INTRODUCTION

The key factor in the development of pulpal inflammation and apical periodontitis is the presence of bacteria [42]. It has been widely accepted that bacteria and/or their products are the main aetiological factors in the initiation and progress of these diseases [10]. Consequently, the central focus of root canal treatment has been directed towards the elimination of bacteria and their substrates from the pulp canal system. This may involve removal of necrotic pulp and tissue debris, removal of an inflamed pulp or, in elective treatment, the removal of healthy tissue. Retreatment of failing cases is addressed in Chapter 13.

Historically, a mechanistic approach to root canal treatment was frequently adopted, but in recent years a greater awareness of the complexities of the root canal system (Fig. 6.1) has led to the development of newer techniques, instruments and materials. These new developments have greatly enhanced the clinician’s ability to achieve the biologically-based objectives of root canal treatment, which include:

1. Removal of all tissue, bacteria and bacterial products and substrates from the root canal system.
2. Shaping of the root canal system to facilitate placement of a root canal filling.
3. Filling of the shaped canal system coupled with an adequate and timely coronal restoration.

Traditionally the ‘endodontic triad’ concept of cleaning, shaping and filling has been promulgated widely. However, considering that a major goal of root canal treatment is removal of microorganisms from the complex root canal system, it would therefore appear that ‘shaping to facilitate cleaning and filling’ might be a more appropriate concept. These objectives must be achieved while ensuring conservation of tooth structure and maintaining canal shape.

**PREOPERATIVE ASSESSMENT**

Once a diagnosis has confirmed the need for root canal treatment, then a treatment plan that includes the marginal periodontal status and restorability of the tooth is essential before treatment commences. In addition to the clinical examination this assessment includes radiological evaluation of the tooth.

Good quality preoperative radiographs (preferably from two different angles) are indicated (Fig. 6.2). These films must not be distorted, and must be processed properly to ensure a permanent record. Alternatively, digital radiographs should be filed and a permanent copy stored. Use of a paralleling technique and a film-holder (Fig. 6.3) will minimize distortion of the radiograph and facilitate accurate preoperative, postoperative and review comparisons.

Periapical films are the radiographic views most frequently used during root canal treatment. However, other intraoral and extraoral views can often contribute to the overall preoperative assessment and to diagnosis. These additional films include bitewing, panoramic and occlusal films. For example, a supplemental bitewing radiograph may be useful in detecting suspected caries not readily visible on the periapical radiograph or to determine the relationship of the pulp chamber to the external surface of the tooth (Fig. 6.4).

The tooth to be treated should be located centrally on the periapical film with at least 2 mm of peri-radicular tissue visible beyond and around the apex. A subsequent film should be exposed with the X-ray beam angled 15°–20° to the original exposure. This shift in angulation results in an apparent change in the position of the roots and is called the parallax effect. Both horizontal and vertical parallax techniques can be used. A good quality film (Fig. 6.2) will provide information concerning the general tooth form and the relationship of the tooth to the surrounding structures. Furthermore, it will reveal evidence about the number of roots, their length, and the relationship of the roots to the crown of the tooth. Moreover, it can provide details of previous dental disease and treatment, as well as the resultant pulp reactions such as narrowing of the pulp.
chamber and root canals or presence of pulp calcifications. However, interpretation of radiographs can be misleading if certain concepts are not understood; for example, teeth with irreversibly inflamed or necrotic pulps frequently show no radiological changes. Likewise radiological evidence of peri-radicular lesions may not become obvious until the dense cortical plate of bone has undergone some resorption [8,9].

The radicular anatomy of teeth is variable, as is the relationship of the roots to the surrounding bone. A number of anatomical structures overlie the roots such as the zygomatic arch, mandibular and maxillary tori and the maxillary sinus; they frequently confuse radiological interpretation of the image. It must be appreciated that a radiograph is merely a two-dimensional shadow of a three-dimensional object. In addition, interpretation of radiographs has been shown to be highly subjective [29,30,31,72].

