Australian Endodontic Journal
The Journal of the Australian Society of Endodontology Inc.,
the Australian and New Zealand Academy of Endodontists and
the Asian Pacific Endodontic Confederation

Aust Endod J 2019; 45: 111–121

LITERATURE REVIEW

Adaptation of mineral trioxide aggregate to dentine walls compared with other root-end filling materials: A systematic review

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Keywords
adaptation, endodontic surgery, mineral trioxide aggregate, systematic review.

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doi: 10.1111/aej.12259

(Accepted for publication 12 January 2018.)

Abstract

This systematic review analysed the literature comparing marginal adaptation of mineral trioxide aggregate (MTA) with other filling materials in root-end cavities. The PubMed, Ovid, Web of Science, SCOPUS, and Cochrane library databases were searched using appropriate keywords related to root-end filling materials and adaptation. Of 38 articles assessed, 20 met the inclusion criteria. No in vivo study was identified. In 10 studies, MTA gave the best marginal adaptation results, but no significant differences were found between MTA and any of the tested filling materials in seven studies. There was great variability in the study designs including analysed surface, unit of gap measurement and magnification amount during analysis. On the basis of available evidence, MTA presented good marginal adaptation to dentine walls. This review identified the need for the development of standardised methods to evaluate the adaptation property of root-end filling materials in ex vivo studies as well as in clinical studies evaluating outcome.

Introduction

Endodontic surgery is a viable treatment option when non-surgical attempts prove unsuccessful or unlikely to result in a better outcome (1). This treatment approach aims to remove diseased tissues and untreated apical ramifications and to provide an apical seal to decrease the risk of apical pathosis (2). Hence, the placement of a root-end filling has been recommended because it can prevent egress of any remaining bacteria or their byproducts and allow for the formation of a normal periodontium across its surface (2,3).

Traditionally, endodontic surgery was performed using surgical burs for root-end cavity preparation and amalgam for root-end filling (2). Precisely locating, cleaning and filling all the complex apical ramifications were unpredictable. The root-end cavity preparation using burs risked perforation of the root-end and generally lead to insufficient depth and retention of the filling material. Modern endodontic surgical concepts include the use of ultrasonics for root-end cavity preparation and biomaterials for root-end filling (2). The use of ultrasonic tips provides centred and deep root-end cavities with a decreased risk of root perforation (4). According to a recent meta-analysis, root-end cavity preparation with ultrasonics was significantly superior in achieving high clinical success rates when compared with traditional root-end cavity preparation with burs (5). In 1993, mineral trioxide aggregate (MTA), a calcium silicate-based biomaterial was introduced as a root-end filling material (6) and since then has been accepted as the gold standard because it is a biocompatible material with good physical and chemical properties (7). However, MTA has difficult handling characteristics and long setting time that can result in material washout in a moist surgical site (8). Recently, ongoing research for the ideal root-end filling material has lead to new biomaterials that have mostly similar constituents to MTA (9–12).

The sealing ability of a root-end filling material potentially will affect the long-term outcome of endodontic surgery (3). The quality of the seal achieved by root-end filling materials has been evaluated by several leakage studies using various methodologies such as dye penetration (13), bacterial penetration (14), radioisotope penetration (15), electrochemical method (16) and fluid transport method (17). However, the clinical relevance of these methodologies is controversial because the results of these *in vitro* studies do not correlate with clinical outcomes (18), so much so that such research is generally no longer accepted in the mainstream endodontic literature.

Assessing the quality of marginal adaptation is an alternative methodology that indirectly compares the sealing ability of root-end filling materials (19). The presence of marginal gaps between a root-end filling material and root dentine may potentially be responsible for apical leakage (19–21), which may result in apical pathosis (3). Thus, this property is crucially important for the selection of a root-end filling material (22).

To date, studies have reported conflicting results on the adaptation of MTA as a root-end filling (20,21,23). Therefore, the aim of this systematic review was to analyse marginal adaptation studies based on contemporary concepts of endodontic surgery using ultrasonic tips for root-end cavity preparation and which compared MTA with other materials.

Literature search methodology

Data sources and the search strategy

This systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (24). The free form of the research question was the following: 'Does root-end filling with MTA present better quality of marginal adaptation to dentine walls than other materials in root-end cavities prepared with ultrasonic tips?' The population, intervention, comparison and outcome (PICO) strategy was used for the structured review question as follows:

P: Fully formed human teeth undergoing root-end surgery with ultrasonic root-end preparation
I: Root-end filling with MTA
C: Root-end filling with other materials
O: Quality of marginal adaptation of the materials to dentine walls

The search strategy covered electronic databases and identified articles published through to 28 September 2017. No publication year or language limits were set. The electronic databases searched were the following: PubMed (MEDLINE), Ovid (MEDLINE), Web of Science (all databases), SCOPUS and the Cochrane library. The main search terms were apicoectomy, root-end resection, root-end filling, marginal adaptation, mineral trioxide aggregate. These keywords and terms were selected from articles published in following three endodontic journals: Journal of Endodontics, International Endodontic Journal and Australian Endodontic Journal. The keywords and terms were enriched during the electronic database searches. The search strategy used is depicted in Table 1.

