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Hydraulic Cements for Various Applications in Endodontics: Part 2

Abstract: The first article in this two-part series described the properties and use of hydraulic cements for intra-coronal applications, mainly for vital pulp therapy and as a barrier for regenerative endodontic procedures. In Part 2, the intra-radicular and extra-radicular uses are discussed. Hydraulic cements are a unique set of materials that set in the presence of water and, when set, they are resistant to deterioration in a damp environment. The use of hydraulic cements within the root canal (root canal sealer and apical plug) and when used at the periodontal–endodontic interface (perforation repair and root-end filler) is described and illustrated with clinical cases.

CPD/Clinical Relevance: Hydraulic cements are indicated for a number of procedures in endodontics and this is supported by an extensive and increasing body of evidence with respect to their efficacy.

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Hydraulic cements are unique materials that set in the presence of water and do not deteriorate when placed in a damp environment. As a result, their use is becoming more commonplace in contemporary endodontics. Hydraulic cements have been classified based on their specific use[1] as their environmental interactions are dependent on the location they are placed in. They can be used intra-coronally (pulp capping and barrier regenerative endodontics), intra-radicularly (root canal sealer and apical plug) and extra-radicularly (perforation repair and root-end filler).

The first article in this two-part series described the development, material chemistry and hydration of the hydraulic cements, and also illustrated the clinical use of intra-coronal materials. The use of hydraulic cements used as sealers, apical plugs, root-end fillers and perforation repair materials, each illustrated with clinical cases, are discussed in this article.

Intra-radicular materials

The intra-radicular materials include the root canal sealers and the materials used for apical plugs. The properties of these materials are very diverse. The requirements of hydraulic cements used for intra-radicular indications are shown in Table 1.

Examples of hydraulic root canal sealers include BioRoot RCS (Septodont, Saint-Maur-des-Fossés, France), which is a Type 4 material, and Totalfill BC sealer (FKG, La Chaux-de-Fonds, Switzerland), a Type 5 material.[1] This classification is described in detail in Part 1.[2] The materials used for apical plugs can be various, with ProRoot MTA (Dentsply-Sirona, Tulsa, OK, USA) or Biodentine (Septodont) being examples.

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Material chemistry

Totalfill BC sealer (FKG) and BioRoot RCS (Septodont) are classed as different material types since the latter needs to be mixed with water for hydration while the former is ready-mixed and will hydrate after contact with the environmental liquids. Both sealers are composed primarily of tricalcium silicate and zirconium oxide as the radiopacifier. The liquid in BioRoot RCS (Septodont) is composed of water, calcium chloride and a hydro-soluble polymer.[3] In addition to the tricalcium silicate and zirconium oxide, Totalfill BC sealer (FKG) also includes calcium phosphate and a non-aqueous vehicle.[4]

Material properties

BioRoot RCS (Septodont) is mixed with water and thus, its setting time of 324 (±1) minutes is controlled.[5] Totalfill BC sealer (FKG) does not have a fixed setting time because it depends on the environmental moisture.[3] Both hydraulic sealers have been reported to have high solubility,[5,6] which increases with time, but has been attributed to improper *in vitro* testing of the materials.[7,8]

The calcium ion release also varies between the different sealers. The water-based sealer

Essential requirements
■ Dimensionally stability ■ Adequate radiopacity ■ Ability to form a seal with dentine ■ Non-irritant to the peri-radicular tissues (biocompatible) ■ Ability to induce peri-radicular healing ■ Antimicrobial ■ Easy to mix and handle ■ Chemically and physically compatible with other restorative materials that may be required to obturate the root canal, such as gutta-percha
Additional characteristics for root canal sealers
■ Low viscosity and ability to flow, acting as a lubricant for the insertion of the master apical point ■ Not be adversely affected by obturation techniques that employ heat2

Table 1. The essential requirements for both apical plug materials and root canal sealers, and additional characteristics that root canal sealers need to exhibit.

a

b

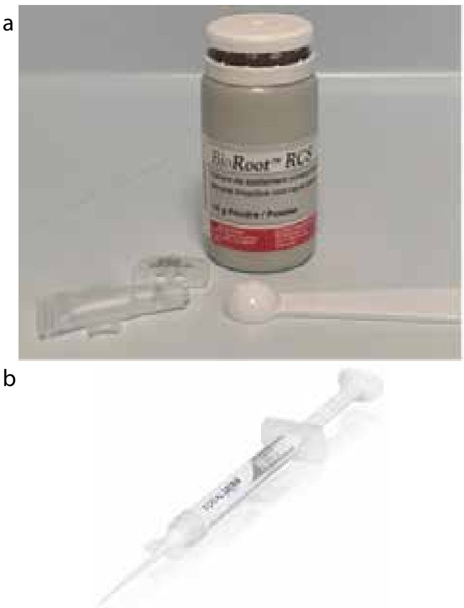

Figure 1. Material presentation **(a)** BioRoot RCS (Septodont) showing the powder, scoop and pre-dosed pipettes and **(b)** syringe and cannula of Totalfill BC sealer (FKG).