During the preoperative assessment it may become evident that a tooth requires coronal build-up, crown lengthening or extrusion before a rubber dam clamp can be placed and root canal treatment started. Localized periodontal surgical procedures or electrosurgery are recommended frequently when caries or fractures extend more than 2–3 mm subgingivally. Before the tooth can be restored adequately, a sound dentine margin should protrude at least 1 mm above the free gingival margin that is...
normally 1–2 mm from the sulcus depth. This implies that the dentine margin should be approximately 3 mm above the crestal bone. The combined connective tissue and epithelial attachment from the crest of the alveolar bone to the base of the gingival sulcus is called the biological width. It is important that restorations do not encroach on this normal soft tissue attachment.

**PREPARATION OF THE CLINICAL CROWN**

Preliminary procedures involve isolation of the tooth and removal of all dental caries. Existing restorations may need to be removed completely especially if defective [1]. Even if dental caries does not dictate the complete removal of the restoration, it is often beneficial to do so as hidden fracture lines in the proximal areas become visible (Fig. 6.5). If cast restorations are present, it is important to assess the integrity of the restoration and its cement lute, and to decide whether to retain or to remove the restoration. If the tooth is at risk of fracture, a provisional crown or an orthodontic band should be placed prior to treatment. Orthodontic bands provide an excellent option when there has been extensive loss of coronal tooth tissue. These bands are supplied in a wide variety of sizes and are readily adjusted and cemented to the existing tooth structure.

Failure to prepare the crown adequately prior to root canal treatment can result in:

- bacterial contamination from saliva or caries during or between treatments;
- displacement of restorative materials into the canal;
- fracture of unsupported tooth structure between visits or after treatment.

Isolation of the tooth with rubber dam is a necessary prerequisite for endodontic treatment. It is essential for protection of the airway. The inhalation or swallowing of instruments by a patient in the absence of rubber dam is a serious but preventable accident and is indefensible.

The rubber dam application technique is a matter of choice for the individual clinician. A wide variety

Figure 6.5 The maxillary premolar (a) shows a crack in the floor of the mesial box after removal of the restoration and staining; (b) the mandibular molar shows a crack on the distal aspect after removal of the crown and staining.
of clamps are available but a skilled clinician will normally use a limited range. Winged clamps are most suitable for the fast and efficient placement of rubber dam (Fig. 6.6). These winged clamps allow the dentist to place the clamp, dam and frame in one action. In recent years an increasing number of reports of allergies to latex have been reported and therefore non-latex rubber dam has been developed. A complete dam placement kit should include:

- rubber dam;
- rubber dam punch;
- clamp forceps;
- selection of clamps;
- dental floss;
- caulking agent.

Occasional improvisation is necessary when routine rubber dam placement proves difficult. Examples include cases where the tooth in question has undergone extensive coronal tissue loss or where the tooth to be treated is the abutment for a fixed bridge. These situations frequently necessitate clamping an adjacent tooth and stretching the dam over the tooth to be treated, using a ‘split-dam’ technique (Fig. 6.7). Following placement, minor defects in the adaptation of the dam can be corrected with a caulking agent such as OraSeal (Ultradent, Salt Lake City, UT, USA) or cyanoacrylate [67].

Excellent reviews of rubber dam placement have been published [50,65,66]. In general, rubber dam application prior to endodontic treatment should be a simple procedure and will enhance both treatment and patient comfort.

**ACCESS CAVITY**

The main function of the access cavity is to create an unimpeded pathway to the pulp space and the apical foramen of the tooth. Many problems encountered during root canal treatment can be
avoided or eliminated by a properly designed access opening. The major consideration in all access openings is that conservation of coronal tooth structure should never preclude the proper design and purpose of the access opening [36].

The design of the access cavity to the pulp chamber should reflect the anticipated position of the underlying root canal orifices. The relationship between the pulp chamber and external anatomical outlines must be assessed on the preoperative radiographs. Careful analysis of the radiographs and careful alignment of the bur will reduce the possibility of mishaps during access preparation (Fig. 6.8). Inadvertent overextension of a bur either vertically through the floor of the chamber into the furcation or laterally can be prevented by taking these precautions. Occasionally, in cases where an extra-coronal restoration is severely tilted relative to the roots or in cases with sclerosed root canal systems, access to the pulp canal chamber may best be created prior to placing rubber dam to permit more accurate orientation of the rotary instruments to the root outline.

