in Fig. 1A) are likely to exhibit more pronounced canal transportation than relatively straight canals (34, 61–68).

Torque scores generated during preparation depend on a variety of parameters, and perhaps the most important factor is the size of the contact area between root-canal dentin and the instrument (103, 104). This size and with it the amount of friction is influenced by instrumentation sequences (104) and by using instruments with varying tapers (103, 104). Regardless, a crown-down approach is superior to stepping back in decreasing fracture risks by preventing a large portion of an instrument from engaging root dentin ("taper lock") (103). In addition, the operator can modify torque by varying axial pressure (98). It has been argued that greater operator experience and extensive preclinical training is related to less taper lock (105, 106). In fact, manufacturers recommend a light touch for all techniques using rotary NiTi instruments to avoid forcing rotary instruments into taper lock. The same effect might result in certain anatomical situations, such as when canals merge (Fig. 1A, palatal canal). Clinically, NiTi rotary instruments are subjected to a combination of torsional load and cyclic fatigue (107, 108) and ongoing research aims to clarify relative contributions of both factors to instrument separation.

Various operator-related factors may further contribute to shaping results. Although little operator experience is considered a risk factor for file separation (105, 109), novice clinicians shaped root canals successfully both in vitro (27, 110–112) and clinically (40) with various NiTi instruments. Nevertheless, is has been recommended to attend continuous education courses, practice with extracted teeth, and follow manufacturers' guidelines when using these instrument to avoid potential mishaps clinically (113).

Most recommended instrument sequences include a crown-down portion, in which larger files precede smaller ones, which then in turn progress further apically. This approach is mandatory to reduce frictional intracanal stresses and may improve shaping characteristics with hand files (46). However, it does not seem to significantly alter shaping patterns with NiTi instruments, at least for ProFile (49, 65).

Regarding instrument sequence, the use of a patency file, i.e., a fine file that is passively passed through the apical foramen, has been suggested for most rotary techniques. However, this issue is controversial, in particular, because infected dentin chips may be forced into periapical areas (Fig. 2B); a large proportion of dental schools in the United States does not teach this concept (114). Moreover, Goldberg and Massone (115) demonstrated that the use of patency files of varying sizes did not prevent the occurrence of preparation errors.

The clinician also can choose rotational speed; again, this setting seems more important for file separation incidence (116) than for shaping outcomes (117, 118). Although most engine-driven systems use continuous rotary motion [Fig. 1 (A and B)], oscillation also is used (Fig. 1C) to allow a filing action of an instrument. Not surprisingly, rotary instrumentation produces round or oval cross-sections (82, 84), leaving substantial canal wall areas untouched. Theoretically, nonround canal cross-sections with recesses and fins may be more completely prepared with filing strokes compared with rotary movements; unfortunately, circumferential filing does not increase the amount of instrumented canal walls (119), but leads to increased dentin removal into danger zones and to canal transportation (120).

Finally, the use of friction-reducing agents—irrigation solutions (e.g., NaOCl or EDTA) or intracanal lubricants—has been recommended for NiTi rotary instrumentation (16). Again, evidence regarding canal transportation when using lubricants is limited (121), but dentin demineralization with EDTA led to increased transportation in canals instrumented with NiTi hand files (122). In summary, for most rotary NiTi systems, absolute canal transportation scores do not exceed 150 μm and gross preparation errors are rare; hence, these preparation systems can be considered safe and efficient canal shaping tools.

Determination and Maintenance of Working Lengths

Some additional considerations are required for the successful clinical use of NiTi rotary instruments. One of these is the effect of rotary instrumentation techniques on apical tissues, e.g., the amount of extruded debris. Filing techniques lead to more extruded debris compared with the balanced force technique (123, 124). Similarly, Lightspeed and ProFile Series 29 both forced significantly less debris apically compared to step-back instrumentation with K-Files (125, 126) and extruded similar amounts as Flex-R files used in balanced force motion (126, 127). Extrusion of debris, dentin mud, or microorganisms is considered to play a role in flare-ups and, even more importantly, in treatment failures (128–130). Figure 2B illustrates the action of a fine file in apical canal areas in the presence of compacted dentin debris. A patency file should be used with care, because it may force accumulated debris apically, possibly including microbes. However, a recent report indicates little risk of inoculating microbes into the periapical region with a patency file (131).

