

## Classification and Nomenclature of Commercial Hygroscopic Dental Cements

William HA, Bill KAHLER, Laurence J WALSH

### ABSTRACT

**Objective:** Under the Global Medical Device Nomenclature (GMDN) system, the newly introduced term 'hygroscopic dental cement' (HDC) encompasses MTA as well as cements based on bioceramics, calcium silicate or calcium sulphate. Many HDCs have a long history of use in dentistry. There is a need for a consistent, logical and informed approach to the nomenclature of traditional and novel HDCs.

**Methods:** Commercial manufacturers of HDC were contacted requesting information on the compositions of products. Manufacturers that were unknown to the authors, that were unable to be contacted, that wished to be excluded from this paper, or that did not send their information on compositions in due time were not included.

**Results:** The compositions of commercial HDCs include various hybrids of calcium silicates, calcium aluminates, calcium phosphates, calcium sulphate as well as zinc sulphates. Furthermore, there are variations in the radiopacifier as well as additives that change the handling or setting processes.

**Conclusion:** The inclusion of different additives to HDCs enables variation in handling properties such that they now exist as distinct putties and sealers as well as cements.

**Keywords:** Bioceramics, calcium silicate cements, endodontic sealers, mineral trioxide aggregate, root canal sealers, terminology

### HIGHLIGHTS

- The term 'bioceramics' is poorly-defined and should be avoided in academic literature.
- Hygroscopic dental cement is a defined term that encompasses MTA and similar cements.
- The composition of MTA-branded materials may not comply with the original patent composition of MTA.
- Products that are not mixed with water will not set like cements that are mixed with water.
- As the compositions vary, the properties of one hygroscopic dental cement cannot be assumed to match the properties of another hygroscopic dental cement.

### INTRODUCTION

A range of cements are used in clinical dental practice, including zinc oxide eugenol cements (ZOE), zinc phosphate cements, polycarboxylate cements, glass ionomer cements (GIC) and mineral trioxide aggregate (MTA) cements. The latter was introduced by Torabinejad in the early 1990s (1). There are now many types of cement on the market that, like MTA, use water as a major reagent in a setting process involving hydration reactions. Such cements differ from products where water-based solutions contain ions or compounds that react in the setting process, rather than the water itself.

The Global Medical Device Nomenclature (GMDN) is a system of internationally

agreed terms for identifying and categorising medical devices that is used by regulators, manufacturers and healthcare systems to objectively categorise data relating to market surveillance, adverse event reporting and other management activities (2). Under the GMDN, the newly introduced term 'hygroscopic dental cement' (HDC) refers to 'a non-sterile substance intended for professional use as a dental cement (e.g. luting agent, liner, base, pulp-capping material) and/

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From the School of Dentistry (W.H. ✉ w.ha@uq.edu.au, B.K., L.J.W.), University of Queensland, Queensland, Australia.

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or direct dental restorative material whereby the majority of the setting reaction is based on the hardening reaction of a hygroscopic inorganic compound(s) [e.g. calcium silicates, calcium aluminates, zinc sulphate, calcium sulphate] with water (hydration). It is available as a powder intended to be either mixed with water prior to application or react with dentinal fluid in situ. After application, this device cannot be reused' (2).

Despite increasing interest in the use of HDCs in clinical practice, many practitioners are unsure of how the various products differ one from another. Because there is no standardised nomenclature for describing these products, clinicians can easily become confused. Using the term 'bioceramics' for some HDCs that require water to set into a solid form is confusing as this term also includes metal oxides and glasses used in fixed prosthodontics (3).

The aim of this article is to review recent advancements in HDC materials to propose an appropriate nomenclature to facilitate a better understanding of the similarities and differences between materials. This new classification scheme describes existing products on the global market, and can be expanded to new types of hydraulic or alkaline cements that are developed. The chemical additives used to modify the cements are discussed since such modifications have clinical implications.