The pulp chamber must be completely unroofed. The pulp chamber dimensions can vary enormously and reflect the nature of the ‘insults’ that the tooth suffered since eruption. In addition, mineralized deposits are frequently found in the chamber and root canal system (Fig. 6.9).

A well-designed access cavity (Fig. 6.10) permits:
- complete debridement of the pulp chamber;
- visualization of its floor;
- unimpeded placement of instruments into the root canals;
- conservation of tooth tissue.

Coronal and cervical obstructions that may have a restrictive effect on canal exploration and instrumentation need to be eliminated [47].

Irrigation of the pulp chamber with sodium hypochlorite (NaOCl) during access cavity
preparation is used to dissolve tissue and aid in debridement of the chamber. This will also reduce the opportunity for the inadvertent inoculation of microorganisms from the pulp chamber into the root canal system. Ultrasonically energized tips (Fig. 6.11) are useful adjuncts during debridement of the pulp chamber to break up calcific masses with relative safety and to facilitate removal of debris. These instruments are contra-angled to enhance access.

ROOT CANAL ORIFICES

A sound knowledge of the anatomy of the tooth is very important to the practice of predictable and successful endodontics. The number of canals and their approximate positions can be predicted from a knowledge of dentinogenesis and the nature of root formation. No technological advances or innovations can fully compensate for a lack of understanding of the anatomical features of the pulp chamber, which along with the root canal space are always located in the cross-sectional centre of the crown and root respectively [36]. The location of canal orifices is best achieved with good illumination and a dry pulp floor. Magnification with either loupes or a microscope is usually considered beneficial; however the microscope is better for detecting orifices [91]. Careful inspection of the floor will usually reveal anatomical ‘guidelines’ (Fig. 6.10) that will facilitate identification of the orifices even in calcified cases. If the orifice is not immediately apparent,
a sharp DG 16 probe can be used to explore along the anatomical landmarks on the pulp floor. Re-assessment of the relationship of the internal anatomical features to the external outlines will also help with orientation during a search for orifices that are difficult to locate.

In extensively calcified canals transillumination or the use of dye may provide some guidance for orifice identification and instrument progression. Even extensively calcified canals may contain pulp tissue and judicious use of a variety of instruments usually facilitates entry into the canal system. A number of ultrasonically energized instruments have been designed for this purpose. Despite being relatively safe, care must be taken if perforation of the root is to be avoided. Radiographs taken with radiopaque markers in the chamber can help confirm the direction of instrumentation (Fig. 6.12). When using rotary instruments such as Müller burs or long-shank small round high-speed tungsten-carbide burs, frequent re-evaluation of bur position visually and/or radiographically will reduce procedural errors. The direction of search can then be adjusted if necessary and the procedure continued. Furthermore, enlargement of the canal orifices prior to instrumentation facilitates mid-root and apical instrumentation, and enhances irrigation.

**WORKING LENGTH DETERMINATION**

Planning a final point for instrumentation and filling depends on the philosophy of treatment, while establishment of this point can be determined in a number of ways. It is necessary to establish the length of the tooth accurately during root canal treatment [12,13,18,33,37,46]. The most widely accepted method for establishing working length has been the use of radiographs. In this method...
[40], an estimated working length is initially established by measuring from an accurate, non-distorted, preoperative radiograph. A file, preferably ISO size 15 or greater, is then placed to the estimated working length and a second radiograph is exposed. If the tip of the file is within 1 mm of the ideal location then the radiograph can be accepted as an accurate representation of the tooth length. If adjustments of 2 mm or more need to be made, working length should be reconfirmed with a new radiograph [19]. This method usually provides acceptable results. However, radiographs are frequently difficult to interpret especially in posterior teeth. In addition it is widely accepted that the apical foramen may be distant from the radiographic apex further confusing interpretation.