BioRoot RCS (Septodont) exhibits a higher calcium ion release compared to Totalfill BC sealer (FKG), which depends on the diffusion of ions through a non-aqueous matrix that delays, or restricts, the calcium ion formation and release.[4] Furthermore, the presence of calcium phosphate monobasic in Totalfill BC sealer (FKG) also modifies the hydration reaction.[9]

The biological characteristics of sealers are important since they are in contact with the periodontal ligament and the bone in the apical region. Thus, both the biological properties of the sealer itself and that of any elutions are important. Elutions and even direct seeding of cells over the materials showed a high degree of cell proliferation.[10–14] The cytotoxicity was dose dependent.[12] Comparison of different pre-mixed materials shows that the material chemistry influences the cell viability, cell attachment and cell migration rates and this was higher for materials releasing higher levels of calcium.[15,16] The hydraulic sealers also have an osteogenic[17,18] and an anti-inflammatory effect.[19] Both Totalfill BC sealer (FKG) and BioRoot RCS (Septodont) have been shown to be antimicrobial.[19–22] There is a synergistic antimicrobial effect when sodium hypochlorite solution and hydraulic sealers are used in combination.[23] Prior dentine disinfection is necessary as the use of sodium hypochlorite over the dentine enhances the effect of the hydraulic sealers.

The Type 4 hydraulic calcium silicate-based sealers (such as BioRoot RCS, Septodont) are recommended for use in cold condensation techniques, such as the laterally condensed technique or single cone obturation. These sealers are water based, and the heat generated during warm vertical compaction will evaporate the water in the sealer leading to irreversible changes in the chemical and physical properties.[3] Totalfill BC sealer (FKG) is not affected by the rise in temperature[24,25] as both the inorganic components (tricalcium silicate and zirconium oxide) and the organic vehicle are impervious to the heat generated during the obturation procedure; thus this sealer can be used for warm vertical compaction of gutta-percha techniques.

The hydraulic cement sealers have not been shown to bond to gutta-percha. Interaction of hydraulic sealers with root dentine results in the mobilization of silicon from the sealer to the tooth structure.[26] As the sealer comes in contact with pre-treated dentine, the irrigation protocol for optimal sealer interaction is thus important. The reported bioactivity when hydraulic cements interact with phosphate-containing solutions, such as tissue fluids, has led to a drive to use phosphate-buffered saline as the final irrigating solution. However, this will lower the surface pH of the sealer and will lead to a reduction in its antimicrobial action.[22] Sodium hypochlorite solution potentiates the antimicrobial effect of hydraulic sealers.[23] EDTA is effective in removing the smear layer, but since it is a calcium chelator, it will cause chemical alterations to the sealers upon contact.[27] The pushout bond strength of hydraulic sealers was also reduced in the presence of EDTA.[28]

Presentation of root canal sealers

BioRoot RCS (Septodont) is supplied as a powder and a liquid form that must be mixed by hand for 1 minute. The master apical gutta-percha point may then be coated sparingly with the root canal sealer before being inserted to length in the root canal (Figure 1a). Totalfill BC sealer (FKG) is supplied as a single syringe, and it is delivered through a plastic cannula that enables deep penetration inside the root canal (Figure 1b).

Clinical cases

Endodontic sealer

An 18-year-old patient with a history of trauma was referred with asymptomatic chronic peri-radicular periodontitis in UL1. The tooth was discoloured and had been previously root canal-treated with a screw post-retained composite resin to restore the missing tooth structure. The screw post was removed, and the tooth was root canal re-treated. A GP cone matched to the master apical file was used to obturate the root canal using a single cone obturation technique with Totalfill BC sealer (FKG) (Figure 2).

