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# Endodontic Update: 50 Years of Progress

**Abstract:** The science of endodontology and the practice of endodontics have changed immeasurably in the last 50 years. Improved understanding of the aetiology of peri-radicular diseases, in particular the central role of micro-organisms, has driven a more biological approach to treatment. Advances in technology have brought to market sophisticated armamentaria that have facilitated and enhanced clinical delivery. The development of biomaterials and the refinement of clinical techniques have contributed to improved outcomes for both non-surgical and surgical endodontic treatments. The present article summarizes the changes in this field in the past 50 years, and updates the reader on contemporary clinical endodontic practice.

**CPD/Clinical Relevance:** An awareness of historical developments in the field of endodontics provides useful context and an increased understanding of current practices

**Dental Update 2023; 50: 411–420**

The practice of endodontics has changed markedly in the past 50 years. This may be attributed to a better understanding of the aetiology of endodontic pathology, in particular the realization of the central role of micro-organisms in the disease process. This has led to a more biological approach to treatment, facilitated by new technologies comprising hi-tech equipment, the development of dental materials and biomaterials and the refinement of clinical techniques. The present article aims to chart the advancements in the field of endodontics over the past 50 years and illustrate how these improvements have simplified clinical technique, contributing to enhanced treatment outcomes.

## Aetiology

### Role of micro-organisms

A little over 50 years ago, in 1965, the first study that showed that the presence of micro-organisms was required for peri-radicular pathology to develop in gnotobiotic animals was published.[1] Subsequent work in the early 1980s demonstrated that infected teeth in a monkey model developed peri-apical lesions whereas non-infected teeth did not[2] and the significant role of anaerobes was understood.[3] It has now been established that a primary endodontic infection is polymicrobial with aerobes, facultative anaerobes and strict anaerobes present, with the anaerobic species predominating with little microbial specificity. The composition in terms of number of species and species type varies as to the site in the root canal system and whether the case is a primary or secondary treatment.[4–6]

As well as bacteria, other micro-organisms, such as the herpes viruses, fungi and archaea have been identified in the root canal system,[7] although their role in the aetiology of peri-radicular disease is still unclear.[7] Archaea are a highly diverse group of prokaryotes that are distinct from bacteria in genetic, biochemical and structural terms.

### Identification of micro-organisms

In the past, culture techniques were used to test for the presence of, and to identify, the main morphotypes. However, culture techniques have their limitations, such as challenges in sampling, contamination being difficult to eradicate and culturing,

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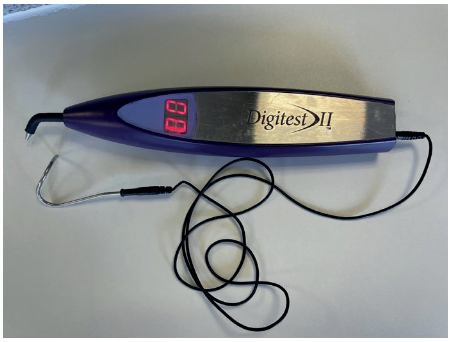

**Figure 1.** An example of an electric pulp testing device, Digitest II Pulp Vitality Tester (Parkell, Edgewood, NY, USA).

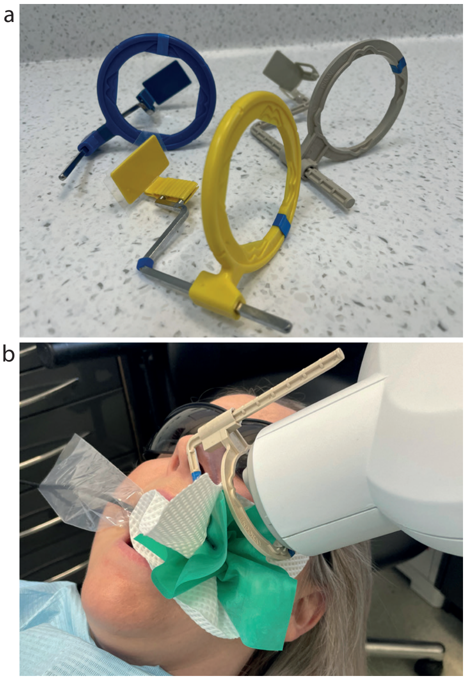

**Figure 2. (a,b)** Long-cone film holders, together with an EndoRay II Film Holder (Rinn, Dentsply Sirona, Charlotte, NC, USA) and being used clinically. The latter film holder was developed so that it can be used peri-operatively to determine working length with files in the canals (diagnostic file radiograph) or gutta percha cones placed to length to verify the extent of canal preparation prior to obturation in the case of a cone fit radiograph.

