Till Dammaschke

Calcium silicate-based sealers: The end of thermoplastic obturation?

Abstract: All obturation techniques require a certain amount of root canal sealers in order to fill small irregularities along the canal wall. Epoxy resin-based sealers have been the gold standard to date. A more recent development is represented by calcium silicate-based sealers (CSS), which derive from calcium silicate-based cements (MTA). CSS are proven to be biocompatible and bioactive. A hydroxyapatite-like precipitate forms on the surface of CSS when they come in contact with tissue fluid so that these sealers are not recognized as foreign bodies, even in cases of sealer extrusion. After their setting, CSS release OH^- and Ca^{2+} ions over a longer period of time through which they potentially exhibit certain antibacterial effects and support the healing of periapical inflammation. For this reason, consideration has been given to the idea of filling root canals mainly with CSS and minimizing the proportion of gutta-percha. To date, however, no long-term clinical studies have been performed to confirm the advantages of this new concept.

Although gutta-percha has been successfully used for root canal obturation for a very long time, there are different perspectives with regard to which root canal filling technique is better: cold or warm (thermoplastic) obturation. After the exposure of sufficiently filled root canals with saliva, microorganisms always infiltrate into the root canal system regardless of the obturation method. Until now, no known obturation method leads to a bacteria-proof sealing of the root canal. Thus, in terms of clinical success rates, no superiority of the frequently recommended thermoplastic root canal filling technique compared with cold lateral compaction could be demonstrated.

As a rule, CSS are not approved for thermoplastic obturation, as these sealers are water-based; there is the concern that high temperatures of up to 200 °C will remove too much water from the sealer, which can have a negative impact on its properties. It is questionable whether such high temperatures are clinically achieved during thermoplastic obturation.

A disadvantage of CSS is their higher solubility compared to epoxy resin sealers. In the long term, this can lead to the dissolution of the root canal filling. In the studies that have been performed to date, however, no difference in the clinical success rates between epoxy resin sealers and CSS has been determined. Overall, CSS represent an interesting alternative to conventional root canal sealers. In principle, the success of a root canal treatment depends not only on the obturation technique, but above all, on the complete removal of the infected tissue, the permanent disinfection of the root canal system and the bacteria-proof post-endodontic restoration.

Keywords: calcium silicate; thermoplastic obturation; root canal filling techniques; root canal sealer

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Translation from German: Cristian Miron
Citation: Dammaschke T: Calcium silicate-based sealers: The end of thermoplastic obturation? Dtsch Zahnärztl Z Int 2021; 3: 71–79
Peer-reviewed article: submitted: 16.07.2020, revised version accepted: 12.08.2020
DOI.org/10.3238/dzz-int.2021.0009

1. Introduction

Epoxy resin-based sealers such as AH Plus (Dentsply Sirona, Konstanz, Germany) have become the standard material for root canal obturation in case of both cold and warm obturation methods. Currently, they are considered to be the "gold standard" among root canal sealers [26]. However, these sealers have a major disadvantage: they are not bioactive [21]. Moreover, epoxy resin-based sealers show a certain toxicity during setting, but after curing, prove to be virtually insoluble and non-cytotoxic [29, 30]. Thus, extrusion of epoxy sealers does not normally cause harmful reactions of the periapical tissue, except in cases where the sealer is displaced into the mandibular nerve canal, where this root canal filling paste – like all other sealers – has a neurotoxic effect [24].

The latest development in the field of sealers is calcium silicate-based root canal filling pastes. The goal is to make use of the known positive properties, particularly biocompatibility and bioactivity, of calcium silicate-based cements such as Mineral Trioxide Aggregate (MTA; e.g. ProRoot MTA, Dentsply Sirona, Ballaigues, Switzerland; MTA-Angelus, Angelus, Londrina, Brazil) or Biodentine (Septodont, Saint-Maur-des-Fossés, France) for conventional orthograde root canal fillings. The main components are di- and/or tricalcium silicates, which is why these root canal filling pastes are also referred to as "calcium silicate-based sealers" (CSS) [14] (Fig. 1 and 2). Often, the term "bioceramic" is used incorrectly in context with these calcium silicate-based sealers [50]. More specifically, these sealers can be considered "hydraulic" because they set in contact with both air and water [5]. CSS even require water to set completely. In contrast to conventional sealers, calcium silicate-based sealers do not require that the root canal lumen is as dry as possible in order to ensure optimal setting conditions. The setting properties of CSS are not affected by the presence of residual moisture in the root canal [16].

Figure 1 Calcium silicate-based sealers (CSS) can be divided into 2 dosage forms: premixed, one-component ready-to-use CSS in syringes and two-component CSS made of powder and water or 2 pastes, which need to be mixed before use. An example of a one-component MTA-based sealer containing calcium silicate (EndoSeal MTA; Maruchi, Wonju, Korea) for direct application into the root canal.

Calcium hydroxide is formed during the setting of CSS, which is known to trigger biological healing processes [10, 49]. CSS are therefore bioactive. In contact with simulated body fluid, the formation of a hydroxyapatite-like surface has also been reported for CSS [36, 45]. Since this layer does not cause a foreign body reaction, CSS can be considered biocompatible, even when they are extruded at the apex or when they come in contact with periapical tissues.