Apical plug

A 45-year-old female patient was referred for specialist treatment on UL1. The tooth had been asymptomatic, but on pre-operative investigation prior to replacement of the unsightly crown, an open apex and associated peri-radicular radiolucency were discovered. The root canal was accessed and chemo-mechanically prepared using sodium hypochlorite and manual canal

Figure 2. (a–d) Clinical case showing suboptimal obturation in UL1. The tooth was root canal re-treated and obturated with a matched GP cone and Totalfill BC sealer (FKG) using a single cone obturation technique.

Figure 3. (a) UL1, which had been restored with a metal-ceramic crown, has an incompletely formed root apex and an associated peri-apical radiolucency. **(b)** It was root canal treated and **(c)** an apical plug of Biodentine (Septodont) placed. **(d)** Radiograph was taken at the 6-month follow up appointment with healing of the peri-radicular tissues evident.

preparation at the first visit. An apical plug of Biodentine (Septodont) was placed and backfilled with thermo-plasticized gutta-percha (Gutta Percha Obturator, DiaDent, Chungcheongbuk-do, Korea) at the second visit. Although the Biodentine is not as radiopaque as gutta-percha and mineral trioxide aggregate (MTA), it is the most suitable material to use, particularly in anterior teeth owing to the risk of tooth discolouration with MTA.[29,30] The patient was recalled after 6 months and a peri-apical radiograph was taken that clearly showed a partial resolution of the lesion with the onset of bony infill (Figure 3). The use of hydraulic cements as apical plugs has enabled the endodontic management of immature teeth with non-vital pulps to be performed in one to two visits, with the single visit showing a slightly higher success rate when compared to the two visits[31] as opposed to long-term calcium hydroxide therapy.

Section summary

Hydraulic cements may be used successfully in the root canal system, namely as a root canal sealing material and placed as an apical plug. The requirements for the materials in these two situations are very different. The sealers need to have an adequate flow and film thickness, while apical plugs are used in bulk and need to be compactable. The antimicrobial properties are important for both material types with the biological properties and the mineralizing ability being more important for apical plugs.

Extra-radicular materials

The extra-radicular use of hydraulic materials includes root-end surgery as root-end fillings and surgical repair of root perforations. The same hydraulic cements that are used for the non-surgical repair of root perforations and for apical plugs (as previously described) may be used. These materials have been classified as extra-radicular materials, because, although they are in contact with root dentine, most of the material is in contact with blood and tissue fluids. The requirements of the materials used for these indications are listed in Table 2.

For both indications, MTA (eg ProRoot MTA, Dentsply-Sirona) or premixed materials such as TotalFill BC (FKG) may be chosen. Biodentine (Septodont) has also been used successfully for such procedures.[32]

Presentation of materials used for extra-radicular procedures

Some formulations of MTA, such as ProRoot MTA (Dentsply-Sirona) and MTA Angelus (Angelus, Londrina, Brazil) are provided as a powder and a liquid to be mixed together on a glass slab.

- Dimensional stability
- Coefficient of thermal expansion close to that of dentine
- Adequate radiopacity
- Ability to form a seal with the dentine
- Non-irritant to the peri-radicular tissues (biocompatible)
- Not be adversely affected by moisture, so can be used in wet environments without detriment
- Antimicrobial
- Easy to mix and handle
- Quick setting, particularly when used for perforation repair
- Chemically and physically compatible with other restorative materials when used for perforation repair

Table 2. Requirements of materials that may be used for extra-coronal indications.

a

b

Figure 4. (a) MTA carrier and various tips (Produit Dentaires, Vevey, Switzerland). **(b)** MTA pellet block (G Hartzell & Son, Concord, CA, USA).

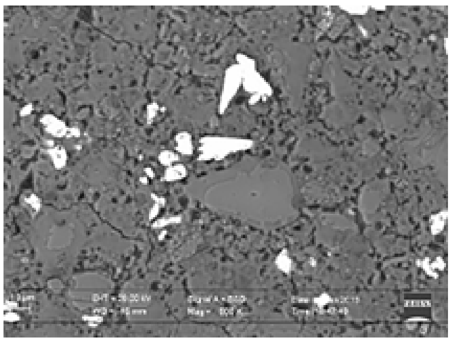

Figure 5. Scanning electron micrograph of MTA showing the cement particles coated by the reaction by-product and cement matrix composed of calcium silicate hydrate, calcium hydroxide and bismuth oxide. (Reproduced with permission from Camilleri.[80])

The powder to liquid dosage provided by the manufacturer should be maintained, and the use of smaller amounts than that provided in the sachet with undetermined quantities of liquid is discouraged. The addition of more water than instructed by the manufacturer will lead to deterioration in the physical properties of the material.[33–35] These formulations contrast with TotalFill BC RRM (FKG), which is pre-mixed and is applied directly at the site. This product is available in three formats, namely putty, fast-set putty and a paste supplied in a syringe with a narrow-bore, tipped plastic cannula for ease of application. Delivery to the surgical site is usually made using an MTA carrier (Figure 4a), which can be used with a number of angled tips or the use of a MTA pellet block (Figure 4b), which makes a pellet of the material to be carried to the surgical site on the tip of an endodontic plugger.

