Contemporary endodontics – part 2

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VERIFIABLE CPD PAPER

IN BRIEF
- Discusses advances in instrumentation, disinfection and root filling.
- Provides tips for reducing the risk of instrument fracture, ensuring reliable apex locator readings, and removing intracanal obstructions.
- Emphasises the importance of cuspal protection for endodontically treated posterior teeth.
- Outlines contemporary (micro)surgical endodontic techniques and materials.

The aim of this paper is to present the contemporary developments in root canal treatment, restoration of the endodontically treated tooth, and advanced endodontic procedures, such as root canal retreatment and surgical endodontics.

INSTRUMENTATION

The aim of instrumentation is to create adequate space for disinfectants to penetrate the root canal system, remove inflamed and infected debris, and create a suitable shape for the subsequent root filling. Instrumentation can be carried out using a variety of file systems which may be manufactured from stainless steel (SS) or nickel-titanium (NiTi). Straightening of curved root canals can be a major problem with SS files, especially larger sized files (>ISO size 20). To help overcome this NiTi files may be used. Instrumentation using NiTi files was first described over 20 years ago[1] and their popularity has steadily increased with most dental schools in the United Kingdom teaching their use.

The principle advantage of NiTi in endodontics is its super-elasticity. Compared to SS files of the same diameters, NiTi files are very flexible. This increased flexibility, even with increasing diameters, allows curved root canals to be easily instrumented without major transportation or other iatrogenic errors. NiTi files are also very efficient at removing dentine and their built-in taper allows the root canal to be machined to a predetermined

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shape (Fig. 1). The clinical benefits include shorter preparation time, fewer files are required to prepare the root canal, and there is less operator and patient fatigue.

The dental market is replete with many brands of NiTi files; the differences between brands include the cross-sectional shape, taper, tip sizes, and presence or absence of radial lands. The majority of NiTi files are manufactured by a grinding process; however, newer manufacturing processes allow blanks to be twisted into shape (eg Twisted Files, SybronEndo, Orange, CA, USA). It has been reported that these twisted NiTi files are more resistant to fatigue and fracture.[2,3] Other new NiTi file systems use a reciprocation technique (eg WaveOne, DENTSPLY Maillefer, Ballaigues, Switzerland; & Reciproc, VDW, Bayerwaldstr, Germany). Files are rotated in a clockwise-anticlockwise movement using a specialised motor. The main benefit of these systems is root canal preparation using one single file in the majority of cases.

Regardless of which file system or material (NiTi or SS) is chosen, it is advisable to use a crown-down technique to:
- Prevent pushing apically or extruding infected necrotic pulp and dentine
- Eliminate coronal interferences, thus reducing the risk of iatrogenic errors
- Introduce irrigants to the apical portions of the root canal at an early stage
- Maintain working length during subsequent instrumentation
- Improve tactile feedback during hand instrumentation of the apical portion of the root canal.
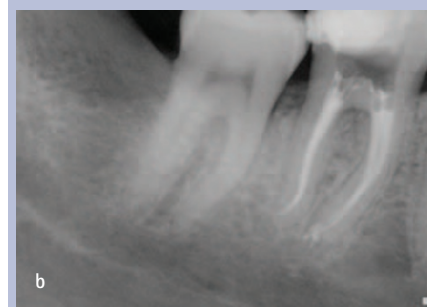

Fig. 1 (a) NiTi files are very flexible. (b) A root canal system which has been efficiently prepared with NiTi files, note that the curvatures have been maintained

Despite manufacturers heavily advertising NiTi files, it must be stressed that NiTi files are not a panacea. Small sized hand files (≤ISO size 20) are still necessary to explore root canals and create a glide path for NiTi files. Major disadvantages of NiTi files include cost, unexpected fracture, and

they cannot be used for all cases. The inappropriate use of any endodontic instrument, including NiTi files, may result in iatrogenic errors including fracture. There are several ways to reduce the risk of instrument fracture (Table 1, Fig. 2).