Sjögren et al. (129) demonstrated that obturation end points 0- to 2-mm short of the radiographic apex render significantly improved long-term results in teeth affected with apical periodontitis compared to overextended obturations (success rates of 94% and 76%, respectively). Importantly, success rates in vital cases were not altered by obturation material in the periapical space (129); furthermore, a recent clinical study on endodontic treatment with NiTi instruments failed to show any significant effect of overfilling on healing rates (42). In earlier studies (129, 132), apical stops were prepared using stainless steel K-files and Hedström files in the step-back technique, and apical file sizes often were ISO 40 or larger. Although the incidence of canal transportation is not mentioned in those studies, the instrumentation technique may have resulted in shape aberrations. Recently, using a fluid-filtration model, Fan et al. (133) showed that obturated root canals with irregular shapes leaked significantly more compared with those with little or no canal transportation.

To decrease instrumentation risks, preparations 2- to 3-mm short of the radiographic apex were recommended for apical stop preparations in vital cases (134). However, the same authors suggested procedures for nonvital cases entailing sufficiently wide canal shapes 0- to 1-mm coronally of the apical constriction. This strategy should be modified for continuously rotating NiTi instruments. Firstly, as shown with μCT scans (Figs. 1 and 2) and histological analyses (135), a classical apical constriction may not present in at least 50% of the cases. Second, as shown in plastic blocks and extracted teeth (136), instruments with modified tips and smooth transition angles will shape apical stops rather imperfectly. Third, active cutting blades should not touch the most apical canal area in curved canals to minimize canal transportation (3). All these facts indicate, besides biological requirements, that a perfect determination and maintenance of working length is required. Modern electronic canal length measurement devices are highly reliable to identify canal lengths within 0.5 mm (137). Removing coronal obstructions early, during crown-down, will further enhance length measurement accuracy by way of affording a straight access to apical canal areas (138). Furthermore, engine-driven rotary techniques have been shown rarely to lose or gain working lengths of > 0.5 mm (34, 61–68). In summary, length control seems to be simplified, but a three-dimensional concept of the apical dental anatomy is required to adjust instrumentation lengths to a specific clinical case.

Apical Width

Principles of a standardized root canal preparation are mainly based on concepts of apical canal geometry developed in the 1950s (139), which suggested apical canal diameters of 0.27 to 0.33 mm. However, detailed anatomical analyses indicate that the concept for such a standardized root-canal preparation (140) to an apical stop coronal to the constriction may be problematic, again because the "classical" singular constriction was not present in > 50% of the canals evaluated (135) and because of possible sequelae of canal over-enlargement, in particular vertical root fracture.

Classical bacteriological studies indicated that mechanical instrumentation alone resulted in a significant reduction of bacteria counts (141). Infected canals in that study were prepared to ISO size 40 apical stops using stainless-steel Hedström files with working lengths 1-mm short of the root apices. Bacteria counts were equally reduced in a clinical study on teeth presenting with apical periodontitis when NiTi rotary instruments were compared with conventional stainless-steel types (142). Shaped canals had significantly reduced bacteria counts in the first session and progressively more so in subsequent instrumentation appointments. Nevertheless, viable bacteria were still detected at the fourth session, and the authors concluded that disinfecting irrigants should always significantly reduce viable bacteria counts (91, 143).

Irrigants are commonly delivered using a syringe and needle system, but a study using radio-opaque liquids indicated that the apical penetration of the irrigants is only 1 mm beyond the needle tip (144). Furthermore, Usman et al. (145) demonstrated that the amount of irrigant delivered increased with numbers of recapitulations. This information and regularly available needle types (27- and 30-gauge, equivalent to 0.42 and 0.31 mm, respectively) suggest that canal diameter and curvature play an important role in irrigation efficacy.

Figure 3 illustrates two possible shaping outcomes for mandibular molars: a wider preparation to an apical stop with no excess sealer and some straightening (Fig. 3A); on the other hand, a small apical dimension, preparation to the radiographic terminus, and thermoplastic obturation with some surplus sealer and an acute apical curve (Fig. 3B). It is a matter of continuous debate whether a smaller apical preparation allows sufficient antimicrobial action to take place (91, 146, 147). To that end, hybrid instrumentation techniques have been advocated, for example the combination of a tapered instrument (e.g., ProFile) for a crown-down section and a flexible instrument (e.g., Lightspeed) for an apical enlargement to sizes of up to #55 in mesial roots of mandibular molars (91, 148).