Electronic apex locators work on the principle that the impedance between the periodontal membrane and the oral mucosa is constant at $6.5 \text{ kN}$ [82]. Recent apex locators (Root ZX, AFA, Justy, Endex-Plus) have been reported to be accurate to within 0.5 mm in >90% of cases [20,74]. The apex locator is significantly more reliable than the radiograph for determining working length [62]. As a consequence of their accuracy, apex locators allow for a reduction in the number of radiographs necessary to determine the working length especially in teeth where the apex is difficult to visualize on the radiograph. These findings indicate that apex locators should be regarded as the primary means of determining the working length during endodontic procedures. Moreover, in a recent long-term retrospective study in which an apex locator was the sole determinant of working length in infected root canals with periradicular lesions, a high success rate was achieved [57].

**ROOT CANAL IRRIGATION**

Regardless of the instrumentation technique or system used, the use of irrigants is essential for debridement of the canal system [15,80]. Consequently the preparation of root canal systems involves both mechanical and chemical components; hence the concept of ‘chemomechanical’ preparation. Irrigation with appropriate solutions contributes to the cleaning of the canal system in several ways including:

- rinsing of debris;
- lubrication of the canal system which facilitates instrumentation;
- dissolution of remaining organic matter;
- antibacterial properties;
- softening and removing the smear layer;
- penetrating into areas inaccessible to instruments thereby extending the cleaning processes.

Ideally the irrigant should be non-toxic and have a low surface tension in addition to being stable, inexpensive and easy to use.

A plethora of irrigants have been used. Currently, the most widely used irrigant is NaOCl, which has both antibacterial and tissue-dissolving properties. The effectiveness of this irrigant has been shown to depend on its concentration and time of exposure. Higher concentrations of NaOCl have greater tissue-dissolving properties [38]. However, the greater the concentration, the more severe the potential reaction should some of the irrigant be inadvertently forced into the tissues; hence, various concentrations of NaOCl, varying from 0.5% to 5.25%, have been recommended [54]. Those using the lower concentrations are attempting to minimize the postoperative sequelae should irrigant be inadvertently introduced into the tissues, whilst those using the higher concentrations are attempting to maximize the tissue-dissolving and antibacterial properties of the NaOCl. Accidental extrusion of NaOCl into the periradicular tissues may result is tissue damage accompanied by varying degrees of pain, swelling and bruising. To prevent procedural errors with NaOCl:

- avoid forceful injection of the irrigant;
- use specially designed side-venting needles;
- use carefully in the presence of resorbed or open apices and perforations.

The use of calcium hydroxide as an intracanal medicament between visits has been shown to enhance disinfection following use of NaOCl. This synergism has beneficial effects for the chemomechanical preparation of the canal system. Other irrigants used in root canal chemomechanical preparation include chlorhexidine [48], iodine potassium iodide (IKI) [70] and electrolytically activated water [49].
During root canal preparation a layer of ‘sludge’ is formed by the action of the instruments against the canal walls. This material is deposited on the canal wall and is called the ‘smear layer’. The smear layer has both organic and inorganic components and exists as a superficial loosely bound layer and a deeper adherent layer [51]. Considerable debate has occurred as to whether or not the smear layer should be removed. Complete removal of the smear layer may open up dentinal tubules to the passage of microorganisms from the root canal into the body of the dentine. On the other hand, failure to remove the smear layer will possibly allow bacteria to remain in the canal system and impairs the adaptation of the root filling to the dentine wall by preventing the movement of filling material into the dentine tubules. Removal of the smear layer is beneficial to root canal sealing [43], and significantly less micro-leakage occurs when these ‘smear-free’ canals are filled with thermoplasticized gutta-percha [86]. A very close adaptation of thermoplasticized gutta-percha to the dentine wall has been shown following smear layer removal [35].

Removal of the smear layer is best achieved by irrigating the canal system with NaOCl throughout the preparation procedure to prevent accumulation of debris on the canal walls and to flush out the canal system. A final rinse with 17.5% ethylene diamine tetra-acetic acid (EDTA) is recommended for removal of the inorganic component [7]; EDTA is also produced commercially in a paste form for lubrication during the instrumentation procedure. The effects of chelating agents such as EDTA are self-limiting.