In 2007, the Chief Dental Officer in England issued guidance stating that endodontic reamers and files should be treated as single-use.[4] Although this guidance was primarily concerned with reducing the risk of prion transmission, there was also a practical benefit with reduced risk of instrument fracture due to cyclical fatigue. In 2010, an update of this guidance was issued stating that endodontic files and reamers may be re-used on the same patient as long as the instruments were marketed as being re-useable and certain requirements were met with regards to cleaning and storage of these instruments.[5]

Traditionally, the working length of a root canal can be determined in several ways, eg tactile sensation, working length radiograph, or blood at the tip of paper points. The process of determining the working length by placing premeasured files into root canals and taking a parallel radiograph can sometimes be arduous, time consuming and inaccurate. Contemporary endodontics makes use of the electronic apex locator (EAL) which has superior accuracy in determining the working length when compared to traditional techniques.[6] Depending on the generation and manufacturer, EALs work by detecting the distance from either the apical foramen or apical constriction in a circuit that measures either electrical resistance or impedance. It is not necessary to routinely take working length radiographs when EAL readings are consistently reliable (Table 2). This has the obvious benefit of reducing radiation exposure to patients.

DISINFECTION

The root canal system cannot be disinfected to a sufficient level by solely using endodontic files (NiTi or SS).[7] The uniform nature of endodontic files prevents complete mechanical preparation of all surfaces or anatomical complexities of the root canal system. It has been shown that 35% or more of the root canal surface area is left unchanged after instrumentation.[8] Instrumentation should therefore be supplemented with disinfection (Fig. 3).

Table 1 Ways to reduce the risk of instrument fracture

Wetting the root canal with irrigant
Examining instruments before and after each use for deformations
Discarding instruments that have deformed
Using instruments with light apical pressure
Avoiding use of NiTi files in root canals with sharp curvatures
Using NiTi files with the appropriate motor with auto reverse capability
Single-use instruments

Table 2 Ensuring reliable readings from an apex locator

Reconfirm the 'zero' reading on the display several times
Compare the 'zero' reading to the estimated working length
Avoid contact of the file and file clip with metallic restorations
Check there is contact between the lip hook and the oral mucosa
Check the batteries are charged and cord connections are secure
Prevent excessive liquid (saliva, blood, irrigant) entering the root canal system eg use rubber dam and paper points

Fig. 2 (a) A dedicated endodontic handpiece and motor should always be used. These motors allow the torque setting and RPM to be preset depending on the file system used. **(b)** Files should always be checked before and after removal from the root canal for signs of deformation

There are many newer irrigants on the market, including electrochemically activated water and ozonated water; however, there is a paucity of evidence to suggest they are superior to sodium hypochlorite which remains the gold standard. Sodium hypochlorite is antimicrobial and antibiofilm, and it dissolves organic tissue, ie necrotic pulp and microbes. In contemporary endodontics the effects of irrigants may be optimised by alternating and agitating the irrigant.

Alternating irrigants

A 'dual' or 'triple' irrigant approach combines the favourable properties of several irrigants. Our understanding of the individual properties of each irrigant is good; however, we are only starting to understand the interactions of these irrigants. Protocols vary on when to alternate irrigants and which should be used as the final rinse. A favoured method is alternating sodium hypochlorite, which removes organic material, with a chelating agent (eg ethylenediaminetetraacetic acid) or an organic acid (eg citric acid), which removes inorganic material. This facilitates removal of microbes, necrotic pulp and the smear layer, which is created during instrumentation of dentine. Removal of the smear layer is advocated as it may contain and protect microbes as well as prevent proper adaptation of root filling materials to the root canal wall.[9]

Chlorhexidine and iodine compounds (eg povidone-iodine and iodine-potassium-iodide) have also been advocated as additional irrigants for root canal (re) treatment due to their broad anti-microbial spectrum. It has been recently shown that alternating sodium hypochlorite with povidone-iodine had no accumulative influence on outcome of treatment, and alternating sodium hypochlorite with chlorhexidine solution significantly reduced the outcome of treatment.[10] In addition concerns have been raised about allergic reactions to iodine compounds and the toxic and carcinogenic precipitate parachloroaniline, which forms after mixing sodium hypochlorite and chlorhexidine.[11]

