6

Filling of Root Canals After Minimally Invasive Preparation

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6.1 Introduction

Instrumentation creates space for canal irrigation, disinfection and root filling. All of these phases have an impact on the method and size of instrumentation, depending on the philosophy of the dentist and the limitations and requirements set by the equipment used in each phase,

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especially in root filling. Optimal root filling has many requirements which have been difficult if not impossible to fulfil. Gutta-percha has been and still is the core material of choice in root fillings, but it requires the use of a sealer in order to obtain better short- and long-term seal. Thermoplastic obturation methods and warm vertical condensation techniques have been introduced in the 70s to overcome the vulnerability of the most popular endodontic sealer materials which undergo shrinkage and wash out upon setting. In order to apply such obturation techniques there is a need for an access cavity with a large tapered preparation on the coronal part of the root canals to allow a hydraulic condensation of a soften gutta-percha, minimizing the layer of such sealers. The use of large tapered instruments has been shown to weaken the tooth potentially leaving the root unnecessarily susceptible to fracture [1, 2].

With the introduction of the operative microscope almost 3 decades ago, the concept of minimally invasive endodontics has gradually been introduced and taught to specialists and general practitioners (Fig. 6.1a, b). The use of operative microscope with high magnification provides a high-precision clinical work preventing unnecessary removal of tooth structure that is imperative for successful treatment, thus reducing tooth weakening, non-restorable cases, micro-cracks and coronal leakage.

This chapter presents a panorama of presently available material and methods suggested for root canal filling to adapt to the minimally invasive preparation concept.

6.2 Terminology

The term obturation is what most people use to describe the third stage of root canal therapy after root canal instrumentation and irrigation. Obturation by definition is to “close off a space”, but makes no requirement for filling that space [3–7]. In fact, the term obturation is more appropriate for a retro-filling in apicoectomy procedures, since the root canal space is closed off but the contents of the root canal are not disturbed. Root canal filling is a much more appropriate description of what clinicians are attempting and thus a better term to use.

6.3 Rational for Root Canal Filling

Root canal filling is performed as the third phase of root canal therapy after microbial control through mechanical shaping and chemical cleaning, where microbes are prevented from re-entering the root canal space (vital teeth) following their removal by instrumentation and irrigation (infected necrotic teeth). The aim of root canal filling is to maintain the low microbial load left within the root canal system below the threshold for clinical and radiographic success (Fig. 6.2), limiting the intra-canal infection found in the main canal and dentinal tubules communicating with the peri-radicular tissues (Fig. 6.3).

It also assumes that a coronal filling of sufficient quality will be placed as soon as possible after the canal/s are filled. At the present time, it is also assumed that it is not possible to sterilize the root canal and physically remove all biofilms from

Fig. 6.1 (**a**) The use of operative microscope in the endodontic specialty practice; (**b**) systematic teaching to general practitioners on the use of operative microscope

Fig. 6.2 Endodontic therapy on a non-vital case with an apical periodontitis. With an adequate treatment protocol to control intra-canal infection, the root filling will maintain the low microbial load below the threshold for clinical and radiographic success

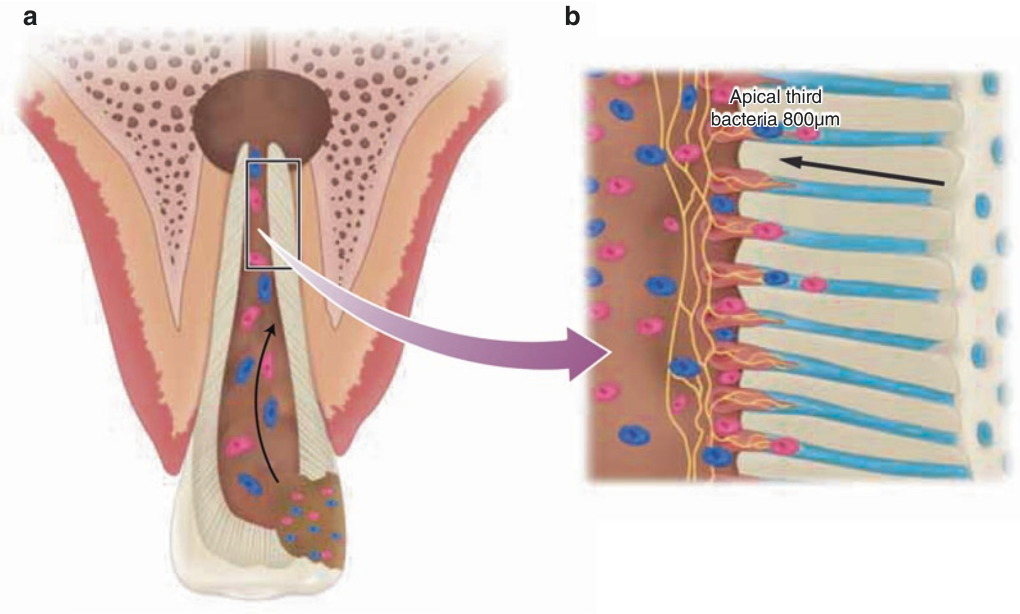

Fig. 6.3 Illustration demonstrating the intra-canal infection in the main canal (**a**) and in the dentinal tubules (**b**)

its complex anatomy. Thus, there are three basic requirements from a root canal filling [8] (Fig. 6.4):

(a) Guarantee a tight apical seal to prevent influx of periapical fluids, which may nourish surviving microbes in the root canal.
(b) Isolate surviving microbes in the root canal space so that they cannot multiply and/or communicate with the peri-radicular tissues.
(c) Stop coronal leakage after the root canal and crown is filled.

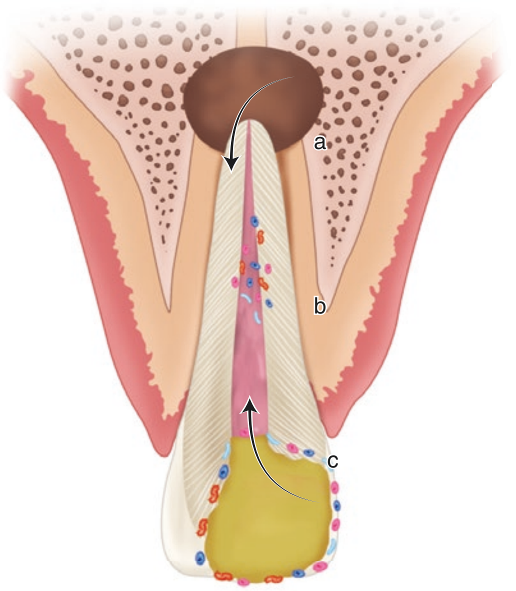

Fig. 6.4 Three basic requirements from a root canal filling: (**a**) Guarantee a tight apical seal to prevent influx of periapical fluids, which may nourish surviving microbes in the root canal; (**b**) Isolate surviving microbes in the root canal space so that they cannot multiply and/or communicate with the peri-radicular tissues; (**c**) Stop coronal leakage after the root canal and crown is filled

6.4 Materials and Techniques

Filling the root canal requires the development of adequate materials and techniques to maximize the properties of those materials. Figure 6.5 reports the list of Grossman's ideal properties of a root canal filling material [9]. Not much has changed since Grossman constructed his list of requirements over 70 years ago. Clinicians still use a core material to take up as much space as possible and a sealer to fill the voids between the core material(s) and the dentin.

6.4.1 Core Materials

Gutta-percha (GP) and silver points have been the most used core materials over the last 100 years [10–12]. In 2017, a position statement from the American Association of Endodontists [13] recommended to discontinue the use of silver points due to: (1) corrosion in the presence of blood and tissue fluids; (2) staining of the tooth and surrounding tissues; (3) inability to perform post and cores after root filling and (4) difficulty to remove in apical surgery retrograde preparations. Thus, GP is the primary core material in use today. Cones of GP contain approximately 20% GP and 80% fillers used for colouring and radiographic contrast [14]. GP comes in its natural form (alpha phase) or manufactured form (beta phase) [14–17].

6.4.2 Types of Sealers

As mentioned, sealers are the most important factor for the quality of the seal in root filling. Many different sealers have been used over the last 50 years, including those based on chloroform mixed with GP, zinc oxide–eugenol, calcium hydroxide, silicon, glass-ionomer cement and epoxy or methacrylate resins [14, 17, 18]. All are mixed and introduced in the canal in a fluid form and have enough working time to allow the practitioner to place the root canal filling to his/her satisfaction before placing the coronal restoration. It is then assumed they will then harden by a setting reaction in a reasonable time after placement into the canal.

6.4.3 How Well Do Traditional Filling Materials and Methods Perform?

The traditional root filling comprises a standard GP core and round accessory cones combined with a sealer to fill the space between the GP points themselves and the GP and the dentinal walls. The GP core material acts only as a filler and does not seal the canal. In fact, when tested in an in vitro model microbes are able to travel throughout the length of the canal in 2 h if only gutta-percha is present in the canal without sealer

[19]. The leakage can be delayed for up to 30 days with the use of a sealer [4] (Fig. 6.6).

Despite sealers are the materials in root filling that actually provide resistance to leakage, traditional sealers have serious shortcomings in that they generally shrink on setting and wash out in the presence of tissue fluids [4, 14, 20–27] (Fig. 6.7).

In addition sealers do not bond to the gutta-percha core material, leaving gaps (Fig. 6.8) with potential for microbial leakage (Fig. 6.9) when the sealer shrinks on setting [28].