## METHODS

Commercial manufacturers of HDCs were contacted requesting detailed information on the compositions of products. Manufacturers that were unknown by the authors, that were unable to be contacted, or that wished to be excluded from this paper, were not included. Of these products, their chemical compositions were searched in the PubMed search engine and compared with information provided by the manufacturer.

## REVIEW

### Current terms in the literature

#### Mineral trioxide aggregate

While the term MTA is in common use, it has been argued by Darvell that this has 'no chemically-meaningful sense' (4). The origin of the term MTA is found in the early research of Torabinejad et al. (5), who invented MTA, rather than in the original patent, which described 'a cement composition in which, in a preferred embodiment, the principal composition is Portland cement' together with 'an additive...to render the overall cement composition radiopaque' (6).

European Standard EN 197-1 defines Portland cement as consisting of 'at least two-thirds by mass of calcium silicates ( $3\text{CaO}\cdot\text{SiO}_2$  and  $2\text{CaO}\cdot\text{SiO}_2$ ), with the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. The ratio of  $\text{CaO}$  to  $\text{SiO}_2$  shall not be less than 2.0.

The magnesium oxide content ( $\text{MgO}$ ) shall not exceed 5.0% by mass' (7).

Thus, by combining the patent with the original research articles on MTA one could therefore define MTA as 'Portland cement with a radiopacifier'. Under such a definition, materials such as Biodentine™ (Septodont, Saint Maur des Fosses, France) and BioAggregate® (Innovative BioCeramix, Vancouver, Canada) could be included within the grouping of MTA as their composition includes calcium silicates within the range found in Portland cement as well as radiopacifiers (8, 9). Nevertheless, there are other products that likewise contain a high percentage of calcium silicates but are not commonly considered MTAs and, indeed, show significant differences in their properties (9).

#### Bioceramics

The term 'bioceramic' appears to be first mentioned when describing a related product, BioAggregate, produced by the same manufacturer (Innovative BioCeramix) (10). The term is used on all of their products and often is used to collectively refer to MTA and other HDCs, which is problematic (11). As ceramics are non-metallic inorganic materials, the term 'ceramics' encompasses practically all of the powdered components of MTA, zinc phosphate, zinc oxide eugenol and GICs. The term 'bioceramics' in a dental setting refers to prosthetic restorative materials as opposed to HDCs (12).

#### Hydraulic silicate cements, calcium silicate cements, hydraulic calcium silicate cements

There is a history of use in the literature for 'hydraulic silicate cement', 'calcium silicate cement' and 'hydraulic calcium silicate cement' (13-15). The term 'hydraulic cement' is a term that originates in the engineering literature and refers to materials that react 'under water', which can be extended to include GICs and related glass-based cements that set using acid-base aqueous reactions (16). As GICs contain calcium aluminium fluorosilicate, any of the terms 'hydraulic silicate cement', 'calcium silicate cement' or 'hydraulic silicate cement' could therefore include GICs. Changing the descriptor from 'hydraulic' dental cement to 'hygroscopic' dental cement would clarify that the material reacts with water, which would then exclude GICs.

An excessive emphasis on calcium silicates excludes other HDCs that react directly with water, particularly those that include calcium sulphate or calcium phosphate.

#### Confusion in the literature

The 'ideal formulation' described within a patent is not necessarily the composition of a final commercialised product, as ongoing research and development since the patent was awarded may have revealed that a different composition may be preferred. Furthermore, the protection afforded by a patent is limited to the countries where the patent has been applied for and granted.

Therefore, a product with a patent can have 'copycat' products appear in other countries where protection was not applied.

An example of confusion in the literature is TheraCal LC® (Bisco, Schaumburg, USA). TheraCal LC is a cement-modified resin composite and has been referred to as a 'light-curable MTA cement', when, in fact, there is no light-initiated setting of the Portland cement (17). Rather, only the resin component (polyethylene glycol dimethacrylate) undergoes photopolymerisation (18). The material is supplied as a single component, which is applied onto the tooth, in the same manner as a flowable resin. The setting reaction is based on light-initiated cross-linking of the polyethylene glycol dimethacrylate, which is a slightly water-soluble di-functional methacrylic monomer (17). Thus, the setting reaction depends upon polymerisation of the resin component, rather than a reaction with water, thus excluding this material from the classification of HDCs.