Agitating irrigants

Most irrigants have poor surface tension and cannot completely flow within the anatomical complexities of the root canal system. In addition, air can become trapped in the apical portion of the root canal preventing apical irrigation (vapour lock concept). There are many agitation techniques and devices available to help

circulate and replenish irrigants. These can be divided into manual and machine-assisted (Table 3).[12] The most commonly used manual technique is syringe-needle positive pressure agitation. The risk of causing a 'hypochlorite accident' is reduced by using a premeasured side-venting needle and applying gentle pressure. Contemporary endodontics utilises passive ultrasonic irrigation (PUI) where ultrasonic energy is applied to a small file that floats passively within the root canal.[13] The resulting acoustic microstreaming produces turbulence around the file which agitates the irrigant and improves its delivery (Fig. 3).

ROOT FILLING

Root filling aims to prevent reinfection of the disinfected root canal system, entomb any remaining microbes, and prevent entry of periapical tissue fluid into the root canal system, which may act as a nutritional supply for any remaining microbes. Gutta-percha (GP) used in conjunction with a root canal sealer are still the most widely used root filling materials. There are alternative polymer-based root filling materials which manufacturers claim can form a 'mono-block' root filling. However, there is no definitive evidence that one particular contemporary root filling material is significantly better in achieving healing of apical periodontitis. Broadly speaking root canals can be filled using either single cones, cold lateral compaction, or warm vertical compaction. It is more accurate to describe the technique as 'compaction' rather than 'condensation' as the density of the root filling material is not being altered.

Single cone technique

Historically, the single cone technique involved placement of silver points; however, these were shown to corrode due to poor apical seal.[14] The single cone technique has regained popularity with the introduction of GP or polymer-based points which match the taper and tip size of the rotary NiTi master apical file. The single cone technique is simple and quick; however, this technique relies heavily on sealer to fill areas of the root canal system. Sealer is the weakest link in a root filling and so the ratio of sealer-to-root-filling should be kept low.

Table 3 Irrigant agitation techniques and devices
Manual
Syringe and needle agitation
Gutta-percha agitation
Machine-assisted
Sonic devices (<20 kHz) eg EndoActivator system
Ultrasonic devices (>20 kHz) eg PUI
Pressure alternation devices eg EndoVac system
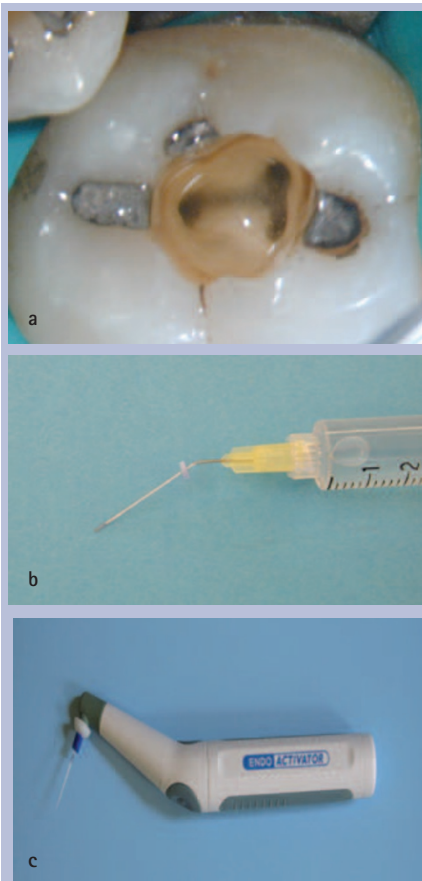
Fig. 3 (a) The root canal system and pulp chamber should be continuously flooded with irrigant. (b) A side-venting endodontic irrigant needle will help reduce the likelihood of a hypochlorite accident. (c) The EndoActivator cordless handpiece, energising the irrigant with a sonic or ultrasonic device will enhance the disinfection of the root canal system, a smooth polymer tip is placed in each canal and activated for 2–3 minutes