Thus, in order to maximize the sealing ability of sealers, but minimize their shortcomings, the sealer used in traditional root canal filling techniques needed to be as thin as possible. Since the GP core is generally produced in a cone shape with a round diameter, it is very difficult to keep the sealer thin in most root canals as they are generally irregular in shape and may have many communications.

Many in vitro, in vivo animal studies and clinical outcome studies on the traditional methods of

Fig. 6.5 Grossman's ideal properties of a root canal filling material

- Introduced **easily** in to the root canal
- It should **impervious** to moisture
- It should **seal** the canal laterally as well as apically
- It should **not shrink** after being inserted
- It should be **bacteriostatic** or least should discourage growth
- It should be **radiopaque**
- It should not **stain** tooth structure
- It should **not irritate** periapical tissue
- It should be **easily removed** from the root canal it necessary
- It should be **sterile** or easily and quickly sterilised immediately **before** insertion

Grossman, 1936

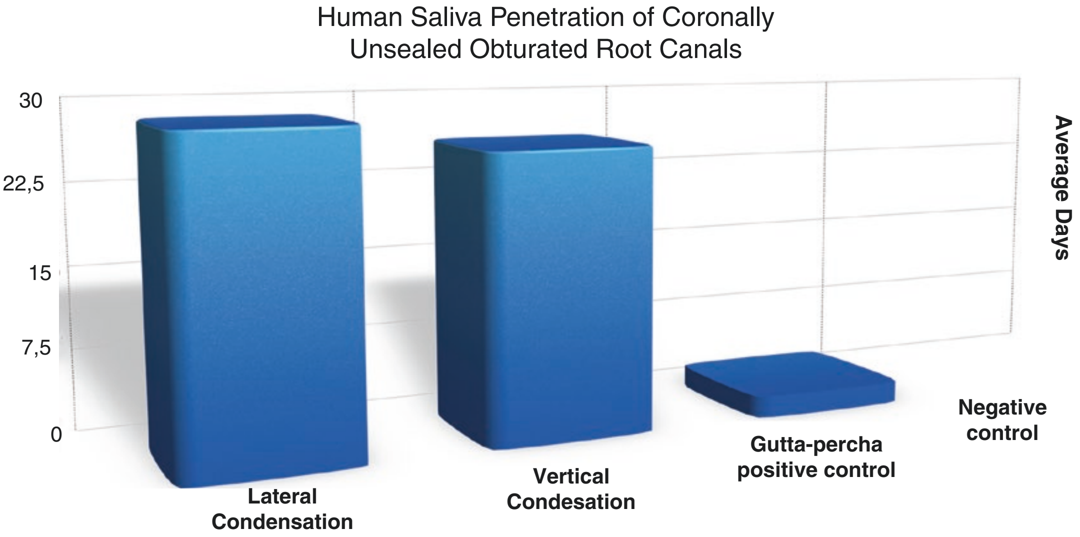

Fig. 6.6 In vitro evaluation of saliva penetration of root canals. Note that the seal achieved with GP alone is indistinguishable from the negative control. (From Khayat et al. [4])

Fig. 6.7 Table showing expansion/contraction of popular sealers. Silicone and epoxy resin-based sealers expand slightly before shrinking [14]

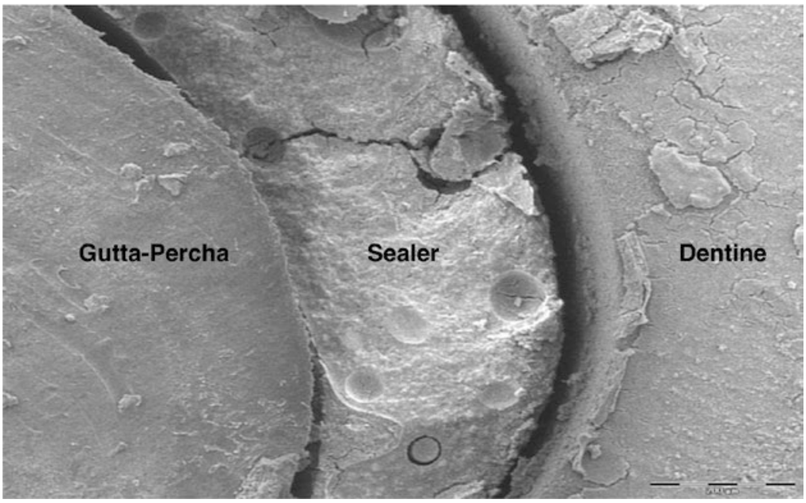

Fig. 6.8 SEM image of the cut surface of a root filled with gutta-percha and a resin-based sealer. Note the gap between the GP and sealer (courtesy of Dr. Eldeniz [28])

single-cone or lateral condensation techniques uniformly show that the traditional filling materials do not seal the root canal [27, 28]. Sabeti et al. [4] found no difference in the outcome when a canal was root filled compared to left empty. This study emphasizes the susceptible quality of our root filling techniques and the importance of the coronal restoration for root canal success [4–18, 20–27].

A review and meta-analysis showed no differences in the clinical outcome of root canal obturation by warm GP or cold lateral condensation, except in overextention that was more likely to occur in the warm GP obturation group in comparison with the lateral condensation group [29]. Friedman et al. in outcome studies also showed no statistical differences in the obturation methods used (lateral and vertical condensation) on teeth with and without apical periodontitis [30]. However, the recall rate of these studies was very low and below 20%. In the latest publication of these studies [31], Chevigny et al. discussed that obturation techniques appeared as a significant outcome predictor for teeth with apical periodontitis, but it should be important to confirm these data with properly designed randomized controlled trials [30].

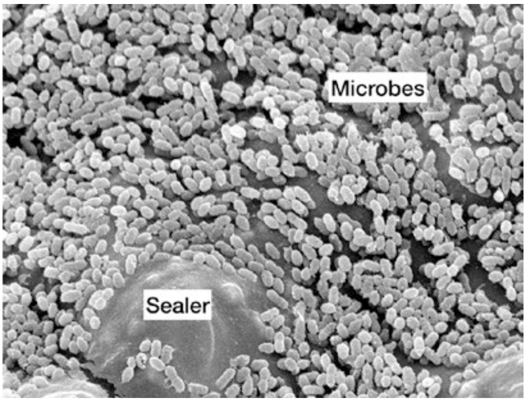

Fig. 6.9 SEM picture with microbial leakage when a resin-based sealer shrinks on setting (courtesy of Dr. Ørstavik [25])

6.5 Attempts to Improve Root Canal Fillings

The most influential attempt to improve the performance of root canal filling was by Herbert Schilder in the 1960s [32, 33]. Schilder recognized that one of the problems in filling was that the round gutta-percha core materials were unable to keep the sealer in a thin layer because the canals themselves were mostly oval. Thus, in too many areas the sealer was thick and vulnerable to shrinkage and wash out. Schilder heated gutta-percha in order to make it pliable and able to be moved into these non-round areas and keeping the sealer as thin as possible. Additionally, the hydraulic nature of the technique resulted in many accessory canals being visualized on the radiograph due to the sealer and/or gutta-percha being forced into these small spaces, creating a detailed picture on the radiograph with the impression that a superior "3D" filling had been placed (Fig. 6.10). This is the well-known warm vertical compaction technique by Schilder [34].

The logic behind this technique was comprehensive and the outstanding radiographic results were universally accepted as a technique for specialists or "advanced" generalists. The technique has been improved on the following years after its introduction and was named as continuous wave compaction technique by Buchanan [35]. This technique has several phases and requires a selection of instruments and devices: (1) selection of a greater taper GP corresponding to the last instrument; (2) selection of a plugger to be pre-fitted 4–5 mm from the working length; (3) the canal is coated with a thin layer of root canal sealer; (4) the primary GP cone is inserted at the working length (WL) minus 0.5 mm; (5) compaction heat carrier-plugger instrument is activated and stopped to the reference point (4–5 mm from WL); (6) the apical GP is now lightly condensed with selected hand pluggers; (7) a layer of sealer may be re-applied on the coronal part of the apical GP plug; (8) the back-filling of the coronal part is done by using a GP gun; (9) the coronal part now is condensed with large pluggers.

However, this technique can be technically sensitive, and it may do little to overcome the weak points of the original single-cone or lateral condensation techniques [30]. Once the heated gutta-percha cools, it may shrink even more than the sealer does on setting [36, 37]. In addition, the shrinkage of the GP and sealer (instead of sealer only) may result in a larger gap between the gutta-percha and sealer [28], exaggerating the weakness of no bond between the two. Furthermore, many points on the root canal wall force the sealer out, resulting in gutta-percha filling the canal without any sealer in that particular area of the root [38].

Even if the warm GP techniques may leave less voids and obtain a better 3D compaction of the filling materials [39, 40], other studies have shown no benefit in sealing the root canal with the heated vertical condensation technique compared to the traditional lateral condensation technique [38].

