Instrumentation creates space for canal irrigation, disinfection and root filling. All of these 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, especially in root filling. Optimal root filling has many requirements which have been difficult if not impossible to fulfill. 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 term and long term seal. However, numerous studies on leakage after root filling have suggested that complete, permanent sealing of the canal against leakage from the oral cavity is usually not obtained. This review takes a critical look at presently available methods for canal instrumentation and filling, and challenges these as far less than optimal with regard to ease of operation, time and technical skills required, weakening of the root/tooth structure and quality of the seal. The authors discuss the above factors from the point of view of bioceramic materials in root filling. Is there a hope of a better future in root filling?

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Terminology: obturation or root canal filling

The term obturation is what most people use to describe the second stage of root canal therapy. Obturation by definition is to “close off a space” but makes no requirement for filling that space (1–5). 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 we are attempting and thus a better term to use.

Rational for root canal filling

Root canal filling is performed as the second phase of root canal therapy after microbial control, 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 filling is to maintain the (low) microbial load left within the root canal and communicating with the peri-radicular tissues below the threshold for clinical and radiographic success. It also assumes that a top filling of sufficient quality will be placed as soon as possible after the canal/s are filled.

1 Stop coronal leakage after the root canal and crown is filled.
2 Entomb surviving microbes in the root canal space so that they cannot multiply and/or communicate with the periradicular tissues.
3 Prevent influx of periapical fluids, which nourish surviving microbes in the root canal.

Materials and techniques

Filling the root canal requires the development of adequate materials and techniques to maximize the properties of those materials.
Figure 1 is the list of Grossman for the ideal root canal filling material.

Not much has changed since Grossman constructed his list of requirements over 70 years ago. We 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. The sealer may also act as a lubricant.

Core materials
Gutta-percha and silver points have been the most used core materials used over the last 100 years. In 2011 in an AAE position statement (7–10) it was 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 gutta-percha is the primary core material in use today. Cones of gutta-percha contain approximately 20% gutta-percha and 80% fillers used for coloring and radiographic contrast (11). Gutta-percha comes in its natural form (alpha phase) or manufactured form (beta phase) (11–13).

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. These include those based on chloroform mixed with GP, zinc oxide–eugenol, calcium hydroxide, silicon, GIC and epoxy or methacrylate resins (11,14,15). All are mixed and introduced in a liquid form and have enough working time to allow the practitioner time to place the filling to his/her satisfaction before placing the top filling. It is assumed they will then harden by a setting reaction in a reasonable time after placement into the canal.

How well do traditional filling materials and methods perform?
Many in vitro, in vivo and clinical outcome studies have been performed primarily on the traditional methods of single cone or lateral condensation techniques and when taken together it is quite clear that the root filling fails miserably in its primary function of sealing the root canal (14–17). In vitro, in vivo animal studies and clinical outcomes studies uniformly show that the traditional filling materials used in the way described above do not seal the root canal. In fact one study by Sabeti et al. (1) found no difference in the outcome when a canal was root filled compared to left empty. This study emphasizes the poor quality of our root filling techniques and the importance of the coronal restoration for root canal success.

What is the problem and can we improve with newer materials and/or techniques
The traditional root filling comprises of a standard gutta-percha core and round accessory cones combined with a sealer to fill the space between the gutta-percha points themselves and the gutta-percha and dentin wall.

The gutta-percha core material acts only as a filler and does not seal the canal. Figure 2 shows that when tested in an in vitro model microbes will travel throughout the length of the canal in 2 hours if only gutta-percha is present in the canal without sealer. The leakage can be delayed for up to 30 days with the use of a sealer.

Sealers are the materials in root filling that actually provide whatever resistance to leakage that is
achieved. Traditional sealers have serious shortcomings in that they generally shrink on setting and wash out in the presence of tissue fluids (2,11,16–22) (Fig. 3).

In addition sealers do not bond to the gutta-percha core material, leaving a gap with potential for microbial leakage when the sealer shrinks on setting (2,11,16–22) (Fig. 4.)

Thus in order to maximize the sealing ability of sealers, but minimize their shortcomings, the sealer needed to be as thin as possible. Since the gutta-percha 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 oval in shape and have many communications. As shown in Figure 2 above, while gutta-percha alone will leak in 2 hours, the addition of a sealer provides additional seal for up to 30 days only.

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 (23,24). 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 used 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. The logic behind this technique was comprehensive and the outstanding radiographic results were universally accepted as a technique for specialists or “advanced” generalists. However if analyzed logically, the technique does little to overcome the weak points of the original single cone or lateral condensation techniques. Once the heated gutta-percha cools it shrinks even more than the sealer does on setting (25,26). In addition, the shrinkage of the gutta-percha and sealer (instead of sealer only) results in a larger gap between the gutta-percha and sealer, 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.