Material chemistry

Materials that are used for surgical procedures can be Type 1–5.[1] ProRoot MTA (Dentsply-Sirona) is a Type 1 material composed of Portland cement and bismuth oxide as the radiopacifier, which is mixed with water to form calcium silicate hydrate, calcium hydroxide and ettringite/monosulphate.[36–38] The hydration proceeds by the formation of calcium silicate hydrate that coats the cement particles, and calcium hydroxide is deposited in the cement matrix and leached in solution (Figure 5).

MTA Angelus (Angelus) is also composed of cement and radiopacifier. The material is different from ProRoot MTA (Dentsply-Sirona) in that the radiopacifier is calcium tungstate and is not associated with the tooth discolouration seen with bismuth oxide.[29,30,39–45] Furthermore, MTA Angelus (Angelus) also contains calcium oxide, which modifies the hydration reaction. This is not added by the manufacturer, but results from the burning process during the cement manufacturing.[46]

The TotalFill BC root repair materials (RRM) (FKG) are composed of tricalcium silicate, zirconium oxide, tantalum oxide, calcium phosphate monobasic and a non-aqueous vehicle.[47,48] The hydration of the tricalcium silicate results in the formation of calcium silicate hydrate and calcium hydroxide. Zirconium oxide and tantalum oxide are included as radiopacifiers, and calcium phosphate monobasic is a source of phosphate ions to enable biomineralization. This can lead to a reduction in the calcium ion release by the materials.[9]

Material properties

An adequate radiopacifier is important in surgical procedures to enable radiographic visualization on recall. Thus, materials that show a high radiopacity are preferred. These include ProRoot MTA (Dentsply-Sirona),[49] which has bismuth oxide as the radiopacifier, and TotalFill BC root repair materials (RRM) (FKG),[50] which also has sufficient radiopacity. Setting time is not a main consideration for root-end fillers, but rather the ease of delivery and handling, which has been addressed by the pre-mixed Type 5 materials that can be syringed to the surgical site.

The physical properties that are crucial for materials used during surgery are their solubility, dimensional stability and washout. The solubility of MTA has been shown to range from negligible[49] to high (22–31%),[51,52] dependent on the water–powder ratio. The addition of more water to MTA increases its solubility.[51,52] The dimensional stability of root-end filling and perforation repair materials is important as any shrinkage can lead to a gap between the material and the tooth, with the risk of microbial recolonization, while expansion may lead to root fracture. MTA was shown to be dimensionally stable even when the water–powder ratio was varied.[53] This contrasts with other data that show cement shrinkage, particularly in the early stages of setting, and that physiological-based solutions affected the setting of the materials.[54]

Washout is also an important characteristic for root-end filling and perforation repair materials. This can be short term, which happens when the area where the material is placed is irrigated prior to flap closure or a restoration is placed, or long term by the action of the body fluids on the materials. The washout resistance of MTA was shown to be low.[54–57] A number of products include an anti-washout gel as a mixing liquid, replacing water (Neo MTA Plus, NuSmile, Houston, TX, USA), which increases the washout resistance of the cements.

The biological properties of extra-radicular materials are very important, and these are very well investigated for MTA. MTA in contact with peri-radicular tissues resulted in the expression of inflammatory mediators and cytokines at certain times,[58] which is similar to Biodentine (Septodont)[59] and worse than TotalFill BC RRM (FKG).[60] MTA used as a root-end filling material caused less peri-radicular inflammation fibrous capsule formation. In addition, the presence of cementum on the surface of MTA was a frequent finding.[61,62] The presence of infection and bacteria led to compromised healing in cases of root perforation.[63]

The Type 5 pre-mixed materials also exhibited good cell viability comparable to MTA,[64,65] but showed reduced cell viability in the early ages when compared to MTA Angelus (Angelus).[66] This could be attributed to the time taken for the environmental moisture needed for hydration of pre-mixed materials to hydrate the tricalcium silicate. Perforation repair materials need to be more antimicrobial as they are in contact with contaminated dentine. MTA exhibits antimicrobial properties.[67,68] The presence of blood contamination has a buffering effect on the MTA, and ProRoot MTA (Dentsply Sirona) was shown to be less antimicrobial when in contact with blood.[69] Interaction of MTA with blood results in the deposition of calcium carbonate on the material surface.[70] Similar findings were shown for TotalFill BC RRM (FKG) when used as a root-end filling material.[47] The presumed bioactivity, where calcium phosphate crystals are precipitated on the material surface,[71] is an *in vitro* phenomenon only, and has never been demonstrated clinically.