A recently identified complication of the warm compaction technique is the need for a larger taper to be used to instrument the mid-coronal portion of the canal, in order to place a heated plugger within 4 mm of the working length. The use of large tapered instruments (NiTi orifice openers or Gates-Glidden burs) has recently been shown to produce micro-fractures in the root [41–45]. Additionally, the thinning of the root dentin proportionally weakens the tooth

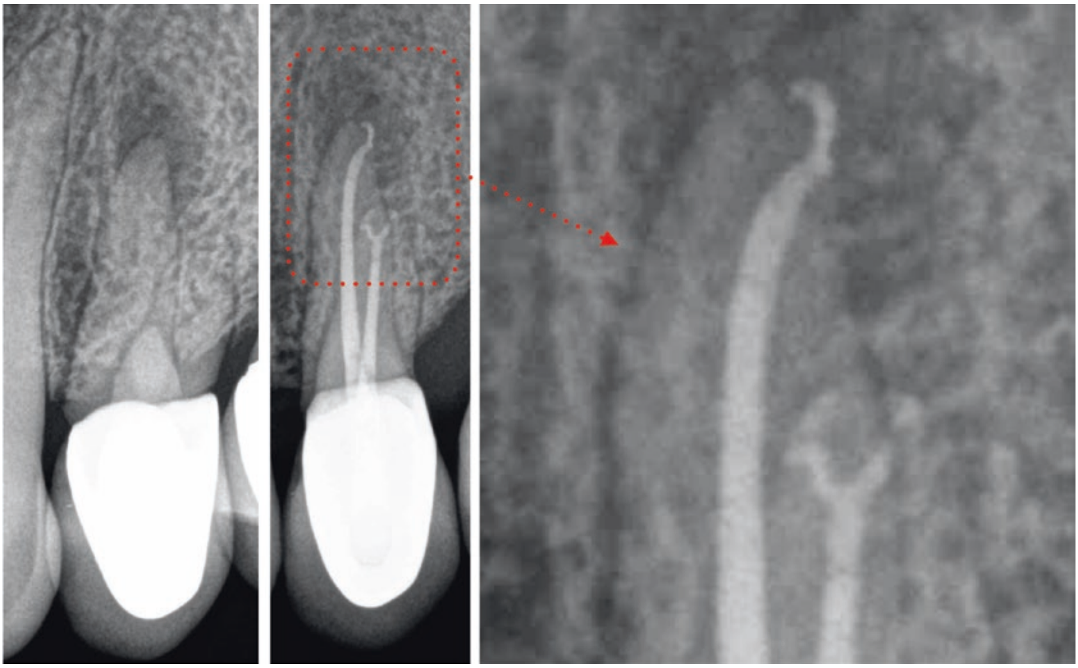

Fig. 6.10 Upper premolar root filled with the well-known warm vertical compaction technique

potentially leaving the root unnecessarily susceptible to fracture [42, 44–46].

This may be the main limitation to adopt this technique in particularly conservative root canal preparation and access cavity: in most of these cases the clinician may have difficulties to keep the heat carrier-plugger to 4–5 mm from the working length to properly execute the warm compaction of the apical GP. If it will remain more coronal than 5 mm from the working length, GP master point will be not modified by the heat in its last millimetres and the consequence may be presumably the presence of a single cone surrounded (covered) by sealer in the apical third of the canal.

To overcome the several and sensitive steps on the continuous wave compaction technique, a carried-based GP material and technique has been developed [47]. Thermafill (Dentsply-Sirona Endodontics, Baillagues, Switzerland) has been the most popular of these carried-based GP materials. Pirani et al. [48] have recently shown on a 5-year retrospective study that the survival and healing rates after root canal treatment with Thermafil were comparable to those previously reported for conventional root filling techniques. The major disadvantage of a carrier-based technique in minimally invasive endodontic procedures may be the technical difficulty to insert the obturator through small coronal spaces without a straight-line access. This may increase the possibility to bend the obturator in an unnatural way, to detach the GP from the carrier, to cover the orifices of the other root canals of multi-rooted teeth with excess of GP flowing coronally and to fill undercuts in conservative access cavities with stocky sealers and GP, being very difficult to be cleaned after filling procedures.

Another attempt to improve root filling performance was the introduction of a methacrylate core-sealer resin [49]. The idea behind of this newly introduced material was to effectively bond to the resin core material (monoblock), thus eliminating one gap consistently present in the other techniques. The methacrylate resin was also aimed to chemically bond to clean dentin on the root walls. The use of these materials did not require large tapered canal preparation and warm vertical condensation techniques to minimize the layer of the sealer used which fits perfectly on the minimally invasive endodontic preparations.

While in vitro and in vivo studies results for this material were generally positive compared to traditional techniques [50–55], Strange et al. [56] have recently demonstrated on a low recall rate (21.6%) study, a statistically poorer clinical outcome for this material (Resilon) and technique compared to traditional gutta-percha/AH Plus. Thus, methacrylate-based sealers demonstrated the same shortcomings of the traditional sealers (shrinkage and wash out) and are also extremely technique-sensitive materials. In routine root canal instrumentation techniques, where sodium hypochlorite is used, the oxygen that is produced made the sealer particularly difficult to use and resulted in many cases where the sealer failed to set or disintegrate [57].

6.6 Bioceramic Materials

Bioceramics (BC) are ceramic materials specifically designed for medical and dental use. During the 1960s and 1970s, these materials were developed for use in the human body such as joint replacement, bone plates, bone cement, artificial ligaments and tendons, blood vessel prostheses, heart valves, skin repair devices (artificial tissue), cochlear replacements and contact lenses [58]. Bioceramics are inorganic, non-metallic, biocompatible materials that include alumina and zirconia, bioactive glass, coatings and composites, hydroxyapatite and resorbable calcium phosphates and radiotherapy glasses [59–61]. They are chemically stable, non-corrosive and interact well with organic tissue.

Bioceramics are classified as:

- Bioinert: non-interactive with biologic systems.
- Bioactive: durable in tissues that can undergo interfacial interactions with surrounding tissue.
- Biodegradable, soluble or resorbable: eventually replace or are incorporated into tissues.

There are numerous bioceramics currently in use in dentistry and medicine [62]. Alumina and zirconia are bioinert ceramics used in prosthetics. Bioactive glass and glass ceramics are available for use in dentistry under various trade names. In addition, porous ceramics such as calcium phosphate-based materials have been used for filling bone defects. Some calcium-silicate-based materials (MTA—mineral trioxide aggregate, ProRoot® MTA Root Repair; DENTSPLY-Tulsa Dental Specialties, Tulsa, US) and bioaggregates (DiaRoot® BioAggregate; DiaDent, Almere, The Netherlands) have also been used in dentistry as materials for root repair and for apical root filling.

6.6.1 Bioceramics in Endodontics

Calcium-silicate-based materials used in endodontics are generally wide known as Bioceramics or Bioactive Endodontic Cements (BECs) [63, 64], but due to the wide range of materials undergoing this definition, materials for endodontic use should be better defined as "hydraulic cements", in both their version as root canal sealer (RCS) or repair/root-end material (RRM), as they are all based on the same active ingredient: tricalcium silicate [65].

These materials used in endodontics can be categorized by composition, setting mechanism and consistency [28, 58, 66]. There are sealers and pastes, developed for use with gutta-percha and putties, designed for use as the sole material, comparable to MTA [66]. Some are powder/liquid systems that require manual mixing. The mixing and handling characteristics of the powder/liquid systems may be technique sensitive and produce waste. Pre-mixed bioceramics require moisture from the surrounding tissues to set. The pre-mixed sealer, paste and putty have the advantage of uniform consistency and lack of waste. These pre-mixed bioceramics are all hydrophilic [66].

6.6.2 Available Hydraulic Endodontic Cements (Tables 6.1–6.3)

Few clinicians realize that original MTA is a classic hydraulic cement with the addition of some heavy metals [62]. MTA is one of the most extensively researched materials in the dental field [67–74]. It has the properties of all bioceramics, i.e. high pH when unset, biocompatible and bioactive when set and provides an excellent seal over time [72]. However, it has some disadvantages. The initial setting time might be long, it requires mixing, it is not easy to manipulate and it is hard to remove [67]. Clinically both grey and white MTA may stain dentin, presumably due to the heavy metal content of the material or the inclusion of blood pigment while setting [75]. Finally, MTA is hard to apply in narrow canals, making the material poorly suited for use as a sealer, even if clinical techniques have been suggested [76]. Efforts have been made to overcome these shortcomings with new compositions of MTA or with additives to make it more fluid. However, these formulations affect its physical and mechanical characteristics, consequently affecting its performance [77, 78].

Biodentine (Septodont, Saint-Maur-des-Fosses, France) is considered a second generation of endodontic bioactive materials, which has similar properties to MTA and thus can be used for all the applications set out above for MTA [79, 80]. Its advantages over MTA are it has a shorter setting time (approximately 12–15 min) and has a compressive strength similar to dentin [81]. A major disadvantage is that it is triturated for 30 s in a preset quantity (capsule), making waste inevitable in the vast majority of cases, since only a small amount is usually required. BioRoot RCS (Septodont) is a new mixable powder/liquid calcium-silicate-based material, which has a fluid consistency to be used as root filling sealer [82].

In 2007, a Canadian research and product development company (Innovative BioCeramix, Inc., Vancouver, Canada) developed a pre-mixed, ready-to-use calcium silicate-based material, iRoot® SP injectable root canal sealer (iRoot® SP) [66]. Since 2008 these endodontic pre-mixed bioceramic products are available in North America from Brasseler USA as EndoSequence® BC Sealer™, RRM™ (Root Repair Material™, a syringable paste) and RRM-Fast Set Putty™. Recently, these materials have also been marketed as Totalfill® BC Sealer™ [28]. In the last years several companies have developed pre-mixed bioceramic materials, which are today available on the market [62].

Both forms (sealer and putty) of these pre-mixed hydraulic cements are similar in chemical composition (calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic and fillers) and have excellent mechanical and biological properties and good handling properties [83–116]. They are hydrophilic, insoluble, radiopaque, aluminium-free and with high pH and sealability properties [83–116].

