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# Adhesion capacity of bioceramics and resin-based sealer to root dentin : An integrative review

Elio Joaquin Noah LLOP

Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

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Trabalho realizado sob a Orientação de Prof. Doutor Pedro Jorge Bernardino

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# Agradecimentos

First of all, I would like to thank my parents without whom all this would never have been possible.

To my brothers, "les Llop", you are the best, I wish you the best in the world.

To my grandparents for all the support you have given me, you have always been there for me.

To my dear Diane, thank you for everything. For all those moments spent in Portugal, or elsewhere.

To the "bairro ignez" crew, to Covid without whom we wouldn't have spent all these moments.

To "mi casa es tu casa" for all those memorable parties.

To my partner, Mathieu, future colleague, with whom we had a great time.

To all my friends that I met here, I won't forget you, we are a big family now.

Finally, thank you to all my teachers who passed on their knowledge and their passions to me. In particular to Professor Pedro Bernardino for his patience and his knowledge which allowed me to finish this work which puts a final point to all these years.

Thanks to you all.

# Resumo

**Objetivo** : O objetivo deste trabalho foi realizar uma revisão sistemática integrativa para avaliar e comparar a capacidade de selamento dos cimentos de obturação biocerâmicos com os cimentos de obturação à base de resina, considerados cimentos "gold-standard" aos dias de hoje.

**Método** : Foi realizada uma revisão bibliográfica no PubMed (através da Biblioteca Nacional de Medicina) considerando que tal base de dados inclui as principais revistas na área da odontologia e biomateriais. Foram aplicados os seguintes termos de pesquisa: "epoxy resin" AND "endodontics" AND "sealing ability"; "bioceramics" AND "endodontics" AND "sealing ability"; "bioceramics" AND "tubular penetration" OR "epoxy resin" AND "tubular penetration".

**Resultados** : A pesquisa inicial na base de dados produziu um total de 193 artigos, dos quais 3 artigos duplicados foram eliminados. Nos restantes 190 artigos, os títulos e resumos foram lidos procurando concordância com os critérios de inclusão do presente estudo e depois 140 estudos foram descartados porque não incluíam informação significativa sobre a capacidade de selagem dos vários seladores. A avaliação dos títulos e resumos resultou na seleção de 24 estudos potenciais, dos quais 11 artigos foram excluídos após a leitura completa relativa à falta de dados disponíveis.

**Discussão :** As vantagens dos cimentos biocerâmicos são múltiplas. De facto, são bioativos, biocompatíveis, permitem a biomineralização, e têm uma alta taxa de penetração nos túbulos dentinários. No entanto, são solúveis em contacto com fluidos fisiológicos.
Os cimentos à base de resina têm algumas limitações. Eles são hidrofóbicos, o que os pode impedir de penetrar e aderir bem aos túbulos dentinários mal secos e à gutta-percha.

**Conclusão** : Através destes diferentes estudos podemos concluir que os cimentos biocerâmicos tiveram uma penetração tubular mais profunda, maior resistência de ligação, excelente selagem apical com aderência química com túbulos dentinários (estrutura tipo tag), mais fácil de reprocessar se necessário em comparação com os cimentos à base de resina. A única parte inconclusiva foi sobre a resistência bacteriana, são necessários mais estudos.

# Abstract

**Purpose :** The main aim of the present study was to carry out an integrative review to evaluate and compare the apical sealing ability of bioceramic-based sealer with resin-based sealer, which is considered the gold standard in term of sealing and adhesion.

**Method :** A bibliographic review was performed on PubMed (via National Library of Medicine) considering such database includes the major journals in the field of dentistry and biomaterials. The following search terms were applied: "epoxy resin" AND "endodontics" AND "sealing ability"; "bioceramics" AND "endodontics" AND "sealing ability"; "bioceramics" AND "tubular penetration" OR "epoxy resin" AND "tubular penetration".

**Results :** The initial search in the available database yielded a total of 193 articles of which 3 duplicate articles were eliminated. On the remaining 190 articles, the titles and abstracts were read seeking concordance with the inclusion criteria of the present study and then 140 studies were discarded because they did not include significant information on the sealing ability of the various sealers. The evaluation of titles and abstracts resulted in the selection of 24 potentially studies of which eleven articles were excluded after full reading concerning the lack of available data.