Another example is MTA Fillapex® (Angelus, Londrina, Brazil) which is a two-paste system, within one paste contains salicylate resin, fumed silica and bismuth trioxide (as the radiopaque agent), while the second paste contains MTA (40%), fumed silica, titanium dioxide, and 1,3-butylene glycol disalicylate resin (19). In the setting reaction, this resin reacts with calcium hydroxide released from the MTA. This same calcium hydroxide-based reaction occurs in Dycal Radiopaque Calcium Hydroxide (Dentsply Sirona, USA) (19, 20). Therefore, MTA Fillapex contains a HDC but its setting reaction is not specifically based only on a reaction with water, which excludes it from being included within the HDC grouping.

### Confirmation of compositions

Multiple studies have assessed the compositions of HDCs. Commonly used methods are energy dispersive X-ray spectroscopy (EDX), X-ray powder diffraction (XRD), X-ray fluorescence (XRF), X-ray photoelectron spectroscopy (XPS) and inductively coupled plasma-atomic emission spectroscopy (ICP-AES) (9-23). All methods involve measuring interactions with electromagnetic radiation, which is dependent on the elements that are present.

The atomic composition of BioAggregate, when assessed using XRF, was found to primarily consist of the elements oxygen, calcium, silicon, tantalum and phosphorus (9). Likewise, the composition of Biodentine assessed using XRF, XPS, EDX and ICP-AES all revealed that the cement is primarily the elements oxygen, calcium, silicon and zirconium (21-23). Using EDX, EndoCem MTA was found to contain oxygen, calcium, silicon, aluminium and bismuth (24). Likewise, using EDX, EndoCem Zr was found to contain oxygen, calcium silicon, aluminium and zirconium (24). An EDX assessment of grey MTA Plus found this to be composed primarily of oxygen, calcium, silicon and bismuth (25). MM MTA, when assessed using EDX and ICP-AES, was found to primarily contain oxygen, calcium, silicon, bismuth and aluminium (23, 26).

The composition of MTA Angelus has been examined using XRF, EDX and ICP-AES, all of which show that the major elements present are oxygen, calcium, silicon, bismuth and aluminium (9, 21, 23, 26). Comparable studies of MTA Cap using EDX and ICP-AES identified oxygen, calcium, silicon, tungsten and aluminium as major component elements (23). Likewise, studies of Neo MTA Plus using EDX also revealed oxygen, calcium, silicon and tantalum (25).

Finally, the composition of ProRoot MTA, when assessed using EDX, XRD, XPS and ICP-AES has been found to be primarily the elements oxygen, calcium silicon, aluminium and bismuth, while BioRoot RCS when examined using EDX, was found to primarily contain calcium, silicon and zirconium (22-24, 26, 28-30).

For the above analyses, it must be emphasised that all listed elements are present as compounds, rather than as pure elements. Calcium is generally present as calcium silicates, aluminium as calcium aluminate, bismuth as bismuth oxide, zirconia as zirconium oxide, tantalum as tantalum oxide and tungsten as calcium tungstate. This has been confirmed through communication with the manufacturers. Furthermore, XRD studies have revealed the presence of different types of calcium silicates, aluminates and radiopacifiers (9, 23, 26-29, 31, 32). One study has utilised Rietveld refinement to determine the quantities of these components (33). Moreover, some cements contain organic additives, such as polycarboxylic acid in Biodentine. Such organic additives can be identified with XPS, but their precise composition cannot be identified (22).

For many commercial HDCs there is no published literature on their composition. For products where there is some published data, not all components have been recorded nor has their presence verified. This is particularly the case when organic additives are present.