**Figure 3.** An example of a commercially available apex locator Denta Port ZX (J Morita MFG Corp, Kyoto, Japan)

especially the strict anaerobes, problematic. Nowadays, molecular biology techniques are available that have significantly advanced the knowledge of the micro-organisms implicated in peri-radicular disease. The polymerase chain reaction (PCR) test has greatly enhanced the understanding of the diversity of endodontic micro-organisms, many of which are, as yet, uncultivated, unclassified or especially rare. This technique works by amplifying the 16S rRNA gene, so permitting cloning, and then sequencing. It has become the reference method for bacterial identification.[8,9] These molecular techniques are more precise, sensitive and permit a more reliable identification of micro-organisms. They were first used to detect endodontic bacteria in 2001.[10] PCR technology has developed further, with numerous derivatives available to the microbiologist, so enhancing the versatility of the techniques.

## Aids to diagnosis

### Sensitivity testing

A diagnostic challenge is to determine the health or otherwise of the dental pulp. Pulpal vitality, by definition, is the presence of a blood supply and is regarded as 'the only available true indicator of the actual state of pulpal health.'[11] Sensitivity tests, such a thermal tests, electric pulp testing and preparing a test cavity, may be used, but are based on eliciting a neural response, which is very different. The results of such tests must therefore be interpreted with caution because of the high incidence of false positives and negatives.[12] This is especially so in teeth that have been traumatized, are immature or are undergoing orthodontic therapy which, despite having a viable pulpal blood supply, may not respond.[13] Equally, neural tissue may still respond to a stimulus without an intact vasculature. The shortcomings of these tests have led to the development of other methods of measuring blood flow, such as pulse oximetry, thermometry and laser Doppler flowmetry. The latter test was determined to be the most accurate in a study carried out in 2018,[14] but has not been universally adopted because of cost and difficulty in producing suitable hardware that can be used intra-orally.

In everyday practice therefore, many clinicians use cold and electrical stimuli as sensitivity tests. Frozen water ice sticks or a compressed gas, such as ethyl chloride, which evaporates rapidly generating a cold temperature, may be employed. Ethyl chloride was used for many years, but many clinicians have moved onto Endo-Frost (Roeko, GmbH, Sonthofen, Bayern, Germany) because it generates a much colder temperature of -50°C, compared with -20°C. This method should be complemented by the use of electric pulp testing (Figure 1).

These devices work by passing an electrical current through the tooth to which the patient may respond. The degree of response may give an indication as to the health or otherwise of the pulp, but should be treated with caution as previously discussed. Furthermore, it should be borne in mind that, just because a pulp has a blood supply, it does not mean that it is healthy.

## Radiography

The use of X-ray radiation to make images has been used in dentistry since 1896, and in endodontics since 1899. Its main uses have been as follows:

- In the diagnosis of peri-radicular disease often seen on an intra-oral peri-apical radiograph as a radiolucent area.
- As part of the preoperative assessment to assess radicular and canal anatomy with often two films taken from different angles.
- To permit the determination of working length.
- To verify the correct apical canal preparation by means of a cone fit (trial point) radiograph.
- A post-operative view thus demonstrating technical quality and so providing a baseline view from which to monitor ongoing peri-radicular healing in the maintenance phase of care.

In an attempt to produce a more standardized view, and eliminate positioning errors commonly seen with the original bisecting angle technique, long-cone collimation and film holders were introduced (Figure 2). The use of a long-cone technique produces an image closer to the actual size of the object, which could be measured to give an indication of approximate working length.

Only the minimum number of radiographs should be taken.[15] The invention and use of apex locators obviates the need to take a diagnostic file radiograph in most endodontic cases (Figure 3). Apex locators work on the principle of impedance, that is resistance to the passage of electrical current through tissues. When the file is inserted into the canal and reaches the apex, the electrical resistance is decreased and registered by the apex locator. For an explanation of the physics behind this technology the reader is directed to the paper by Nekoofar *et al.*[16]

Another development in radiographic technology was the introduction of digital radiography. Not only is image generation quicker, but it greatly decreases the X-ray dose given to the patient to effect the image.[17] It is cleaner and requires less hardware than the traditional wet film, which needed to be processed using baths of chemicals. The digital imaging systems found in contemporary clinical practice use phosphor plates and sensors.[17]

The limitations of 2D images are well documented, and in the recent past, further development of radiographic technology has resulted in cone beam computed tomography (CBCT), which provides a three-dimensional image that can be scrutinized by the clinician to glean potentially valuable information, thus aiding diagnosis and pre-operative assessment. Such a view will be small volume and high resolution in nature.

