The properties of Mineral Trioxide Aggregate and how it can be manipulated

Australian Society Of
ENDODONTOLOGY

Lecture Notes, 25 November 2015
Dr William Ha BDSc GCRC
PhD Candidate (Endodontic Biomaterials)

Acknowledgements

Research Supervisors
Dr Bill Kahler
Prof Laurie Walsh

Co-researcher
Assoc Prof Peter Duckmanton

Inviting Organisation
Australian Society of Endodontology – New South Wales

Research Funding
Funding from Australian Society of Endodontology
& Australian Dental Research Foundation
Travel grants from the International Association of Dental Research
& Japanese Association of Dental Research

Part 1. Age of evolution of MTA and Bioceramics

Bioceramics & Hydraulic Dental Cements

MTA and MTA like cements are often called 'bioceramics'. However, this can be misleading as it groups MTA and MTA cements with medical and prosthetic ceramics such as artificial joints and artificial bone-like structures. Medical and prosthetic ceramics are structures which are produced and set in a factory or laboratory. These products are generally unreactive.

MTA powder is reacts with water to for a crystalline structure. A term which is in line with cement technologists is to use the term 'hydraulic dental cement' as hydraulic cements are cements which are mixed with water to form a slurry that later becomes a hard material.

Usage and Training

It is commonly believed that cost is the biggest barrier to use. However, a recent survey (yet to be published) of the ASE illustrates that the biggest barrier to use is education on the usage of the material.[1]

Calcium hydroxide & MTA

$Ca(OH)_2$ paste is the gold standard of endodontic antibacterial medication. Its main antibacterial effect relates to its pH. It takes 7 days for $Ca(OH)_2$ paste, at pH 12, for the surrounding dentin to reach a pH of 9, where bacterial growth in teeth is inhibited.[2]

Ideal Properties	**$Ca(OH)_2$ paste**	**$Ca(OH)_2$ cement**	**MTA**
Brands	Calcipulp, Pulpdent, Calyxl	Dycal, MTA Fillapex, Life	ProRoot MTA, MTA Angelus
Key / Majority Reactants:	As below	Butylene glycol disalicylate$_{(l)}$ + $Ca(OH)_{2(s)}$	$2(CaO)_3(SiO_2)_{(s)}$ + $2(CaO)_2(SiO_2)_{(s)}$ $+12H_2O_{(l)}$
Key / Majority Products:	$Ca^{+}_{(aq)} + 2OH^{-}_{(aq)}$ + Gel-like thickening agent (eg Methylcellulose)	Calcium disalicylate$_{(S)}$ + $2H_2O_{(l)}$	$2[(CaO)_3(SiO_2)_2{\bullet}4H_2O]_{(s)} + 4Ca^{+}_{(aq)} + 8OH^{-}_{(aq)}$
State & Handling	Paste	Thick Paste that solidifies into flaky cement	Hard Paste that solidifies into rock like cement
Immediate pH:	12.5	9-10	12.5
Antibacterial effect	Strong	Mild	Strong
Long term state:	Soluble	Semi Soluble	Insoluble
Promotes healing	✔✔✔	✔	✔✔✔
Seals the tooth	✖✖✖	✖	✔✔✔
Clinical indication	Therapeutic dressing	Liner	Permanent restoration

$Ca(OH)_2$ resin-cements do not release $Ca(OH)_2$,[3] they consume it. They contain $Ca(OH)_2$ in their formulation, however, in their setting reaction, $Ca(OH)_2$ is consumed in resinous cement. Their pH is therefore less than the other $Ca(OH)_2$ mediums which do not consume $Ca(OH)_2$ in the setting reaction.[4]

What is MTA?

Mineral trioxide aggregate (MTA) and procedures

MTA is not a resin cement. It is Portland cement (PC) (calcium silicate) cement that reacts with water to produce $Ca(OH)_2$ as its byproduct and therefore is a setting cement that has the same pH as $Ca(OH)_2$.[5] MTA contains 20% Bi_2O_3 (w/w) to establish radiopacity as set Portland cement alone is indistinguishable from dentine.[6] Over a period of several months, the pH of the tooth next to MTA progressively drop in alkalinity.[7]

What is Portland cement?