### Hygroscopic dental cement classifications

The definition of HDCs includes products with calcium silicates as well as others where components react with water to produce crystalline solid structures 'hydrates'. Some examples of components in HDCs are given in Table 1.

Tables 2 and 3 summarise confirmed compositions of commercially available packable hygroscopic dental cements that are likely to be included under the GMDN term for HDCs. Grey and white formulations within brands are not listed as separate entities as their compositions are generally the same, albeit, with different levels of iron and aluminium (28).

Most current HDCs are hybrid materials. For example, for MTA cements, the Portland cement component, which constitutes 80% of the material, contains both calcium silicate and calcium aluminate (1). Most hybrid cements are often predomi-

**TABLE 1.** Table 1. Examples of reactions of various HDCs with water (22)\*

HDC	Products
Calcium silicates	
$2(\text{CaO})_3\text{SiO}_2+7\text{H}_2\text{O}$	$(\text{CaO})_3(\text{SiO}_2)_2\cdot 4\text{H}_2\text{O}+3\text{Ca}(\text{OH})_2$
$2(\text{CaO})_2\text{SiO}_2+5\text{H}_2\text{O}$	$(\text{CaO})_3(\text{SiO}_2)_2\cdot 4\text{H}_2\text{O}+\text{Ca}(\text{OH})_2$
Calcium aluminate	
$2(\text{CaO})_3\text{Al}_2\text{O}_3+21\text{H}_2\text{O}$	$2(\text{CaO})_3\text{Al}_2\text{O}_3\cdot 6(\text{H}_2\text{O})+9\text{H}_2\text{O}$
Calcium phosphates	
$3\text{Ca}_4\cdot(\text{PO}_4)_2\cdot\text{O}+2\text{H}_2\text{O}$	$\text{Ca}_{10}\cdot(\text{PO}_4)_6\cdot(\text{OH})_2+\text{Ca}(\text{OH})_2$
Calcium sulphates	
$\text{CaSO}_4\cdot\frac{1}{2}\text{H}_2\text{O}+\frac{3}{2}\text{H}_2\text{O}$	$\text{CaSO}_4\cdot 2\text{H}_2\text{O}$
Zinc sulphate & Zinc oxide	
$\text{ZnSO}_4\cdot\text{H}_2\text{O}+\text{ZnO}$	$\text{Zn}_2(\text{OH})_2\text{SO}_4$
$\text{ZnSO}_4+\text{ZnO}+\text{H}_2\text{O}$	$\text{Zn}_2(\text{OH})_2\text{SO}_4$

\*This list details the most common HDC reactions, though there are other reactions that exist. Furthermore, when multiple HDC ingredients are present in a material, reactions may occur between the HDCs and not just with the water.

nately one particular type of HDC, particularly calcium silicate cements (13). Calcium sulphate, in the form of  $\text{CaSO}_4\cdot\frac{1}{2}\text{H}_2\text{O}$  (gypsum), although a commonly used a cement in the form of dental plaster, is found mixed within other HDCs. This is illustrated in Tables 2 and 3.

Tables 2 and 3 list the commercial packable HDC permanent restoratives. It is evident that the commercial products contain calcium silicates. However, this does not mean that calcium silicate is a mandatory ingredient. For example, calcium sulphate cements that are used for bone augmentation procedures can also be used for pulp therapy (34). These products have not been included here as the use of a bone graft material for pulp therapy is 'off-label' and further research is required. Also, EndoBinder® (Binderware, São Carlos, Brazil) is a calcium aluminate cement with no calcium silicates, and is a permanent restorative HDC but has not yet been commercialised (35).

Table 4 lists the commercial packable HDC intermediate restoratives. These cements are comprised of mixtures of zinc oxide and zinc sulphate.

The GMDN currently has dental restorative materials divided into subcategories based upon their setting reactions. Examples include HDCs, composite resins and GICs. However, all endodontic obturants are encompassed under the one category of 'Endodontic filling/sealing material,' which includes obturation cones, thermoplastic obturation materials, endodontic sealers and root-end filling materials.