In comparison to other root canal sealers, CSS are thus biocompatible and bioactive [29, 30] (Fig. 3 and 4). In terms of biocompatibility and bioactivity, CSS are clearly superior to other sealers, which can be advantageous for the treatment outcome [16]. For this reason, consideration has been given to deviate from the previous treatment concept of "as much gutta-percha and as little sealer as possible", and instead, to fill root canals mainly (but not exclusively) with CSS. Gutta-percha should only be introduced into the root canal using the single cone technique – regardless of the fit – in order to make the most of the biological effects of CSS. However, long-term clinical studies are not yet available to confirm the advantages of this new concept.

The aim of this review article is to elucidate the new CSS within the framework of the various root canal filling techniques that employ gutta-percha such as the single cone, lateral compaction and thermoplastic obturation as well as to present the current state of research.

2. Gutta-percha

Gutta-percha has been successfully used for root canal obturation for well over 120 years. The material is virtually insoluble, inert, biocompatible, has a weak antibacterial effect due to its zinc oxide content, can be cold and warm processed, condensable and dimensionally stable. Although gutta-percha is not perfect for obturation, it is still the material of choice for most root canal fillings [11]. However, it is still controversially discussed as to which root canal filling technique is preferable, particularly with regard to cold versus warm (thermoplastic) obturation with gutta-percha [27]. There is general agreement that all obturation techniques require a certain amount of root canal sealer in order to fill small irregularities along the root canal wall, or more specifically, the lateral or accessory canals and the exposed dentinal tubules, so as to ensure a better adaptation of the gutta-percha to the canal walls. Also, a tight seal between gutta-percha and canal walls is pursued [27]. In performing this, the amount of sealer should be as low as possible. Many commercially available root canal sealers can be used as long as they are (virtually) insoluble, biocompatible (or at least well tolerated by the tissue) in addition to being non-resorbable and non-shrinking during setting [11].

Figure 2 Example of a two-component calcium silicate-based sealer consisting of powder and water (BioRoot RCS; Septodont, Saint-Maur-des-Fossés, France). For powder and water-based sealers, the consistency can be adjusted to match the clinical situation.

3. Cold obturation technique

3.1 Single cone technique

A distinction is made between the single-cone and lateral compaction techniques when performing cold root canal fillings. The goal of the single-cone technique is to insert a precisely fitting gutta-percha cone in combination with a sealer into the root canal in such a way that the entire canal is densely filled. The areas of the root canal where the gutta-percha cone is not marginally adapted should be filled by the sealer [11, 39]. The principal disadvantage of the single-cone technique is that the proportion of sealer in the root canal filling is comparatively high for all root canals which do not exactly match the conical shape of the gutta-percha cone after root canal preparation. Due to the possible shrinkage of some root canal sealers during the setting reaction, a maximum possible proportion of gutta-percha is considered an important factor for successful root canal treatment [32, 48]. Higher proportions of sealer can lead to leakage and bacterial infiltration [6], and thus, impair the success of root canal treatment [4, 15]. This is especially a problem in root canals with an oval root canal shape where a circular preparation cannot be attained [11, 39]. Root canals which have been prepared using manual preparation techniques are also not suitable for the single-cone technique because the shape of the prepared root canal and the gutta-percha cone differ too greatly. Thus, a requirement when using the single-cone technique is the uniform and conical root canal preparation with rotary nickel-titanium instruments; the cone should correspond to the shape of the last instrument used for root canal preparation as closely as possible. This reduces the amount of sealer required. Furthermore, another disadvantage of the single-cone technique is that no compaction of the filling material takes place and irregularities in the canal wall and side canals may not be adequately filled [39]. This means that it is possible for irregular root canal sections or root canal areas, which cannot be reached by mechanical instrumentation, to remain unfilled. Also, air inclusions can arise in the sealer.

3.2 Lateral Compaction

In order to densely and completely fill oval or manually prepared root canals with as much gutta-percha and as little sealer as possible, the goal of lateral compaction is to apply smaller accessory gutta-percha cones into the root canal in addition to the master cone. For this purpose, the cold gutta-percha cone which is already in the root canal is laterally pressed with a finger spreader and compacted into the root canal cross-section to create space for more gutta-percha cones. However, one complication of lateral compaction can be vertical root fractures which are caused by the force applied with the finger spreader. Whether lateral compaction is actually associated with an increased risk of longitudinal fractures when the force is appropriately applied, has not yet been conclusively elucidated. The application of too much force should nevertheless be avoided [27]. Conversely, it is questionable if sufficient sealer is pressed into all areas of the root canal when too little force is applied.