Cold lateral compaction

Cold lateral compaction is still the most widely used and taught technique. It is relatively cheap and well-adapted root fillings can be achieved; however, it can be time consuming and tiring. If carried out incorrectly, it can result in voids in the root filling and even vertical root fractures.
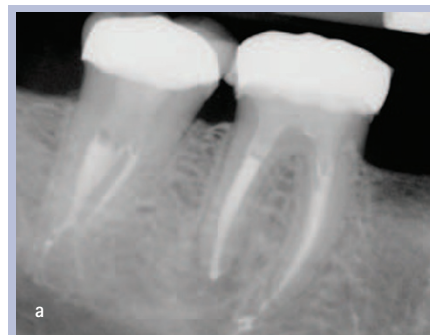
Fig. 4 Regardless of the root filling material and technique employed, the aim is to seal the entire root canal system. Warm vertical compaction in (a) a mandibular second molar with C-shaped root canal anatomy, and (b) in a maxillary central incisor with an internal resorption lesion
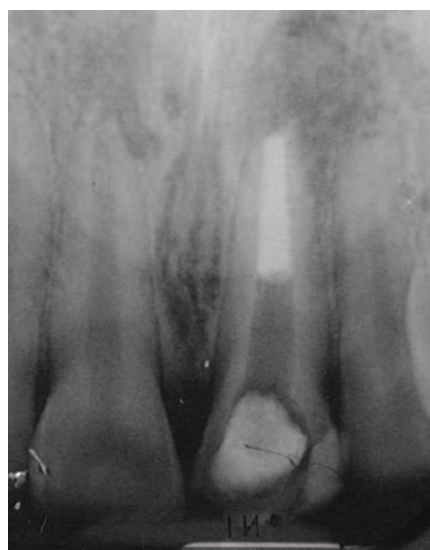
Fig. 5 An immature incisor tooth has been sealed with MTA, no instrumentation was required as the canal was wide enough to allow adequate disinfection, and there was adequate resistance form apically for retention of the root filling material

Warm vertical compaction

Contemporary heated techniques allow thermoplasticised root filling material to flow and be compacted within root canal irregularities, eg isthmuses and lateral canals. This ensures an optimal seal along the entire length of the root canal (Fig. 4). Warm vertical compaction is relatively quick; however, the equipment can be expensive and studies have shown that the incidence of over-extension is greater than when using cold lateral compaction.[15]

Root fillings should always be used in conjunction with a root canal sealer. The root canal sealer should seal any residual voids around the root filling material. Commonly used sealers may be broadly categorised as zinc oxide-eugenol based, epoxy resin based and calcium hydroxide based. More recently adhesive, silicone and calcium phosphate root canal sealers have been introduced onto the dental market. At present there is no good evidence to suggest that any particular type of sealer results in better outcome of endodontic treatment.

Immature teeth

Teeth with wide root canals, in particular immature teeth, are difficult to root fill as there is no taper or apical constriction (resistance form). Traditionally, these root canals were filled with several GP points which were heated together and inserted to form an impression of the root canal. Contemporary endodontics uses calcium silicate cements, eg mineral trioxide aggregate (MTA), to induce a barrier in the apical portion of wide canals using special delivery devices, ultrasonics, and endodontic pluggers. MTA is biocompatible, provides an excellent seal, and induces hard tissue healing (Fig. 5). The remaining mid-portion of the root canal is filled with heated GP. Composite is then placed into the cervical and coronal portion of the root canal to provide coronal seal. This also reduces the risk of root fracture of thin-walled immature teeth.[16]

ROOT CANAL RETREATMENT

Root canal retreatment is indicated in teeth with unsatisfactory root fillings when:
- There are signs and/or symptoms of emerging, recurrent or persisting apical periodontitis