A material that falls under two GMDN codes, one of composition and one of clinical indication, is not ideal as medical devices should only have one identifier (2). This is the case for root-end fillings where amalgam, ethoxy benzoic acid cement

and HDC each have their own separate GMDN term but could also fall under the descriptor for endodontic filling/sealing materials (2).

The existing GMDN term 'Endodontic filling/sealing material' could be replaced by categories for dental materials based on their composition and include possible usage in endodontics. Table 5 illustrates a scheme for the GMDN term 'Endodontic filling/sealing material' to categorise various obturation materials. Table 6 lists the HDC sealers that are commercially available.

### Property modifiers

As well as differences in the composition between various subgroups of HDCs, other modifications influence their properties. These include:

- changing the particle size distribution of the reactant powder;
- altering the radiopacifier;
- presence of chemical accelerators;
- inclusion of supplementary cementitious materials (SCMs);
- inclusion of rheological modifiers; and
- the absence of mixing water.

### Particle size distribution

Altering the particle size distribution influences handling properties and the setting time (36). The smaller the particles, the greater the surface area and thus the faster the rate of reaction (37). More water is needed to adequately wet smaller particles (38). Altering the particle size also influences the flow properties of the material when it is being inserted into the tooth (39).

### Radiopacifier

Although radiopacifiers are not reagents of the hydration setting reaction, they can change or impede the setting reaction leading to some changes to the physical properties of the set cement (40-42). The choice of radiopacifier has other implications, including whether the cement darkens over time or causes darkening of adjacent tooth structure, such as when bismuth oxide is used (43). Different radiopacifiers provide different levels of radiopacity and therefore amounts of radiopacity are expected to vary between products (44, 45).

### Accelerators

With MTA cements, the most common accelerant is calcium chloride, which when used at levels up to 10% can effectively halve the initial and final setting times (46). The addition of calcium chloride increases calcium concentration available to react to form the calcium-silicate-hydrate structures (47). However, how the chloride ions interacts with calcium-silicate-hydrate structures is not universally agreed (47).

**TABLE 2.** Commercial packable hygroscopic dental cement permanent restoratives (Part 1, A-I)

Commercial Brands	Manufacturer	Cement type						Additives		Mixing solution	
		Calcium silicates	Calcium aluminates	Calcium sulphates	Calcium phosphates	Radio-opacifier	Phyllo-silicates	CaCl <sub>2</sub>	Mixed with distilled H <sub>2</sub> O or PBS	Mixed with aqueous gel	Premixed with non-aqueous liquid
BioAggregate® RCRFM, DiaRoot® BioAggregate RCRFM	Innovative BioCeramik Inc (Vancouver, Canada)	•		•	•	Ta <sub>2</sub> O <sub>5</sub>			•		
Biodentine®	Septodont (Saint-Maur-des-Fossés, France)	•				ZrO <sub>2</sub>		•		•	
CEM Cement®	BioniqueDent (Tehran, Iran)	•	•	•	•				•		
Endocem MTA	Maruchi (Wonju-si, South Korea)	•	•	•	•	Bi <sub>2</sub> O <sub>3</sub>	•				
Endocem Zr	Maruchi (Wonju-si, South Korea)	•	•	•	•	ZrO <sub>2</sub>	•				
Grey MTA Plus®	Avalon Biomed (Bradenton, USA)	•		•	•	Bi <sub>2</sub> O <sub>3</sub>			•		
Harvard MTA Universal HandMix	Harvard Dental International (Hoppegarten, Germany)	•	•			?			?		?
Harvard MTA Universal OptiCaps®, Zendo MTA Universal											
Harvard MTA XR Fast OptiCaps, Zendo MTA Firm Fast											
Harvard MTA XR Flow EWT OptiCaps®											
Harvard MTA XR Flow Fast OptiCaps®, Zendo Flow Fast											
Harvard MTA XR OptiCaps®, Zendo Firm Fast											
iRoot® BP, EndoSequence® BC RRM/MTM, TotalFill® BC RRM/MTM Putty	Innovative BioCeramik Inc (Vancouver, Canada)	•		•	•	ZrO <sub>2</sub> & Ta <sub>2</sub> O <sub>5</sub>					•

? Information was withheld by the manufacturer for commercially confidential reasons.