4. Warm (thermoplastic) obturation techniques

Due to the disadvantages of cold root canal filling techniques, warm thermoplastic obturation techniques were recommended to increase the amount of gutta-percha in the filling. Ideally, using this technique, the entire root canal system, including the accessory canals and apical ramifications, can be filled with gutta-percha instead of just sealer. Since the root canal filling is performed under pressure, the heated and thus liquefied gutta-percha is pressed into the side canals in a more or less controlled manner [22, 40]. It is easier, faster and safer to fill wide lumen or irregularly-shaped root canal systems using thermoplastic root canal filling techniques. Even for complex root canal anatomies (e.g. deep branching of root canals) or root canals with a very irregular cross-section (e.g. c-shaped canals; internal granuloma), thermoplastic obturation seems to have a clear advantage [27].

When using the "Continuous Wave Technique" according to Buchanan, a temperature of 200 °C is generally recommended when heating the gutta-percha cone. The applied sealer should therefore be compatible with the thermoplastic obturation and remain stable at the temperature interval used, as this can otherwise lead to chemical deterioration or more serious changes in the material's properties. Conceivable consequences are the clumping together of the sealer or premature or absent setting [27]. In literature, there is controversy regarding which sealer groups are compatible with thermoplastic obturation techniques. For example, it was recommended that sealers containing epoxy resin should only be subjected to a maximum temperature of 100 °C. Otherwise, chemical changes can occur. In contrast, CSS continue to be chemically stable up to 125 °C even if they are not approved by the manufacturers for warm filling techniques. In comparison, sealers containing zinc oxide eugenol are not thermostable at all [3]. In another study, it was also determined that epoxy resin-based sealers are not compatible with thermoplastic obturation techniques – this is in contrast to calcium hydroxide-based sealers [9]. On the other hand, other authors could not find any significant physical or chemical changes in epoxy resin or zinc oxide-eugenol-based sealers through heat treatment [18].

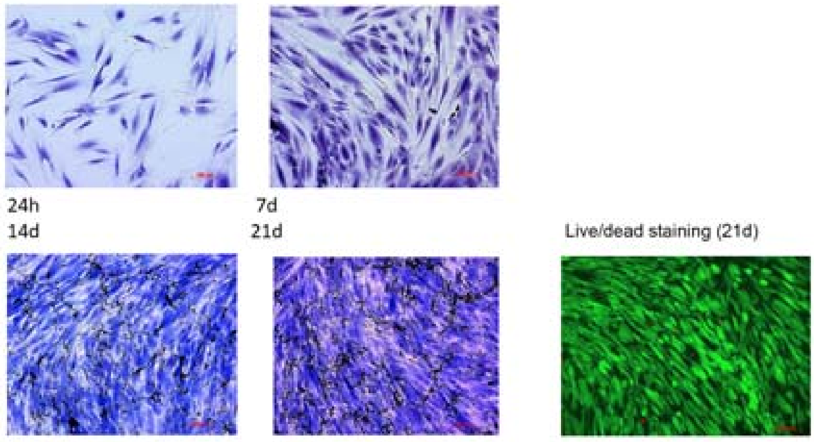

Figure 3 Human osteoblasts after direct contact with an eluate of BioRoot RCS and after up to 21 days in vitro. In the BioRoot RCS group, all osteoblasts survived contact with a 1:2 dilution of the extract and significant cell proliferation was observed. This speaks for the biocompatibility and bioactivity of CSS (Richardson staining and live (green)/dead (red) staining; magnification x 100) [30].

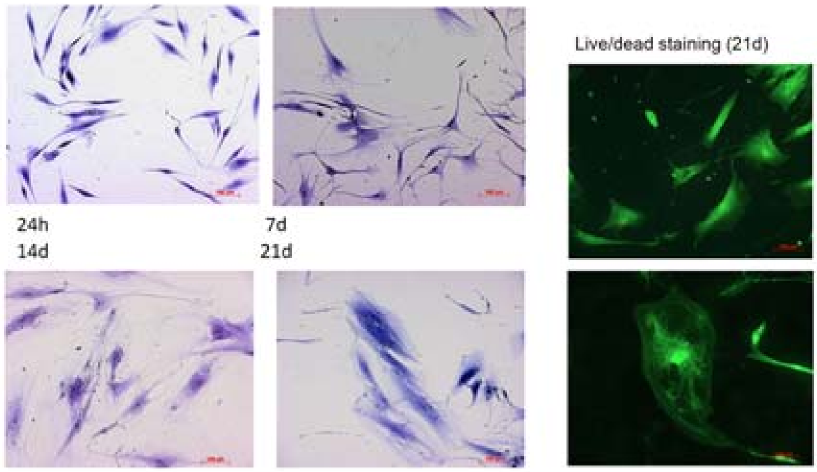

Figure 4 In the AH Plus group (Dentsply Sirona, Konstanz, Germany), almost all human osteoblasts died in the first days after addition of the sealer extract in a 1:10 dilution. In the Richardson stain and the life/death stain, only a few cells were visible after 14 and 21 days, respectively. In contact with AH Plus, the morphology of the osteoblasts was altered; they are enlarged due to a longer incubation time (days 14 and 21; magnification x 100) [30].