**Discussion :** .The advantages of bioceramic cements are multiple. Indeed, they are bioactive, biocompatible, allow biomineralization, and have a high penetration rate into the dentinal tubules. However, they are soluble in contact with physiological fluids.
Resin-based cements have some limitations. Resin-based cements are hydrophobic, which may prevent them from penetrating and adhering well to poorly dried dentinal tubules and gutta-percha.

**Conclusion :** Through these different studies we can conclude that bioceramic sealers had deeper tubular penetration, higher bond strength, excellent apical sealing with chemical adhesion with dentinal tubules (tag-like structure), easier to reprocess if needed compared to the resin-based sealers. The only inconclusive part was on the bacterial resistance, further studies are required.

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# Abbreviatures

BC – Bioceramic

BCC - Bioceramic-impregnated gutta percha cone

GP – Gutta percha

CT - Computed tomography

SEM - scanning electron microscopy

BHI - brain-heart infusion

XRD - X-ray diffraction

EDTA - Ethylenediaminetetraacetic acid

MTA- Mineral Trioxide Aggregate

NaOCl - Sodium hypochlorite

# 1. Introduction

Mineralised dental tissues, including the pulp, can be exposed to different types of aggression, requiring endodontic treatment by the dentist. Before starting any endodontic therapy, it is essential to first understand the pathological process affecting the tooth, the complicated architecture of the tooth and the complex anatomy of the root canal system, as well as the treatment goals, the intended treatment outcomes. (1)

Treatment of irreversible pulpitis and pulp necrosis are the two most common reasons for endodontic therapy. If the clinical condition warrants it, it's also advised in the case of healthy pulp. For example, the need for a root anchor, root amputation, or a haematoma.
Endodontic therapy follows a triangular logic: the endodontic network is shaped, disinfected, and obturated. To preserve asepsis and antisepsis, which are fundamental to its performance, it must be performed in an airtight operating area. (2)

The aim of the shaping and irrigation is to get rid of the pulp, necrotic tissue, and irritating compounds. It is a physicochemical phase, with physical/mechanical shaping by endodontic tools and chemical sanitization by sodium hypochlorite, which is continuously refreshed during treatment. These are interconnected phases because one cannot exist or be useful without the other. The objective of this procedure is to prevent bacterial (re)contamination of the root canal network by placing a substance in this area and closing the entire endo network. (3)

Obturation materials are used at this stage. They must be biocompatible and durable, insoluble in tissue fluids, radiopaque, and simple to remove. Two types of filling materials are used at this stage: a neutral semi-solid substance (gutta-percha) and a root canal cement that allows a bond between the core material and the dentinal walls. In current obturation techniques, the gutta-percha plays the role of filler, and the cement (whether zinc oxide-eugenol, epoxy resin, calcium hydroxide, bioceramics.) the role of sealant. Unfortunately, the cement is the weak point of the filling. (4)

Bioceramics are amongst the recently introduced materials in endodontics which have changed the face of endodontics. Ceramics are inorganic, non-metallic materials made by the heating of raw minerals at high temperatures. Bioceramics are biocompatible ceramic materials or metal oxides with enhanced sealing ability, antibacterial and antifungal activity applied for use in medicine and dentistry. They have the ability to either function as human tissues or to resorb and encourage the regeneration of natural tissues. (5)

Furthermore, it has an alkaline pH, resulting in antibacterial activity and adequate biocompatibility, avoiding inflammatory reactions when overfilled. In previous studies, bioceramics sealers have also demonstrated radiopacity and adhesion to dentinal walls, and these parameters have been used to evaluate root canal filling effectiveness. (6)

Through an integrative review, the present study examined the adhesion capacity of the bioceramic sealer and the resin-based sealer.