Other additives may be present but may not be included here if information was withheld by the manufacturer or if there was no other product that featured the same additive.

**TABLE 3.** Commercial packable hygroscopic dental cement permanent restoratives (Part 2, HT)

Commercial Brands	Manufacturer	Cement type						Additives			Mixing solution	
		Calcium silicates	Calcium aluminates	Calcium sulphates	Calcium phosphates	Calcium phosphates	Radio-opacifier	Phyllo-silicates	CaCl <sub>2</sub>	Mixed with distilled H <sub>2</sub> O or PBS	Mixed with aqueous gel	Premixed with non-aqueous liquid
iRoot® FS, Endosequence® BC RRM Fast Set Putty™, TotalFill® RRM Fast Set Putty	Innovative BioCeramik Inc (Vancouver, Canada)	•	•	•	•	•	ZrO <sub>2</sub> & Ta <sub>2</sub> O <sub>5</sub>					•
MM MTATM	Micro-Mega (Besancon, France)	•	•	•			Bi <sub>2</sub> O <sub>3</sub>					•
MTA Angelus® White, Channels MTA	Angelus (Londrina, Brazil)	•	•	•			Bi <sub>2</sub> O <sub>3</sub>					•
MTA*Caps	Aceton (Mérignac, France)	•	•	•			Bi <sub>2</sub> O <sub>3</sub> & CaWO <sub>4</sub>					?
MTA Plus™	PrevestDenPro (Jammu, India)	•	•	•			Bi <sub>2</sub> O <sub>3</sub>					•
MTA Repair HP	Angelus (Londrina, Brazil)	•	•	•			CaWO <sub>4</sub>					•
NeoMTA Plus™, NuSmile® NeoMTA®	Avalon Biomed (Bradenton, USA)	•	•	•			Ta <sub>2</sub> O <sub>5</sub>					•
Ortho MTA	BioMTA (Seoul, South Korea)	•	•	•			Bi <sub>2</sub> O <sub>3</sub>					•
ProRoot® MTA	Dentsply Sirona (York, USA)	•	•	•			Bi <sub>2</sub> O <sub>3</sub>					•
Retro MTA	BioMTA (Seoul, South Korea)	•	•	•			Bi <sub>2</sub> O <sub>3</sub>					•
SavDen® MTA	Chenselect Co Ltd (Taipei, Taiwan)	•	•	•			Bi <sub>2</sub> O <sub>3</sub> & ZnO					•
TechBioSealer Apex	Isasan (Rovello Porro, Italy)	•	•	•			-					•
TechBioSealer Root-End	Isasan (Rovello Porro, Italy)	•	•	•			Bi <sub>2</sub> O <sub>3</sub>					•
TechBioSealer Capping	Isasan (Rovello Porro, Italy)	•	•	•			-					•
Trioxidant	VladMiVa (Belgorod, Russia)	•	•	•			(BiO) <sub>2</sub> CO <sub>3</sub>					•

? Information was withheld by the manufacturer for commercially confidential reasons.

Other additives may be present but may not be included here if information was withheld by the manufacturer or if there was no other product that featured the same additive.