## Treatment techniques

Traditionally, the practice of endodontics was mechanistic, with no appreciation of the role of biology. Essentially, endodontic infections are caused by bacteria invading the dentine, so causing inflammation of the pulpal tissues and leading to necrosis. The environment of the root canal system provides a protected compartment and insulates micro-organisms against the defence systems of the host. It is incumbent on the clinician to eradicate the infection from the root canal system, with Sjögren *et al*[18] and Sundqvist *et al*[19] showing that the prognosis of primary and secondary root canal treatments, respectively, improve if viable bacteria were absent at the time of canal obturation. In contemporary practice, techniques have developed and refined with improved armamentaria underpinned by a biological approach. It is now clear that some cases diagnosed as irreversible pulpitis do not need to be treated with pulp extirpation and root canal treatment. Partial pulpotomy and protection of the remaining radicular pulp with a bioceramic (hydraulic cement) filling provides a suitable and less complicated treatment option.[20–22]

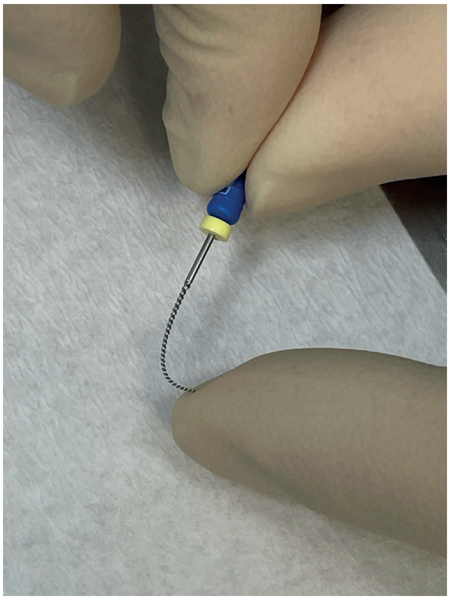

**Figure 4.** A nickel–titanium hand file. Note the extent to which it can be bent without deformation, so called superelasticity.

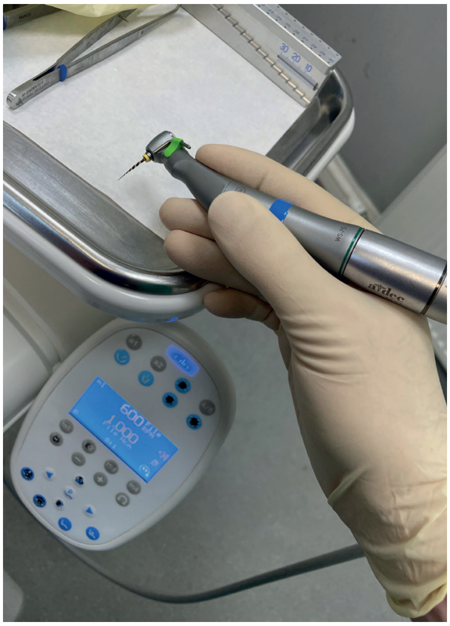

**Figure 5.** An example of a rotary file system in a speed-decreasing endodontic motor.

## Instrumentation

Chemo-mechanical preparation of the root canal system is an essential aspect of root canal treatment, and part of the so-called endodontic triad of shaping canals, cleaning and filling the root canal system as described by Ruddle.[23] The root canals must be prepared mechanically to allow the passage of endodontic irrigants, so facilitating the disinfection of the root canal system.

## Files

The mechanical preparation of the root canals 50 years ago was performed using endodontic reamers before moving onto files. Traditionally, these were constructed of an alloy of stainless steel. The main shortcoming of stainless steel is its high elastic modulus, so there was a tendency to straighten the root canal, particularly with larger file sizes, thus changing the shape of the canal. The use of stainless steel in file construction has largely been superseded by nickel–titanium (NiTi) alloys. These alloys have been described as superelastic, possessing an increased flexibility even with increased taper, so maintaining canal morphology during preparation (Figure 4). For further information on the metallurgical and mechanical characteristics of NiTi alloy and the commercially available associated file systems, the reader is advised to read the excellent review paper by Zupanc.[24] The latest iteration of NiTi files has improved fracture resistance while maintaining flexibility.