## 2. Objective and hypothesis

The main aim of the present study was to carry out an integrative review to evaluate and compare the apical sealing ability of bioceramic-based sealer with resin-based sealer, which is considered the gold standard in term of sealing and adhesion to dentin. It was hypothesized that between the two types of cements (resin-based and bioceramic-based), there are differences in the ability to seal the apical region of a tooth and in the resistance to bacterial infiltration.

# 3. Materials and methods

A bibliographic review was performed on PubMed (via National Library of Medicine) considering such database includes the major journals in the field of dentistry and biomaterials. The following search terms were applied: "epoxy resin" AND "endodontics" AND "sealing ability"; "bioceramics" AND "endodontics" AND "sealing ability"; "bioceramics" AND "tubular penetration" OR "epoxy resin" AND "tubular penetration". Also, a hand-search was performed on the reference lists of all primary sources and eligible studies of this systematic review for additional relevant publications. The inclusion criteria encompassed articles published in the English language, from January 2015 until 2022, reporting the sealing ability, tubular penetration, antimicrobial capacity on tooth root canal dentin surfaces. The eligibility inclusion criteria used for article searches also involved: in vitro cell culture assays; meta-analyses; randomized controlled trials; animal assays; and prospective cohort studies. The exclusion criteria were the following: papers without abstract; case report with short follow-up period, articles that not fit the objectives. Studies based on publication date were not restricted during the search process. The present method was performed in accordance with the search strategy applied in previous studies on integrative or systematic reviews.

# 4. Results

The initial search in the available database yielded a total of 193 articles of which 3 duplicate articles were eliminated. On the remaining 190 articles, the titles and abstracts were read seeking concordance with the inclusion criteria of the present study and then 140 studies were discarded because they did not include significant information on the sealing ability of the various sealers. The evaluation of titles and abstracts resulted in the selection of 24 potentially studies of which eleven articles were excluded after full reading concerning the lack of available data. The results of the selection of articles are shown in the first table.

The main results described in Table 1 are reported as follow :

- EndoSequence BC Sealer® had significantly better sealing ability than AH Plus® at all test periods ($P < 0.001$). SEM showed EndoSequence BC Sealer® had better penetration into dentinal tubules.
- BIO-C showed significantly higher penetration in dentinal tubules than AHP in the cervical, middle and apical thirds of the root canal ($P<0.05$) and better adaptation to the dentinal tubule walls
- The push-out bond strength of TotalFill BC sealer was significantly higher than that of AH Plus sealer ($P < 0.001$). The obturation technique had no significant effect on the bond strength of TotalFill. While the bond strength of AH Plus was significantly affected, warm vertical compaction and single cone groups displayed lower bond strength than cold lateral compaction group ($P < 0.05$).
- TotalFill BC Sealer and Bio-C Sealer were similar regarding radiopacity, volumetric change, and pH values ($P < 0.05$). Bio-C Sealer presented the shortest setting time and the highest flow and solubility ($P <0.05$). AH Plus showed the highest radiopacity and the lowest flow, pH, solubility, and volumetric change ($P <0.05$).