**TABLE 4.** Commercial packable hygroscopic dental cement intermediate restoratives

Commercial Brands	Manufacturer	Cement type			Mixing solution	
		Calcium sulphates	Zinc sulphate & Zinc oxide	Radio-opacifier	Premixed with non-aqueous liquid	Methacrylate resin
Coltosol® F	Coltene (Altstätten, Switzerland)	•	•	ZnO	•	
DuoTEMP®	Coltene (Altstätten, Switzerland)	•	•	ZnO	•	•
Cavit™	3M ESPE (St Paul, USA)	•	•	BaSO <sup>4</sup>	•	
Cavit™ G	3M ESPE (St Paul, USA)	•	•	BaSO <sup>4</sup>	•	
Cavit™ W	3M ESPE (St Paul, USA)	•	•	BaSO <sup>4</sup>	•	

Other additives may be present but may not be included here if information was withheld by the manufacturer or if there was no other product that featured the same additive.

**TABLE 5.** Possible categorisation of obturation materials to supersede 'Endodontic filling/sealing material'.

Gutta Percha (cold or thermoplasticised)
Resin obturation points
Epoxy resin sealers
Diketone resin sealers
Methacrylate sealers
Calcium hydroxide or calcium oxide with salicylate ester sealers
HDC based sealers (see Table 6)
Zinc oxide and eugenol
Glass ionomer cement
Silicone (Polydimethylsiloxane)

### Supplementary cementitious materials (SCMs)

SCMs are mineral admixtures that do not in themselves react with water (48). However, when combined with a HDC, particularly those based on Portland cement, SCMs can react with aqueous calcium hydroxide to form compounds that will be incorporated within the hydrate structures of the HDC (48). The reaction of the aqueous calcium hydroxide from the pores of Portland cement results in lower porosity and higher strengths (48). SCMs are often rich in silica and include slag, fly ash and natural pozzolans (48). Using this approach, Endo-Cem MTA has achieved a faster setting time than ProRoot MTA (Dentsply Sirona, York, USA), but with similar handling characteristics to the latter (49).

### Aqueous Gels / Rheological modifiers

Plasticisers, also known as water reducing agents, work by bonding to the cement particles, and applying their negative charge to the cement particles (50). This causes the particles to spread out more evenly when mixed with water, and as a result less water is required to mix the cement (50). As less water is required to mix the material with water, the set product has greater compressive strength (51). A plasticiser has been included in Biodentine. This agent may also improve bonding to dentine and thereby increase the resistance of the material to dislodging forces (4).

Thickeners can be added to HDCs for several purposes. Adding a thickener to a cement powder can produce a

paste (e.g. for use as an endodontic sealer) or a putty (e.g. for a restoration) (52). Thickeners are typically added to the water component of the HDC, where they alter the flow of the material when it is mixed (52). Examples of this include ProRoot Endosealer® (Dentsply Sirona, York, USA) and EndoCPM® (EGEO Dental, Buenos Aires, Argentina). ProRoot Endosealer powder has the same ingredients as conventional MTA, but the water component is enriched with a water-soluble polymer (53). EndoCPM contains Portland cement, propylene glycol alginate, propylene glycol, sodium citrate and calcium chloride (54). In this product, the propylene glycol serves as the thickening agent because of its ability to form intermolecular links that create a scaffold, while the calcium chloride accelerates the setting reaction (46, 55).

### Absence of mixing water

Some HDCs are supplied as a single component injectable paste with no water, and the setting reaction requires water from the dentine to diffuse through the material to enable the cement to set (56). Because the paste is water-free, a thickening agent is used to create a gel-like consistency. iRoot® SP (Innovative BioCeramix, Vancouver, Canada) is supplied as a single component injectable paste, which does not contain any water. A thickening agent is used to create a gel-like consistency for the paste (56). The manufacturer claims advise that the typical setting time is 4 hours, but this will extend to over 10 hours when the material is placed in dry canals (57). Likewise, iRoot® BP (Innovative BioCeramix, Vancouver, Canada) is the packable version and is placed without any water to then rely upon water from an outside source (such as tooth structure surrounding the cavity preparation) to cause the material to set (58).

The current GMDN term states that the HDCs are 'available as a powder intended to be either mixed water prior to application or react with dentinal fluid in situ'. Some HDCs are commercially available as water-free pastes that react with the water present in dentinal fluid once placed into the tooth. Therefore, the GMDN term should be updated to reflect these products.