6.6.3 Hydraulic Endodontic Cements for Root Filling

Hydraulic endodontic cements are not sensitive to moisture and blood contamination and therefore are less technique sensitive [66]. They are dimensionally stable and expand slightly on setting, making them one of the best sealing materials in dentistry [66, 84, 117–119]. When set they are hard and insoluble consequently ensuring a superior long-term seal [66]. The pH at setting is above 12, which is due to the hydration reaction forming calcium hydroxide and later dissociation into calcium and hydroxyl ions [66, 67, 110, 117] (Fig. 6.11a, b). When unset the material has antibacterial properties [82, 84]. When fully set it is biocompatible and even bioactive [84–95]. When hydraulic cements come in contact with tissue fluids, they release calcium hydroxide, which interact with phosphates in the tissue fluids, to form hydroxyapatite [66] (Fig. 6.11c). This latter property may also explain some of the tissue-inductive properties of the material [66]. For the reasons above, these materials are now the material of choice for pulp capping, pulpotomy, perforation repair, root-end filling and obturation of immature teeth with open apices, and given their properties, they are becoming more and more popular as sealers for root canal filling of mature teeth with closed apices [58, 62, 66].

Table 6.1 MTA materials commercially available

Name	Manufacturer	Composition	Setting time
ProRoot mineral trioxide aggregate (grey)	Dentsply Tulsa dental specialties, Johnson City, TN, USA	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminate, calcium sulphate dihydrate (gypsum) and calcium aluminoferrite liquid: distilled water	Initial setting time has been reported from 70 to 74 min, while the final setting time is 210–320 min
Tooth-coloured ProRoot mineral trioxide aggregate (white)	Dentsply Tulsa dental specialties, Johnson City, TN, USA	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminate, calcium sulphate dihydrate or gypsum liquid: distilled water	4 h
Angelus MTA (grey and white)	Angelus, Londrina, Brazil	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminate, calcium oxide, aluminium oxide, silicon dioxide liquid: distilled water	The initial setting time of white angelus MTA has been reported to be about 8.5 ± 2.4 min; however, other studies reported 130–230 min as the setting time for angelus MTA
PD MTA white	Produits Dentaires SA, Vevey, Switzerland	SiO_2, K_2O, Al_2O_3, Na_2O, Fe_2O_3, SO_3, CaO, Bi_2O_3, MgO Insoluble residues of CaO, KSO_4, $NaSO_4$ and crystalline silica. To mix with distilled water	The material starts setting after approximately 10 min and the final setting time is 15 min. It is not necessary to wait for the final setting to continue the treatment procedure
Endocem MTA	Maruchi, Wonju, Korea	CaO, Al_2O_3, SiO_2, MgO, Fe_2O_3, SO_3, TiO_2, H_2O/CO_2, bismuth oxide	4.5–15 min
MicroMega MTA	MicroMega, Besancon, France	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, bismuth oxide, calcium sulphate dehydrate and magnesium oxide	The manufacturer has claimed that the MicroMega MTA setting time is 20 min; however, there are reports that announced MM MTA has a setting time of 120–150 min
MTA bio	Angelus; Londrina, or angelus Solucoes Odontologicas, PR, Brazil	Portland cement and bismuth oxide	The initial setting time of MTA bio is 11 min. The final setting time of the material is 23.22 min
MTA plus (white)	Avalon biomed Inc., Bradenton, FL, USA	Tricalcium silicate, $2CaOSiO_2$, Bi_2O_3, $3CaOAl_2O_3$ and $CaSO_4$	MTA plus setting time is 128 ± 8 min. In contact with moisture the material needs longer time to set
MTA plus (grey)	Avalon biomed Inc., Bradenton, FL, USA	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminium oxide, calcium sulphate and $Ca_2(Al,Fe)_2O_5$	Initial setting time at 37 °C: ~15 min when thickly mixed with gel; otherwise longer for sealer (~3 h)
OrthoMTA	BioMTA, Seoul, Korea	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, free calcium oxide and bismuth oxide	324.0 ± 2.1 min
RetroMTA	BioMTA, Seoul, Korea	Calcium carbonate, silicon oxide, aluminium oxide and hydraulic calcium zirconia complex; liquid: water	Initial setting time of 150–180 s and final setting time of 360 min
Aureoseal MTA	Giovanni Ogna and Figli, Muggio, Milano, Italy	The powder consists of Portland cement, bismuth oxide, setting-time controllers, plastifying agents and radiopaque substances. The liquid is distilled water	No setting time has been reported for the material
CPM MTA	EGEO SRL, Buenos Aires, Argentina	MTA, calcium chloride, calcium carbonate, sodium citrate, propylene glycol alginate and propylene glycol	The initial setting time of end-CPM is 6–15 min, while the material's final setting time is 22–27 min

Table 6.2 Hydraulic endodontic cements for root repair

Name	Manufacturer	Composition	Setting time
BioAggregate	Innovative BioCeramix, Vancouver, BC, Canada	Tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, amorphous silicon oxide and tantalum pentoxides liquid: deionized water	Based on the manufacturer data sheet, BioAggregate has a setting time of 240 min
Biodentine	Septodont, Saint-Maur-desFosses Cedex, France	Tricalcium silicate, dicalcium silicate, calcium carbonate, zirconium oxide, calcium oxide, iron oxide liquid: Calcium chloride, a hydrosoluble polymer and water	The setting time of biodentine has been reported as 6.5–45 min
Calcium-enriched mixture (CEM) cement	BioniqueDent, Tehran, Iran	Calcium oxide, silicon dioxide, Al_2O_3, MgO, SO_3, P_2O_5, Na_2O, Cl and H&C Liquid: water-based solution	50 min
EndoBinder	Binderware, Sao Carlos, Brazil	Al_2O_3 and CaO	60 min
Endocem Zr	Maruchi, Wonju, Korea	Calcium oxide, silicon dioxide, aluminium oxide, magnesium oxide, ferrous oxide, zirconium oxide	–
EndoSequence, RRM, RRP	Brasseler, Savannah, GA, USA	Zirconium oxide, calcium silicates, tantalum oxide, calcium phosphate monobasic and filling and thickening agents	The setting time of EndoSequence putty is 61.1 ± 2.5 min and the final setting time is 208 ± 10 min
TotallFill, RRM, RRP	FKG Dentaire, La-Chaux-De-Fonds, Switzerland	Zirconium oxide, calcium silicates, tantalum oxide, calcium phosphate monobasic and filling and thickening agents	The setting time of EndoSequence putty is 61.1 ± 2.5 min and the final setting time is 208 ± 10 min
NeoMTA plus	Avalon biomed Inc., Bradenton, FL, USA	Tricalcium silicate, dicalcium silicate, tantalite, calcium sulphate and silica	NeoMTA plus has had a 50- to 60-min setting time when prepared with putty consistency; otherwise, when used as a root canal sealer with loose consistency, it may take 5 h to set
Quick-set	Avalon biomed Inc., Bradenton, FL, USA, patent pending	Monocalcium aluminate powder that contains bismuth oxide (as a radiopacifier) and hydroxyapatite	12 min
iRoot FS (fast setting), iRoot BP (injectable) and iRoot BP plus (putty)	Innovative BioCeramix Inc., Vancouver, Canada	iRoot FS: Calcium silicates, zirconium oxide, tantalum oxide and calcium phosphate monobasic iRoot BP (BioCeramix Inc.) and EndoSequence BC sealer (Brasseler USA) have had the same formula including zirconium oxide, calcium silicates, tantalum oxide, calcium phosphate monobasic, and filler and thickening agents	iRoot FS showed setting after 1 h, iRoot BP and iRoot BP plus became solid after 5–7 days
Tech biosealer capping, tech biosealer root end, tech biosealer apex	Isasan, Como, Italy	Mixture of white CEM, calcium sulphate, calcium chloride, bismuth oxide, montmorillonite	The final setting time of various types of tech biosealer differ from each other. Tech biosealer capping has a final setting time of 55 min

Table 6.3 Hydraulic endodontic cements for root canal filling

Name	Manufacturer	Composition	Setting time
BioRoot RCS (root canal sealer)	Septodont, Saint-Maur-desFosses Cedex, France	Tricalcium silicate, zirconium oxide (opacifier) and excipients in its powder form, and calcium chloride and excipients as an aqueous liquid	Less than 4 h
Endosequence BC (bioceramic) sealer	Brasseler, Savannah, GA, USA	Zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, filler and thickening agents	Setting time is 4 h measured according to ISO 6876:2001. However, in very dry root canals, the setting time can be more than 10 h
TotallFill (bioceramic sealer)	FKG Dentaire, La-Chaux-De-Fonds, Switzerland	Zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, filler and thickening agents	Setting time is 4 h measured according to ISO 6876:2001. However, in very dry root canals, the setting time can be more than 10 h
iRoot SP (sealer)	Innovative BioCeramix Inc., Vancouver, Canada	iRoot SP:Zirconium oxide, calcium silicates, calcium phosphate, calcium hydroxide, filler and thickening agents	4 h
Tech biosealer Endo	Isasan, Como, Italy	Mixture of white CEM, calcium sulphate, calcium chloride, bismuth oxide, montmorillonite	Tech biosealer Endo has a final setting time of 77 min
EndoSeal MTA	Maruchi, Wonju, Korea	Calcium silicates, calcium aluminates, calcium aluminoferrite, calcium sulphates, radiopacifier and a thickening agent	12.31 min
MTA Fillapex	Angelus Industria de Produtos Odontologicos S/A, Londrina, Brazil	A MTA root canal sealer with nanoparticles of silica	The material's setting time is 19.3 min. In dry conditions, the material fails to set
TheraCal LC (light cured)	Bisco Inc., Schaumburg, IL, USA	CaO, Sr glass, fumed silica, barium sulphate, barium zirconate, Portland cement type III and resin containing Bis-GMA (bisphenol A-glycidyl methacrylate) and PEGDMA (polyethylene glycol-dimethacrylate)	The setting time has been reported to be 0.3 min because of the use of light cure technology