5. Cold vs. warm obturation techniques

Whether thermoplastic filling techniques do indeed lead to improved success rates in comparison to the single-cone or lateral compaction techniques is controversially discussed in literature. One study reported a 10 % higher thermoplastic obturation success rate in cases of apical periodontitis in comparison to (cold) lateral compaction [20], although not many studies substantiate this finding, and instead, they show that there is no difference [11]. According to a meta-analysis, cold lateral compaction and thermoplastic root canal filling techniques can be considered equivalent in terms of success rates [35]. Ten clinical studies, 9 of which were randomized, were included in this meta-analysis, where 1748 previously untreated teeth were either obturated using cold lateral compaction or thermoplastically

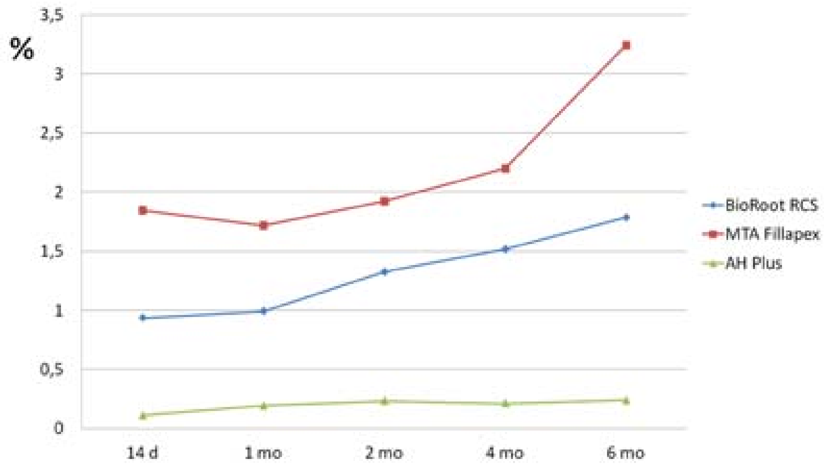

Figure 5 Solubility of BioRoot RCS, MTA Fillapex (Angelus, Londrina, Brazil) and AH Plus in phosphate-buffered saline (PBS) to simulate body fluid The solubility of CSS BioRoot RCS and MTA Fillapex was significantly increased compared to AH Plus. However, the solubility of BioRoot RCS did meet the ISO 6876:2012 requirements of less than 3 % over a 6-month period [45].

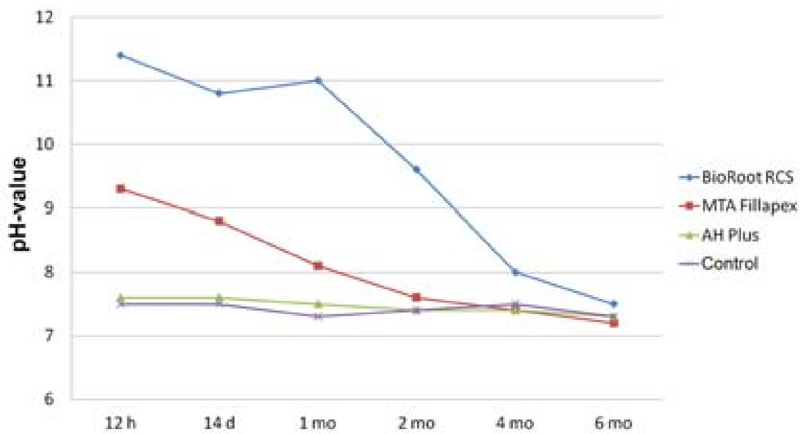

Figure 6 pH values of BioRoot RCS, MTA Fillapex and AH Plus in phosphate buffered saline (PBS) to simulate body fluid. BioRoot RCS maintains a basic pH in phosphate buffered saline for up to 4 months in vitro. This can be explained by the release of OH^- ions from the sealer (control = PBS without sealer) [45].

using warm gutta-percha. An evaluation was performed over a period of 1–5 years. While both methods – cold lateral compaction and thermoplastic obturation – showed statistically similar levels of postoperative complaints, long-term results and filling quality, thermoplastic obturation frequently resulted in significantly more extrusion of the root canal filling material [35].

6. Bacteria-proof root canal fillings

In principle, microleakage compromises the result and success of every root canal treatment [6]. Thus, a root canal filling that is as bacteria-proof as possible is desirable. Yet, no root canal filling technique, neither warm nor cold, has so far been able to achieve a reliable bacteria-proof obturation of the root canal system [31, 41]. After appropriately filled root canals are exposed to saliva, microorganisms penetrate into the root canal system. Within a period of 3–60 days, an exposed root canal filling made of gutta-percha and sealer, which is exposed to the oral environment, exhibits microbial leakage along the root canal filling regardless of the obturation method [31, 41].