**TABLE 6.** Commercial hygroscopic dental cement endodontic sealers

Commercial Brands	Manufacturer	Cement type				Radio-opacifier	Additives		Mixing solution			
		Calcium silicates	Calcium aluminates	Calcium sulphates	Calcium phosphates		Phyllo-silicates	Premixed Ca(OH) <sub>2</sub>	CaCl <sub>2</sub>	Mixed with distilled H <sub>2</sub> O or PBS	Mixed with aqueous gel	Premixed with non-aqueous liquid
Apatite Root Sealer <sup>IP</sup>	Dentsply Sirona (York, USA)				•							•
Apatite Root Sealer IID	Dentsply Sirona (York, USA)				•	CH <sub>3</sub>					•	
Apatite Root Sealer III	Dentsply Sirona (York, USA)				•	CH <sub>3</sub> & Bi <sub>2</sub> O <sub>3</sub>						•
BioRootTM	Septodont (Saint-Maur-des-Fossés, France)											•
Endoseal <sup>IP</sup>	Maruchi (Wonju-si, South Korea)	•				ZrO <sub>2</sub>						•
EndoSeal MTA	Maruchi (Wonju-si, South Korea)	•	•	•	•	ZrO <sub>2</sub>						•
iRoot <sup>®</sup> SP, EndoSequence <sup>®</sup> BC SealerTM, Total Fill <sup>®</sup> BC SealerTM	Innovative BioCeramik Inc (Vancouver, Canada)	•			•	ZrO <sub>2</sub>						•
ProRoot <sup>®</sup> ES Endo Root Canal Sealer	Dentsply Sirona (York, USA)	•	•	•	•	Bi <sub>2</sub> O <sub>3</sub>						•
TechBioSealer Endo	Isasan (Rovello Porro, Italy)	•	•	•	•	Bi <sub>2</sub> O <sub>3</sub>						•
MTA Fillapex, Channels MTA	Angelus (Londrina, Brazil)	•	•	•	•	CaWO <sub>4</sub>						•
Root Canal Sealer <sup>*</sup>												

<sup>o</sup> Discontinued, \*MTA Fillapex is not viewed as a HDC but is listed here as it contains HDC components.

Other additives may be present but may not be included here if information was withheld by the manufacturer or if there was no other product that featured the same additive.

## Clinical and Research Consequences

There are commercial products that are more like resins than HDCs, as well as HDCs that are placed without first mixing them with water. Without a functional classification of these products, clinicians would assume that all these HDCs perform identically. More research is needed to compare the subtypes of HDCs, particularly resin and HDCs that are placed without water.

The terms 'bioceramic', 'MTA' and 'calcium silicate cement' can be misleading as not all properties are shared amongst such materials. Clinicians should be aware of the differing compositions of cements as these differences result in variations in performance. Differences in the choice of radiopacifier and its percentage composition can result in significant differences in radiopacity.

## CONCLUSION

HDCs, particularly those involving calcium silicates, have become an integral part of clinical practice, including endodontics and restorative dentistry. Some HDCs have been modified to create variants, which are either flowable, for use as an endodontic sealer or highly viscous and putty-like for packing into defects.

While there is a growing body of evidence supporting the use of HDCs, much of the existing literature relates to the original ProRoot MTA composition, and the data from this cannot simply be extrapolated to all HDCs because of the influence of changes in composition. One cannot simply assume equivalence even between HDCs of the same type (such as MTA) because of variations in particle size distribution, thickeners, accelerants and other components that can affect handling properties and setting reactions.

There is a growing body of evidence supporting the use of HDC. However, most of this relates to the original ProRoot MTA composition. As some HDCs can be more different than others, care should be considered when assuming equivalence between products.

Unlike the restorative cements, the existing GMDN scheme groups all endodontic obturation materials under the same term. The creation of separate terms based on material composition will improve the understanding of products that have similar compositions and uses, and better distinguish these from those with contrasting compositions.

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