Fig. 6.11 (**a**, **b**) Hydration reaction of bioceramic material in contact with water with the release of $Ca(OH)_2$; (**c**) precipitation reaction of the bioceramic which releases calcium hydroxide and interacts with phosphates in the tissue fluids forming hydroxyapatite

- **Hydration Reactions (a, b)**

$$2[3CaO{\cdot}SiO_2]+6H_2O \rightarrow 3CaO{\cdot}2SiO_2{\cdot}3H_2O+3Ca(OH)_2 \quad \textbf{(a)}$$

$$2[2CaO{\cdot}SiO_2]+4H_2O \rightarrow 3CaO{\cdot}2SiO_2{\cdot}3H_2O+Ca(OH)_2 \quad \textbf{(b)}$$

- **Precipitation Reaction**

$$7Ca(OH)_2+3Ca(H_2PO_4)_2 \rightarrow Ca_{10}(PO_4)_6(OH)_2+12H_2O \quad \textbf{(c)}$$

6.6.4 Properties of Hydraulic Endodontic Cements

To date, more than 90 studies have been performed on calcium-silicate hydraulic endodontic cements [83–119]. The vast majority of these studies have shown that the properties conform to those expected of a bioceramic material and are similar to MTA.

6.6.4.1 Biocompatibility and Cytotoxicity

Several in vitro studies report that BC materials display biocompatibility and cytotoxicity that are similar to MTA [83–94]. Cells required for wound healing attach to the BC materials and produce replacement tissue [84]. In comparison to AH Plus® (Dentsply-Maillefer) and Tubli-Seal™ (Kerr Endodontics), BC Sealer showed a lower cytotoxicity [83, 84]. On the other hand, one study concluded that BC Sealer remained moderately cytotoxic over the 6-week period [94] and osteoblast-like cells had reduced bioactivity and alkaline phosphatase activity compared to MTA and Geristore® (DenMat) [95]. A recent study comparing the results of apicoectomies done with MTA or bioceramic putty on dogs showed the bioceramic putty to be slightly better than the MTA, presumably due to its superior handling properties [96].

6.6.4.2 pH and Antibacterial Properties

BC materials have a pH of 12.7 while setting, similar to calcium hydroxide, resulting in antibacterial effects [97]. BC Sealer was shown to exhibit a significantly higher pH than AH Plus for a longer duration [98]. Alkaline pH promotes elimination of bacteria such as *E. faecalis*. In vitro studies reported EndoSequence paste produced a lower pH than white MTA in simulated root resorption defects [97] and EndoSequence paste, putty and MTA had similar antibacterial efficacy against clinical strains of *E. faecalis* [98].

6.6.4.3 Bioactivity

Exposure of MTA and EndoSequence Putty to phosphate-buffered saline (PBS) resulted in precipitation of apatite crystalline structures that increased over time, suggesting that the materials are bioactive [99, 100]. iRoot SP exhibited significantly lower cytotoxicity and a higher level of cell attachment than MTA Fillapex, a salicylate resin-based, MTA particles containing root canal sealer [100]. EndoSequence Sealer had higher pH and greater Ca2+ release than AH Plus [98] and was shown to release fewer calcium ions than BioDentine® and White MTA [100].

6.6.4.4 Bond Strength

One study reported that iRoot SP and AH Plus performed similarly and better than EndoREZ® (Ultradent) and Sealapex™ (Kerr Endodontics) [101]. Another study found that iRoot SP displayed the highest bond strength to root dentin compared to AH Plus, Epiphany® and MTA Fillapex, irrespective of moisture conditions [102]. In a push-out test, it was similar to AH Plus and greater than MTA Fillapex [103]. When iRoot SP was used with a self-adhesive resin cement, the bond strength of fibre posts was not adversely affected [104]. Smear layer removal had no effect on bond strengths of EndoSequence Sealer and AH Plus, which had similar values [105]. The presence of phosphate-buffered saline (PBS) within the root canals increased the bond strength of EndoSequence Sealer/gutta-percha at 1 week, but no difference was found at 2 months [106]. Because of the low bond values in these studies, it is doubtful that any of these findings are clinically significant.

6.6.4.5 Resistance to Fracture

iRoot SP was shown in vitro to increase resistance to the fracture of endodontically treated roots, particularly when used with bioceramic impregnated and coated gutta-percha cones [107]. Fracture resistance was increased in simulated immature roots in teeth with iRoot SP and in mature roots with AH Plus, EndoSequence Sealer and MTA Fillapex [108]. Similar results were reported for EndoSequence Sealer and AH Plus Jet sealer in root-filled single-rooted premolar teeth [109].

6.6.4.6 Microleakage

Microleakage was reported to be equivalent in canals obturated with iRoot SP with a single-cone technique or continuous wave condensation and in canals filled with AH Plus sealer with continuous wave condensation [110]. A recent study showed a superior sealability of EndoSequence putty compared with grey MTA [111].

6.6.4.7 Solubility

High levels of Ca2+ release were reported from iRoot SP, MTA Fillapex, Sealapex, and MTA-Angelus, but not AH Plus. Release of Ca2+ ions is thought to result in higher solubility and surface changes [112]. However, the study tested the materials following ANSI/ADA spec. No. 57, which is not designed for pre-mixed materials that require only the presence of moisture to set. This could be the reason for the difference in findings in this study and in vivo observations.

6.6.4.8 Retreatment

Removal of EndoSequence Sealer and AH Plus were comparable in a study comparing hand instruments and ProTaper Universal retreatment instruments [113]. However, none of the filling materials could be removed completely from the root canals [114] and none of the retreatment techniques completely removed the gutta-percha/iRootSP sealer from oval canals [115].

6.6.5 Hydraulic Endodontic Cements: An Ideal Core-Sealer System for Filling Minimally Invasive Preparation?

The present trend to reduce coronal taper of root canal preparation to help maintenance of coronal tooth structure at the level of the pericervical dentin 4 mm above and below the cemento-enamel junction makes subsequent phases of the root canal treatment most difficult to be performed from a technical point of view [1, 2]. Despite present irrigant activation techniques seems to adequately clean middle and coronal thirds of the root even in minimally invasive root canal preparation with minimal taper [120], the root canal filling procedures for warm obturation techniques may be impaired by this modified shape of instrumentation. A high root canal taper has been traditionally advocated to adequately perform the classic vertical compaction [121] or the modified continuous wave of compaction techniques [35] to permit the heat-carrier/plugger to reach 4–5 mm from the working length and exert the correct apical-lateral condensation forces. Conservative access cavities and minimally instrumented canals in terms of taper, while maintaining an adequate apical enlargement to permit debridement and disinfection of the most delicate apical area, may limit the heat carriers/pluggers currently available to reach the apical third, thus reducing the efficiency of the warm compaction techniques. For the same reasons, even a carrier-based technique may suffer of the same clinical limitations in these clinical conditions, being a limited coronal space an important limitation in practically executing this technique.

Hydraulic endodontic cements for filling root canals have some properties that may potentially change the root filling techniques in general and in minimally invasive instrumentation procedures in particular:

1. The hydraulic cements for root canal filling are highly hydrophilic and thus the natural moisture in the canal and tubules is an advantage, as they set in the presence of humidity, unlike most other sealers, specially the hydrophobic resin-based sealer, where moisture is detrimental to their performance.
2. When unset, the hydraulic cements have a pH of above 12. Thus, its antibacterial properties are similar to calcium hydroxide. Setting is dependent on physiologic moisture in the canal; therefore, it will set at different rates in different environments, but since they have a high pH, any delay in setting can be argued as a benefit, pending they will set properly.
3. These sealers do not shrink but expand slightly and are insoluble in tissue fluids.
4. Hydraulic endodontic cements are generally used in conjunction with a GP point that may be impregnated and coated on the surface with a nano-particle layer of bioceramic, which may reduce the gap between the sealer and the core and has shown to improve the seal of the filling.

5. Contrarily to the classic warm compaction techniques using GP and traditional sealers, in which compaction forces aim to reduce as much as possible the film thickness of the sealer, hydraulic calcium-silicate-based endodontic cements for root canal filling should be left undisturbed at a certain thickness in contact with the root canal walls and especially in the apical third, to act as the effective sealing part of the obturation materials. For this reason, high and deep condensation forces and high temperatures are not needed for these new filling materials.

The properties listed above, particularly in the presence of a sealer that does not shrink and is insoluble in tissue fluids, should change the long held rule that in root filings the core material should take up as much space as possible in order to mask the shortcomings of the sealer and by keeping the sealer as thin as possible. In fact, if it was possible to fill the root canal in a homogeneous way, ideally the need for a core material may be questionable. As it stands, the GP is only used to deliver the hydraulic cement through a hydraulic condensation and now the sealer can be the main component of the root filling.

6.6.6 Root Filling Technique with the Hydraulic Endodontic Cements

The single-cone technique [122] has been suggested to be used in conjunction with the use of hydraulic cements and has gained more and more popularity, if applied together with these materials in order to leave the sealer enough thickness to act as the main filling material. More importantly, the requirement to gain space for a plugger 4 mm from the working length is no longer required, allowing the practitioner a much more conservative antimicrobial instrumentation protocol for root canal treatment and leaving a thicker and stronger root. Interestingly when the taper is not excessive and the gutta-percha point is used primarily as a plugger to move the sealer into the canal irregularities and accessory canals, a radiographic picture similar to the classical warm vertical condensation technique is often seen (Figs. 6.12, 6.13, 6.14). In this way these kinds of sealers are ideal to be used combined with the minimally invasive endodontic techniques (Fig. 6.15).