To make Portland cement, stones, are crushed, ground and placed in an oven that reaches temperatures of around 1500 degrees Celsius. The output material is ground further, until it becomes a powder known as Portland cement. This process breaks the bonds that held the stones together so when you add water, the bonds will reform and produce a stone-like cement material.

What is Bismuth oxide?

Bismuth oxide has a high effective atomic number and is therefore radio-dense. It will absorb X-rays and will therefore appear 'white' on radiographs. It does not directly react with MTA, however, it provides steric interference in the setting reaction of MTA.[8]

Chemical Reactions in the setting of MTA

Reactants		Products
Portland Cement Calcium Silicates Calcium Aluminates	→	Calcium-silicate-hydrate Calcium-aluminate-hydrate
Water		Calcium hydroxide
	→	Water
Unreacted Bismuth Oxide	→	*Unreacted Bismuth Oxide*

Setting Time of MTA Indentation

MTA Angelus is marketed as taking 15 minutes to set, ProRoot as 4 hours and Biodentine as 12 minutes. However, the testing methodology is different for each company and therefore it can be inaccurate to compare brands if the testing is different.[8]

ProRoot MTA

ProRoot MTA is provided as sachets are intended to be one-use only, however, many clinicians opt to use the sachets multiple times to save on cost-per-use. This is, however, against the manufacturer's instructions. Their advertised setting time of 4 hours is based on a test to resist indentation by 5MPa.[8] However, clinicians can carefully place other restorative materials above MTA after 10 minutes as the MTA has reached sufficient hardening.[9]

MTA Angelus

MTA Angelus comes in a re-sealable jar, which is easier to store for re-use than ProRoot. Its advertised setting time of 15 minutes is based on a test to resist indentation by 0.3MPa.[8] Therefore it's frivolous to compare it with ProRoot MTA based on advertised setting time.

Biodentine

Biodentine is provided with powder in a capsule with an aqueous solution must be poured into the capsule prior to mixing. It does in fact set faster than the other MTAs, however, it is not hard enough to be a conventional restorative material, such as glass ionomer cement (GIC).

ProRoot MTA	Biodentine	Who's better?
75% Calcium Silicates and aluminates	85% calcium silicates	ProRoot is less soluble[10]
5% Gypsum	10% Calcium Carbonate	Biodentine sets faster.[10]
20% Bismuth Oxide	5% Zirconium Oxide	ProRoot is more radiopaque[10]
100% distilled water	Water with 15% Calcium chloride and polycarboxylate	Biodentine has a greater hardness[10]

MTA Fillapex

MTA Fillapex is essentially dycal mixed with MTA powder. It is a flowable endodontic sealer and should not be used for endodontic repairs of teeth or for pulp therapy. It requires water to diffuse from the dentine to set the sealer and therefore the setting time is uncertain. Furthermore, it higher solubility and greater cytotoxicity than other endodontic sealers (such as AH Plus) and therefore the long-term seal of the tooth can be inferior.[11-14]

Property	AHPlus	MTA Fillapex
Clinical Success	Many and long studies	Lab studies and pulp caps studies
Radiopacity	Better	Worse[15]
Film Thickness	Better	Worse[16]
Cytotoxicity	Better	Worse[17]
Bond strength	Better	Worse[18]
Antibacterial activity	Worse	Better[19]
Solubility	Better *(Less soluble)*	Worse[11] *(More Soluble)*

TheraCal LC

TheraCal LC has been reported, and marketed, as having high calcium ion release and as being able to create an alkaline pH,[20, 21] however the assays used involved placing the material into water and measuring changes over only a few days. TheraCal is not mixed with water on placement and therefore it cannot be expected to perform as such, in vivo. Compared to Vitrebond and Ultrablend Plus, TheraCal LC has less cytotoxicity, however, it has not yet been compared to MTA.[22]

Differences between MTA brands and "MTA Brands"