Table 1 Example of the search strategy (Pubmed)

No.	Search strategy	Results
1	((((((((apicoectomy)) OR (apicectomy)) OR (root-end resection)) OR (root end resection)) OR (pulpectomy)) OR (pulpotomy)) OR (root canal therapy)) OR (root canal filling materials)) OR (endodontics)	39 063
2	((((obturation material)) OR (obturation)) OR (filling)) OR (filling material)	58 504
3	((((((retrograde)) OR (retro-filling)) OR (retro filling)) OR (retrofilling)) OR (root-end)) OR (root end)	69 938
4	((((((marginal)) OR (adaptation)) OR (fit)) OR (discrepancy)) OR (gap)) OR (gaps)	728 704
5	(mineral trioxide aggregate) OR (MTA)	6813
6	#1 AND #2 AND #3 AND #4 AND #5	50

Screening and selection of the studies

Initially, the titles identified in the searches were screened. If the title indicated possible inclusion, the abstract was then evaluated. In case of any doubt, the full text of the article was read. Following the evaluation of the abstracts, articles considered eligible for the review were identified and all of the full-text articles were assessed. Two reviewers working independently from one another assessed all the citations. Studies were selected for inclusion if they fulfilled all of the following criteria:

1. *In vivo* or *ex vivo* studies performed on fully formed human teeth
2. Studies comparing the marginal adaptation of MTA with other root-end filling materials
3. Studies evaluating the marginal adaptation at the interface of the root-end filling material and dentine in terms of presence of gaps
4. Root-end cavities prepared using surgical ultrasonic tips
5. The assessment method did not involve microleakage.

Studies failing to meet any of these criteria were excluded.

Data extraction

Data extraction for the included studies was completed using a systematic data collection form designed to summarise each study. All aspects of treatment that could potentially affect the study outcomes were identified and included in the data form. Data were extracted by one reviewer directly from the full texts of articles and a second reviewer independently verified the extracted data. The following variables were recorded: authors, year of publication, study design (*in vivo* or *ex vivo*), type of teeth, tested material, whether the root-end cavity was cleaned before placement of filling material, storage time between the placement of filling materials and analysis, storage in a moist environment after the placement of filling materials, analysed surface (transverse or longitudinal), type of analysis (quantitative or qualitative), evaluation method, unit of gap measurement, magnification amount during analysis and outcomes pertinent to the aim of the review.

Each study was analysed in terms of similarities so that a meta-analysis could be performed. However, because of considerable methodological heterogeneity a meta-analysis was not indicated. Instead, a descriptive analysis of the results of the individual studies was undertaken.

Quality assessment (Risk of bias)

The methodological quality of each included study was critically evaluated based on the following parameters:

1. Was the calculation of an adequate sample size performed before starting experiments?

2. Were the samples randomly divided into groups?

3. Were the root-end procedures performed by a single operator?

4. Was the experience of the operator who performed the root-end procedures reported?

5. Were the materials prepared and/or used according to the manufacturer's instructions?

6. Were the root-end procedures performed under magnification?

7. Were the analyses performed by evaluator/s blinded to the groups?

After collecting these items, the studies were classified with a high, moderate or low risk of bias. Studies that failed to report five items or more were classified as high risk, studies that failed to report three to four items were classified as moderate risk, and studies that failed to report two items or less were classified as low risk.

Results

The electronic systematic searches yielded a total of 235 studies from all the databases. Of these, 70 were identified in Web of Science, 58 in Scopus, 50 in Pubmed, 50 in Ovid and seven in the Cochrane library. After removal of duplicates and data screening based on title and abstract, a total of 38 citations were selected for full-text reading. No additional studies were identified after the cross-reference analysis. Following the full-text reading, 18 studies were excluded, and the reasons for exclusion were the following: using burs for root-end cavity preparation (25–34), no comparison of MTA with another filling material (35–39), inadequate detail regarding root-end cavity preparation (40,41) and one study had exactly the same data as a previously published study (42). Finally, 20 studies were found to be eligible for inclusion in this systematic review. Of these, 19 were in English (9–12,20,21,23,43–54) and one study was in Portuguese (55), which was translated by the principal author. All of the included studies were *ex vivo* studies, no *in vivo* studies were identified.

The literature review was organised into two sections: (i) methodologies of marginal adaptation studies, and (ii) comparative analysis of root-end filling materials.

Methodologies of marginal adaptation studies

The summary of characteristics of the included studies is shown in Table 2. The methodology, type of preparation of the samples, the chosen surface for analysis and the type of analysis varied in these studies. Of the 17 SEM studies, five performed a replication technique to obtain acrylic copies of natural teeth (9,12,20,21,44) while 11 analysed natural teeth (11,43,45–51,53,55) and one used both natural teeth and replicas (54).

The analysis in the studies was either qualitative or quantitative, or both. In two studies qualitative analysis was performed by interpreting the images in terms of the presence or absence of gaps (23,47) while in four studies scoring scales indicating the distribution of gaps in relation to cross-sectional quadrants were used (48,50,53, 55). In 15 studies, quantitative analysis was performed by measuring the gap amounts (9–12,21,43–46,49,50,52–54,56). In one study, the margin types were categorised as continuous, overfilled, underfilled and non-continuous and the percentages were calculated according to a formula (20). In nine studies, image analysis programs were used to measure the length, width, area or volume of gaps (10,12,20,21,45,49,52–54).

Comparative analysis of root-end filling materials

The main outcomes are summarised in Table 2 and the classification of the materials is shown in Table 3. In seven studies, MTA was associated with the best marginal adaptation (21,43,45,46,50,52,55), whereas two associated it with the worst results (23,54). In three studies, MTA presented similar marginal adaptation results with a resin composite material (44), calcium silicate cement clinker (49) and intermediate restorative material (IRM) (11) while showing better performance than the remaining filling materials. No significant difference was found between MTA and any of the tested filling materials in seven studies (9,12,20,47,48,51,53). According to one study, Biodentine showed better adaptation than MTA