When MTA is used to repair perforations in the crown of the tooth, it will subsequently come into contact with other materials required to provide the definitive restoration. If a zinc oxide eugenol-based (ZOE) cement or glass polyalkenoate cements (GIC) are used to layer over MTA, detrimental microstructural changes occur in the latter material. With ZOE, zinc inhibits cement hydration and thus a layer of unset MTA is present at the material interface. With GIC, the acidity disrupts the microstructure of MTA.[72] When placing composite resin over MTA, the use of a bonding agent is important to avoid changes at the material interface.[73] The placement of bonding agent over partially set MTA allows for immediate tooth restoration with composite resin. Other literature suggested that the placement of a restoration should be delayed until the MTA is fully set.[74] The placement of a wet cotton pellet to cover the MTA surface until material reaches the final set is thus recommended.

a

b

Figure 6. Peri-apical radiographs showing UR7. **(a)** Taken immediately post-obturation and **(b)** after the furcal perforation had been repaired with Biodentine (Septodont) and the access cavity definitively restored.

Section summary

Hydraulic cements used in extra-radicular situations are placed in contact with the peri-radicular tissues. The physical and biological properties of such cements are conducive in these indications, and their use has contributed to the improved prognosis of such procedures seen in recent years.

Clinical cases

Perforation repair

A 58-year-old male patient was referred by his GDP who could not locate two of the three root canals, and had perforated into the furcation of UR7. This tooth was important because it was the distal abutment of the three-unit conventional bridge in the upper right quadrant. The previously undiscovered root canals were located using an operating microscope, and following thorough chemo-mechanical preparation of the root canal system, the root canals were obturated using GP and BioRoot RCS (Septodont). The perforation was repaired with Biodentine (Septodont) at the same appointment as the obturation of the root canals. A coronal seal was established using Vitrebond Plus (3M) and the access cavity restored with resin composite (Figure 6).

a

b

c

d

Figure 7. (a) The pre-operative peri-apical radiograph of UL6 showing the peri-radicular radiolucency on the mesio-buccal root. **(b)** The post-operative peri-apical radiograph of UL6 following the root-end microsurgery and placement of a root-end filling using ProRoot MTA (Dentsply Sirona) in the mesio-buccal root. Peri-apical radiographs taken after **(c)** 1 year and **(d)** 4 years, respectively, after root-end surgery on the mesio-buccal root of UL6. Note the peri-radicular healing achieved.

Root-end filling

A 47-year-old female patient presented with pain localized to UL6. She had had extensive endodontics and fixed prosthodontics performed in Russia some years earlier. Radiographically, there was a peri-apical radiolucency associated with the mesio-buccal root of UL6 and a diagnosis of acute on chronic peri-radicular periodontitis was made (Figure 7a). Peri-radicular microsurgery was identified as the treatment of choice given the presence of the extensive restoration and risks of dismantling the tooth to attempt an orthograde approach. ProRoot MTA (Dentsply Sirona) was chosen as the root-end material (Figure 7b). Radiographic monitoring at appropriate intervals continues, and there is evidence of peri-radicular healing (Figure 7c,d).

Clinical performance

There is very limited information on the clinical performance of MTA used to repair root perforations. MTA used as a root-end filling material using a microsurgical approach is associated with high success rates.[75] However, regardless of the hydraulic nature and claimed superior properties, MTA used for this indication exhibits similar clinical outcomes as IRM (Dentsply)[76,77] and Super-EBA cement (Bosworth, Skokie, IL, USA),[78] even in the long term.[79]

Conclusion

The physical and biological properties of the hydraulic cements are such that they can be used in a range of endodontic procedures. They set in the presence of water and do not deteriorate when wet. This article has illustrated the use of such materials in various endodontic procedures, namely intra-radicularly (root canal sealer and apical plug) and extra-radicularly (perforation repair and root-end filler). Their efficacy and clinical performance are supported by an increasing body of evidence.

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 paper.

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