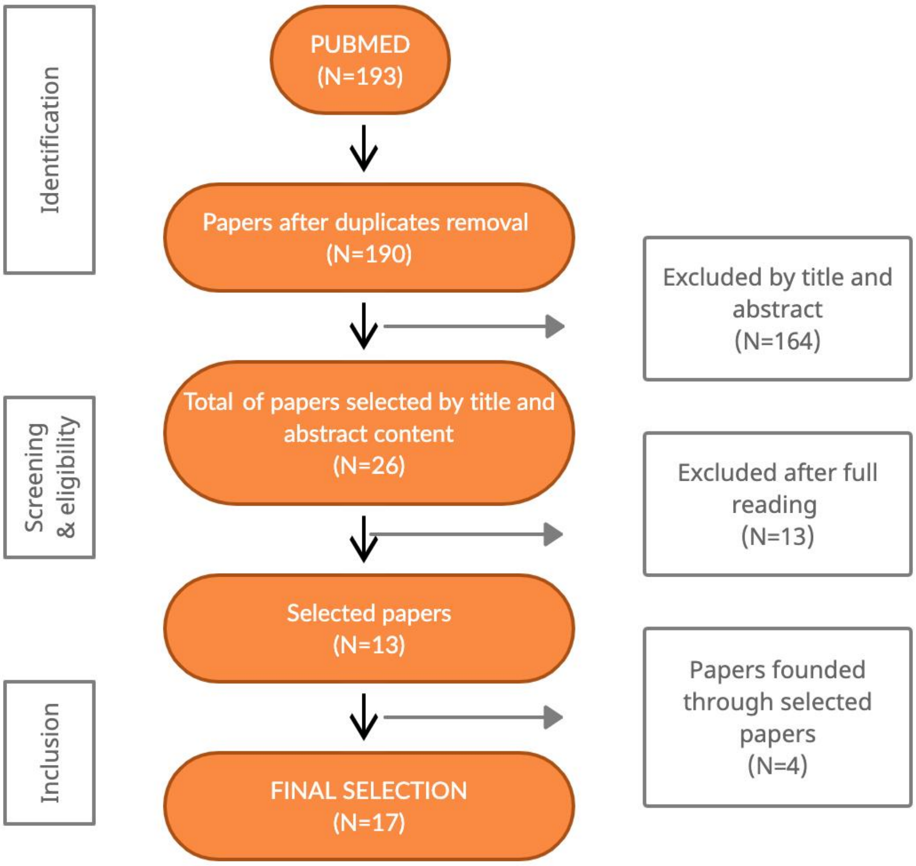


Figure 1 - Flow diagram of the search strategy used in this study.

*Table 1 - Relevant data gathered from the retrieved studies.*

| Title/Authors/year | Purpose | Materials and methods | Results | Conclusion |
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| Sealing ability of three hydrophilic single-cone obturation systems: An in vitro glucose leakage study. ***Hegde et al. (2015)*** | Compare the corono-apical sealing ability of three single-cone obturation systems using a glucose leakage model. | 90 freshly extracted human maxillary single-rooted teeth was selected, and their crowns were cut. The root canal of each sample was instrumented using a rotary crown down technique and then divided into four experimental ($n \geq 20$ each) and two control groups ($n \geq 5$ each) | The four experimental groups presented significantly different glucose leakage values at all test periods ($P < 0.05$). At the end of the observation period, the cumulative glucose leakage values of groups 2 and 3 were significantly lower than those of groups 1 and 4 ($P < 0.05$) | C-points/smart-paste Bio and BC impregnated gutta-percha/endo-sequence BC sealer combinations provided the superior sealing ability over the lateral condensation technique. |
| Biocompatibility and biomineralization assessment of bioceramic-, epoxy-, and calcium hydroxide-based sealers ***Bueno et al. (2016)*** | Evaluate the rat subcutaneous tissue response to implanted polyethylene tubes filled with Smartpaste Bio, Acroseal, and Sealapex and investigate mineralization ability of these endodontic sealers. | Forty Wistar rats were assigned to the three sealers groups and control group, ($n = 10$ animals/group) and received subcutaneous implants containing the test sealers, and the control group were implanted with empty tubes. After days 7, 15, 30, and 60, animals were euthanized and polyethylene tubes were removed with the surrounding tissues. Inflammatory infiltrate and thickness of the fibrous capsule were histologically evaluated. Mineralization was analyzed by Von Kossa staining and polarized light. Data were tabulated and analyzed via Kruskal-Wallis and Dunn's test. | No difference was observed among groups after days 30 or 60. Von Kossa-positive staining and birefringent structures observed under polarized light revealed a larger mineralization area in Sealapex-treated animals followed by Smartpaste Bio-treated animals. At the end of the experiment, all tested sealers were found to be biocompatible. | All sealers induced biomineralization, except Acroseal, which induced a mild tissue reaction. |
| The Tubular Penetration Depth and Adaption of Four Sealers: A Scanning Electron Microscopic Study ***Chen et al. (2017)*** | Evaluate the tubular penetration depth of four different sealers in the coronal, middle, and apical third of root canals as well as the adaptation of these sealers to root canal walls. | 50 single-rooted teeth were prepared in this study. Forty-eight of them were filled with different sealers (Cortisomol, iRoot SP, AH-Plus, and RealSeal SE) and respective core filling materials. Then the specimens were sectioned and scanning electron microscopy was employed to assess the tubular penetration and adaptation of the sealers. | Maximum penetration was exhibited by RealSeal SE, followed by AH-Plus, iRoot SP, and Cortisomol. As regards the adaptation property to root canal walls, AH-Plus has best adaptation capacity followed by iRoot SP, RealSeal SE, and Cortisomol. | The tubular penetration and adaptation vary with the different sealers investigated. RealSeal SE showed the most optimal tubular penetration, whereas AH-Plus presented the best adaptation to the root canal walls. |