Delivery of the irrigant is usually achieved by placing a side-venting needle 1–2 mm short of the working length of the canal. Alternatively, ultrasonically energized files can be used. Their effectiveness is due to the creation of acoustic microstreaming and to the effective delivery of irrigant to the apical part of the root canal system [3,4].

**INSTRUMENTATION TECHNIQUES**

Access to the apical part of the root canal will largely depend on adequate coronal preparation. All root canal systems are curved in one or more planes with the degree and extent of curvature varying from root to root. Elimination of coronal obstructions will greatly enhance the instrumentation procedures in the apical part of the root. Irrespective of the instrumentation technique used, the apical part of the canal system is invariably the least well-cleaned and prepared part of the root canal system. Contrary to the idealized picture depicted in many texts, the morphology of the apical canal system is complex and highly variable. Five major apical morphological forms have been described [22] (Fig. 6.13). Experimental clearing of roots has confirmed these variations and underscores the importance of a chemomechanical approach to preparation especially in the apical third of the canal system.

Preparation of the root canal system requires considerable skill, particularly in cases with more severely curved canals or complex anatomical features. Despite advances in instrument design, the experience and tactile skills of the operator
remain important [34]. Considerable efforts have been devoted to the study of instrument design and metallurgy in an attempt to produce an ideal instrument. The advances in design have been driven, in part by development of new alloys, and in part by an increase in understanding of the anatomy of the root canal system.

Regardless of the instrumentation procedure or instrument type used, the goals of shaping and cleaning of the root canal systems are:

- debridement of the root canal system;
- development of a continuously tapering preparation;
- avoidance of procedural errors.

Maintaining the anatomy of the apical constriction (Fig. 6.14) during canal shaping is essential for predictable healing of the apical tissues, in addition to mechanically retaining the filling material within the confines of the canal system. Long-term studies have shown improved success rates when instrumentation and filling procedures are maintained within the canal system approximately at the level of the cemento-dentinal junction [90].

Historically, canal preparation techniques have included the standardized and serial preparation techniques that focus on achieving a round apical preparation with either a small or minimal taper from apex to coronal aspect of the preparation. In recent decades the concept of the ideal preparation has altered to take into consideration a greater understanding of the natural anatomy of the root canal system moving away from the more rigid mechanistic approach.

Canal preparation techniques can be broadly divided into those that adopt an ‘apical to coronal’ preparation procedure and those that adopt a ‘coronal to apical’ approach.

**Crowndown technique**

Most recently many clinicians have used coronal to apical techniques to clean and shape root canals. There are several advantages:

- elimination of debris and microorganisms from the more coronal parts of the root canal system thereby preventing inoculation of apical tissues with contaminated debris;
- elimination of coronally placed interferences that might adversely influence instrumentation;
- early movement of large volumes of irrigant and lubricant to the apical part of the canal;
- facilitation of accurate working length determination as coronal curvature is eliminated early in the preparation.

The crowndown and stepback techniques of preparations aim to produce a similar result, i.e. a flared preparation with small apical enlargement.

The essentials of the coronal to apical approach to root canal cleaning and shaping are as follows:

- development of straight-line access from the occlusal or lingual surface into the pulp chamber;
- removal of all overhanging ledges from the pulp chamber roof;
- removal of lingual ledges or cervical bulges that form due to the deposition of dentine in the cervical part of the tooth;
- development of divergent walls in the pulp chamber from the cavosurface margin to the chamber floor;
- cutting of a funnel-shaped preparation, with its narrowest part located in the tooth apically, in a stepwise manner in the coronal, middle and apical parts of the root canal.

