Bioactive endodontic materials for everyday use: a review

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Bioceramic materials are at the forefront of modern dentistry. Bioactive bioceramic endodontic materials promote pulpal and periapical tissue healing and are easy to use. Dentists can choose among many endodontic materials, depending on their needs. This article highlights the major differences among commercially available bioactive tricalcium silicate bioceramics, commonly known as *mineral trioxide aggregate* materials, to enable dentists to make appropriate decisions in the selection of these materials.

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Choosing the best dental material for a specific clinical task can be challenging. Many dental materials are marketed as *new and improved* while listing the shortcomings of other products. However, when many options are available, sometimes the history and proven clinical success of the originating products in any material category can be the determining factor in selection. In endodontics, numerous bioactive bioceramics, commonly known as *mineral trioxide aggregate* (MTA), have been introduced to worldwide markets in recent years. These materials are based on tricalcium silicate powder with a radiopaque additive. Depending on the product, these MTA-type cements are used for pulp capping, pulpotomy, apexogenesis, apexification, perforation repair, root canal filling, or root canal sealing with gutta percha.

Some bioceramic materials are bioactive. According to the International Organization for Standardization, materials are bioactive when they form apatite in body fluids, including synthetic body fluids.[1] Tricalcium silicate materials are included in this category because they induce the formation of a layer of hydroxyapatite on their surface. The bioactivity occurs because the materials release calcium and hydroxide ions. The high pH of MTA materials causes the phosphate ions in body fluids to precipitate with the calcium ions and form hydroxyapatite. These products require water for setting, making them ideal for use in high-moisture environments, such as the oral cavity.

ProRoot MTA (Dentsply Sirona) was the first commercial MTA to be launched in the marketplace (1998) and is one of the most commonly researched MTA cements.[2] ProRoot MTA has remained the standard while there has been an influx of similar materials in the market, aiming to improve on factors such as handling and setting time and to eliminate the tooth discoloration that can result from use of these products. Clinicians often find it difficult to understand the differences among these products. This review will discuss the clinically relevant differences of these materials, including material properties.

Clinical handling

The original tricalcium silicate material, including prototypes, was a cement powder that was mixed with water. One reported drawback of the original powder-water mix was the consistency, often described as *wet sand*.[3-6] This mix was difficult to handle and required specialized instruments for placement. The mixed but unset material was compacted into perforations, pulpotomies, and root-end fillings.[3] Table 1 details the costs and components of various commercially available MTA-type materials.

Some newer materials, such as MTA Angelus (Angelus Indústria de Produtos Odontológicos) and BioAggregate (Innovative BioCeramix; also known as *DiaRoot*, DiaDent Group), use the traditional powder-water mixing technique.

Table 1. Prices and components of selected MTA products as of December 2017.[a]

Product	Size (g)		Cost (US$)			Supplied components		Radiopacifier (oxide)
	Kit	Dose	Kit	Gram	Dose	Powder	Liquid	
ProRoot MTA Root Repair Material (white & gray)	5.00	0.50	265.05	53.01	26.51	5× Foil sachet	Water	Bismuth
ProRoot ES	3.00	0.25	180.00	60.00	15.00	Foil sachet	Gel	Bismuth
MTA Angelus	5.00	0.14	199.95	39.99	5.59	5× 1-g Bottle	Water	Bismuth
MTA Plus	2.50	0.10	98.75	39.50	3.95	Desiccant bottle	Gel	Bismuth
MTA Plus	8.00	0.10	276.50	34.46	3.46	Desiccant bottle	Gel	Bismuth
NeoMTA Plus	2.50	0.10	117.00	46.80	4.68	Desiccant bottle	Gel	Tantalum
NeoMTA Plus	7.00	0.10	287.60	41.09	4.11	Desiccant bottle	Gel	Tantalum
EndoSequence BC Sealer	2.00	0.13	145.52	72.76	9.70	Premixed syringe	NA	Zirconium
EndoSequence Root Repair Material (Putty Kit)	3.00	0.10	447.82	149.27	14.93	Premixed jar	NA	Zirconium/ tantalum
EndoSequence Root Repair Material (Syringe Kit)	3.00	0.20	378.00	126.00	25.20	Premixed syringe	NA	Zirconium/ tantalum
EndoSequence Root Repair Material (Fast-Set Putty)	0.30	0.30	154.93	516.40	154.93	Premixed syringe	NA	Zirconium/ tantalum
Biodentine	19.50	0.70	217.30	20.70	14.49	Capsules	NA	Zirconium
BioAggregate	6.00	1.00	188.50	31.42	31.42	Foil sachet	Water	Tantalum
Endocem	0.30	0.30	35.00	116.67	35.00	Centrifuge tube	NA	Bismuth
Endocem Zr	0.30	0.30	35.00	116.67	35.00	Centrifuge tube	NA	Zirconium
OrthoMTA	1.00	0.20	55.00	55.00	11.00	Centrifuge tube	Water	Bismuth
RetroMTA	2.40	0.30	120.00	50.00	15.00	Foil sachet/ampules	Water	Zirconium

Abbreviations: MTA, mineral trioxide aggregate; NA, not applicable.