	ProRoot MTA	MTA Angelus	Biodentine	MTA Fillapex	TheraCal LC
What is it really?	PC + Bismuth Oxide	PC + Bismuth Oxide	Modified PC + ZrO	Dycal + PC	Flowable resin + PC
Clinical Uses	Endodontic repair	Endodontic repair	Endodontic repair	Endodontic Sealer	Pulp caps only
Packaging	One-use only satchels	Re-sealable jar	Manually combined, capsule mixed	Two part mixing paste syringe	Single one component syringe
Setting speed*	4 hours	15 Minutes	12 Minutes	2 hours	Light Cured
Evidence base	Very extensive studies	Extensive studies. Chemically almost identical to ProRoot MTA	Mostly small trials and case reports. Promising results	Performance equal to or less than AH26	Mainly anecdotal and lab studies
Cost to buy	2 grams (4 satchels) $370.51	1gram jars for $123	5 capsules $92.40		
Cost per use	$92.63 for one-use only $26.47 for re-using packet	$17.57 per use	$18.48 per use		
Supplier	Dentsply	Gunz	Halas	Gunz	Erskine Dental & Amalgadent

Brands hitting our shores

The alternative MTA brands seem to be fundamentally the same but they have different particle sizes and some additives so they will handle slightly differently. Nevertheless, they still are cement powder mixed with water.[8]

Some of these contain zirconium which has a lower atomic number than bismuth so they could be less radiopaque. Otherwise, their main ingredients are the same as ProRoot MTA so you should expect similar clinical outcomes.[8]

	Calcium Silicates	Calcium Aluminates	Calcium Sulfate	Bismuth Oxide	Zirconium Oxide	Calcium Carbonate	Silicon Dioxide	Phyllosilicates	Rheological Modifier	Calcium Chloride
Biodentine	y				y	y			y	y
EndoCem MTA	y	y	y	y				y		
EndoCem Zr	y	y	y		y			y		
EndoSeal	y	y	y		y			y		
MM MTA	y	y	y	y		y		y		
MTA Angelus	y	y		y						
MTA Plus	y		y	y			y		y	
Ortho MTA	y	y		y						
ProRoot MTA	y	y	y	y						
Retro MTA	y	y			y					
Trioxident	y	y	y	y					y	

Other hydraulic dental cements (‘Bioceramics’)

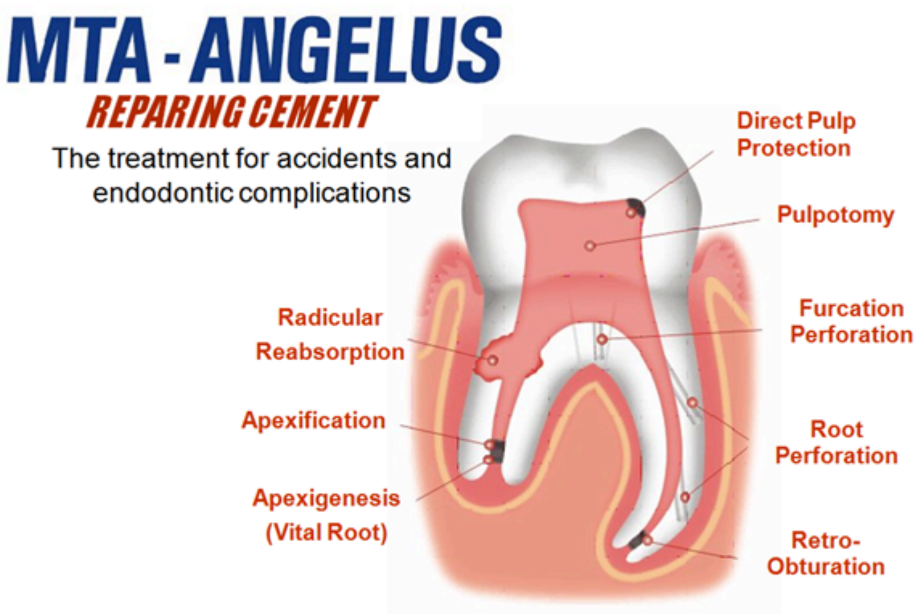
	Calcium Silicates	Calcium Aluminates	Calcium Phosphate	Calcium Sulfate	Radiopaque filler	Mix with H_2O solution	Placed without mixing with	$Ca(OH)_2$ present prior to	Thickening agent
BioAggregate RCRFM & DiaRoot RCRFM	y		y		y	y			
iRoot SP, EndoSequence BC Sealer	y		y		y		y	y	y
iRoot BP & EndoSequence (Putty & Injectable RCFRM)	y		y	y	y		y	y	y