The clinician has to carefully decide with which instrument and how wide to shape a given canal to achieve antimicrobial efficiency without overly weakening tooth structure. Most NiTi instruments used according to current guidelines allow wider shapes without major preparation errors and without excessively reducing radicular walls. Remaining dentin thickness was > 0.58 mm with GT rotaries, ProFile, and Hero (27, 79) and other NiTi rotary instruments (O. Peters, unpublished data, compare Fig. 1A4 to C4). Earlier studies had indicated considerable thinning of dentin walls after ultrasonic instrumentation (149), which may predispose roots to vertical fracture (150). In summary, antimicrobial efficacy of endodontic therapy is of prime importance and depends, at least partly, on preparation length and width.

FIG 3. Two examples of endodontically treated mandibular molars demonstrating two extremes in the spectrum of existing shaping paradigms. (*A*) Tooth was shaped to a size larger than #55 with a combination of ProFile and Lightspeed rotary instruments. Modified and reprinted with permission from Card SJ, Sigurdsson A, Ørstavik D, Trope M. The effectiveness of increased apical enlargement in reducing intracanal bacteria. J Endodon 2002;28:779–83. (*B*) Tooth, displaying acute curvatures apically in both the distal and mesial root-canal systems, was treated with GT rotary instruments. Modified and reprinted with permission from Buchanan LS. The standardized-taper root canal preparation: part 6. GT file technique in abruptly curved canals. Int Endod J 2001;34:250–9.

Conclusions

Clinically, it is important to envisage the specific purpose of canal shaping extending beyond antimicrobial efficacy. During the last four decades, several authors have reported that canal preparation has a great influence on the outcome of obturation procedures (151–153). Although common sense suggests this to be true, there is surprisingly little evidence for that proposition. In fact, although clinicians and researchers agree that canals must be obturated to the end point of the preparation, the recommended procedures to achieve that goal differ widely. For example, for lateral compaction, it was suggested that spreader penetration as close as 1 mm to working length is desirable for an adequate apical seal (154). These experiments were performed using canals with curvatures of < 20 degrees, and consequently, there were few, if any, procedural errors. Unfortunately, the preparation techniques used in those studies were not detailed. Experiments using a fluid transportation model indicated that canal transportation was well correlated with leakage (133, 155). In those studies, apical stops were prepared with size 50 Lightspeed instruments or with hand files in canals with significant curvatures, varying from 21 to 38 degrees. The incidence of canal transportation assessed from double-exposure radiographs was significantly less for the Lightspeed group compared with the hand-filed group. In addition, none of the Lightspeed-prepared specimens exhibited microleakage, whereas 40% of the specimens instrumented with K-Files did show leakage. Similarly, cases treated with NiTi instruments clinically showed a low incidence of preparation errors, satisfactory obturation as judged from radiographs, and significantly improved healing compared with a control group treated with stainless-steel instruments (41). A recent clinical study comparing three rotary preparation paradigms (Lightspeed, ProFile .04, and Profile .04 and .06) indicated an overall healing rate of 86.7% in cases that included retreatments and cases with periapical lesions (42). No difference in healing rates between the three systems were detected, indicating other unidentified factors that influence periapical healing (156).

Nickel-titanium rotary instruments have become an important adjunct in endodontic therapy. Despite the existence of one ever-present risk factor—dental anatomy—shaping outcomes with these instruments are mostly predictable. Current evidence indicates that wider apical preparations are feasible and with that probably improved irrigation efficacy and obturation quality. NiTi rotary instruments require an extensive in vitro training period to minimize separation risks and should be used to case-related working lengths and apical widths. Despite superior in vitro results compared with stainless-steel hand instruments, randomized clinical trials are required to evaluate clinical outcomes when using NiTi rotaries in endodontic therapy.

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Dr. Peters is associate professor and head, Division of Endodontology, Clinic for Preventive Dentistry, Periodontology and Cariology, University of Zürich, Switzerland. Dr. Peters also is affiliated with the Endodontic Division, Department of Preventive and Restorative Dental Sciences, University of California San Francisco.

Address requests for reprints to Dr. Ove Peters, Clinic for Preventive Dentistry, Periodontology and Cariology, Center of Dental and Oral Medicine and Cranio-Maxillofacial Surgery, University of Zürich, Plattenstr. 11, CH-8028 Zurich, Switzerland. E-mail: ove.peters@zzmk.unizh.ch.

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