The benefits of using the crowndown technique are multiple and greatly influence the achievement of predictable success with root canal treatment. The clinical benefits of the crowndown technique are:

- ease of removal of pulp stones;
- enhanced tactile feedback with instruments by removal of coronal interferences;

*Figure 6.14* The anatomy of the apical constriction must be maintained during canal preparation.
enhanced apical movement of instruments into the canal;
enhanced working length determination due to minimal tooth contact in the coronal third;
increased space for irrigant penetration and debridement;
rapid removal of pulp tissue located in the coronal third;
straight-line access to root curves and canal junctions;
enhanced movement of debris coronally;
decreased deviation of instruments in canal curvatures by reducing root wall contact;
decrease in canal blockages;
iminization of instrument separation by reducing contact with canal walls;
predictable quality of canal shaping;
predictable quality of canal cleaning;
faster preparation which may allow one-visit root canal treatment.

The biological benefits of the crowndown technique are:

- rapid removal of contaminated, infected tissue from the root canal system;
- removal of tissue debris coronally, thereby minimizing pushing debris apically;
- reduction in postoperative pain that may occur with apical extrusion of debris;
- better dissolution of tissue with increased irrigant penetration;
- easier smear layer removal because of better contact with chelating agents;
- enhanced disinfection of canal irregularities due to irrigant penetration.

The basic steps common to all ‘crown to apical’ techniques involve early coronal and mid-root flaring and enlargement before proceeding to the apical part of the canal. The initial coronal flaring can be completed most efficiently with either Gates-Glidden burs or with rotary NiTi instruments, such as orifice shapers (Dentsply Tulsa Dental, Tulsa, OK, USA) designed specifically for this purpose. Early coronal flaring significantly reduces the change in working length during canal preparation [21]. As an instrument initially moves into the coronal third of the canal, the pathway is enlarged; the approach permits rapid irrigant penetration and facilitates further movement of small instruments deeper into the root canal. This entire process is continued until the working length can be determined easily. This then allows unimpeded placement of instruments to the middle and apical parts of the canal system. Irrigants and lubricants will penetrate more easily and will facilitate passage of instruments in an apical direction.

‘Crown to apical’ instrumentation techniques that have been proposed include the crown-down pressureless technique, the Roane technique [68], the ‘double flare’ technique [25], and the modified double-flare technique [71]. Numerous protocols have been detailed for use with a crown-down preparation technique. A composite protocol for use with a ‘coronal to apical’ preparation is:

1. Access development to remove cervical bulges in posterior teeth or lingual bulges in anterior teeth.
2. Eliminate pulp chamber obstructions.
3. Gates-Gliddens sizes 4, 3, 2, or orifice shapers to enlarge canal orifices; irrigate.
4. Coronal to mid-root enlargement using instruments from large to small; irrigate.
5. Explore canal and establish working length with small instrument (size 10 or 15) using apex locator and/or radiograph; irrigate.
6. Sizes 10, 15, 20 hand instruments to working length; irrigate.
7. Introduce large files to coronal part of canal; when apical resistance is met the file is removed and cleaned; irrigate.
8. Introduce progressively smaller files deeper into the canal again until resistance is encountered; irrigate.
9. Establish apical preparation size; irrigate.
10. Complete preparation to achieve desired taper.

**Stepback technique**

The most widely used preparation technique until recently has been the stepback or telescope technique first described in the 1960s [17] and later modified [56]. It replaced earlier non-tapering preparation techniques and aimed to reduce instrument transportation in the apical part. It has been effectively superseded by crowndown techniques. The following are the stages of a stepback preparation.
**Stage 1**

1. Access.
2. Establish working length with a pathfinder instrument.
3. Lubricate a fine instrument and place to length with a ‘watch-winding’ motion (a watch-winding motion implies a gentle clockwise and anti-clockwise rotation of a file with minimal apical pressure); irrigate.
4. Place the next larger size file to length; instrument circumferentially; irrigate.
5. Repeat the process until a size 25 K-file (or a file two to three sizes larger than the first file that binds at the apex) reaches working length.

Recapitulate between files by placing a small file to working length.

This completes the apical preparation; stage 2 involves flaring of the preparation.

**Stage 2**

1. Place the next file in the series to a length 1 mm short of the working length; instrument circumferentially, irrigate and recapitulate.
2. Repeat this process placing the next larger file in the series to 2 mm short of the working length; instrument circumferentially, irrigate and recapitulate.
3. Repeat the process with successively larger files at 1 mm increments from the preceding file. It is important not to omit any instrument in the sequence.