Not only bacteria, but also endotoxins are able to penetrate into root canal fillings and produce an inflammation of the periapical tissue. Endotoxins are part of the outer cell membrane of Gram-negative bacteria and are released when these bacteria decompose. Endotoxins may penetrate the root canal filling material faster than bacteria and may trigger an apical inflammatory response [1]. Based on numerous evidence-based studies available to date, it can thus be concluded that the seal of the post-endodontic coronal restoration is just as important for the success of a root canal therapy as the actual root canal filling itself. There is no significant difference between the two factors with regard to the healing chance after root canal treatment [23]. Coronal leakage is considered one of the main causes endodontic treatment failure [1]. Leakage of the coronal restoration is therefore the most likely explanation for the recurrence of apical periodontitis [37] and not the type of root canal filling technique applied and how high the proportion of sealer is.

7. Solubility of calcium silicate based sealers

When weighing the advantages and disadvantages of the various root canal filling techniques that have been presented above, and the idea of deviating from the postulate of "as much gutta-percha and as little sealer as possible" in the case of CSS, an aspect requiring closer examination emerges: although sealers containing epoxy resin are considered nearly insoluble, the solubility of CSS is significantly higher than that of AH Plus for example [36, 45]. This can negatively affect the treatment concept "as much sealer and as little gutta-percha as possible".

According to the ISO 6876:2012 standard, the decrease in sealer weight should be less than 3 % during the initial 24 hours after storage in double-distilled water [28]. Higher solubility has been reported in some studies performed on CSS BioRoot RCS and iRoot SP. Conversely, other publications on iRoot SP, BioRoot RCS, Endoseal MTA and Endo C.P.M. sealer confirm a solubility of less than 3 %. Overall, the data found in literature that relates to this topic has been inconsistent so far [16].

Figure 7 Radiograph after root canal filling with gutta-percha and BioRoot RCS on tooth 16 (cold, lateral compaction).

Figure 8 Radiograph showing apical healing at the mesial root 6 months after root canal treatment on tooth 16.

(Fig. 1–8: T. Dammaschke)

The solubility is in large part dependent on the storage medium. In double-distilled water (as specified in ISO 6876:2012 [28]), the solubility of CSS is significantly higher than in simulated body fluid (phosphate-buffered saline, or PBS) [36, 45]. A long-term study showed that the solubility of a CSS (BioRoot RCS) also met the requirements of ISO 6876:2012 over a period of 6 months when stored in PBS [45] (Fig. 5).

Owing to its solubility, the volume of the CSS decreases within 7 days after being stored in distilled water and PBS. However, no significant difference in void formation was observed between CSS and AH Plus during the storage period [44]. All sealers have voids after root canal filling regardless of the type of sealer used [34]. Although TotalFill BC-Sealer (FKG Dentaire, La Chaux-de-Fonds, Switzerland) has a higher solubility than AH Plus, this CSS showed volumetric stability when evaluated by micro-computer tomography (micro-CT) [43].

In principle, however, the solubility of CSS seems to be associated with a positive biological result due to the release of ions from the sealer [50]. The solubility of the sealers is therefore a double-edged sword. This is because, on the one hand, sealers should be as insoluble as possible in order to tightly seal the root canal for years. On the other hand, it is known that in order to attain bioactive and biocompatible effects, ions from the sealers must dissolve in the surrounding tissue. It is recognized that even in conditions that simulate body fluids in vitro, CSS have high levels of Ca^{2+} and OH^- ion release. But, also silicon ions are released [7, 10, 49]. All of these ions are known to contribute to the healing of apical lesions.

The release of OH^- ions also leads to a basic pH value in vitro for a period of up to 4 months [45] (Fig. 6). This may explain the proven antimicrobial effects of CSS [33, 47, 51]. For example, Endosequence BC-Sealer and BioRoot RCS are effective against E. faecalis, both directly after application and in the set state [8, 33]. CSS are also active against many other microorganisms in the root canal [16]. The antibacterial effect is enhanced through their contact with dentin [8, 47].

With respect to the apical sealing capacity of CSS, the data found in literature has been contradictory so far. Compared to conventional sealers, the new CSS have been certified to have a comparable or even better apical sealing capacity. Conversely, other studies found significantly increased apical microleakage [16]. During the setting process, CSS interact with the surface of root canal wall dentin and this process can continue for months. To what extent this reduces the solubility of a CSS over time and lead to an improvement in the sealing of the root canal can be speculated [42]. Yet, a matter of concern is that, due to a possible dissolution process of the CSS, especially in the apical third, a recolonization with microorganisms can occur and this can subsequently contribute to a reinfection of the root canal system.

The voids that are formed in the apical region when sealer dissolution occurs can lead to a recolonization by microorganisms. In principle, this can happen in 3 ways: 1. penetration of microorganisms from coronal regions, 2. persistence of microorganisms in the apical region (biofilm in the root canal), 3. reinfection with, for example, biofilm outside of the canal or infected soft tissue.

8. Calcium silicate-based sealer und thermoplastic obturation

In order to avoid the issue of CSS solubility and keep the proportion of sealer as low as possible, one could be inclined to employ thermoplastic obturation methods. However, most CSS have not yet been approved by manufacturers for warm root canal filling techniques because CSS require moisture for setting and thermoplastic obturation could remove too much moisture from them. This could compromise the material's properties [9, 27].