Fig. 6 A diseased outcome is usually a result of inadequate disinfection and/or re-infection of the root canal system. (a) Poorly compacted root filling, note the voids. (b) An underextended root filling, note the unfilled apical portion of the root canals. (c) A separated instrument has prevented disinfection of the apical portion of the root canal system

- When the coronal restoration requires replacement
- When internal bleaching is to be performed.[17]

It is important to find out the cause of post-treatment disease associated with an endodontically treated tooth. The clinician must identify any non-endodontic reason, eg root fracture, as root canal retreatment will be inappropriate and in these situations the tooth should be extracted. Endodontic causes of failure essentially revolve around existing infection or re-infection. In cases where there is post-treatment disease associated with a well-executed endodontic treatment, it is unlikely that root canal retreatment will improve the outcome; in these cases other treatment options should be considered including surgical endodontics or extraction. Post-treatment disease associated with a poorly endodontically-treated tooth may be as a result of not using rubber dam, poor access resulting in missed untreated root canals, inadequate

Fig. 7 Ultrasonic tips for use in root canal (re)treatment

instrumentation (eg working length not reached, poor taper), inadequate disinfection (eg insufficient volume and turnover, use of irrigant which has no antimicrobial action), inadequate root filling (eg root filling does not extend to within 2 mm of the radiographic apex, contains voids), and/or iatrogenic errors (eg fractured instrument, perforation, ledge) (Fig. 6). Other rarer causes of post-treatment disease include extraradicular infections eg periapical actinomycosis, cystic apical periodontitis, a foreign body reaction, or scar tissue healing;[18] however, evidence in

Fig. 8 (a) Under-prepared root canal system has resulted in symptoms from this endodontically treated tooth. (b) An axial reconstructed image from a CBCT scan of the area revealed the presence of an uninstrumented fourth root canal. (c) Root canal retreatment was carried out, at the one year follow-up there was complete healing as the entire root canal system was adequately disinfected and sealed

Table 4 Benefits of single visit endodontic treatment

Benefits to patient
- Reduced risk of inter-appointment leakage and/or catastrophic split of the tooth
- Reduced risk of developing nosocomial endodontic infections
- One episode of travel, leave from work, child care, time to worry, occasion of pain.

Benefits to dentist
- Time gained
- No loss of treatment information eg reference points
- Cost effective

Benefits to health care system
- Reduced costs
- Shorter waiting times

relation with these causes of post-treatment disease are contradictory.

Root canal retreatment is generally considered more difficult to carry out than root canal treatment as there are usually intracanal obstacles to overcome. These include:

- Removal of root filling materials. Gross removal of gutta-percha or polymer based root filling materials can be achieved using Gates Gliddens drills and rotary nickel-titanium retreatment files. Solvents, such as chloroform, are effective at dissolving gutta-percha and certain root canal sealers. Their use should not be standard practice as they smear root filling material along the root canal walls and inside dentinal tubules[19] and there are concerns over chloroform being possibly carcinogenic to humans[20]
- Removal of other intracanal materials such as silver points, posts (cast, prefabricated, metal, fibre) or fractured instruments (files, spiral fillers, Gates Gliddens drills). There are a variety of techniques and equipment available to remove these obstructions. Contemporary endodontics mainly utilises specialised ultrasonic tips (Fig. 7) to retrieve these materials directly or after gently removing dentine around the material. Post removal trephines and extractors should be avoided if possible as they can weaken the remaining tooth structure
- Correction of iatrogenic errors such as ledges or perforations.

The success of root canal retreatment is dependent on the following (Fig. 8):
- Locating all root canals
- Negotiation, and subsequent instrumentation of the root canal(s) to the ideal working length
- Adequate disinfection of the entire root canal system
- Sealing (including the coronal seal) of the root canal system.