Table 2 Descriptive data of included studies

Studies	Tooth type	Materials	Cavity cleaning	Storage time after root-end filling	Storage in moisture
Peters&Peters, 2002 (20)	Human maxillary and mandibular molars	ProRoot MTA, Super EBA	Y	24 h	Y
Gondim *et al.*, 2003 (21)	Human canine teeth	ProRoot MTA, Super EBA, IRM	Y	24h	Y
Xavier *et al.*, 2005 (43)	Human single-rooted teeth	MTA Angelus, Super EBA, Vitremer	N	Immediately	N
Tobón-Arroyave *et al.*, 2007 (23)	Human single-rooted maxillary and mandibular teeth	ProRoot WMTA, Super EBA, IRM	Y	30 min	N
Costa *et al.*, 2008 (54)	Human single-rooted teeth	WMTA Angelus, white, a calcium silicate cement clinker, Vitremer, GC Fuji Ortho LC, silver amalgam without zinc	N	Immediately	N
Gomes *et al.*, 2009 (55)	Maxillary molar teeth	MTA, Super EBA, ZOE, Ketac-CEM, N-Rickert, IRM, Amalgam	N	Immediately	N
Rosales-Leal *et al.*, 2011 (44)	Single-rooted anterior teeth	ProRoot MTA, Clearfil AP, Cavalite, Amalgam, Vitrebond, IRM	N	24 h	Y
Munhoz *et al.*, 2011 (45)	Human maxillary canine teeth	WMTA Angelus, Sealer 26	N	36 h	Y
Shahi *et al.*, 2011 (46)	Human single-rooted teeth	ProRoot GMTA, ProRoot WMTA, white calcium silicate cement clinker, gray calcium silicate cement clinker	Y	48 h	Y
Almeida *et al.*, 2012 (47)	Human maxillary and mandibular canine teeth	WMTA Angelus, Super EBA	Y	Immediately	N
Oliveira *et al.*, 2013 (48)	Human single-rooted maxillary anterior teeth	ProRoot MTA, IRM, Amalgam, Super EBA, Epiphany/Resilon	N	24 h	Y
Rosa *et al.*, 2014 (49)	Human maxillary molars	WMTA Angelus, a calcium silicate cement clinker, Super EBA	N	1 week	Y
Shokouhinejad *et al.*, 2014 (9)	Human single-rooted teeth	ProRoot WMTA, Endosequence Root Repair Putty, Endosequence Root Repair Paste	N	1 week	Y
De Conto *et al.*, 2014 (50)	Human single-rooted mandibular incisors and canines	WMTA Angelus, Vitremer	N	2 weeks	N
Ravichandra *et al.*, 2014 (10)	Human mandibular premolar teeth	Biodentine, ProRoot WMTA, Glass ionomer cement type II	Y	1 week	Y
Soundappan *et al.*, 2014 (11)	Maxillary central incisors	ProRoot MTA, IRM, Biodentine	N	5 days	Y
Mokhtari *et al.*, 2015 (51)	Human single-rooted teeth	ProRoot MTA, a ceramic-based material (experimental)	N	24 h	N
Bolhari *et al.*, 2015 (12)	Human single-rooted teeth	ProRoot MTA, Biodentine, Bioaggregate, CEM	N	96 h	Y
Kim *et al.*, 2016 (52)	Human single-rooted teeth	ProRoot MTA, Super EBA	N	24 h	Y
Küçükkaya Eren *et al.*, 2017 (53)	Human maxillary central incisors	MTA Angelus, Biodentine, CEM	N	24 h	Y

Studies	Analysed surface	Analysis type	Method	Unit of gap measurement	Magnification amount	Main findings
Peters&Peters, 2002 (20)	Transverse	Quantitative	SEM	Percentage (length)	200×	No difference was found among materials
Gondim *et al.*, 2003 (21)	Transverse	Quantitative	SEM	mm^2 (area)	300×	ProRoot MTA presented the best adaptation results

(continued)

Table 2 (continued)

Studies	Analysed surface	Analysis type	Method	Unit of gap measurement	Magnification amount	Main findings
Xavier *et al.*, 2005 (43)	Transverse	Quantitative	SEM	μm (width)	1800×	MTA Angelus presented the best adaptation results
Tobón-Arroyave *et al.*, 2007 (23)	Longitudinal	Qualitative	Stereomicroscopy	Score	50×	ProRoot WMTA was associated with the worst results
Costa *et al.*, 2008 (54)	Transverse	Quantitative	SEM	N	230×	Both glass ionomer cement showed better adaptation than MTA
Gomes *et al.*, 2009 (55)	Transverse	Qualitative	SEM, Optical microscopy	Score	50×, 150×	MTA presented the best adaptation results
Rosales-Leal *et al.*, 2011 (44)	Transverse	Quantitative	SEM	μm (width)	N	ProRoot MTA and Clearfil AP presented the best adaptation results
Munhoz *et al.*, 2011 (45)	Transverse	Quantitative	SEM, 3D profilometry	μm (depth) and μm^2 (area)	50×, 150×	WMTA Angelus presented the best adaptation results
Shahi *et al.*, 2011 (46)	Transverse	Quantitative	SEM	μm (width)	16×	ProRoot GMTA presented the best results and followed by white calcium silicate cement clinker
Almeida *et al.*, 2012 (47)	Transverse	Qualitative	SEM	N	70×, 500×	No difference was found among materials
Oliveira *et al.*, 2013 (48)	Transverse	Qualitative	SEM	Score	100×, 500×	No difference was found among materials
Rosa *et al.*, 2014 (49)	Longitudinal	Quantitative	SEM	Percentage (area)	100×	WMTA Angelus and calcium silicate cement clinker presented the best adaptation results
Shokouhinejad *et al.*, 2014 (9)	Transverse, longitudinal	Quantitative	SEM	μm (width)	30×, 500×	No difference was found among materials
De Conto *et al.*, 2014 (50)	Transverse, longitudinal	Quantitative, qualitative	SEM, Digital radiography	μm, score	2000×	WMTA Angelus presented the best adaptation results
Ravichandra *et al.*, 2014 (10)	Transverse	Quantitative	CLSM	μm^2 (area)	10×	Biodentine presented the best results and followed by ProRoot WMTA
Soundappan *et al.*, 2014 (11)	Transverse	Quantitative	SEM	μm (width)	1000×	ProRoot MTA and IRM presented the best adaptation results
Mokhtari *et al.*, 2015 (51)	Transverse	Quantitative	SEM	N	N	No difference was found among materials
Bolhari *et al.*, 2015 (12)	Transverse	Quantitative	SEM	μm (width)	200×	No difference was found among materials
Kim *et al.*, 2016 (52)	Three dimensional analysis	Quantitative	Micro-CT	Percentage (volume)	NA	ProRoot MTA presented superior adaptation
Küçükkaya Eren *et al.*, 2017 (53)	Longitudinal	Quantitative, qualitative	SEM	Percentage (area), score	130×	No difference was found among materials

Y, reported in the article; N, not reported in the article; NA, not applicable; MTA, mineral trioxide aggregate.