Property	**ProRoot MTA**	**BioAggregate / DiaRoot**
Clinical Success	Many and long studies	Lab studies and pulp cap studies
Strength	Better	Worse[23]
Radiopacity	Good	No studies
Setting Time	4 hours	4 hours
Sealing Tests	Good	Good[24]
pH / $Ca(OH)_2$	Better	Worse
Solubility	Better *(Less Soluble)*	Worse[25] *(More Soluble)*

Property	AHPlus	Endosequence BC Sealer
Clinical Success	Commonly used in endodontic literature	Case Reports
Radiopacity	Better	Worse[26]
Sealing Tests	Better	Worse[27]
Bacteriostatic	Similar	Similar[28]
Push-out Strength	Better	Worse[29]
Solubility	Better *(Less soluble)*	Worse[14] *(More soluble)*

Part 2. Steps and Preferences

Clinical applications



Success Rates

MTAs success rates are 97.6% in pulp capping, 79% in pulpotomy in permanent teeth and >95% in pulpotomies. [30] In apical barriers the success rate can be expected to be over 90%.[31]

MTA pulp capping

Pulp capping is performed for exposures of the pulp where the pulp itself is not expected to be irreversibly inflamed and currently vital. Aseptic technique is mandatory and any burs used on the tooth should be water-cooled to prevent over heating of the pulp. Once the pulp is exposed using handpieces, haemostasis of the pulp should be achieved via sterile cotton pellet soaked in saline. If haemostasis cannot be achieved it is likely that the area of the pulp is inflamed and you should consider extending your preparation until all inflamed areas of the pulp are removed. Therefore, extend the preparation to a pulpotomy or a pulpectomy. And then place MTA or $Ca(OH)_2$.

$Ca(OH)_2$ has been the gold standard for pulp capping, however, it has problems. $Ca(OH)_2$ is soluble in oral fluids and therefore it can provide an area for bacterial growth once it dissolves. It does not adhere to the tooth and easily dislodges after placement. Instead of $Ca(OH)_2$, MTA can be placed. After placing MTA into pulpal area, place a layer resin-modified glass ionomer cement (RMGIC) over MTA to protect from washing out. Etch the tooth and then wash out the etch. Place prime and bond adhesive and follow with a composite resin restoration. Discussed in more detail in Accorinte.[32]

MTA pulpotomy

Pulpotomies are performed for deep carious exposures or exposures of the pulp where the pulp is not expected to irreversibly inflamed and currently vital. The clinical procedure is otherwise the same as a pulp cap with the key difference being the removal of the pulpal chamber. Much of the above was taken from Barrieshi.[33]

MTA apexification and apical barrier

The larger the apex the greater the chance that the apical region of the tooth will be inadequately obturated and the more difficult it is for the clinician to length control the obturation material. In the past, multiple appointments to dress the canals with $Ca(OH)_2$ were utilized With MTA, this can be done in one visit.

As MTA is antibacterial, sets hard, and promotes bony growth, clinicians can place MTA at the apex with good confidence the tooth is better obturated than if gutta percha (GP) was placed. Teeth with apices wider than a 55 K-file (0.55mm), and/or when apical patency becomes difficult to achieve, the clinician can consider using MTA instead of GP. Place at least 3-5mm thickness of MTA and then restore the rest with GP, resin, or, more MTA.[34]

MTA apicoectomy

Apical infections that do not respond to conventional and adequate root canal therapy can respond to apicoectomy. This is where the last 3mm of the tooth is removed along with any apical infection and the end of the root canal is sealed with MTA. MTA is used because it has excellent sealing properties and will encourage healing of the bone around it, unlike the historical alternative of amalgam.