[a] Prices obtained from manufacturers' websites in December 2017.

These operator-mixed (spatula-mixed) materials allow the clinician flexibility to mix as much or as little as needed for a specific procedure.

To circumvent the handling challenges of the powder-water mixture, some newer products have introduced alternative mixing solutions. MTA Plus (Prevest DenPro), Grey MTA Plus (Avalon Biomed), NeoMTA Plus (Avalon Biomed), and MTA Flow (Ultradent Products) may be mixed with sterile water, but each kit includes a water-based gel. Mixing the gel with the powder allows a clinician to vary the consistency from a puttylike mixture to a thinner viscosity, such as that found in AH Plus Sealer (Dentsply Sirona). With these products, the handling of the material is improved. Washout resistance has also been demonstrated for some of these products.[7] ProRoot ES (Dentsply Sirona) is also a tricalcium silicate–based powder designed for use as a sealer with gutta percha. It reportedly has a finer particle size.[8] This powder is mixed with a water-based gel that contains water-soluble polymers. All of these gel-mixed MTA materials are versatile, allowing clinicians to vary the consistency to suit their needs.

Other products, such as Biodentine (Septodont), OrthoMTA (BioMTA), and Endocem (Maruchi International) come in capsules. These unit-dose capsules have the advantage of consistent, uniform mixing but the disadvantage of a single size and the consequent potential for waste. Biodentine capsules have 0.7 g of powder in a trituration capsule. OrthoMTA and Endocem have 0.3 g of powder in a centrifuge-type tube.

Some products are premixed with an organic liquid and thus are ready to use. Examples of this type are EndoSequence Root Repair Material (Brasseler USA), EndoSequence BC Sealer (Brasseler USA), and TotalFill (sealer or root repair paste, FKG Dentaire). These premixed materials offer convenient, uniform mixtures. However, to vary the viscosity, both the putty and sealer must be mixed. The consistency can vary over time because the shelf life of the products is shortened after opening. These premixed materials rely on body fluids to set the tricalcium silicate powder in the product.

Particle size

The particle size distribution of the tricalcium silicate powders affects handling and setting properties. Smaller particles may penetrate tubules and also hydrate faster than larger particles because of their higher surface-to-volume ratio. If the tricalcium silicate material dissolves during setting and precipitates

Table 2. Tricalcium silicate particle sizes in selected MTA products.[a]

Material	Particle size (mm)		
	Minimum	Median	Maximum
Gray ProRoot MTA	0.17	9.0	79
White ProRoot MTA	0.14	7.1	50
MTA Angelus	0.16	11.2	63
MTA Plus	0.11	5.1	23
NeoMTA Plus	0.20	5.1	45
EndoSequence BC Sealer	0.11	0.3	45
Biodentine	0.20	0.7	52
BioAggregate/DiaRoot	0.16	5.6	70

Abbreviation: MTA, mineral trioxide aggregate.

[a] Source: Carolyn M. Primus, PhD, personal written communication, December 1, 2016.

to penetrate the tubules, sealing is enhanced. Dentinal tubules range in size from 2-5 µm.[9] The data in Table 2 demonstrate that the smallest particles in all the materials are capable of penetrating adjacent dentinal tubules, even before partial dissolution (Carolyn M. Primus, PhD, personal written communication, December 1, 2016).

Particle size is not important for root-end filling or perforation repair but is crucial for endodontic sealer use, where low film thickness is required for use with gutta percha. As a sealer, the material must lubricate the walls to allow easy passage of the gutta percha obturation material to the canal terminus. A sealer must fully conform to both the canal walls and the gutta percha to provide a 3-dimensional root canal fill. Bioceramic sealers have been evaluated in both single-cone and continuous-wave (modified warm vertical) obturation techniques.[10,11] Despite its smaller particle size compared to some other MTA-type materials (including NeoMTA), EndoSequence BC Sealer did not show superior tubule penetration.[10] With nearly equivalent tubule penetration in both the middle and apical thirds of canals, both EndoSequence BC Sealer and NeoMTA were found to be suitable for endodontic obturation.[10]

According to the particle size distributions, no material shown in Table 2 contains 100% nanoparticles (particles smaller than 100 nm). However, EndoSequence BC Sealer had the smallest median particle size.