Table 3 Detailed information regarding the tested materials in included studies

Tested materials	Classification of materials	Manufacturers' details
Amalgam	A liquid mercury and metal alloy mixture	1. Logic+™ SDI, Bayswater, Vic., Australia 2. Amalcap, Vivadent, Liechtenstein
Bioaggregate	Calcium silicate-based cement	Innovative BioCeramix, Vancouver, Canada
Biodentine	Calcium silicate-based cement	Septodont, Saint-Maur-des-Fosses, France
Cavalite	Compomer	Kerr, Rastatt, Germany
CEM	Calcium silicate-based cement	Bionique Dent, Tehran, Iran
Clearfil AP	Composite resin	Kuraray, Osaka, Japan
Endosequence Root Repair Putty/Paste	Calcium silicate-based cement	Brasseler, Savannah, GA, USA
Epiphany/Resilon	Synthetic polymer-based root canal filling material	Pentron Clinical Technologies, Wallingford, CT, USA
Fuji Ortho LC	Glass ionomer cement	GC America Inc., Alsip. IL, USA
Glass ionomer cement type II	Glass ionomer cement	GC United Kingdom, Coopers Court, Newport Pagnell, UK
Gray calcium silicate cement clinker	Calcium silicate-based cement	Sufiyan Cement company, Tabriz, Iran
IRM	Zinc oxide based cement	1. LD Caulk Co., Mildford, DE, USA 2. Dentsply, Konsztanz, Germany
Mineral trioxide aggregate (MTA) Angelus	Calcium silicate-based cement	Londrina, PR, Brazil
Calcium silicate cement clinker	Calcium silicate-based cement	Votorantin, Sao Paulo, SP, Brazil
ProRoot MTA	Calcium silicate-based cement	Dentsply Maillefer, Ballaigues, Switzerland
Sealer 26	Resin based sealer	Dentsply Ind. e Com. Ltda., Petropolis, RJ, Brazil
Super EBA	Zinc oxide based cement	Harry J. Bosworth, Skokie, IL, USA
Vitrebond	Glass ionomer cement	3M ESPE, St. Paul, MN, USA
Vitremer	Glass ionomer cement	3M ESPE, St. Paul, MN, USA
White calcium silicate cement clinker	Calcium silicate-based cement	1. CPB40, Votorantin, São Paulo, SP, Brazil 2. Tehran cement Company, Tehran, Iran

while MTA was better than glass ionomer cement (GIC) (10). In nine studies, the colour of MTA was not specified (11,12,20,21,43,44,48,51–53,55).

Risk of bias

All 20 included studies were assessed for the risk of bias (Table 4) and only 1 (5%) showed low risk of bias, whereas 4 (20%) presented medium risk. The majority of the studies (75%) showed high risk.

Discussion

Endodontic surgery has undergone many changes over the past decades with the use of microscopes, microinstruments and biomaterials. These advancements have been adopted widely and represent contemporary procedures that produce more predictable outcomes compared with traditional techniques. Therefore, to highlight the studies that were designed according to contemporary concepts, the criteria were set to include studies that prepared the root-end cavities with ultrasonic tips and exclude the ones that used burs. In addition, as the introduction of MTA is a benchmark of modern endodontic surgery (2), only the studies that used MTA as one of the root-end filling materials were included in the present review.

Although adaptation of the filling materials was the common outcome measured in the included studies, it was not feasible to perform a meta-analysis due to the heterogeneity among the studies. The unit of gap measurement varied which was defined as either score, length, width, depth, area, volume or percentages of one of these units. Also, the analyses were performed under different magnification between 10× and 2000×. Furthermore, the analysed surfaces (transverse or longitudinal) also varied among the studies. This variability made comparison difficult.

In this systematic review, SEM analysis was the most commonly used technique for the evaluation of marginal adaptation of root-end filling materials (9–12,20,21,43–51,54,55). The main reasons for its popularity is its ability to provide high magnification and good resolution. However, the process of SEM preparation may affect the results because of the high vacuum evaporation and dehydration of the coating process of biological samples that can cause development of artefacts such as cracks in hard tissues and separation or lifting of the filling materials from the surrounding tooth structure (25). To overcome these problems, the

Table 4 Bias risk of individual studies

Studies	Sample size calculation	Teeth randomisation	Single operator	Operator experience
Peters&Peters, 2002 (20)	N	Y	N	N
Gondim *et al.*, 2003 (21)	N	Y	Y	N
Xavier *et al.*, 2005 (43)	N	Y	N	N
Tobón-Arroyave *et al.*, 2007 (23)	N	Y	Y	N
Costa *et al.*, 2008 (54)	N	Y	N	N
Gomes *et al.*, 2009 (55)	N	Y	N	N
Rosales-Leal *et al.*, 2011 (44)	N	Y	N	N
Munhoz *et al.*, 2011 (45)	N	N	N	N
Shahi *et al.*, 2011 (46)	N	Y	N	N
Almeida *et al.*, 2012 (47)	N	Y	N	N
Oliveira *et al.*, 2013 (48)	N	Y	N	N
Rosa *et al.*, 2014 (49)	N	Y	N	N
Shokouhinejad *et al.*, 2014 (9)	N	Y	N	N
De Conto *et al.*, 2014 (50)	N	Y	N	N
Ravichandra *et al.*, 2014 (10)	N	Y	N	N
Soundappan *et al.*, 2014 (11)	N	Y	N	N
Mokhtari *et al.*, 2015 (51)	N	Y	N	N
Bolhari *et al.*, 2015 (12)	N	Y	N	N
Kim *et al.*, 2016 (52)	N	Y	Y	N
Küçükkaya Eren *et al.*, 2017 (53)	N	Y	N	N