Variations to the classic technique include:

- initial enlarging of the coronal aspect with Gates-Glidden drills;
- use of small Gates-Glidden burs in the mid-root level;
- use of Hedstrom files to flare the preparation.

The stepback approach allowed creation of a small apical preparation with larger instruments used at successively decreasing lengths to create a taper. The taper could be altered by changing the interval between the stepback positions. In other words, the taper of the final preparation could be increased by reducing the stepback intervals from 1 to 0.5 mm between each file. The stepback technique has been considered to minimize procedural errors, such as transportation, ledging and apical perforation, over previous techniques [88].

However despite the advances of the stepback preparation over the standardized preparation in producing a tapered preparation, these ‘apex to coronal’ techniques tended to result in significant apical extrusion of debris [6,22,52,64,69]. Apical blockage, canal deviation and alteration of working length have also been frequently encountered with the stepback technique. In addition, apical extrusion of debris during root canal instrumentation has been associated with postoperative pain or discomfort [73,85].

**Calcified canals**

The basic principles apply to preparation of calcified canals. As with patent canals, once the access cavity to a calcified canal is completed, the pulp chamber is rinsed with NaOCl. If the orifices are identified as being calcified, an ultrasonically energized tip (Fig. 6.11) can be used to loosen debris in the orifice. The tip of the ultrasonic instrument can be used either to activate the solution in the chamber or it can be placed into the calcified orifice in an attempt to provide some initial patency. The use of either a NaOCl or EDTA soak for up to 10 minutes along with the use of an ultrasonic tip in these cases may remove some of the mineralized or partially mineralized tissue in the orifices. A small K-file, or a specific file designed for canal penetration (e.g. Pathfinder, Kerr Sybron), can be used to begin canal penetration. At this point, a small orifice shaper can be used to provide a tapered orifice penetration that facilitates further irrigant penetration and allows for the continued use of small K-files, or in some cases a size 15 0.04 tapered instrument, to penetrate further into the canal. The clinician can return to a small ultrasonic tip to penetrate further into the canal. Gates-Glidden burs will not be beneficial as they have a non-cutting tip. This procedure will take time and patience, and the clinician should resist the temptation to try to drill a canal into the root, as this invariably leads to deviation and potential root perforation.
NICKEL-TITANIUM INSTRUMENTS

Following the introduction of nickel-titanium (NiTi) alloy to endodontic instrument design [87], many new NiTi hand and rotary instruments have become available. The clinical and mechanical properties of these NiTi instruments have been compared with those of stainless-steel instruments; various aspects of instrument performance in canal preparation such as the efficacy of canal preparation, cleanliness of the canals after preparation, the shaping ability of the instruments and fracture properties of the instruments have been examined [2,11,24,28,41,44,63,76,83,84]. There is a general acceptance that rotary NiTi instruments produce well-shaped canals in an efficient manner with the creation of fewer iatrogenic problems than stainless-steel files. However, direct comparison between stainless-steel and NiTi instruments is difficult unless the instrument design is identical [45]. In addition, most testing procedures have been done in vitro, frequently in plastic simulated canals, and long-term clinical evidence of the superiority of one instrument type is unavailable.

CONTROVERSIES IN ROOT CANAL CLEANING AND SHAPING

A number of issues remain unresolved concerning endodontic treatment procedures; these include:

- Where should the preparation end?
- When should the preparation end?
- Should apical patency filing be performed?
- Should treatment be completed in one or multiple visits?

Where should the preparation end?