Numerous studies have shown no benefit in sealing the root canal with the heated vertical condensation technique compared to the traditional lateral condensation technique (27,28). A recently identified complication of the former technique is the need for a larger taper to be used to instrument the 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 has recently been shown to produce micro-fractures in the root (29–33). Additionally the thinning of the root dentin proportionally weakens the tooth potentially leaving the root unnecessarily susceptible to fracture (30,32,33).

Another attempt to improve root filling performance was the introduction of Resilon (34). The gutta-percha component of the core point was removed and replaced by an equivalent volume of resin. The result was a point that was indistinguishable from the original gutta-percha point. A methacrylate resin sealer was then used and effectively bonded to the resin core material, thus eliminating one gap consistently present in the other techniques. The methacrylate resin was also able to chemically bond to clean dentin on the root wall. This material could be used both with the traditional cold techniques and the Schilder type warm vertical techniques.

While the in vitro, in vivo and selected outcome results for this material were generally positive compared to traditional techniques (35–40) many practitioners complained about its clinical performance. Methacrylate sealer demonstrates the same shortcomings of the traditional sealers (shrinkage and wash out) and is also extremely technique sensitive. In routine root canal instrumentation techniques

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Fig. 4. SEM picture of cut root filled with gutta-percha and AH Plus sealer. Note the gap between the GP and sealer. Image from Eldeniz et al. Endod Topics 2005.

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Bioceramic sealer
where sodium hypochlorite is used, the oxygen which is produced made the sealer particularly difficult to use and resulted in many cases where the sealer failed to set. EndoRez is also a methacrylate resin sealer with similar properties and technique sensitivity to Resilon. This is a cold lateral technique, as the gutta-percha is coated with a resin layer.

**Bioceramic root filling materials: a new era?**

Bioceramics are ceramic materials specifically designed for use in medicine and dentistry. They include alumina and zirconia, bioactive glass, coatings and composites, hydroxyapatite and resorbable calcium phosphates, and radiotherapy glasses (41–43). Bioceramics are widely used for orthopedic applications (joint or tissue replacement), for coatings to improve the biocompatibility of metal implants, and function as resorbable lattices which provide a framework that is eventually dissolved as the body rebuilds tissue (41–44).

Bioceramics are classified as:

* **Bioinert**: Non-interactive with biological systems.
* **Bioactive**: Durable in tissues that can undergo interfacial interactions with surrounding tissue.
* **Biodegradable, soluble or resorbable**: Eventually replace or incorporate into tissues.

There are numerous bioceramics currently in use in dentistry and medicine. 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. Also some calcium silicates (MTA (Tulsa Dental)) and BioAggregate (DiaDent) have been used in dentistry as root repair materials and for apical root filling materials.

**Properties of endodontic bioceramic materials**

Endodontic bioceramics are not sensitive to moisture and blood contamination and therefore are not technique sensitive (41,43–47). They are dimensionally stable and expand slightly on setting, making them one of the best sealing materials in dentistry (43,45–50). When set they are hard and insoluble consequently ensuring a superior long-term seal. 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 (43,46,51) (Fig. 5).

When unset the material has antibacterial properties. When fully set it is biocompatible and even bioactive. When bioceramic materials come in contact with tissue fluids, they release calcium hydroxide which interact with phosphates, in the tissue fluids, to form hydroxyapatite (51) (Fig. 6).

This latter property may explain some of the tissue-inductive properties of the material. 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, as well as the sealer for root canal filling of mature teeth with closed apices (52).

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**Fig. 5. Hydration reaction of bioceramic material in contact with water.**

**Fig. 6. Precipitation reaction of the Bioceramic.**
Available bioceramic materials in endodontics

Mineral trioxide aggregate (MTA)

Few clinicians realize that original MTA is a classic bioceramic material with the addition of some heavy metals. MTA is one of the most extensively researched materials in the dental field (53–58). 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. However, it has some disadvantages. The initial setting time is at least 3 hours, it requires mixing (resulting in considerable waste), it is not easy to manipulate, and is hard to remove. Clinically both gray and white MTA stain dentin, presumably due to the heavy metal content of the material or the inclusion of blood pigment while setting (43,59,60). Finally, MTA is hard to apply in narrow canals, making the material poorly suited for use as a sealer. Efforts have been made to overcome these shortcomings with new compositions of MTA or with additives. However, these formulations affect MTA’s physical and mechanical characteristics, consequently affecting its performance.