Studies	Manufacturer's instructions	Magnification used during specimen preparation	Blinding of the evaluator	Classification
Peters&Peters, 2002 (20)	N	Y	N	High
Gondim *et al.*, 2003 (21)	Y	Y	N	Moderate
Xavier *et al.*, 2005 (43)	Y	N	N	High
Tobón-Arroyave *et al.*, 2007 (23)	Y	Y	Y	Low
Costa *et al.*, 2008 (54)	Y	N	N	High
Gomes *et al.*, 2009 (55)	Y	N	N	High
Rosales-Leal *et al.*, 2011 (44)	N	N	N	High
Munhoz *et al.*, 2011 (45)	N	Y	Y	High
Shahi *et al.*, 2011 (46)	N	N	N	High
Almeida *et al.*, 2012 (47)	Y	Y	Y	Moderate
Oliveira *et al.*, 2013 (48)	Y	N	N	High
Rosa *et al.*, 2014 (49)	Y	N	Y	Moderate
Shokouhinejad *et al.*, 2014 (9)	Y	N	N	High
De Conto *et al.*, 2014 (50)	Y	N	N	High
Ravichandra *et al.*, 2014 (10)	Y	N	N	High
Soundappan *et al.*, 2014 (11)	Y	N	N	High
Mokhtari *et al.*, 2015 (51)	Y	N	N	High
Bolhari *et al.*, 2015 (12)	Y	N	N	High
Kim *et al.*, 2016 (52)	N	Y	Y	Moderate
Küçükkaya Eren *et al.*, 2017 (53)	Y	N	N	High

Y, reported in the article; N, not reported in the article.

replication technique was used by some of the included studies (9,12,20,21,44,54). In this technique, an impression of the resected root-end is taken and an epoxy resin is poured into the impression to obtain a resin replica that may be more resistant than natural teeth to the preparation procedures. Another drawback of SEM evaluation is that it gives no three dimensional information and therefore only linear or area analysis can be performed. One study used a 3D profilometer that provided colour axonometric images of the surface representing each depth with different colours (45). However, a 3D model of the total volume of the root-end filling material cannot be obtained with 3D profilometry. According to that study, 3D profilometry produced similar results to the SEM regarding the marginal adaptation (45). Only one study evaluated adaptation using micro-CT, and MTA presented better quality than Super-EBA (52).

Based on the results of the present review, MTA was superior in terms of marginal adaptation by showing good performance in most of the studies (9,11,12, 20,21,43–53,55). The success of MTA can be related to its bioactivity by promoting apatite deposition in tissue fluid which improves the sealing ability and contributes to filling the marginal porosities around restorations (57). Besides bioactivity, another property of a root-end filling material can also affect the marginal adaptation is viscosity. Materials with low viscosity can penetrate into irregularities and open dentinal tubules on the prepared surfaces (58,59). However, penetration into tubules is not only dependant on the viscosity of the material but also on the particle size of the material. Fine particles of MTA have the potential to penetrate into open tubules (60). Despite the favourable results in most of the studies, in two studies MTA presented inferior adaptation results compared with other materials (23,54). The different results among the studies could be related to the variability in the study designs. The storage time and storage conditions following the placement of filling materials may affect the results of the adaptation analysis. It was well-established that MTA requires moisture and time for its complete setting (7). As shown in Table 2, the filling materials were stored in a moist environment for at least 24 h in most of the studies. Importantly, the materials were not stored in a moist environment in the two studies that associated MTA with inferior results (23,42). In most of the studies, the materials were prepared according to the manufacturers' instructions. The differences in the preparation of the materials including different powder-liquid ratios, curing periods and mixing techniques could also affect adaptation. Marginal adaptation of the filling materials to dentine walls may not be only dependent on the material properties, but also on the condition of the cavity surfaces. Although ultrasonic tips work under continuous irrigation, debris may persist in the cavity after the preparation procedure (61). To obtain a clean root-end cavity free from dentine chips and gutta-percha, it may be necessary to perform additional irrigation after root-end cavity preparation. In only six studies included in the present review, the root-end cavities were cleaned before the placement of the materials (10,20,21,23,46,47). According to the outcomes of these studies, it is not possible to directly correlate the cleanliness of root-end cavity and marginal adaptation quality of the materials.

No significant differences were found among calcium silicate-based materials in three studies (9,12,53). This can be explained by the similar composition and characteristics of calcium silicate-based materials such as dimensional stability, porosity and particle size (62–64). On the other hand, in one study, Biodentine presented better adaptation results than MTA (10), while in another MTA showed better adaptation than Biodentine (11). Conflicting results could be related to the methodological differences. In the former study (10), the filling materials were evaluated under 10× magnification with confocal laser scanning microscopy in terms of the amount of gap area while in the latter study (11), the evaluation was performed under 1000× magnification using SEM in terms of the amount of gap width. Furthermore, the influence of the operator could affect outcomes. Importantly, none of the included studies reported details regarding the operator experience or calibration of the operator before the experiments and the majority of them (85%) failed to report that the procedures were performed by a single operator.