In any case, given the irregular shape of the root canals especially in the coronal and middle thirds and the fact that a deep compaction is no more required with hydraulic cements, a “mild

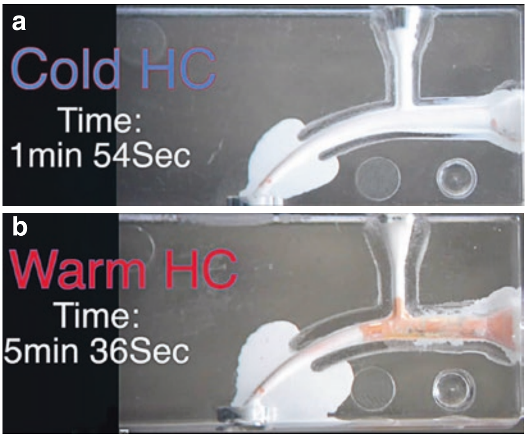

Fig. 6.12 Clinical demonstration of the cold hydraulic condensation (HC) on a simulated canal (**a**), compared to the warm vertical HC (**b**). Note that cold HC (**a**) is almost 400% less time consuming compared to (**b**) (courtesy by Dr. Allen Ali Nasseh)

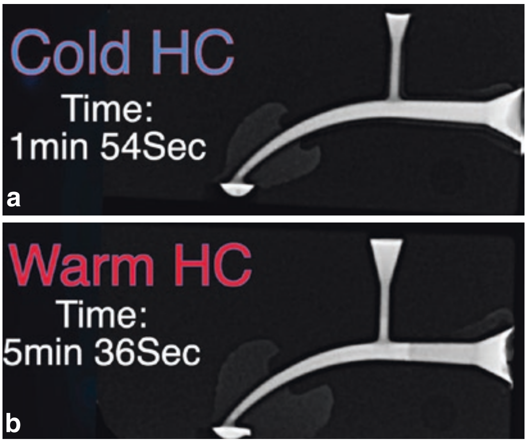

Fig. 6.13 Radiographic radiopacity of a simulated using the cold HC technique (**a**) compared to the warm HC technique (**b**). No differences are shown between these techniques (courtesy of Dr. Allen Ali Nasseh)

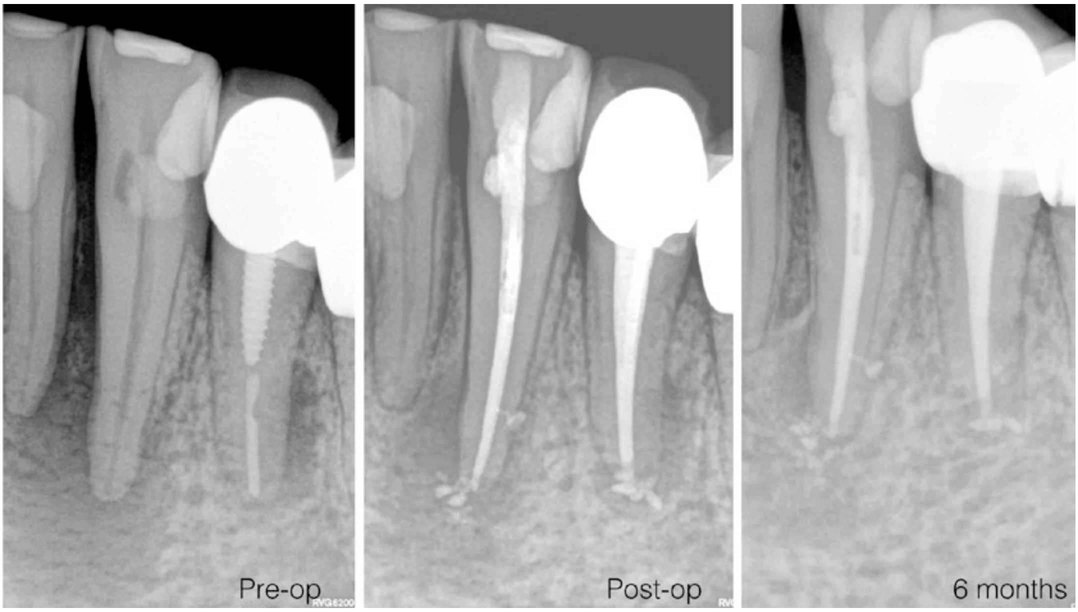

Fig. 6.14 Clinical case showing the radiographic aspect of a root filled with the cold hydraulic condensation technique

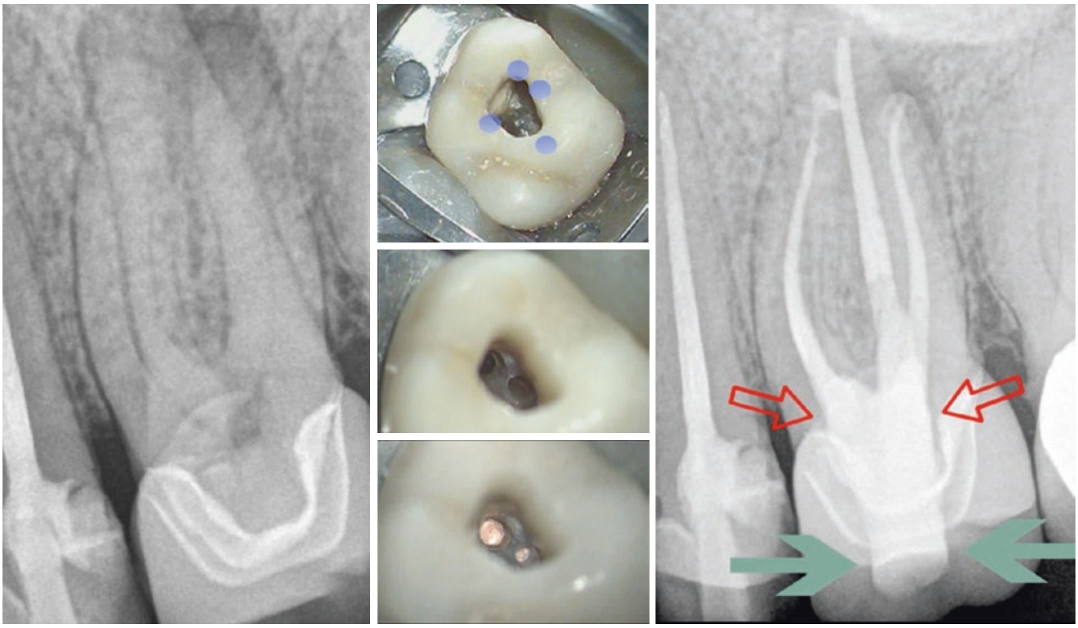

Fig. 6.15 Endodontic case root filled with the hydraulic endodontic cements. This type of sealers and technique are ideal to be used combined with the minimally invasive endodontic techniques

warm compaction technique" may also be suggested to be used with these sealers to unify the advantages of a warm compaction in filling the lateral irregular spaces, without impairing their thickness and their properties with the application of high and deep heat and compaction forces especially in the most delicate apical third of the root (Figs. 6.16 and 6.17). This clinical tech-

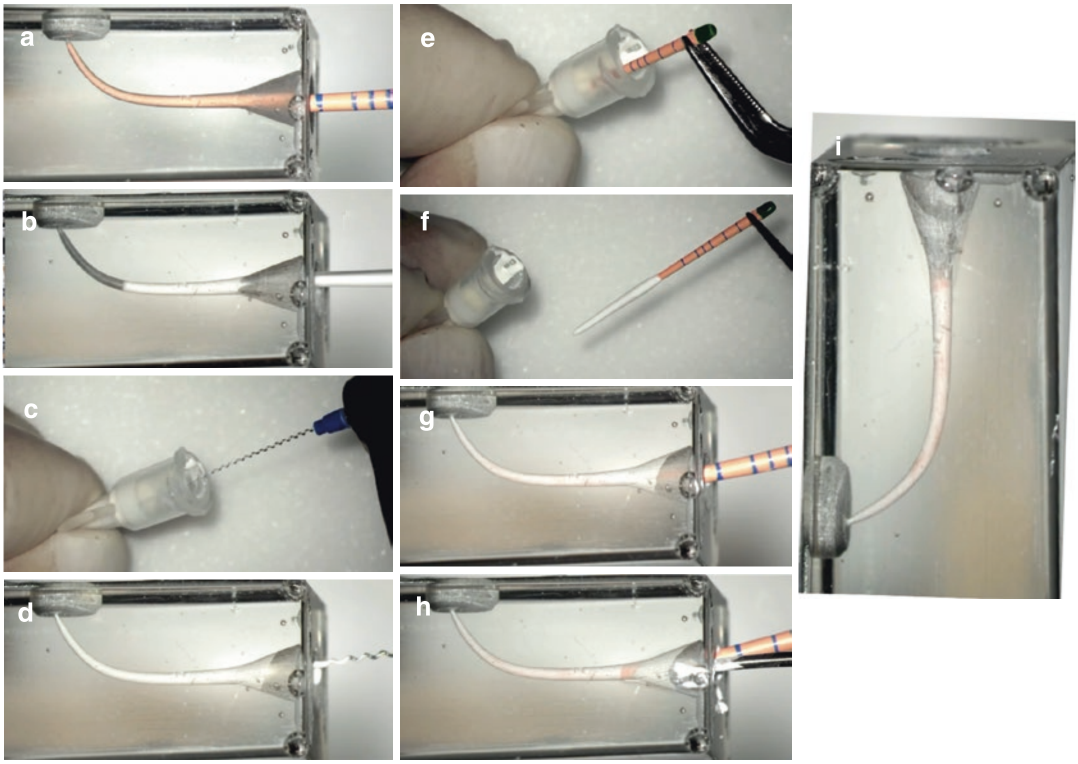

Fig. 6.16 Demonstration of the use of the hydraulic endodontic cements on a simulated canal in a transparent resin block. (**a**) Selection of a gutta-percha point to the correct working length; (**b**) application of the hydraulic cement using a transparent tip; (**c**) use of the tip as a depot for the sealer; (**d**) distribution of the sealer by a lentulo spiral; (**e**, **f**) coating the tip of the GP point; (**g**) placing the GP point inside the canal to the working length; (**h**) searing off the coronal part of the GP point with a heat plugger; (**i**) final case