Trends in Australia[35]

ProRootMTA is the most common MTA in Australia, followed by MTA Angelus. Almost all endodontists use MTA while less than half of dentists in the ASE use MTA. MTA is the material of choice by endodontists for perforations, apexifications, apicoectomy and regenerative endodontics.

For apexifications, endodontist generally perform single visit MTA barrier placement while general dentists generally perform multiple visit calcium hydroxide apexification.

Most endodontists prefer to use sodium hypochlorite as their final irrigant prior to MTA placement.

Staining and MTA

NaOCl will react with bismuth oxide to produce a dark brown precipitate. Therefore, if MTA is used in aesthetically important areas, the tooth should be adequately irrigated with saline to remove NaOCl residue darkening the MTA.[22] Regardless of NaOCl use, darkening of the MTA is expected and $Ca(OH)_2$ should be considered if the darkening of MTA is not viewed as acceptable.[36]

Part 3. Tips, Tricks and Science

Acidic Environments with MTA

The setting of MTA features alkaline reagents and products which can be attacked by acids resulting in changes in final structure, greater leakage and less adhesion to tooth structure.[9,10] Endodontic infections will create an acidic environment which would degrade the MTA. To neutralize the acid environment, dressing the canal with $Ca(OH)_2$ for 1–2 weeks before MTA placement will improve the properties of the set MTA.[12] If placement of $Ca(OH)_2$ is not feasible, substantial irrigation of NaOCl is recommended to neutralize the acid.[37]

$Ca(OH)_2$ dressings can also impair the properties of MTA as the various additives, such as methylcellulose and carboxymethylcellulose, can retard the setting of the PC in MTA.[16,17] Therefore, if a dressing of $Ca(OH)_2$ paste is used, extensive irrigation should be carried out to ensure that no remaining dressing material is present, as remnants of the cellulose thickener will retard the setting of MTA.[37]

EDTA, etch and tooth conditioners must be adequately washed away before MTA placement.[37] NaOCl irrigants have pH values above 11 and will neutralize any remaining acids when used to rinse canals.[18]

Fluid contamination effects on MTA

MTA, when set in the presence of blood, will have reduced compressive strength, reduced micro-hardness and less resistance to displacement.[29-31] Hemorrhagic contamination should be minimized as it impairs the quality of the set MTA.[37]

Working time

As MTA is mixed, water starts to evaporate from the reacting mass as well as being consumed by the setting MTA. Therefore, the workability dramatically changes in a short amount of time. MTA's working time is 6 minutes.[38] A trick to extend the working time is to cover the MTA with wet gauze so less water will evaporate from the setting MTA.

Mixing Tricks

The instructions for use state 3 parts power, to 1 part water, by mass. After mixing, if the work time has elapsed, extra water can be added to make the MTA workable again. MTA can be mixed on a glass slab or paper mixing pad, however, paper mixing pads are flimsy and it's easy to spill the MTA.

To adjust the wetness of the MTA, two cotton rolls can be kept at hand, one dry and one wet. If the mix is dry, squeeze the cotton roll and it will release gently water into the MTA. Ideally, use a Pasteur pipette. If a mixture is too wet, a cotton roll can be used to dab the MTA which will suck up the excess water. The ideal mixture can have amounts lifted with the flat plastic in one whole piece without dripping or crumbling off the instrument.

Alternative mixing solutions

MTA should be mixed with sterile or distilled water. In the absence of water, local anaesthetic can be used, however, the reaction is lower and the set material is weaker.[35,36] NaOCl solution will accelerate the setting reaction of MTA, however, it will result in a weaker compressive strength.[35,36] Chlorhexidine gluconate, as a mixing solution for MTA, should not be used as it completely inhibits the setting reaction of MTA.[37]

MTA Carriers

Amalgam carriers and normal hand instruments can be used for large restorations. Damp cotton pellets held by tweezers seem easier to use than traditional packers for compacting MTA. For smaller restorations, MTA carriers can be used. Examples include MAP MTA Carrier, MTA Carrier, and the Dovgan carrier. If excess mixed MTA is left within a carrier after the appointment, the tip may become clogged and seemingly unusable. If this occurs, submerge the carrier in vinegar and use sharp-tipped instruments such as probes and K files to scratch the MTA out from the carrier.