In clinical outcome studies, MTA exhibited a higher healing rate than resin composite fillings (65), while presented similar success rates to Super EBA or IRM when used as root-end filling materials (66–68). Moreover, the clinical performance of MTA was comparable to another calcium silicate-based material in a randomised controlled study (69). Based on the findings of the present review, Super-EBA or IRM presented inferior marginal adaptation than MTA in the five included studies (21,43,49,52,55), while no significant difference was found among the materials in four studies (11,20,47,48). In one study, Super EBA and IRM were associated with better outcome compared with MTA in terms of adaptation (23). Consequently, the adaptation property of a filling material may not be a significant factor affecting clinical outcome, which implies that other clinical factors exist that contribute to controlling intraradicular infection. A recent systematic review that aimed to clarify the clinical effect and safety of different materials for root-end filling revealed that more high-quality randomised controlled trials are required to determine the benefits of any one material over another (70). As no *in vivo* study was identified in the present systematic review, clinical studies are necessary to obtain information on the relation between the clinical outcome and the adaptation property of root-end filling materials. It should be noted that there are difficulties in performing such studies including patient factors (health, habits, age and gender) and tooth-related factors (type, quality of previous endodontic treatment, status of present restoration, the presence and size of the lesion), which are usually beyond the operator's control unlike the treatment-related factors (material selection and surgical technique) (71). These factors must be considered in the planning of clinical studies. Moreover, experience and expertise of the operator could be one of the key factors influencing the success or failure of endodontic surgery (72). Hence, standardisation of study design and outcome criteria should increase the quality of work and provide more powerful data regarding outcomes.

Overall, MTA adapted well to dentine walls in most studies. However, standardisation in the design of these studies is lacking. The literature is also lacking on the clinical relevance of adaptation of root-end filling materials but does imply the existence of other, as yet unidentified factors that affect biological outcome.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors. The authors deny any conflicts of interest related to this study.

Authorship declaration

All authors have contributed significantly, and are in agreement with the manuscript.

Conflicts of interest

The authors deny any conflicts of interest related to this study.

References

1. el-Swiah JM, Walker RT. Reasons for apicectomies. A retrospective study. Endod Dent Traumatol 1996; 12: 185–91.
2. Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. J Endod 2006; 32: 601–23.
3. Johnson BR. Considerations in the selection of a root-end filling material. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999; 87: 398–404.
4. Plotino G, Pameijer CH, Grande NM, Somma F. Ultrasonics in endodontics: a review of the literature. J Endod 2007; 33: 81–95.
5. Setzer FC, Shah SB, Kohli MR, Karabucak B, Kim S. Outcome of endodontic surgery: a meta-analysis of the literature–part 1: Comparison of traditional root-end surgery and endodontic microsurgery. J Endod 2010; 36: 1757–65.
6. Torabinejad M, Watson TF, Pitt Ford TR. Sealing ability of a mineral trioxide aggregate when used as a root end filling material. J Endod 1993; 19: 591–5.
7. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review–Part I: Chemical, physical, and antibacterial properties. J Endod 2010; 36: 16–27.
8. Orosco FA, Bramante CM, Garcia RB, Bernardineli N, de Moraes IG. Sealing ability, marginal adaptation and their correlation using three root-end filling materials as apical plugs. J Appl Oral Sci 2010; 18: 127–34.
9. Shokouhinejad N, Nekoofar MH, Ashoftehyazdi K, Zahraee S, Khoshkhounejad M. Marginal adaptation of new bioceramic materials and mineral trioxide aggregate: a scanning electron microscopy study. Iran Endod J 2014; 9: 144–8.
10. Ravichandra PV, Harikumar V, Deepthi K *et al.* Comparative evaluation of marginal adaptation of Biodentine(TM) and other commonly used root end filling materials-an invitro study. J Clin Diagn Res 2014; 8: 243–5.
11. Soundappan S, Sundaramurthy JL, Raghu S, Natanasabapathy V. Biodentine versus mineral trioxide aggregate versus intermediate restorative material for retrograde root end filling: an invitro study. J Dent (Tehran) 2014; 11: 143–9.
12. Bolhari B, Ashofteh Yazdi K, Sharifi F, Pirmoazen S. Comparative scanning electron microscopic study of the marginal adaptation of four root-end filling materials in presence and absence of blood. J Dent (Tehran) 2015; 12: 226–34.
13. Abdal AK, Retief DH. The apical seal via the retrosurgical approach. I.A. preliminary study. Oral Surg Oral Med Oral Pathol 1982; 53: 614–21.
14. Chong BS, Pitt Ford TR, Watson TF, Wilson RF. Sealing ability of potential retrograde root filling materials. Endod Dent Traumatol 1995; 11: 264–9.
15. Delivanis P, Tabibi A. A comparative sealability study of different retrofilling materials. Oral Surg Oral Med Oral Pathol 1978; 45: 273–81.
16. Mattison GD, von Fraunhofer JA, Delivanis PD, Anderson AN. Microleakage of retrograde amalgams. J Endod 1985; 11: 340–5.
17. Yoshimura M, Marshall FJ, Tinkle JS. *In vitro* quantification of the apical sealing ability of retrograde amalgam fillings. J Endod 1990; 16: 5–12.
18. Wu MK, Wesselink PR. Endodontic leakage studies reconsidered. Part I. Methodology, application and relevance. Int Endod J 1993; 26: 37–43.
19. Stabholz A, Friedman S, Abed J. Marginal adaptation of retrograde fillings and its correlation with sealability. J Endod 1985; 11: 218–23.
20. Peters CI, Peters OA. Occlusal loading of EBA and MTA root-end fillings in a computer-controlled masticator: a scanning electron microscopic study. Int Endod J 2002; 35: 22–9.
21. Gondim E, Zaia AA, Gomes BP, Ferraz CC, Teixeira FB, Souza-Filho FJ. Investigation of the marginal adaptation of root-end filling materials in root-end cavities prepared with ultrasonic tips. Int Endod J 2003; 36: 491–9.
22. Gartner AH, Dorn SO. Advances in endodontic surgery. Dent Clin North Am 1992; 36: 357–78.
23. Tobon-Arroyave SI, Restrepo-Perez MM, Arismendi-Echavarria JA, Velasquez-Restrepo Z, Marin-Botero ML, Garcia-Dorado EC. *Ex vivo* microscopic assessment of factors affecting the quality of apical seal created by root-end fillings. Int Endod J 2007; 40: 590–602.