Another fundamental change in file technology was the development of rotary file systems (Figure 5). An electrically driven micromotor is used to either rotate or oscillate (reciprocate) the files depending on the product. Many products have a torque controller to decrease the incidence of torsional fracture of the file during use. These instruments are extremely efficient in preparing root canals, which can be achieved in a few minutes. However, the clinician can be lulled into a false sense of security because the canal irrigants will not have had sufficient dwell time to be effective, as described later.

Endodontic files used in contemporary practice are tapered (Figure 6). This is to maintain canal shape, enhance penetration

**Figure 6.** An example of a rotary file, ProTaper Gold (Maillefer, Ballaigues, Switzerland).

**Figure 7.** An operating microscope being used during a dental procedure. Note the close support and involvement of the dental nurse facilitated by their ability to see the procedure on the wall-mounted screen.

of the irrigants to the most apical aspect of the root canal and facilitate subsequent canal obturation. Both hand and rotary tapered files are available.

## Instrumentation techniques

Many instrumentation techniques have been introduced and modified over the years. Ingle introduced the standardized technique in 1961,[25] which was followed by other techniques, such as step back, serial preparation,[26,27] anti-curvature filing[28] and crown down pressureless in 1980,[29] step down,[30] double flare,[31] balanced force,[32] modified double flare,[33] culminating with passive step back in 1994 by Torabinejad.[34] These hand techniques aimed to increase the efficiency of the mechanical debridement of the root canal while preserving radicular dentine. A fuller description of each of the listed techniques is not possible owing to space constraints, hence references are supplied to allow the interested reader to explore further.

## LASERs

Light amplification by stimulated emission of radiation (LASERs) have been used in endodontics for two purposes. First, a photon-induced photoacoustic streaming (PIPS) pulsed Er:YAG laser[35] has been used to activate irrigants in the root canal system[36–38] resulting in their increased penetration.[39] The other use of a LASER, or more commonly these days, a light-emitting diode (LED), is in the technique of antimicrobial photodynamic therapy (aPDT). One such system works by the combination of a photosensitizer, such as pharmaceutical grade tolonium chloride, which preferentially binds to the cell wall of rapidly dividing cells (eg micro-organisms) and light at a wavelength of 635 nm± 2 nm. When sufficient light energy is applied, the photosensitizer activates, producing singlet oxygen species that are toxic to the protoplasm, so rendering the micro-organism unviable.[40] This technique is used as an adjunct in the disinfection protocol of the root canal system, increases kill rate and, indirectly, survival of the tooth.[41]

## Microscopy

A significant advancement in endodontics was the adoption of the operating microscope. Working at a higher magnification significantly facilitates the visualization of the operating field, so aiding the identification and access into small canals,[42] preserving tooth tissue and refining clinical technique, such as the retrieval of separated (broken) instruments.[43] Many microscopes have built-in high-definition cameras capable of capturing still and moving images, which may be used for medico-legal purposes. This also increases the engagement and involvement of the dental nurse during the procedure (Figure 7) and serves as an invaluable teaching aid. Another significant feature of this instrumentation is the illumination, which is a critical factor in aiding vision.

## Irrigation protocols

### Chemicals for irrigation

Endodontic irrigants may be divided into those that remove the smear layer (chelating agents) and those that disinfect the root canal system. Sodium hypochlorite solution (NaOCl) is the most commonly used chemical in the latter category. It has been used for many years because it is an effective antimicrobial with a broad spectrum of antimicrobial action. Furthermore, it is an excellent organic tissue solvent, acts as a lubricant, is fast acting and an effective proteolytic agent,[44–46] but must be changed regularly and allowed to dwell in the canal for 30 minutes. While the use of this chemical has been constant over this 50-year period, the concentration of the solution has changed over time, and globally, with lower concentrations (0.5%) used in Scandinavia and up to 6% in the US.

The smear layer contains bacteria and nutrients for bacterial growth and impedes irrigant penetration into dentinal tubules,[47] hence its removal is desirable. This may be achieved by the use of chelating agents such as ethylene diamine tetra-acetic acid (EDTA)[48] used in a 17% solution, or a solution of 20% citric acid. These agents scavenge bi- and tri-cationic ions, such as calcium and iron, respectively, but cannot completely remove the organic components, with NaOCl being required to do this.[44,49]

In contemporary practice, some endodontists favour the use of iodine-containing compounds as part of their disinfection regimen of the root canal system. Iodine potassium iodide (IKI) is available as an irrigating solution comprising a 2% solution of iodine in 4% aqueous potassium. This inorganic compound releases iodine and works by denaturing proteins, nucleotides and fatty acids, leading to cell death.[50] Iodine-containing chemicals are broad-spectrum antimicrobial agents effective against bacteria, fungi, viruses and spores.