nique aims to use the smallest electric heat plugger at the lowest temperature possible for the shortest time possible to compact the materials at half-length of the root or maximum 7–8 mm from the working length (Fig. 6.18). This aims to obtain what we can call a "champagne cork" effect, mechanically pushing the sealer through the cold cone in the apical third to increase the filling of lateral spaces without impairing sealer properties as the heat applied through the GP point so coronally will not be transferred to the sealer in the apical third. This technique may be easily applied in minimally invasive access cavity and root canal preparations, as it requires bringing the plugger only in the middle third of the root.

The amount of sealer introduced into the canal should be controlled so that only a modest amount is used and the surplus is not introduced in the periapical tissues. The syringe delivery system should not be positioned deeper than the interface of the coronal and middle third of the root canal (Figs. 6.16b and 6.17a). The bioceramic sealer flows easier than conventional resin-based sealers due to its particle size (<2 μ) and this mandates a degree of practice. A gutta-percha cone (ideally nano-coated with bioceramic particles) is matched to the root canal preparation (Fig 6.16a). Unlike traditional compaction techniques where the volume of gutta-percha needs to minimize the volume of sealer, the GP cone is used primarily to deliver the hydraulic cement to the apical seat without heat or pressure (GP act as a deliver device/plugger). It will allow hydraulic movement of the sealer into the irregularities of the root canal and

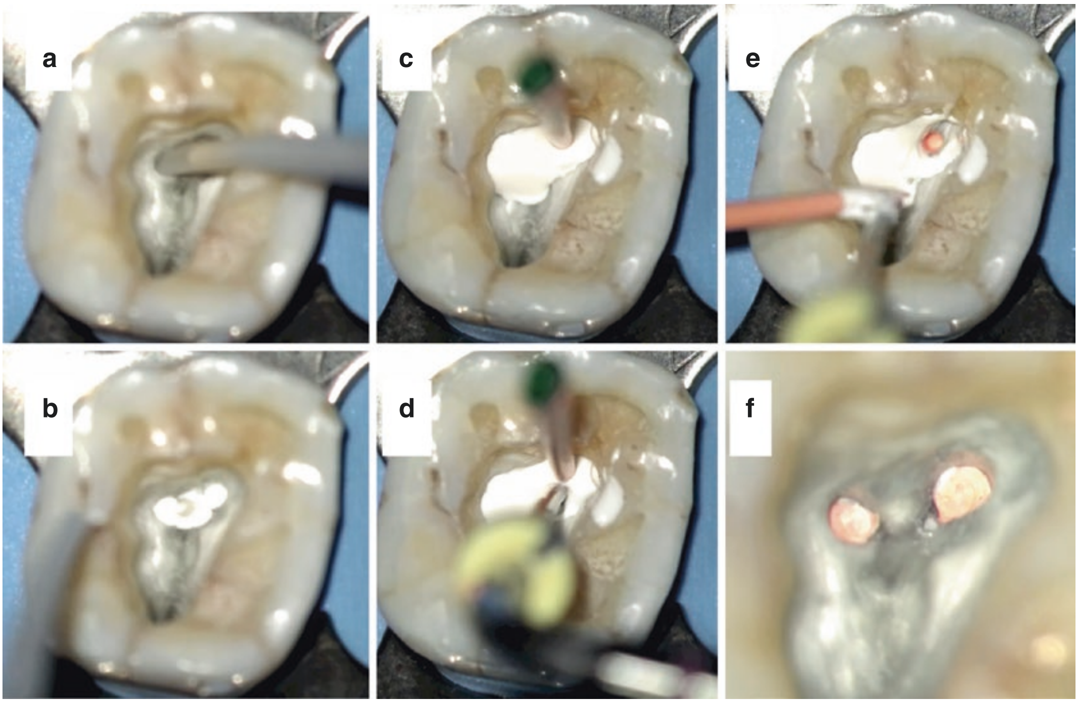

Fig. 6.17 Demonstration of the use of the hydraulic endodontic cement on the upper first molar. (**a**, **b**) Application of the hydraulic cement using a transparent tip; (**c**) placing the GP point inside the canal to the working length; (**d**, **e**) searing off the coronal part of the GP point with a heat plugger; (**f**) final image

accessory canals, thus reducing possible voids formation related to the injection of the sealer only; the bioceramic being bioactive and adherent to the interfacial dentin creates a true impervious apical seal. In addition, the GP will act as a pathway for post preparation and retreatment.

Depending on the shape of the apical region (circular or ovoid) and the intimacy of fit of the master GP cone, the master file used to apically gauge and size can be coated with sealer and introduced in a counterclockwise manner to deposit the sealer at the apical terminus. The master cone coated with a thin layer of sealer is then slowly introduced to the apical seat to avoid trapping air or excess sealer and preventing it seating fully (figure). The gutta-percha handle is cut with heat at the orifice or below for a canal footing or a post-space (Figs. 6.16h and 6.17d).

All variables in an equation are interdependent. In the case of endodontic success, each procedural event is accountable for the positive treatment outcome; however, regardless of its importance, if a concomitant event does not provide a suitable biologic conclusion, failure ensues. The shrinkage and instability of root canal sealers has mandated their use in thin layers and necessitated techniques to ensure this requirement. Bio-minimalism in canal space preparation requires a filling material that replicates the internal anatomy of the root canal space, adheres to interfacial dentin and creates an impervious, irreversible seal at all portals of exit.

Some drawbacks should be pointed out when using the hydraulic endodontic cements: as discussed previously, unlike traditional sealers, the setting reaction of bioceramic sealers is initiated by moisture (hydrophilic) in the canal; therefore drying the canal with solvents or alcohol are not recommended [123, 124]. Also, the high temperature by the heat pluggers exciding 200 °C might dry out the liquid sealer and turn in on charcoal-like material losing all its advantageous

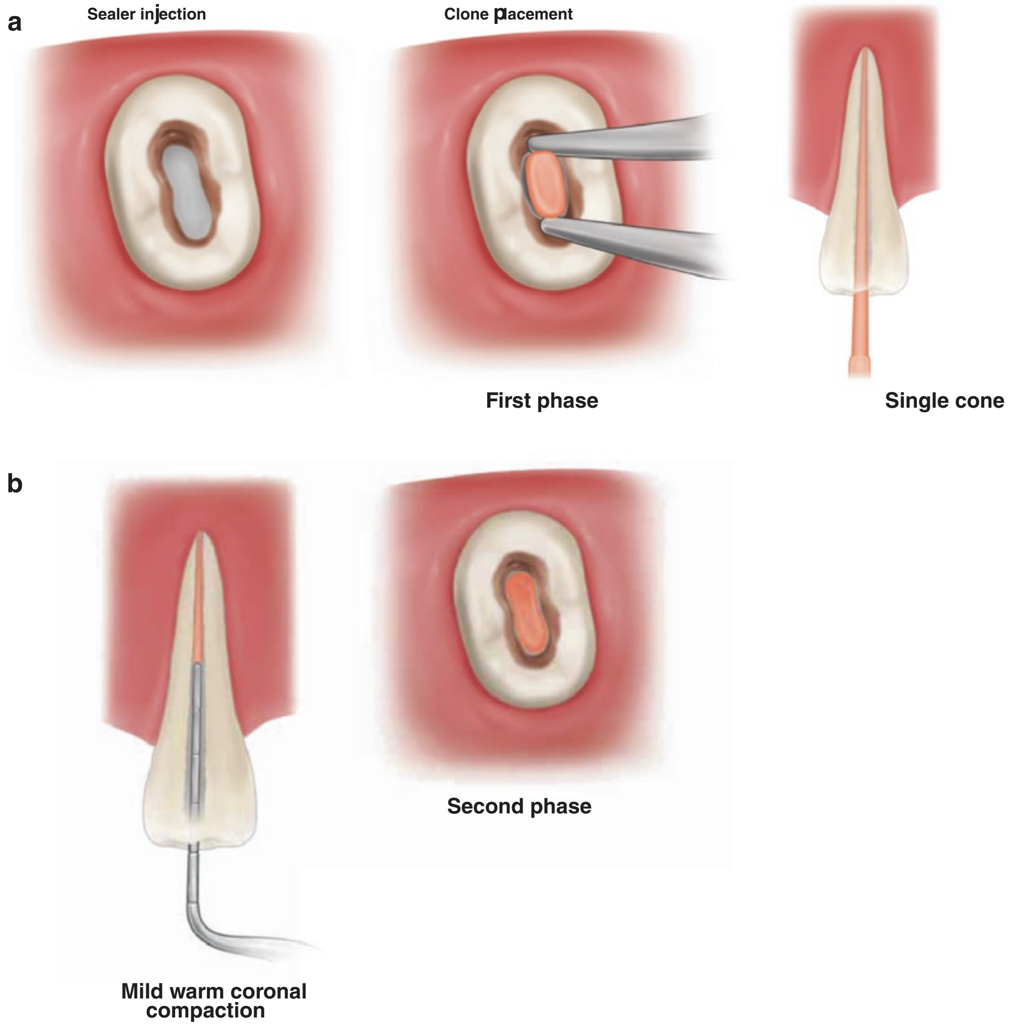

Fig. 6.18 Representative drawings of the “mild warm compaction technique”. (**a**) In the first phase the hydraulic cement is injected in the root canal and the máster GP cone is inserted at the working length; (**b**) in the second phase a mild warm compaction to mid-root is performed

properties [125, 126]. Therefore, a single-cone technique with the searing off the coronal part of the GP or the modified “mild warm compaction” technique described above is recommended.