SINGLE-VISIT ENDODONTIC TREATMENT

It is not possible to achieve a consistently microbe-free root canal system whether using traditional or contemporary endodontics. The aim of endodontic (re)treatment is to control infection by reducing the number of microbes below a threshold at which healing of the apical tissues is possible. Proponents of multi-visit endodontic treatment advocate the use of an interappointment medicament to fully eradicate infection within the root canal system. Calcium hydroxide is the gold standard interappointment medicament due to its antimicrobial and tissue dissolving capacity. However, it is difficult to place properly and fully remove,[21,22] and concerns have been raised about long-term dressing with calcium hydroxide which may increase the risk of root fracture.[23] *In vitro* evaluation of calcium hydroxide has shown it can alter the dentine matrix reducing the flexural strength of dentine.[24] A recent study concluded that bacteria commonly involved in nosocomial infections are often retrieved in root canals with post-treatment endodontic disease; single-visit endodontics reduces the chances of this infection to occur.[25]

The current evidence appears to show that there is no significant difference in the outcome of treatment between single-visit and multiple-visit endodontic treatment,[26-29] or incidence of post operative pain.[30-33] The benefits of single-visit treatment are abundant (Table 4).

RESTORATION OF THE ENDODONTICALLY TREATED TOOTH

Restoration of the endodontically treated tooth is necessary to restore function, aesthetics, and also provide coronal seal and cuspal protection. Endodontically treated teeth are at an increased risk of fracture compared to vital teeth due to:

Fig. 9 (a) An endodontically treated tooth restored with a temporary IRM restoration, (b) placement of a well-adapted composite dowel core, (c) a metal-ceramic crown cemented into place will reduce the likelihood of the tooth fracturing in the future

- Loss of pulpal sensory feedback[34]
- Loss of coronal tooth structure as a result of caries, previous restorations and access cavity preparation
- Excessive irrigation[35] and/or long-term interappointment dressing[23]
- Loss of radicular tooth structure due to over-instrumentation or post preparation, especially cast metal post preparation.[36]

Placement of direct restorations, eg plastic restorations and when necessary fibre or metal posts, should be carried out be immediately after root canal treatment is completed. This is the ideal time as the clinician has immediate knowledge of the pulp chamber anatomy, the access cavity is readily accessible, the tooth is thoroughly disinfected, and the tooth is still under rubber dam isolation. If indirect restorations, eg crowns, are planned, these should be placed with the minimum of delay (Fig. 9). This can be within one to two weeks if the quality of the root canal filling is considered adequate. If there is early evidence of post-treatment disease or root canal treatment was compromised by iatrogenic errors, then the tooth should be restored with a provisional restoration, eg laboratory fabricated provisional crown, and any complex restorations should be delayed until there is evidence of healing.

Traditionally, endodontically treated molar teeth were restored with amalgam Nayyar cores and, when indicated, cast or prefabricated metal posts. Contemporary endodontics utilises adhesive materials and techniques, including composite-dowel cores and fibre posts, to restore endodontically treated teeth. The main benefits of adhesive restorations include:[37]

- Immediate post-endodontic placement which gives the clinician direct control over the design of the restoration, and provides immediate coronal seal and cuspal protection
- The ability to preserve and bond to tooth structure which would have otherwise been removed for placement of traditional non-adhesive materials
- Similar modulus of elasticity to dentine when compared to metal restorations
- Improved aesthetics
- Reduced laboratory costs.

Traditionally, it was recommended that both endodontically treated premolars and molar teeth should be restored with cuspal coverage restorations (eg crowns) to improve their survival.[38] Recent research suggests that, in the short-term (3-5 years), it is sufficient to restore endodontically treated premolar teeth with fibre posts and composite cores without the additional need for a crown.[39-41] It is still recommended that endodontically treated molar teeth are restored with restorations that provide full coronal coverage.[42]

SURGICAL ENDODONTICS

Surgical endodontics, including incision and drainage, apical surgery, and replantation, is performed in cases with apical periodontitis when non-surgical approaches are technically difficult or impractical.[17]

| Table 5 Indications for surgical endodontics |
|---|
| Exploration, eg to confirm suspected root fracture |
| Biopsy required eg cyst or sinister lesion suspected |
| High quality root canal treatment which cannot be improved upon by a non-surgical approach |
| Blocked canal eg fractured instrument or ledge |
| Dismantling the tooth may be damaging or impractical eg long post or tooth is a bridge abutment |
| Root resorption eg external cervical resorption |