Chemicals such as MTAD, QMiX and chlorhexidine digluconate among others may also be used in the disinfection regimen, and the reader is referred to a recent article published in *Dental Update* for further information.[51]

Delivery of these irrigants has been facilitated by the adoption of conventional syringe irrigation with 30-gauge needles, which are flexible and side-venting.[51]

## Ultrasonics and sonics

In an attempt to enhance the penetration of irrigants into the dentinal tubules, as well as tissue dissolution,[52] the use of ultrasonic and sonic devices has been introduced,[53] whereby ultrasonic waves at 20–26 kHz are transmitted to a liquid. The use of ultrasonic irrigation has been shown to improve the cleanliness of the canal by acoustic streaming,[54] efficiently remove the smear layer and bacteria,[55] and reduces post-operative pain.[54] Such passive ultrasonic irrigation (PUI) can improve the seal of root canal fillings.[56] More recently other methods have been developed to improve cleaning of the root canal system. These include continuous ultrasonic irrigation and Gentle Wave (Sonendo Inc, Laguna Hills, CA, USA).

Sonic activation activates the irrigant at frequencies of 1–6 kHz. While some studies report enhanced cleaning,[52] others have shown that sonic activation provided no additional advantage compared with conventional techniques.[57]

## Biofilm

It is now understood and accepted that endodontic micro-organisms exist in established biofilms that are found on the walls of root canal systems.[58] A biofilm has been defined as 'a highly organized structure consisting of bacterial cells enclosed in a self-produced extracellular polymeric matrix attached on a surface.'[58] As these structured biofilms may not be easily disrupted and are considered to be difficult therapeutic targets,[59] the antimicrobial challenge is increased and an effective antibiofilm strategy is required, comprising chemo-mechanical debridement as already described.

## Intra-canal medicaments

If the root canal is not to be obturated until a subsequent appointment, then it is usual to place a paste in the canal to provide an antimicrobial environment, and to fill the dead space. The use of non-setting calcium hydroxide became popular in the mid-1980s[60] because of its antibacterial effects, with its routine use becoming commonplace in the 1990s after papers by Orstavik[61] and Sjögren[62] corroborated the findings of earlier work. However, more recently, questions have been asked as to whether non-setting calcium hydroxide can fully eradicate micro-organisms found in the root canal system when used as an intra-canal inter-appointment medication. A systematic review and meta-analysis by Sathorn *et al* in 2006[63] concluded that this material, when assessed by culturing, has limited effectiveness in eradicating bacteria from the root canal system, but it may depend on the preparation of the calcium hydroxide.[64] Recently, modifications to calcium hydroxide using nanotechnology may improve its antimicrobial effects.[65]

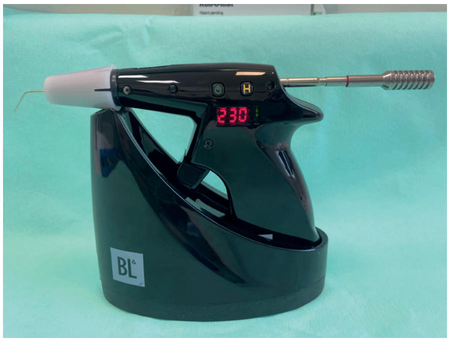

**Figure 8.** An example of a device used in a heated obturation technique (SuperEndo-beta, B&L Biotech Inc, Gyeonggi-do, Korea).

**Figure 9.** An internal resorptive defect in UR3 obturated using a heated obturation technique.

## Obturation techniques

Once the root canals have been prepared chemo-mechanically, then they should be filled or obturated with a dental material.[23] The purpose of this is to prevent, or slow, the re-infection of the root canal system by micro-organisms, and to rid the root canal system of dead space, which may lead to pain if the patient is in a pressurized environment.