After heating BioRoot RCS to over 100 °C, water loss and an irreversible change in the chemical structure of the material have been reported. Moreover, reversible changes in the chemical structure of iRoot SP after heating above 125 °C have been described [3]. In another study, the chemical or physical properties of iRoot SP were not affected by heat treatment [12]. However, the type and duration of heat application differed between the studies. But, precisely the type and duration of heat application could influence the results of such in vitro studies [3, 18, 46]. The simulation of heat treatment should reflect the clinical situation as closely as possible in order to obtain results with clinical relevance. Thus, intracanalicular temperatures and clinically relevant heating times should be considered when investigating the effect of thermal treatment on sealers during thermoplastic obturation [17].

In this respect, it is questionable whether these high temperatures in the range of 100–200 °C can be achieved during thermoplastic obturation of the root canal. In a recently published in vitro study, the highest measured temperature using the "Continuous Wave Technique" was 56 °C and this likely has little influence on the sealer [17]. In summary, information regarding the effect of clinically relevant temperatures on CSS is limited.

Only one product, Sealer Endosequence BC Sealer HiFlow (Brasseler USA, Savannah, USA), that is also sold as Total Fill BC Sealer HiFlow (FKG Dentaire) is recommended for thermoplastic obturation of the root canal. According to the manufacturer, this sealer should only be used in combination with low melting gutta-percha. In the only study to date which heated BC Sealer HiFlow accordingly, its chemical composition was not changed through thermal treatment. Also, the flow rate, film thickness and setting time were not clinically affected [12].

9. Clinical studies on calcium silicate-based sealers

Since their introduction onto the market in 2007, CSS have been tested numerous times in vitro and they show positive results. This confers them a promising perspective for future clinical applications. Yet, there have been relatively few clinical studies on CSS [19]. In a randomized, controlled trial using 114 teeth, no significant difference in postoperative pain was found between the conventional AH Plus Sealer and the CSS Total Fill BC Sealer. Root canal fillings without sealer extrusion rarely lead to postoperative pain. The choice of sealer has no influence on the likelihood of complaints [25]. A further study obtained comparable results. The results also showed that there was no significant difference between the AH Plus and iRoot SP groups with regard to the incidence of postoperative pain. However, painkiller medication was consumed significantly more frequently after root canal treatment when AH Plus Sealer was used as compared to when iRoot SP Sealer was used [2].

Root canal fillings using the single-cone technique in combination with Endosequence BC Sealer can achieve high success rates. After a 30-month average follow-up period, 90.9 % of root canal treatments were evaluated as being successful; 83.1 % of the cases were classified as healed and 7.8 % as healing. In 47.4 % of cases, sealer extrusion occurred, although this did not have a significant effect on the success of treatment [13]. In a direct comparison between the single-cone technique using CSS (BioRoot RCS) and warm vertical compaction using an epoxy-based sealer (AH Plus), no significant difference in success rates was observed after one year. Based on CBCT imaging, success rates of 80 % using AH Plus (warm vertical compaction) and 84 % for BioRoot RCS (single-cone technique) were determined. Periapical radiographs showed success rates of 89 % (AH Plus) and 90 % (BioRoot RCS). This difference was not statistically significant. In view of these results, the authors see a clinically validated justification that advocates for the use of the single-cone technique with CSS, even though the study was non-randomized [50].

10. Conclusion

Although there are insufficient studies regarding their long-term clinical success, CSS have become a relevant alternative to epoxy-based sealers. The validity of clinical studies available to date should certainly be viewed with caution due to their short follow-up periods. However, there is a clear tendency for root canal treatment with CSS to be successful [19] – even with the single-cone technique and without thermoplastic obturation (Fig. 7 and 8).

In a micro-CT analysis, the obturation quality of two filling methods was compared: the single-cone technique with the CSS EndoSequence BC and thermoplastic obturation with AH Plus sealer. No significant difference in filling volume and voids was observed. Using both filling methods, a comparable root canal filling quality could be achieved. Neither one of the two methods in combination with its respective sealer was able to fill the root canal system completely [38].

Due to their biocompatibility and bioactivity, CSS in combination with cold obturation methods represent an alternative to thermoplastic obturation methods. However, the question of whether cold or warm obturation is the better technique when CSS are used remains unanswered.

CSS will probably not lead to the end of thermoplastic obturation methods. However, according to current data, it must be mentioned that thermoplastic obturation methods are not entirely necessary for successful endodontic treatment.

In principle, it is worth considering that the success of root canal treatment and the healing of inflammatory processes is not only associated to the obturation technique, but also directly to the sufficient removal of infected tissue, microorganisms and their toxins along with the correct disinfection of the root canal system, as well as a bacteria-proof restoration of the endodontically treated tooth.

Conflicts of interest

Till Dammaschke states that he received honoraria from Septodont for lectures.