Lee block (Also known as, "MTA Pellet Forming Block")

Many clinicians like to insert their MTA as blocks or pillars into a defect. A simple way to shape your MTA into these ideal pillars is to use a "Lee Block".[39] This is a plastic block that has had bur sized grooves. Freshly mixed MTA is placed into these grooves and then pillars of MTA can be lifted out from the base of the groove using a half hollenback or spoon excavator. The pillars can then be inserted into the tooth. This can be bought or self-made using a fissure bur. If several grooves are made and loaded with mixed MTA the clinician can quickly insert several pillars into the tooth without having to stop to insert more MTA into the block.

Compacting MTA down a canal

Some clinicians like to utilize ultrasonics to compress the MTA with the intent to compact the MTA.[40] However, the collisional vibrations on the setting structure of MTA can disrupt the setting structure, reducing micro-hardness and create porosities if ultrasonics are applied for over 2 seconds.[41]

Removing MTA from tooth walls

MTA can be removed from tooth walls using gentle brushing using cotton pellets, micro-brushes, gentle irrigation with water or using irrigation via ultrasonics. Another method is to twist a K file through a cotton roll, which will turn the K file into a long absorbent brush.

Curing MTA

Much of the historic literature on MTA utilizes a method where a damp pellet is placed above the MTA to protect the material as it slowly set. However, temporizing a tooth with cotton pellets delays completion of the restoration and can compromise the quality of the seal.[39] It is now common to gently place GIC, RMGIC or even resin bonding agents onto MTA. Once these materials have set, the clinician can permanently restore the tooth.

Storage: Packets vs Jars

If sachets of MTA are to be used, they should be used as 'one-use-only' as attempts to using remnant powder will result in lower reactivity of the remnant powder as it has partially reacted with water from the ambient humidity.[42] If sachets are to be used for multiple cases, it would be prudent to pour the remaining powder into small jars to protect the cement from reacting with ambient humidity. Keeping the sachets within a sterilization pouches is inadvisable as sterilization pouches are designed to enable humidity to pass through the packet.

Temperature effects

MTA should not be stored in the refrigerator as this will result in reduction in surface hardness, greater porosity and leakage.[43, 44]

Author Biography:

Dr William Ha
BDSc, GCRC, PhD Candidate (University of Queensland)

Dr Ha is a part time dentist and a part time PhD student researcher in the field of endodontic biomaterials. The focus of his research is the chemical and physical properties of Mineral Trioxide Aggregate, a material used in endodontics and paedodontics. He has articles published in the Australian Dental Journal, Journal of Endodontics and the Journal of the Canadian Dental Association. Dr Ha is the secretary for the QLD branch of the Australian Society of Endodontology, and is a member of Australian and New Zealand Society of Paediatric Dentistry and International Association of Dental Traumatology.

He is also a recreational app developer with two apps on the market. Dental Prescriber, which helps dentists prescribe medications. And, BraceMate, a free app for orthodontic patients wanting to have fun with colours for their braces.

Address:
School of Dentistry, The University of Queensland
Oral Health Centre
288 Herston Road
Herston QLD 4006
For copies of slides or further information, please email w.ha@uq.edu.au

References

1. Foley JI. Use of mineral trioxide aggregate (MTA by postgraduates in restorative dentistry in the UK. Eur J Prosthodont Restor Dent 2011;19:179-183.

2. Nerwich A, Figdor D, Messer HH. pH changes in root dentin over a 4-week period following root canal dressing with calcium hydroxide. J Endod 1993;19:302-306.

3. Angelus. MTA Fillapex - Endodontic Sealer - Scientific Profile. URL: 'https://www.clinicalresearchdental.com/marketing/mta fillapex - scientific profile_medium.pdf'. Accessed 16 April 2013.