Biodentine

Biodentine is considered a 2nd generation bioceramic material which has similar properties to MTA and thus can be used for all the applications set out above for MTA (43,59–62). Its advantages over MTA are that it has a shorter setting time (approx. 10-12 minutes) and has a compressive strength similar to dentin. A major disadvantage is that it is triturated for 30 seconds in a preset quantity (capsule), making waste inevitable in the vast majority of cases, since only a small amount is required.

Endodontic pre-mixed bioceramics

These products are available in North America as EndoSequence® BC Sealer™ (BC Sealer), EndoSequence® Root Repair Material Paste™ (BCRRM Paste Syringable) and EndoSequence® Root Repair Material Putty™ (BCRRM Putty) (Brasseler USA Dental LLC, Savannah, GA). Recently, these materials have also been made available outside North America as TotalFill® BC Sealer™, TotalFill® BCRRM-Paste™ and TotalFill BC RRMPutty™ (Brasseler USA Dental LLC).

All three forms of bioceramics are similar in chemical composition (calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic and fillers), have excellent mechanical and biological properties and good handling properties. They are hydrophilic, insoluble, radiopaque, aluminum-free, high pH, and require moisture to set and harden. Their working time is more than 30 minutes and the setting time is 4 hours in normal conditions, depending on the amount of moisture available. In addition, EndoSequence Fast Set Putty has recently

Fig. 7. Table of expansion/shrinkage of popular sealers (Fig. 3) with the addition of bioceramic sealer. The BC Sealer expands slightly on setting but does not shrink.
been introduced into the market and has all the properties of the original putty, but has a faster setting time (approximately 20 minutes). RRM Putty and RRM Paste are recommended for perforation repair, apical surgery, apical plug, and vital pulp therapy.

**Pre-mixed BC Sealer**

This is the only pure medical grade bioceramic product available as a sealer for endodontic obturation. It has the same basic chemical composition as the other pre-mixed bioceramic products, but is

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**Fig. 8.** Molar roots filled with BC Sealer cut at different distances from the apex. One gutta-percha point is used as a plugger to move the sealer using hydraulic pressure. Note the irregularities are very well filled.

**Fig. 9.** A representative radiograph of a root filled tooth with BC Sealer hydraulically moved with the gutta-percha point. Note that the cold hydraulic technique results in lateral canal “puffs” similar to the warm vertical technique! Courtesy of Dr. Gilberto Debelian.
less viscous making the consistency ideal for a root canal sealer. It is used with a gutta-percha point that is impregnated and coated on the surface with a nano particle layer of bioceramic which eliminates the gap between the sealer and the core and has shown to improve the seal of the filling (50,63).

Properties of the bioceramic sealer and potential changes in root filling technique:
1 The bioceramic sealer is highly hydrophilic and thus the natural moisture in the canal and tubules is an advantage, unlike most other sealers where moisture is detrimental to their performance.

2 When unset, the bioceramic sealer has a pH of above 12. Thus its antibacterial properties are similar to calcium hydroxide (46,47,49,50,64). Setting is dependent on physiologic moisture in the canal, therefore it will set at different rates in different environments, but since it has a high pH any delay in setting can be argued as a benefit.

3 The sealer does not shrink, but expands slightly and it is insoluble in tissue fluids (41–43,45,47–51) (Fig. 7).

4 If used with a gutta-percha point that is impregnated and coated with nano particles of bioce-
ramic, as suggested, it will bond to the core point thus eliminating the gap between the core and sealer.

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 fillings 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 were possible to fill the canal in a homogeneous way, the need for a core material at all is questionable. As it stands, the gutta-percha is used to deliver the bioceramic sealer through hydraulic condensation and now the sealer can be the main component of the root filling. The gutta-percha is used primarily as the delivery device (plugger) to allow hydraulic movement of the sealer into the irregularities of the root canal and accessory canals (Fig. 8). In addition, it will act as a pathway for post preparation and retreatment.

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 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 vertical condensation technique is often seen (Figs. 9-11).

In conclusion, root filling has long been a weak link in root treatment making the endodontist too dependent on the quality of the top filling. The shrinkage of root canal sealers and instability in tissue fluids has necessitated a thin layer of sealer and has resulted in techniques primarily directed to this requirement. In many cases this has led to excessive removal of dentin, making the entire root more susceptible to fracture.

The bioceramic sealer does not shrink and is insoluble in tissue fluids. Now for the first time the sealer 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.

Certainly in apexification cases, where the apex can be sealed and the material contained, a strong case can be made to fill the entire canal with the bioceramic material. For internal resorption cases, it would appear that added strength may be obtained if the entire defect was filled with the bioceramic material.

In fact a legitimate question is whether in retreatment cases, where the next treatment options are surgery or extraction, a core point is required at all.

References


13. Goodman A, Schilder H, Aldrich W. The thermomechanical properties of gutta percha. II. The history