Indications for surgical endodontics are given in Table 5.[43]

Surgical endodontics has been transformed by magnification, micro-instruments, ultrasonics, newer root-end filling materials and modern techniques to manage soft and hard tissues.[44] It has been suggested that pre-operative surgical endodontic protocols should include smoking cessation advice[45] and chlorhexidine rinsing[46] to prevent surgical complications.

Traditionally, soft tissue management included broad based flaps with converging vertical incisions, supposedly to ensure optimal blood flow to the flap. This is no longer advocated as converging incisions sever supra-periosteal blood vessels. Contemporary flaps should have parallel vertical relieving incisions to minimise severing of these blood vessels and optimise soft tissue healing. Vertical incisions, not horizontal incisions, should also be applied when carrying out incision and drainage of a dental abscess. Patients now expect good aesthetics after surgery with gingival recession and loss of interdental

Fig. 10 (a) A conventional dental mirror (left) and a surgical micro-mirror (right). (b) A conventional scalpel blade (left) and a surgical micro-blade (right). (c) Ultrasonic tip for preparing root-end cavities
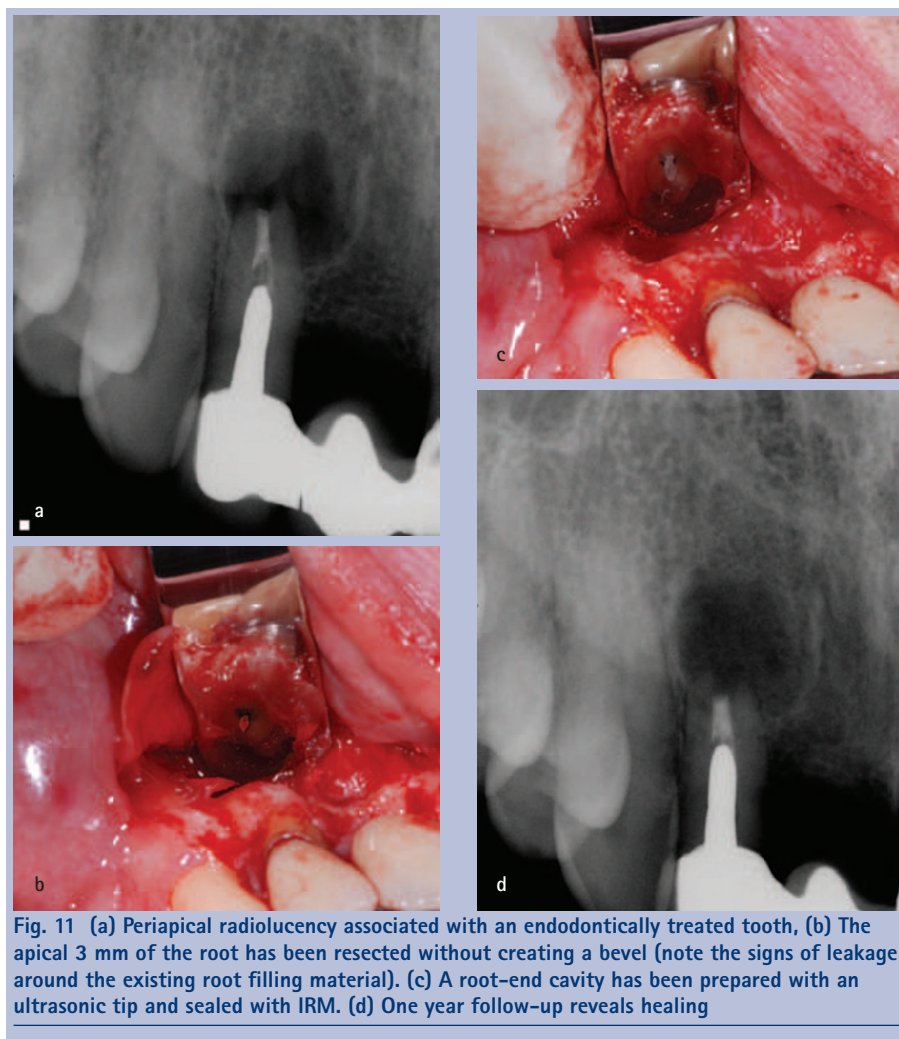
Fig. 11 (a) Periapical radiolucency associated with an endodontically treated tooth, (b) The apical 3 mm of the root has been resected without creating a bevel (note the signs of leakage around the existing root filling material). (c) A root-end cavity has been prepared with an ultrasonic tip and sealed with IRM. (d) One year follow-up reveals healing