One commonly used obturation technique 50 years ago was the use of silver points coated in sealer. This method was fraught with difficulties because, in the majority, the canal was not fully sealed and voids were present. The silver points corroded, producing toxic products and their removal was very difficult if root canal re-treatment was needed, or a post and core was to be placed. For this reason, the standard obturation technique involves the root canals being obturated with a semi-solid material such as gutta percha and an endodontic sealer. The sealer is a paste that acts as a lubricant, so facilitating the passage of the GP cone fully into the canal and filling any voids left by the cone. Modern systems match the shape of the last-used (master apical) file with the cone, a so-called single-cone technique. This is quicker to complete than the traditional cold lateral compaction technique. In this technique, a master apical point was placed into the canal coated in sealer, and a metal instrument, called a spreader, was placed lateral to the cone and a force was applied laterally. This created space to permit the placement of an accessory cone and the process was repeated until the canal was obturated. This was considered for many years to be the gold standard, but was time consuming and the semi-solid nature of the material made it difficult to avoid incorporation of voids in the root filling. To overcome the shortcomings of the latter technique, the use of warm gutta percha techniques gained popularity. The α-polyisoprene isomer of gutta percha has a lower melting point and so can be heated in a gun and syringed into the root canal (Figure 8). Any internal anatomical anomalies can be obturated more easily and the technique is quicker (Figure 9). A master cone is placed apically to restrict the passage of molten material and the canal backfilled. The hardware required for this technique is expensive and is more commonly seen in specialist practice. Peng *et al* reported in 2007[66] that there was no difference in outcomes between heated and cold lateral compaction obturation techniques.

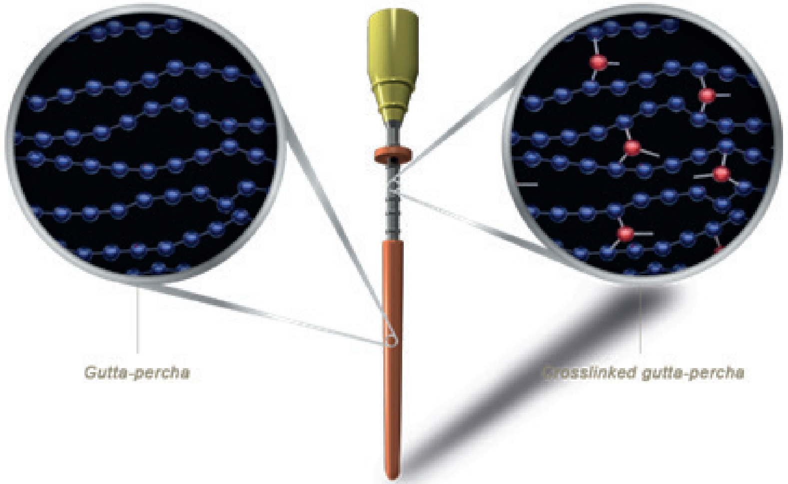

**Figure 10.** An example of a carrier-based obturation system, Guttacore (Dentsply Sirona).

**Figure 11.** A resin-modified polyalkenoate cement used to create a coronal seal by its placement over the gutta percha and pulp chamber floor prior to the provision of a definitive coronal restoration.

Another obturation technique involves the placement of a gutta percha-coated carrier,[67] which has been heated in a small oven until softened. The carrier is then placed to the measured working length and the carrier severed at the canal orifice. An example of one such system is Guttacore (Dentsply Sirona) (Figure 10).

Other systems have appeared on the market that are coated points, for example Totalfill BC points (FKG, La Chaux-de-Fonds, Switzerland) and EndoREZ points (Ultradent, South Jordon, UT, USA). Some systems are impregnated with bioceramic nanotechnology. A recent trend is to use a single cone with a bioceramic sealer and this technique is showing promise.[68,69]

## Materials used in endodontics

Advances in dental materials have significantly contributed to improved outcomes for endodontic treatment. Fifty years ago, the most commonly used sealer was a zinc oxide eugenol-based material. Later, an epoxy sealer AH26 (Dentsply Sirona) was introduced. Over the past 15 years, a number of sealers have been introduced, including those based on epoxy resin, urethane dimethacrylate, polyvinyl and polysiloxane. One goal was to achieve a monobloc, where there was a mechanically homogeneous unit, involving bonding to the root canal wall by the sealer and obturator.[70] This has had limited success.