For this reason, a new version of the sealer optimized for root filling techniques using high temperatures has been developed (BC Sealer HiFlow™, Brasseler). The intention is to lower the material’s viscosity when heated over 200 °C. Even if scientific literature is still lacking to report on the characteristics and behaviour of this material, clinically it can be observed that the material doesn’t dry out when using hot pluggers.

6.7 Use of Dental Operating Microscope During the Root Filling Phase on Minimally Invasive Canal Preparation

In all areas, from exposure of the access cavity and preparation to three-dimensional obturation, the operating microscope provides major advantages over working without appropriate magnification (Fig. 6.19).

Today clinicians have a number of methods, materials and technologically advanced instruments at their disposal to achieve their goals. Poor obturation quality as judged by radiographs has been associated with non-healing in 65% of retreatment cases. The use of the operative microscope will clinically access areas that are imperative for successful treatment and obturation.

All these high-precision work can be done also through micro-mirrors and micro-invasively, avoiding the removal of unnecessary tooth structure that are also imperative for successful treatment, preventing in this way tooth fracture, micro-cracks and coronal leakage (Fig. 6.20).

During the root filling phase the clinicians are able with the microscopic techniques to avoid obturation errors often as a result of inadequate cleaning and shaping (ledges, perforations, inaccurate working lengths and underprepared or overprepared canals), control the apical terminus without excessive material overextending into periapical tissues, control isthmus and irregular areas inside the root canals space condensing the sealers and core material in these areas, and adequately filling the root canal system in three-dimensions and, if inadequate obturation is not a result of an instrumentation error, the clinician should recognize this reversible procedural error and remedy this event.

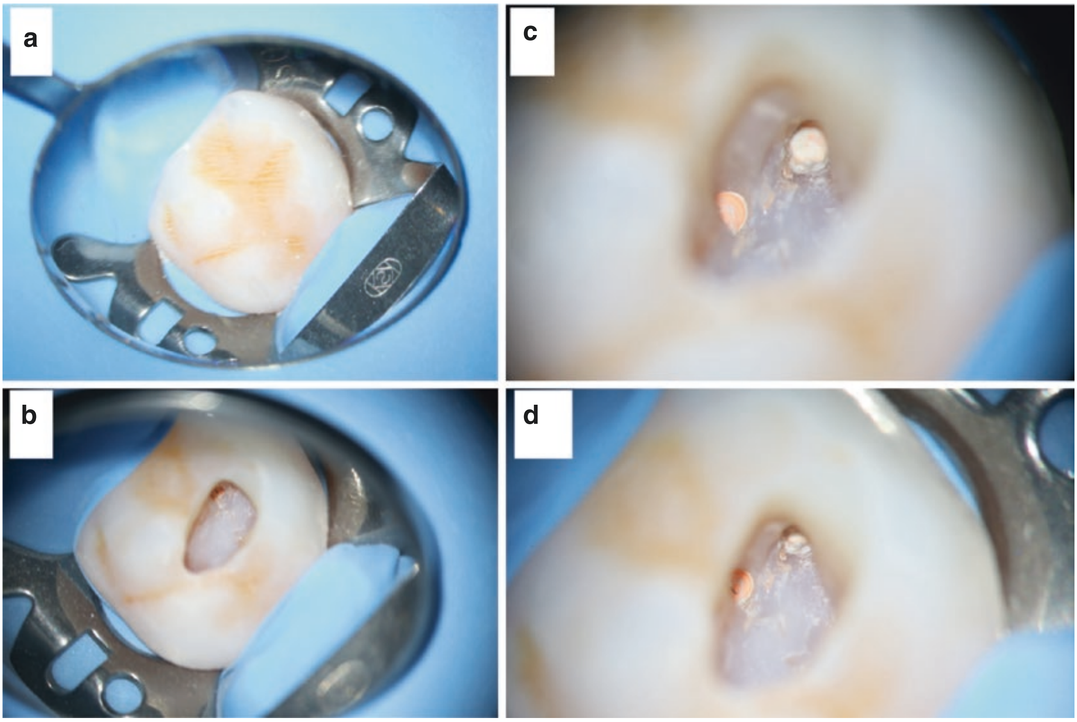

Fig. 6.19 A clinical case showing the minimally invasive access cavity (**a**, **b**) and root canal preparation with the aid of an operating microscope (**c**, **d**)

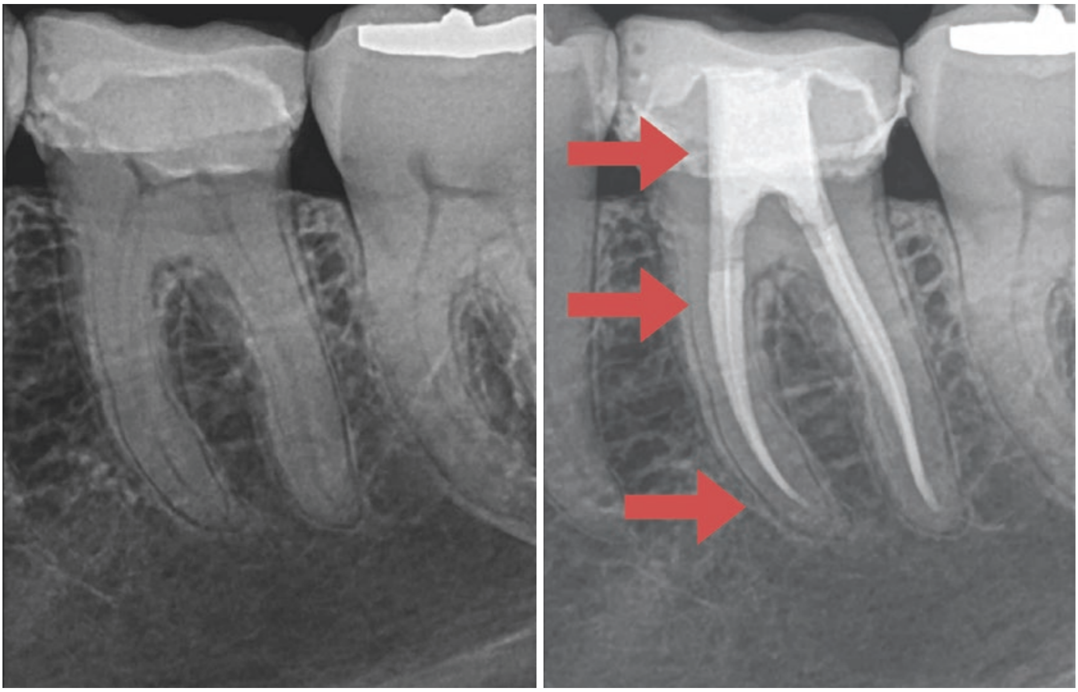

Fig. 6.20 Micro-invasively access cavity opening and root canal preparation has the advantage to avoid the removal of unnecessary tooth structure that is imperative to prevent tooth fracture, micro-cracks and coronal leakage. Lower first molar with a minimally invasive access cavity preparation, shaping and root filling

6.8 Conclusions

Root filling has long been a weak link in root treatment, making the endodontist too dependent on the quality of the coronal filling. The shrinkage of root canal sealers and instability in tissue fluids has necessitated a thin layer of sealer and has resulted in instrumentation techniques with large tapers primarily directed to this root filling techniques requirements. In many cases this has led to excessive removal of dentin on the coronal and middle third of the root canals, making the entire root more susceptible to fracture. The hydraulic endodontic cements do not shrink and are insoluble in tissue fluids. In this way these materials can be the primary filling material with the core material used only to assist in moving the sealer into canal irregularities. This allows the practitioner to perform the microbial control without removing dentin unnecessarily and leaving a stronger root for restorative reconstruction. Combining these materials and filling techniques with low taper NiTi conforming files to conservatively prepare the root canals will fit to the concept of minimally invasive endodontic treatment.

In conclusion, many good techniques are available to the clinician for the root filling phase of root canal treatment. It seems that the use of low taper NiTi conforming files to conservatively prepare the root canals maintaining as much sound peri-cervical dentin as possible and the new calcium-silicate-based hydraulic endodontic cements can predictably fill the root canal space on a more biological and conservative settings. Excess of root filling material can be controlled with high magnification and allow the placement of a deep filling underneath the root canal entrance with a bacterial tight and permanent filling. The combination with a biological root filling material and an optimal tight coronal filling will lead to a more predictable and high successful endodontic therapy.

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