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| Sealing Ability of Alkaline Endodontic Cements versus Resin Cements<br>***Teoh et al. (2017)*** | A saliva challenge model was used to compare resistance to bacterial penetration of these alkaline cements to conventional root fillings that combine gutta percha (GP) with epoxy resin sealers | 140 human roots with single straight canals prepared to standard length and canal size were obturated with mineral trioxide aggregate (MTA) (Nex MTA or MTAmix), with an alkaline calcium hydroxide hard setting cement (Supercal), or with GP and a resin cement (either AH-Plus or Zirmix). Negative control roots were sealed with wax, while positive controls were left open. The test assemblies were gamma sterilised, then the coronal root face was exposed daily to fresh stimulated human saliva diluted in broth. Bacterial penetration was determined by assessing growth in sterile brain-heart infusion (BHI) medium in contact with the root apex. | Using Kaplan-Meier survival analysis, in order of performance from highest to lowest: Negative control, Supercal, Nex MTA, Zirmix, MTAmix, GP + AH-Plus, and the positive control. In addition, statistically significant differences were noted between Supercal and AH-Plus, and between the two MTA cements | Alkaline cements, particularly Supercal, can show considerable resistance to bacterial penetration from constant saliva challenge, and provide superior sealing ability in comparison to resin cements. While this property is due mostly to dimensional stability, the release of hydroxide ions could be a contributing factor to impaired bacterial survival, and this aspect should be explored further. |
| Apical dye leakage of two single-cone root canal core materials (hydrophilic core material and gutta-percha) sealed by different types of endodontic sealers: An in vitro study<br>***Mohamed el Sayed et al. (2018)*** | Compare the apical sealing ability of two single-cone filling materials when sealed with different types of root canal sealers | Eighty extracted maxillary and mandibular canines were selected and their crowns were cut. The root canals were prepared using ProTaper Universal rotary system until size F4 and then divided into seven experimental groups (n = 10 each) and two control groups (n = 5 each). Samples of Groups 1, 2, and 3 were filled with single-cone gutta-percha and AH Plus, MTA Fillapex, and EndoSequence BC, respectively. Samples of Groups 4, 5, and 6 were filled similar to the previous groups with the exception of using a single-cone CPoint. Samples of Group 7 were filled with cold gutta-percha lateral condensation technique. To assess apical microleakage, the apical linear dye penetration was measured microscopically and data were statistically analyzed | All experimental groups showed significantly different dye apical leakage values ($P = 0.000$). No significant differences were found between Groups 1, 2, 4, 6, and 7 ($P < 0.05$). The lowest mean leakage value was observed in Group 6 (0.95 ± 0.56 mm) while Groups 3 (2.68 ± 0.71 mm) and 5 (2.61 ± 0.71 mm) showed significantly higher mean leakage values. | The lowest apical leakage value was observed with single-cone CPoint/EndoSequence BC but without significant differences when compared with single-cone gutta-percha/AH Plus, single-cone gutta-percha/MTA Fillapex, single-cone CPoint/AH Plus, and lateral condensation technique. Higher apical leakage values were observed with single-cone gutta-percha/EndoSequence BC and CPoint/MTA Fillapex. |