In particular, the introduction in 1993 of mineral trioxide aggregate (MTA), an example of an hydraulic cement, has transformed root canal obturation.[71] Hydraulic cements are unique materials that set in the presence of water, do not deteriorate when wet, and, as such, lend themselves for use in a range of endodontic procedures, namely pulp capping,[72] barrier regenerative endodontics,[73] as a root canal sealer,[74] to create an apical plug,[75] perforation repair and as a root-end filling following endodontic surgery.[76] Clearly, these indications have different demands on the properties of the material, which has been modified accordingly. The advantages and properties of these materials include biocompatibility, bioactivity, dimensional stability, antimicrobial activity, radiopacity, appropriate mechanical properties and a coefficient of thermal expansion close to that of dentine. For a more detailed summary of the clinical use of hydraulic cements in endodontics, the reader is referred to the recent articles published in *Dental Update* by Bonsor and Camilleri.[77,78]

## Restoration of the root-filled tooth

Once the root canal system has been disinfected and then obturated, it is imperative that a coronal seal is established to prevent subsequent microbial penetration.[79] It is wise to cover the root filling material with a restorative material separate from the one being used to restore the missing coronal tooth tissue.[80] This is so that if the coronal restoration is lost, then the other microbiological barrier will maintain the coronal seal and protect the root filling. Commonly used materials for this purpose are a glass polyalkenoate cement such as GC Fuji TRIAGE (GC, Leuven, Belgium), which is pink and easy to see, a resin-modified glass polyalkenoate cement such as Vitrebond Plus (3M, Seefeld, Germany) (Figure 11) or a resin composite, with many clinicians favouring a flowable presentation because its rheology allows better adaptation to the pulp chamber floor.

The timing of placement of the definitive coronal restoration has changed fundamentally in the past 30 or so years. The traditional approach was to complete the root canal therapy and then radiographically review the case some 6 months post-operatively to check for evidence of peri-radicular healing. That being the case, a cast restoration was then provided for the tooth. Unfortunately, and not infrequently, unless the tooth had been braced by means of cuspal protection for example, the placement of a copper ring or orthodontic band, many teeth fractured catastrophically, so rendering them unrestorable. Furthermore, oral hygiene practices were also compromised by such a protective device. For this reason, in contemporary dentistry, the provision of the definitive coronal restoration is considered to be an integral part of the endodontic treatment, with this being placed as soon as possible after completion of the root canal therapy.

Advances in dental materials and associated techniques, especially adhesive dentistry, have revolutionized the ability of the clinician to preserve dental hard tissue. The more tooth tissue that has been removed, the weaker the tooth, thus rendering it more liable to fracture. A recent study showed that teeth with less than 30% residual tooth structure had a survival rate of over 80%, whereas a survival of 94% was seen in teeth with greater than 30% of remaining tooth tissue.[81] The maintenance of coronal tooth structure is therefore

**Figure 12.** A lithium disilicate onlay placed on a root filled LL6.

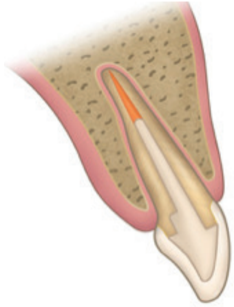

**Figure 13.** A diagrammatic representation of a ferrule. Note the relative positions of the crown and core margins whereby the extra-coronal restoration 2-mm apical to the core material sits on sound tooth.

**Figure 14.** A tray of microsurgical instruments used to perform surgical endodontics.

**Figure 15.** An intra-operative photograph demonstrating a papilla preserved flap.

**Figure 16.** Suturing of a papilla-preserved flap using 6/0 sutures, clinical photograph taken immediately post-operatively.

paramount. A move in the last decade has been the provision of partial casts, such as onlays, in favour of full veneer crowns, especially in endodontically treated teeth.[82] Onlay preparations are much more conservative[83] than full crown preparation, whereby some 70% of the hard tooth tissue is removed.[84] This is especially the case in endodontically treated teeth where significant tooth tissue may already have been lost. Onlays may be constructed from a metal alloy and cemented conventionally, or indeed bonded using a resin composite adhesive system with appropriate treatment of the fitting surface of the onlay. An aesthetic option is also available with the glass ceramic, lithium disilicate, which is bonded to the underlaying tooth structure after etching with hydrofluoric acid and application of a silane coupler on its fitting surface prior to cementation with a resin composite adhesive system (Figure 12).