24. Liberati A, Altman DG, Tetzlaff J *et al.* The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ 2009; 339: b2700.
25. Torabinejad M, Smith PW, Kettering JD, Pitt Ford TR. Comparative investigation of marginal adaptation of mineral trioxide aggregate and other commonly used root-end filling materials. J Endod 1995; 21: 295–9.
26. Shipper G, Grossman ES, Botha AJ, Cleaton-Jones PE. Marginal adaptation of mineral trioxide aggregate (MTA) compared with amalgam as a root-end filling material: a low-vacuum (LV) versus high-vacuum (HV) SEM study. Int Endod J 2004; 37: 325–36.
27. Bidar M, Moradi S, Jafarzadeh H, Bidad S. Comparative SEM study of the marginal adaptation of white and grey MTA and PC. Aust Endod J 2007; 33: 2–6.
28. Badr AE. Marginal adaptation and cytotoxicity of bone cement compared with amalgam and mineral trioxide aggregate as root-end filling materials. J Endod 2010; 36: 1056–60.
29. Baranwal AK, Paul ML, Mazumdar D, Adhikari HD, Vyavahare NK, Jhajharia K. An ex-vivo comparative study of root-end marginal adaptation using grey mineral trioxide aggregate, white mineral trioxide aggregate, and PC under scanning electron microscopy. J Conserv Dent 2015; 18: 399–404.
30. Gundam S, Patil J, Venigalla BS, Yadanaparti S, Maddu R, Gurram SR. Comparison of marginal adaptation of mineral trioxide aggregate, glass ionomer cement and intermediate restorative material as root-end filling materials, using scanning electron microscope: an *in vitro* study. J Conserv Dent 2014; 17: 566–70.
31. Amoroso-Silva PA, Marciano MA, Guimaraes BM, Duarte MA, Sanson AF, Moraes IG. Apical adaptation, sealing ability and push-out bond strength of five root-end filling materials. Braz Oral Res 2014; 28: 1–6.
32. Nagesh B, Jeevani E, Sujana V, Damaraju B, Sreeha K, Ramesh P. Scanning electron microscopy (SEM) evaluation of sealing ability of MTA and EndoSequence as root-end filling materials with chitosan and carboxymethyl chitosan (CMC) as retrograde smear layer removing agents. J Conserv Dent 2016; 19: 143–6.
33. Bors A, Szekely M, Molnar-Varlam C, Antoniac I. Bioactivity of retrograde dental root filling materials. Key Eng Mater 2016; 695: 236–42.
34. Radwan MM, Khallaf ME, Kataia EM. Formulation and characterization of a calcium silicate/calcium phosphate root end filling material; Part II: Adaptability and in-vivo biocompatibility study. Res J Pharm Biol Chem Sci 2016; 7: 2474–80.
35. Sullivan J, Pileggi R, Varella C. Evaluation of root-end resections performed by Er, Cr: YSGG laser with and without placement of a root-end filling material. Int J Dent 2009; 2009: 798786.
36. Zerbinati LP, Tonietto L, de Moraes JF, de Oliveira MG. Assessment of marginal adaptation after apicoectomy and apical sealing with Nd:YAG laser. Photomed Laser Surg 2012; 30: 444–50.
37. Al-Fouzan K, Al-Garawi Z, Al-Hezaimi K, Javed F, Al-Shalan T, Rotstein I. Effect of acid etching on marginal adaptation of mineral trioxide aggregate to apical dentin: microcomputed tomography and scanning electron microscopy analysis. Int J Oral Sci 2012; 4: 202–7.
38. Ghorbanzadeh A, Shokouhinejad N, Fathi B, Raoof M, Khoshkhounejad M. An *in vitro* comparison of marginal adaptation of MTA and MTA-like materials in the presence of PBS at one-week and two-month intervals. J Dent (Tehran) 2014; 11: 560–8.
39. Formosa LM, Damidot D, Camilleri J. Mercury intrusion porosimetry and assessment of cement-dentin interface of anti-washout-type mineral trioxide aggregate. J Endod 2014; 40: 958–63.
40. Gandolfi MG, Sauro S, Mannocci F *et al.* New tetrasilicate cements as retrograde filling material: an *in vitro* study on fluid penetration. J Endod 2007; 33: 742–5.
41. Gandolfi MG, Taddei P, Siboni F, Modena E, Ciapetti G, Prati C. Development of the foremost light-curable calcium-silicate MTA cement as root-end in oral surgery. Chemical-physical properties, bioactivity and biological behavior. Dent Mater 2011; 27: e134–57.
42. Costa AT, Konrath F, Dedavid B, Weber JB, de Oliveira MG. Marginal adaptation of root-end filling materials: an *in vitro* study with teeth and replicas. J Contemp Dent Pract 2009; 10: 75–82.
43. Xavier CB, Weismann R, de Oliveira MG, Demarco FF, Pozza DH. Root-end filling materials: apical microleakage and marginal adaptation. J Endod 2005; 31: 539–42.
44. Rosales-Leal JI, Olmedo-Gaya V, Vallecillo-Capilla M, Luna-del Castillo JD. Influence of cavity preparation technique (rotary vs. ultrasonic) on microleakage and marginal fit of six end-root filling materials. Med Oral Patol Oral Cir Bucal 2011; 16: e185–9.
45. Munhoz MF, Marchesan MA, Cardoso DR, Silva SR, Silva-Sousa YT, Sousa-Neto MD. Quantitative 3D profilometry and SEM analysis of the adaptation of root-end filling materials placed under an optical microscope. Int Endod J 2011; 44: 560–6.
46. Shahi S, Yavari HR, Eskandarinezhad M, Kashani A, Rahimi S, Sadrhaghighi H. Comparative investigation of marginal adaptation of mineral trioxide aggregate (MTA) and PC as root-end filling materials: a scanning electron microscopy (SEM) study. Afr J Biotechnol 2011; 10: 16084–8.
47. Almeida BM, Abad EC, Sampaio Filho HR, Zoffoli JO. *In vitro* evaluation of dentin marginal adaptation of three root-end filling materials inserted with and without surgical microscope. Dent Press Endod 2012; 2: 20–5.
48. Oliveira HF, Goncalves Alencar AH, Poli Figueiredo JA, Guedes OA, de Almeida Decurcio D, Estrela C. Evaluation

of marginal adaptation of root-end filling materials using scanning electron microscopy. Iran Endod J 2013; 8: 182–6.