This question was addressed succinctly in a short paper entitled ‘Where should the root filling end?’ [39]. Current treatment protocols used by many clinicians are frequently based on opinion rather than fact. An illogical belief exists that the quality of treatment provided is determined by the presence of sealer ‘puffs’ visible on a postoperative radiograph: the more the better! There is little or no evidence to support this belief; in fact there is considerable evidence for maintaining all instrumentation procedures and filling material within the root canal system [32,53,78,81]. There should be differentiation between vital teeth, those with infected canals, and retreatment cases, when deciding where to terminate the instrumentation and filling [90]. Based on biological principles and experimental evidence instrumentation should terminate 2–3 mm from the radiographic apex in vital cases. In cases where canals are infected, the position should be 0–2 mm from the apex, while in retreatment cases the ideal termination should be at the apical foramen. However, irrespective of the preoperative condition of the canal system, it is recommended that all instrumentation and filling procedures should not extend beyond the apical foramen.

Discussion on the ideal termination of the preparation and filling procedures presupposes the existence of the ‘ideal’ root apex as described by Kuttler [46]; however it has been found that this ideal apical terminus exists in less than half of teeth [22]. Instead, a number of apical anatomical configurations have been described. No apical constriction may be present especially in the presence of any resorptive process [18,77]. Consequently, it is often very difficult or even impossible to locate either the apical constriction or the apical foramen.

When should the preparation end?

Removal of all microorganisms, tissue and debris is the aim of root canal treatment and hence this can be taken to be the end point of preparation. However, determining when this has been achieved remains difficult clinically [16]. Historically instrumentation procedures have taken little account of canal anatomy, such as fins, webs, anastamoses or apical ramifications. Outdated standardized preparation techniques aimed to enlarge the canal to a predetermined size and circular cross-sectional shape. The presence of white dentine chips has been used as a sign of canal cleanliness; however, a lack of correlation between their presence and the cleanliness of the canal has been demonstrated [88].

Because of the complexities of canal anatomy, the emphasis has shifted to chemomechanical preparation of the canal system [16]. Removal of the smear layer improves disinfection [16]. The import-
ance of an intracanal dressing of calcium hydroxide has been demonstrated as canals can be rendered bacteria-free [14]. An unanswered question is how long should the irrigant be left in the canal system to achieve adequate disinfection of the canal. This concern has fuelled a further controversy; namely can root canal treatment be completed in one visit or should it be done in multiple visits?

**Should apical patency filing be performed?**

There are two concepts of patency filing. The first and original concept aimed to remove debris collected during instrumentation from the apical part of the canal. This involved sequentially rotating files two to four sizes larger than the initial apical file at working length, then rotating the largest apical file again after a final irrigation and drying. This was called ‘apical clearing’ [59], and aimed to achieve:

- better debridement;
- enhanced filling;
- a more defined apical stop.

Apical clearing is recommended in canals which have been prepared with an apical stop. Further, apical clearing in teeth without an apical stop would increase the chances of overpreparation and overfilling.

The second concept of patency filing refers to the placement of small files to and through the apical constriction [56]. The aim is to allow for creation of a preparation and filling extending fully to the periodontal ligament. Evidence to support this concept is unavailable.

**Should treatment be completed in one or multiple visits?**

One-visit root canal treatment has assumed a position of controversy for many reasons. Clinical studies have addressed the advantages and disadvantages. The advantages of one-visit treatment are:

- reduced number of appointments;
- no risk of intra-appointment microbial recontamination;
- use of canal space for immediate post-retention.

The disadvantages are:

- longer appointments may cause patient fatigue;
- inability to control exudates may prevent completion of the procedure.

Those studies concerning postoperative pain [5,23,26,27,55,58,60] as well as effective healing rates [61,79,89] have shown that outcomes are similar, whether completed in one or multiple visits. Many of these studies have used older preparation techniques, which have the potential for less effective canal cleaning. There are some indications and contraindications that should be considered when contemplating this approach to treatment. The indications are:

- uncomplicated teeth with vital pulps;
- fractured teeth where aesthetics is important and extensive restoration is indicated;
- patient unable to return for appointments;
- patient requires antibiotic prophylaxis or sedation.

Contraindications are:

- patients with acute apical periodontitis;
- teeth with severe anatomical anomalies;
- molars with necrotic pulps and periradicular radiolucencies;
- root canal retreatment [78].

One-visit treatment does not sit easily with evidence on canal disinfection in infected cases [14,16].

**REFERENCES**