4. Lombardi T, Di Felice R, Muhlhauser J. Analysis of pH variation of various calcium hydroxide compounds in vitro. Bull Group Int Rech Sci Stomatol Odontol 1991;34:73-78.

5. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod 1995;21:349-353.

6. Hwang YC, Lee SH, Hwang IN, et al. Chemical composition, radiopacity, and biocompatibility of Portland cement with bismuth oxide. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107:e96-102.

7. Heward S, Sedgley CM. Effects of intracanal mineral trioxide aggregate and calcium hydroxide during four weeks on pH changes in simulated root surface resorption defects: an in vitro study using matched pairs of human teeth. J Endod 2011;37:40-44.

8. Ha WN, Bentz DP, Kahler B, Walsh LJ. D90: The strongest contributor to setting time in MTA and Portland cement. J Endod 2015;41:1146-1150.

9. Tsujimoto M, Tsujimoto Y, Ookubo A, et al. Timing for composite resin placement on mineral trioxide aggregate. J Endod 2013;39:1167-1170.

10. Kaup M, Schafer E, Dammaschke T. An in vitro study of different material properties of Biodentine compared to ProRoot MTA. Head Face Med 2015;11:16.

11. Faria-Junior NB, Tanomaru-Filho M, Berbert FL, Guerreiro-Tanomaru JM. Antibiofilm activity, pH and solubility of endodontic sealers. Int Endod J 2013;

12. Waltimo TM, Boiesen J, Eriksen HM, Orstavik D. Clinical performance of 3 endodontic sealers. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001;92:89-92.

13. Tavares CO, Bottcher DE, Assmann E, et al. Tissue reactions to a new mineral trioxide aggregate-containing endodontic sealer. J Endod 2013;39:653-657.

14. Borges RP, Sousa-Neto MD, Versiani MA, et al. Changes in the surface of four calcium silicate-containing endodontic materials and an epoxy resin-based sealer after a solubility test. Int Endod J 2012;45:419-428.

15. Bicheri SAV, Victorino FR. Comparative evaluation of radiopacity of MTA Fillapex® endodontic sealer through a digital radiograph system. RSBO (Online) 2013;10:149-152.

16. Zhou HM, Shen Y, Wang ZJ, et al. In Vitro cytotoxicity evaluation of a novel root repair material. J Endod 2013;39:478-483.

17. Silva EJ, Rosa TP, Herrera DR, et al. Evaluation of cytotoxicity and physicochemical properties of calcium silicate-based endodontic sealer MTA Fillapex. J Endod 2013;39:274-277.

18. Baechtold MS, Mazaro AF, Crozeta BM, et al. Adhesion and formation of tags from MTA Fillapex compared with AH Plus® cement. RSBO (Online) 2014;11:71-76.

19. Kuga MC, Faria G, Weckwerth PH, et al. Evaluation of the pH, calcium release and antibacterial activity of MTA Fillapex. Revista de Odontologia da UNESP 2013;42:330-335.

20. Bisco Inc. TheraCal LC - Resin-Modified Calcium Silicate Pulp Protectant / Liner. URL: 'http://www.bisco.com/catalog/ple_bisco_catitemf.asp?iBrand_Id=156&iCat_Id=28'. Accessed 16 April 2013.

21. Gandolfi MG, Siboni F, Prati C. Chemical-physical properties of TheraCal, a novel light-curable MTA-like material for pulp capping. Int Endod J 2012;45:571-579.

22. Hebling J, Lessa FC, Nogueira I, Carvalho RM, Costa CA. Cytotoxicity of resin-based light-cured liners. Am J Dent 2009;22:137-142.

23. Alsubait SA, Hashem Q, AlHargan N, AlMohimeed K, Alkahtani A. Comparative evaluation of push-out bond strength of ProRoot MTA, bioaggregate and biodentine. J Contemp Dent Pract 2014;15:336-340.