References

1. Alves J, Walton R, Drake D: Coronal leakage: endotoxin penetration from mixed bacterial communities through obturated, post-prepared root canals. J Endod 1998; 24: 587–591

2. Atav Ates A, Dumani A, Yoldas O, Unal I: Post-obturation pain following the use of carrier-based system with AH Plus or iRoot SP sealers: a randomized controlled clinical trial. Clin Oral Investig 2019; 23: 3053–3061

3. Atmeh AR, Hadis M, Camilleri J: Real-time chemical analysis of root filling materials with heating: guidelines for safe temperature levels. Int Endod J 2020; 53: 698–708

4. Bachicha WS, DiFiore PM, Miller DA, Lautenschlager EP, Pashley DH: Microleakage of endodontically treated teeth restored with posts. J Endod 1998; 24: 703–708

5. Berzins DW: Chemical properties of MTA. In: Torabinejad M (ed): Mineral trioxide aggregate. Properties and clinical applications. Wiley Blackwell Publishing, Hoboken, New Jersey 2014, 17–36

6. Bogen G, Kuttler S: Mineral trioxide aggregate obturation: a review and case series. J Endod 2009; 35: 777–790

7. 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

8. Bukhari S, Karabucak B: The antimicrobial effect of bioceramic sealer on an 8-week matured Enterococcus faecalis biofilm attached to root canal dentinal surface. J Endod 2019; 45: 1047–1052

9. Camilleri J: Sealers and warm gutta-percha obturation techniques. J Endod 2015; 41: 72–78

10. Camps J, Jeanneau C, El Ayachi I, Laurent P, About I: Bioactivity of a calcium silicate-based endodontic cement (BioRoot RCS): interaction with human periodontal ligament cells in vitro. J Endod 2015; 41: 1469–1473

11. Castellucci A: Obturation of the radicular spaces. In: Rotstein I, Ingle JI (ed): Ingle's endodontics. 7th Edition. PMPH USA, Raleigh 2019, 669–727

12. Chen B, Haapasalo M, Mobuchon C, Li X, Ma J, Shen Y: Cytotoxicity and the effect of temperature on physical properties and chemical composition of a new calcium silicate-based root canal sealer. J Endod 2020; 46: 531–538

13. Chybowski EA, Glickman GN, Patel Y, Fleury A, Solomon E, He J: Clinical outcome of non-surgical root canal treatment using a single-cone technique with endosequence bioceramic sealer: A retrospective analysis. J Endod 2018; 44: 941–945

14. Dammaschke T: Sealer auf Kalziumsilikatbasis. Der Freie Zahnarzt 2020; 64: 64–71

15. Davalou S, Gutmann JL, Nunn MH: Assessment of apical and coronal root canal seals using contemporary endodontic obturation and restorative materials and techniques. Int Endod J 1999; 32: 388–396

16. Donnermeyer D, Bürklein S, Dammaschke T, Schäfer E: Endodontic sealers based on calcium silicates: a systematic review. Odontology 2019; 107: 421–436

17. Donnermeyer D, Schäfer E, Bürklein S: Real-time intracanal temperature measurement during different obturation techniques. J Endod 2018; 44: 1832–1836

18. Donnermeyer D, Urban K, Bürklein S, Schäfer E: Physico-chemical investigation of endodontic sealers exposed to simulated intracanal heat application: epoxy resins and zinc oxide-eugenols. Int Endod J 2020; 53: 690–697

19. Donnermeyer D: Literatur-Rundschau: Kalziumsilikat-basierte Wurzelkanalsealer – die klinische Datenlage. Endodontie 2020; 29: 209–216

20. Farzaneh M, Abitbol S, Lawrence HP, Friedman S: Treatment outcomes in endodontics – the Toronto study. Part II: initial treatment. J Endod 2004; 30: 302–309

21. Giacomino CM, Wealleans JA, Kuhn N, Diogenes A: Comparative biocompatibility and osteogenic potential of two bioceramic sealers. J Endod 2019; 45: 51–56

22. Gilhooly RMP, Hayes SJ, Bryant ST, Dummer PMH: Comparison of cold lateral condensation and a warm multiphase gutta-percha technique for obturating curved root canals. Int Endod J 2000; 33: 415–420

23. Gillen BM, Looney SW, Gu LS et al.: Impact of the quality of the cornonal restoration versus the quality of the root canal fillings on success of root canal treatment: a systematic review and meta-analysis. J Endod 2011; 37: 895–902

24. González-Martín M, Torres-Lagares D, Gutiérrez-Pérez JL, Segura-Egea JJ: Inferior alveolar nerve paresthesia after overfilling of endodontic sealer into the mandibular canal. J Endod 2010; 36: 1419–1421

25. Graunaite I, Skucaite N, Lodiene G, Agentiene I, Machiulskiene V: Effect of resin-based and bioceramic root canal sealers on postoperative pain: A split-mouth randomized controlled trial. J Endod 2018; 44: 689–693

26. Hergt A, Wiegand A, Hülsmann M, Rödig T: AH Plus root canal sealer – an updated literature review. Endo (Lond Engl) 2015; 9: 245–265

27. Herrmann H-W, Hülsmann M, Schäfer E: Probleme bei der Wurzelkanalfüllung. In: Hülsmann M, Schäfer E (Hrsg): Probleme in der Endodontie. Prävention, Identifikation und Management. 2. Aufl., Quintessenz Verlag, Berlin 2019, 291–322