papilla being unacceptable. The more skilled clinician may choose to perform a papilla-base incision to reduce the risk of interdental papilla loss.[47]

Traditionally, root-end resections were bevelled to aid direct vision for root-end cavity preparation with a bur. Bevelled resections are no longer encouraged as they expose a large number of dentinal tubules which may harbour microbes. Root-end preparation using a bur is also not advisable as there is a risk of transporting the root canal or causing a perforation. Contemporary root-end resection should be perpendicular to the long axis of the root. The root end can then be visualised using micro-mirrors under magnification and prepared using ultrasonic retro-tips (Fig. 10).

Amalgam is no longer favoured as the root-end filling material of choice.[48] Contemporary root-end filling materials include Intermediate Restorative Material (IRM) and calcium silicate cements. The latter has an excellent sealing ability and induces hard tissue barrier formation;

however, it is relatively expensive compared to IRM and not as straightforward to place (Fig. 11).

OUTCOME OF ENDODONTIC TREATMENT

Traditionally, the outcome of root canal treatment was described as either a 'success' or a 'failure'. These terms can be ambiguous as they may be defined differently by the patient or the clinician. For example, a patient may feel that endodontic treatment has been a success as they are symptom-free; however, there may be a buccal sinus or an increased periapical radiolucency. Contemporary endodontics uses the clear terms 'healed', 'healing' or 'diseased' to describe the outcome of treatment. Outcome should be assessed clinically and radiographically for at least one year after root canal treatment.[17] A healed outcome is defined as no signs or symptoms with no periapical radiolucency, and a diseased outcome is defined as presence of a new or increased periapical

radiolucency with or without signs and symptoms.[49] In healing cases where the periapical radiolucency is reduced or not increasing in size, then the patient should be reviewed annually for up to four years.

If a diseased outcome is apparent, then the options available are:
• Keep the tooth under review
• Root canal retreatment
• Surgical endodontics
• Extraction.

The chance of a healed outcome after non-surgical endodontic treatment, ie the chance of curing or preventing apical periodontitis, has been reported to be in the region of 75-95%. If loose criteria are used, ie survival of an endodontically treated tooth, then higher rates of 93-97% have been reported.[42,50] Several factors have been shown to significantly improve the outcome of root canal treatment and retreatment: pre-operative absence of periapical radiolucency, a satisfactory root filling (no voids and extension to 2 mm within the

radiographic apex), and a satisfactory coronal restoration.[51,52] It has also been reported that the outcome of root canal retreatment is significantly better when the primary root canal treatment has not altered the morphology of the root canal system, eg transportation, strip perforations.[53] The chance of a healed outcome after contemporary surgical endodontics can be as high as 95%. There is good clinical rationale and some evidence to suggest that the outcome of surgical endodontics can be improved by using contemporary microsurgical techniques, equipment and materials.

CONCLUSION

Contemporary endodontics still aims to eliminate microbes and prevent re-infection of the root canal system. Contemporary endodontic materials, instruments and equipment are available to the clinician still using traditional techniques. It is hoped that clinicians will develop their approach to endodontics by implementing contemporary techniques and, in doing so, the consistency, efficiency and predictability of endodontic treatment can be improved.

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