24. Bayram HM, Saklar F, Bayram E, Orucoglu H, Bozkurt A. Determination of the Apical Sealing Abilities of Mineral Trioxide Aggregate, Portland Cement, and Bioaggregate After Irrigation with Different Solutions. J Int Oral Health 2015;7:13-17.

25. Saghiri MA, Garcia-Godoy F, Gutmann JL, et al. Push-out bond strength of a nano-modified mineral trioxide aggregate. Dent Traumatol 2013;29:323-327.

26. Candeiro GT, Correia FC, Duarte MA, Ribeiro-Siqueira DC, Gavini G. Evaluation of radiopacity, pH, release of calcium ions, and flow of a bioceramic root canal sealer. J Endod 2012;38:842-845.

27. Ulusoy OI, Nayir Y, Darendeliler-Yaman S. Effect of different root canal sealers on fracture strength of simulated immature roots. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:544-547.

28. Zhang H, Shen Y, Ruse ND, Haapasalo M. Antibacterial activity of endodontic sealers by modified direct contact test against Enterococcus faecalis. J Endod 2009;35:1051-1055.

29. Gade VJ, Belsare LD, Patil S, Bhede R, Gade JR. Evaluation of push-out bond strength of endosequence BC sealer with lateral condensation and thermoplasticized technique: An in vitro study. J Conserv Dent 2015;18:124-127.

30. Srinivasan V, Waterhouse P, Whitworth J. Mineral trioxide aggregate in paediatric dentistry. Int J Paediatr Dent 2009;19:34-47.

31. Witherspoon DE, Small JC, Regan JD, Nunn M. Retrospective analysis of open apex teeth obturated with mineral trioxide aggregate. J Endod 2008;34:1171-1176.

32. Accorinte Mde L, Holland R, Reis A, et al. Evaluation of mineral trioxide aggregate and calcium hydroxide cement as pulp-capping agents in human teeth. J Endod 2008;34:1-6.

33. Barrieshi-Nusair KM, Qudeimat MA. A prospective clinical study of mineral trioxide aggregate for partial pulpotomy in cariously exposed permanent teeth. J Endod 2006;32:731-735.

34. Simon S, Rilliard F, Berdal A, Machtou P. The use of mineral trioxide aggregate in one-visit apexification treatment: a prospective study. Int Endod J 2007;40:186-197.

35. Ha WN, Kahler B, Walsh LJ. Widening the Clinical and Practical Scope of MTA - PhD Coursework. 2015.

36. Belobrov I, Parashos P. Treatment of tooth discoloration after the use of white mineral trioxide aggregate. J Endod 2011;37:1017-1020.

37. Ha WN, Kahler B, Walsh LJ. Clinical Manipulation of Mineral Trioxide Aggregate: Lessons from the Construction Industry and Their Relevance to Clinical Practice. J Can Dent Assoc 2015;81:f4.

38. Wang CW, Chiang TY, Chang HC, Ding SJ. Physicochemical properties and osteogenic activity of radiopaque calcium silicate-gelatin cements. J Mater Sci Mater Med 2014;25:2193-2203.

39. Lee ES. A new mineral trioxide aggregate root-end filling technique. J Endod 2000;26:764-765.

40. Yeung P, Liewehr FR, Moon PC. A quantitative comparison of the fill density of MTA produced by two placement techniques. J Endod 2006;32:456-459.

41. Parashos P, Phoon A, Sathorn C. Effect of ultrasonication on physical properties of mineral trioxide aggregate. Biomed Res Int 2014;2014:191984.

42. Ha WN, Kahler B, Walsh LJ. Particle size changes in unsealed mineral trioxide aggregate powder. J Endod 2014;40:423-426.

43. Saghiri MA, Asgar K, Lotfi M, et al. Effect of storage temperature on sealing ability and solubility of white mineral trioxide aggregate. Acta Odontol Scand 2012;70:536-540.

44. Saghiri MA, Lotfi M, Joupari MD, Aeinehchi M, Saghiri AM. Effects of storage temperature on surface hardness, microstructure, and phase formation of white mineral trioxide aggregate. J Endod 2010;36:1414-1418.