Of course, cuspal protection may be achieved by the direct placement of restorative materials, such as resin composite. The latter material has become more popular in contemporary dentistry, with a recently published systematic review reporting that a direct composite onlay was as effective as one constructed indirectly.[85]

As mentioned earlier, the loss of coronal tooth structure greatly decreases the prognosis of the tooth, not to mention increasing the difficulty and complexity of restoring it. This is illustrated well by the post crown restoration. At one time, a roof-top preparation was advocated, whereby the tooth was reduced to an equigingival level to permit placement of the cast post and core. The high failure rate of these restorations was attributed to the lack of ferrule, that is a 2-mm circumferential amount of dental hard tissue, this permitting the margin of the crown to be placed further apically than that of the core (Figure 13). The effect of this design of post crown was that the crown braced the remaining tooth tissue. Fifty years ago, post crowns were traditionally retained by means of a post and core, usually constructed from metal alloy. The elastic moduli of the metal alloy and the surrounding dentine differed, and during function, could result in fracture of the weaker structure, ie the root, so rendering it unrestorable. Non-metallic posts constructed principally of composite fibres bound together in composite resin have been introduced in the past 20 years. The concept is that the elastic moduli of both structures are similar and therefore, the fibre post and radicular dentine would flex with each other, so decreasing the risk of fracture of the root. The provision of a fibre post is contraindicated unless a ferrule is present because it leads to flexure of the post, leading to fracture or debonding. Often the fracture of the post means that the tooth is relatively undamaged and can be restored. Failure to deal with debonding immediately can lead to caries under the mobile crown, potentially seriously compromising the restorability of the tooth. An additional advantage of the non-metallic post is that they are tooth coloured and potentially easier to restore with a tooth-coloured crown. A systematic review published in 2021 concluded that there was no difference in the failure rates between intra-radicular fibre posts and metal posts, independent of region and the difference in the type of metal post.[86]

## Peri-radicular surgery

The benefits of using the operating microscope to facilitate endodontic procedures have already been discussed. This also includes peri-radicular surgical procedures where the endodontist has a need to raise a mucoperiosteal flap to gain access to the root. Microsurgical techniques have been developed that have been seen to offer many advantages, such as less morbidity, reduced post-operative pain and swelling, quicker healing and better outcomes, when compared with conventional techniques.[87] In order to perform such procedures, microsurgical instrumentation had to be developed and their use learned. Examples of microsurgical instrumentation can be seen in Figure 14.

Microsurgical techniques were developed in this regard, for example papilla-based flaps (Figure 15), to preserve the blood supply and therefore, anatomy of the interdental region. This contrasts markedly with the traditional semi-lunar flaps that were used for many years. Not only did this approach compromise access to the surgical site, but there was also significant scarring post-operatively. This incision is therefore no longer indicated. The use of 6/0 or 7/0 non-resorbable synthetic microsurgical sutures allows apposition of the edges of the flap in exact proximity, so enhancing healing and decreasing post-operative pain and swelling (Figure 16). The small dimensions of these sutures means that surgical knots are best tied with the use of the operating microscope. They are usually removed 2–3 days post-operatively.

The biocompatible and bioactive (tricalcium silicate) cements, as described earlier, have a significant role to play in peri-radicular surgery. Their hydraulic nature lends themselves to be used in the surgical (wet) site, and their advent and use has contributed to the successful outcome of the techniques, which is reported to be 89% at 1 year.[88] This biological approach allows regeneration of the apical tissues, periodontal ligament and bone, which contrasts with the use of dental amalgam or re-inforced zinc oxide eugenol cement that were used for many years as root-end fillings and result in repair only.

## Outcome of treatment

It would be interesting to see whether the advancements in knowledge, technology and techniques seen in the past 50 years have resulted in better outcomes for endodontic treatment. The traditional parameter of success was evidence of peri-radicular healing seen radiographically, with bony infill and resolution of the lesion up to 4 years after completion of treatment. However, with the advent of dental implants, a change from success to survival has become more commonplace in the literature by means of direct comparison. Various studies have looked at survival of endodontically treated teeth. A systematic review published in 2011 quoted figures of 95.4% for primary RCT and 95.3% for re-treatment cases at 4 years.[89] It is regretful that there is a paucity of data relating to outcomes from 50 years ago, making comparison difficult

## Conclusion

There have been significant advances in the practice of endodontics in the last half century. Most significant have been the invention and adoption of the superelastic metal alloys used in the construction of endodontic files, especially when used in a mechanical handpiece, the enhanced magnification and illumination offered by the operating microscope, the biocompatible and bioactive hydraulic cements that permit biological healing by primary intention, and warm obturation techniques that facilitate a more thorough filling of the root canal system. The many other advances described have contributed to a more efficient and easier experience for the operator, and better clinical outcome for the patient. It is interesting to speculate where endodontics will be in another 50 years, but unfortunately, neither author will be alive to see these advancements!

### Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.
Informed Consent: Informed consent was obtained from all individual participants included in the article.

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