A modified version of ProRoot MTA that includes nanoparticles (known currently as *experimental nanoWMTA*) resulted in a higher pH level and calcium ion release than the original product.[12] Furthermore, the calcium ion release continued to be higher in the experimental nanoWMTA for up to 1 week, although the clinical consequences of this finding are currently unknown.

Producing consistently smaller particles involves higher production costs; thus, the price per gram for materials with the smallest particles (such as EndoSequence products) is higher than that of materials with larger particles.

Color stability

Many materials used in endodontics cause tooth discoloration, including antibiotics and certain irrigants.[3,13-16] The composition of ProRoot MTA has been shown to discolor adjacent dentin. Discoloration can be immediate or delayed. The original gray formula of ProRoot MTA was dark gray and could cause immediate discoloration when used for near-coronal applications. Tooth-colored ProRoot MTA solved the immediate staining issue with a lower iron content.[17-22] However, tooth staining has also been noted with white MTA, especially in immature or primary teeth.[14,23]

Bismuth oxide is a commonly used radiopacifier that has been correlated with staining in MTA products.[17,24] Some studies point to the interaction of bismuth oxide with irrigant solutions such as sodium hypochlorite.[25-27] MTA Angelus has been shown to cause tooth staining, particularly after the dentin is irrigated with sodium hypochlorite.[22] MTA Angelus has less bismuth oxide than ProRoot MTA and has been shown to cause less tooth staining after exposure to hypochlorite or chlorhexidine.[26,28] MTA Plus is composed of components similar to those of ProRoot MTA and contains bismuth oxide, resulting in tooth discoloration.[27]

Tricalcium silicate materials also can cause tooth staining when exposed to chlorhexidine or formaldehyde (a component of formocresol used in primary tooth pulpotomies).[28] Light has also been demonstrated to cause staining in bismuth-containing compounds, while no discoloration occurred with Biodentine, Endocem Zr (Maruchi International), and RetroMTA (BioMTA).[24,29] NeoMTA contains tantalum oxide and does not discolor dentin, even with exposure to sodium hypochlorite.[27] EndoSequence Root Repair Material and EndoSequence BC Sealer contain zirconia and tantalum oxides, which prevent these products from discoloring teeth.[30] It has been reported that materials that do not contain bismuth oxide do not display any staining, emphasizing the relationship of bismuth oxide–containing compounds to tooth discoloration.[24,31] The newer tricalcium silicate products materials with radiopacifiers other than bismuth oxide have improved the clinical usefulness of

bioactive endodontic materials, including coronal application (Table 1).

Endodontic materials may also discolor due to blood contamination.[2,16,32] ProRoot MTA has a black surface coating after exposure to blood during the setting reaction.[2] If the material sets adjacent to a blood source, blood may be highly incorporated into the surface along the tissue-material interface, thus altering the surface chemistry of the ProRoot MTA setting.[2] As previously stated, products containing bismuth oxide have more discoloration than those with alternative radiopacifiers. After setting in the presence of blood, however, ProRoot MTA, Biodentine, OrthoMTA, and EndoSequence Root Repair Material all displayed discoloration as measured by a spectrodiometer.[30] Color stability in the presence of blood may be minimally altered by the radiopacifier used. Although the exact mechanism of discoloration is not well understood, one theory is that erythrocyte entrapment within the material and subsequent leaching into the dentinal tubules is the cause.[30]

Although some materials result in tooth discoloration, no evidence suggests this to have a negative impact on biocompatibility. Tooth staining has always been an esthetic concern and is not correlated with product failure or pulpal necrosis. However, discoloration has limited the use of tricalcium silicate materials containing bismuth oxide. Discoloration has not been an issue for most perforation repairs, root-end filling, or use as a sealer material. However, anterior and coronal applications, especially for young or primary teeth, require products that do not discolor.

Conclusion

Having an understanding of the properties, advantages, and disadvantages of various tricalcium silicate–based materials will enable dentists to make informed treatment decisions. This review contains the most recent research as of the time of publication, but new tricalcium silicate bioactive dental materials are introduced each year. Clinicians should use this article as a guide and continue to investigate new materials as they are offered.

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Disclaimer

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