28. International Organization for Standardization: International Standard ISO 6876:2012: Dental root canal sealing materials. International Organization for Standardization, Geneva 2012

29. Jung S, Libricht V, Sielker S, Hanisch MR, Schäfer E, Dammaschke T: Evaluation of the biocompatibility of root canal sealers on human periodontal ligament cells ex vivo. Odontology 2019; 107: 54–63

30. Jung S, Sielker S, Hanisch MR, Libricht V, Schäfer E, Dammaschke T: Cytotoxic effects of four different root canal sealers on human osteoblasts. PLoS One 2018; 13: e0194467. doi: 10.1371/journal.pone.0194467

31. Khayat A, Lee SJ, Torabinejad M: Human saliva penetration of coronally unsealed obturated root canals. J Endod 1993; 19: 458–461

32. Kontakiotis EG, Wu M-K, Wesselink PR: Effect of sealer thickness on long-term sealing ability: a 2-year follow-up study. Int Endod J 2003; 30: 307–312

33. Long J, Kreft JU, Camilleri J: Antimicrobial and ultrastructural properties of root canal filling materials exposed to bacterial challenge. J Dent 2020; 93: 103283. doi: 10.1016/j.jdent.2020. 103283

34. Milanovic I, Milovanovic P, Antonijevic D, Dzeletovic B, Djuric M, Miletic V: Immediate and long-term porosity of calcium silicate-based sealers. J Endod 2020; 46: 515–523

35. Peng L, Ye L, Tan H, Zhou X: Outcome of root canal obturation by warm gutta-percha versus cold lateral condensation: a meta-analysis. J Endod 2007; 33: 106–109

36. Prüllage RK, Urban K, Schäfer E, Dammaschke T: Material properties of a tricalcium silicate-containing, a mineral trioxide aggregate-containing, and an epoxy resin-based root canal sealer. J Endod 2016; 42: 1784–1788

37. Ricucci D, Siqueira JF Jr.: Recurrent apical periodontitis and late endodontic treatment failure related to coronal leakage: a case report. J Endod 2011; 37: 1171–1175

38. Roizenblit RN, Soares FO, Lopes RT, Dos Santos BC, Gusman H: Root canal filling quality of mandibular molars with EndoSequence BC and AH Plus sealers: a micro-CT study. Aust Endod J 2020; 46: 82–87

39. Schäfer E, Nelius B, Bürklein S: A comparative evaluation of gutta-percha filled areas in curved root canals obturated with different techniques. Clin Oral Investig 2012; 16: 225–230

40. Schilder H: Filling root canals in three dimensions. Dent Clin North Am 1967; 11: 723–744

41. Siqueira JF Jr, Rôças IN, Favieri A, Abad EC, Castro AJ, Gahyva SM: Bacterial leakage in coronally unsealed root canals obturated with 3 different techniques. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000; 90: 647–650

42. Steffen R, Coray R, Stratigaki E: Mineraltrioxidaggregat und bioaktive Zement in der Kinderzahnmedizin. Quintessenz Zahnmed 2019; 70: 302–314

43. Tanomaru-Filho M, Torres FFE, Chavez-Andrade GM et al.: Physicochemical properties and volumetric change of silicone/bioactive glass and calcium silicate-based endodontic sealers. J Endod 2017; 43: 2097–2102

44. Torres FFE, Zordan-Bronzel CL, Guerreiro-Tanomaru JM, Chávez-Andrade GM, Pinto JC, Tanomaru-Filho M: Effect of immersion in distilled water or phosphate-buffered saline on the solubility, volumetric change and presence of voids within new calcium silicate-based root canal sealers. Int Endod J 2020; 53: 385–391

45. Urban K, Neuhaus J, Donnermeyer D, Schäfer E, Dammaschke T: Solubility and pH value of 3 different root canal sealers: a long-term investigation. J Endod 2018; 44: 1736–1740

46. Viapiana R, Moinzadeh AT, Camilleri L, Wesselink PR, Tanomaru Filho M, Camilleri J: Porosity and sealing ability of root fillings with gutta-percha and BioRoot RCS or AH Plus sealers. Evaluation by three ex vivo methods. Int Endod J 2016; 49: 774–782

47. Wang Z, Shen Y, Haapasalo M: Dentin extends the antibacterial effect of endodontic sealers against Enterococcus faecalis biofilms. J Endod 2014; 40: 505–508

48. Wu M-K, Wesselink PR: A primary observation on the preparation and obturation of oval canals. Int Endod J 2001; 34: 137–141

49. Xuereb M, Vella P, Damidot D, Sammut CV, Camilleri J: In situ assessment of the setting of tricalcium silicate-based sealers using a dentin pressure model. J Endod 2015; 41: 111–124

50. Zavattini A, Knight A, Foschi F, Mannocci F: Outcome of root canal treatment using a new calcium silicate root canal sealer: a non-randomized clincial trial. J Clin Med 2020; 9: 782 doi: 10.3390/jcm9030782

51. 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

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