49. Rosa RA, Santini MF, Heiden K *et al.* SEM evaluation of the interface between filling and root-end filling materials. Scanning 2014; 36: 252–7.
50. De Conto F, Ericson Flores M, Cucco C, Prates Soares Zerbinati L, Dedavid BA, Gerhardt De Oliveira M. A comparative study of materials and storage modes for human teeth in apicoectomy: scanning electron microscopy analysis. Minerva Stomatol 2014;63:95–102.
51. Mokhtari F, Modaresi J, Javadi G, Davoudi A, Badrian H. Comparing the marginal adaptation of cold ceramic and mineral trioxide aggregate by means of scanning electron microscope: an *in vitro* study. J Int Oral Health 2015; 7: 7–10.
52. Kim M, Kim H, Sangwon K, Yoon TC, Kim E. Effect of Nd: YAG laser irradiation on adherence of retrograde filling materials: evaluation by micro- computed tomography. J Korean Dent Assoc 2016; 54: 865–73.
53. Küçükkaya Eren S, Gorduysus MO, Sahin C. Sealing ability and adaptation of root-end filling materials in cavities prepared with different techniques. Microsc Res Tech 2017; 80: 756–62.
54. Costa AT, Post LK, Xavier CB, Weber JB, Gerhardt-Oliveira M. Marginal adaptation and microleakage of five root-end filling materials: an *in vitro* study. Minerva Stomatol 2008; 57: 295–300.
55. Gomes CC, Accetta RF, Gomes Camoes IC, Freitas FL, Pinto SS. Marginal adaptation of root-end filling materials. Pesqui Bras Odontopediatr Clin Integr 2009; 9: 31–5.
56. Camargo Villela Berbert FL, de Faria-Junior NB, Tanomaru-Filho M *et al.* An *in vitro* evaluation of apicoectomies and retropreparations using different methods. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;110:e57–63.
57. Gandolfi MG, Taddei P, Tinti A, Prati C. Apatite-forming ability (bioactivity) of ProRoot MTA. Int Endod J 2010; 43: 917–29.
58. Winik R, Araki AT, Negrao JA, Bello-Silva MS, Lage-Marques JL. Sealer penetration and marginal permeability after apicoectomy varying retrocavity preparation and retrofilling material. Braz Dent J 2006; 17: 323–7.
59. Shokouhinejad N, Razmi H, Fekrazad R *et al.* Push-out bond strength of two root-end filling materials in root-end cavities prepared by Er, Cr:YSGG laser or ultrasonic technique. Aust Endod J 2012; 38: 113–7.
60. Komabayashi T, Spangberg LS. Comparative analysis of the particle size and shape of commercially available mineral trioxide aggregates and PC: a study with a flow particle image analyzer. J Endod 2008; 34: 94–8.
61. Khabbaz MG, Kerezoudis NP, Aroni E, Tsatsas V. Evaluation of different methods for the root-end cavity preparation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004; 98: 237–42.
62. Asgary S, Shahabi S, Jafarzadeh T, Amini S, Kheirieh S. The properties of a new endodontic material. J Endod 2008; 34: 990–3.
63. Camilleri J, Grech L, Galea K *et al.* Porosity and root dentine to material interface assessment of calcium silicate-based root-end filling materials. Clin Oral Investig 2014; 18: 1437–46.
64. El-Ma'aita AM, Qualtrough AJ, Watts DC. The effect of smear layer on the push-out bond strength of root canal calcium silicate cements. Dent Mater 2013;29:797–803.
65. von Arx T, Hanni S, Jensen SS. 5-year results comparing mineral trioxide aggregate and adhesive resin composite for root-end sealing in apical surgery. J Endod 2014; 40: 1077–81.
66. Song M, Kim E. A prospective randomized controlled study of mineral trioxide aggregate and super ethoxy-benzoic acid as root-end filling materials in endodontic microsurgery. J Endod 2012; 38: 875–9.
67. Chong BS, Pitt Ford TR, Hudson MB. A prospective clinical study of Mineral Trioxide Aggregate and IRM when used as root-end filling materials in endodontic surgery. Int Endod J 2003; 36: 520–6.
68. Kim S, Song M, Shin SJ, Kim E. A randomized controlled study of mineral trioxide aggregate and super ethoxybenzoic acid as root-end filling materials in endodontic microsurgery: long-term outcomes. J Endod 2016; 42: 997–1002.
69. Zhou W, Zheng Q, Tan X, Song D, Zhang L, Huang D. Comparison of mineral trioxide aggregate and iRoot BP Plus root repair material as root-end filling materials in endodontic microsurgery: a prospective randomized controlled study. J Endod 2017; 43: 1–6.
70. Ma X, Li C, Jia L *et al.* Materials for retrograde filling in root canal therapy. Cochrane Database Syst Rev 2016; (12):CD005517.
71. von Arx T, Penarrocha M, Jensen S. Prognostic factors in apical surgery with root-end filling: a meta-analysis. J Endod 2010; 36: 957–73.
72. Carrotte P. Surgical endodontics. Br Dent J 2005; 198: 71–9.