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| Bacterial leakage and micro-computed tomography evaluation in round-shaped canals obturated with bioceramic cone and sealer using matched single cone technique *Yanpiset et al. (2018)* | Evaluate sealing ability of root canals obturated with bioceramic-impregnated gutta percha cone (BCC) or gutta percha (GP), with bioceramic sealer (BCS) or AH Plus (AH; Dentsply-Maillefer), in roundly-prepared canals using matched single-cone technique, based on bacterial leakage test, and to analyze obturation quality using micro-computed tomography (CT) analysis. | Ninety-two distobuccal roots of maxillary molars were prepared using nickel-titanium files to apical size 40/0.06. The roots were divided into 4 groups (n = 20) that were obturated with a master cone and sealer: GP/AH, BCC/AH, GP/BCS, and BCC/BCS. Bacterial leakage model using Enterococcus faecalis was used to evaluate sealing ability for 60-day period. Obturated samples from each group (n = 4) were analyzed using micro-CT. | All groups showed bacterial leakage at 20%-45% of samples with mean leakage times of 42-52 days. There were no significant differences in bacterial leakage among the groups. Micro-CT showed minimal gaps and voids in all groups at less than 1% | In roundly-prepared canals, the single cone obturation with BCC/BCS was comparable to GP/AH for bacterial leakage at 60 days. |
| Interfacial adaptation and penetration depth of bioceramic endodontic sealers *Arikatla et al. (2018)* | Evaluate the interfacial adaptation and penetration depth of Bioroot RCS and MTA Plus sealers to root dentin. | A total of 60 single-rooted mandibular premolar teeth were prepared using Pro Taper rotary Ni-Ti files and were randomly divided into three groups (n = 20 each) according to the type of sealer used for obturation. After obturation with lateral condensation, half of the samples in each group (n = 10 each) were sectioned transversely for measuring tubular depth penetration under confocal laser scanning microscopy. | AH Plus sealer has shown significantly higher depth of penetration and minimum gaps than bioceramic sealers ($P < 0.05$) MTA Plus sealer exhibited significantly more interfacial gaps and less penetration depth than Bioroot RCS ($P < 0.05$) | At all root regions, AH plus sealer exhibited minimum gaps and more tubular penetration whereas MTA Plus sealer exhibited more gaps and less penetration. |

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| Evaluation of the sealing ability of different root canal sealers: a combined SEM and micro-CT study *Huang et al. (2018)* | Analyze the ability of multiple compounds to seal the dentinal tubules using scanning electron microscopy (SEM) and micro-computed tomography (micro-CT). | Twenty-four single-root human mandibular premolars were selected and instrumented with nickel-titanium rotary file and the final file size was # 40/06. They were then randomly allocated into 2 groups, and all samples were filled with single cone gutta-percha (#40/06) and one of the tested sealers (AH Plus and EndoSequence BC sealers). All specimens were scanned using micro-CT and then three from each group were randomly selected for SEM analysis | Twenty-four single-root human mandibular premolars were selected and instrumented with nickel-titanium rotary file and the final file size was # 40/06. They were then randomly allocated into 2 groups, and all samples were filled with single cone gutta-percha (#40/06) and one of the tested sealers (AH Plus and EndoSequence BC sealers). All specimens were scanned using micro-CT and then three from each group were randomly selected for SEM analysis | By using the single cone technique, neither EndoSequence or AH Plus pro-vides a porosity-free root canal filling. The EndoSequence BC sealer may have similar sealing abilities regarding the whole root canal as the AH Plus sealer. A better sealing effect could be obtained in the coronal and middle sections of a root canal than the apical part by using the tested sealers. |
| Comparative apical sealing evaluation of two bioceramic endodontic sealers *Chisnoiu et al. (2019)* | Evaluate, using scanning electronic microscopy, the sealing ability of two bioceramic endodontic sealers, one consecrated and one experimental. | Twenty monoradicular teeth were included in the study. The teeth were endodontically prepared at the working length. The shaping and cleaning involved the use of chelating gel MM EDTA 19% and continuous irrigation with sodium hypochlorite. 2.5%. The radicular filling was performed using gutta-percha in association with a sealer. Ten teeth were filled with consecrated endodontic filling material and the others ten with the experimental bioceramic based sealer. | The evaluation of the sealers using SEM analysis allowed the identification and the measurement of gaps on the radicular dentin/sealer interface and the degree of apical sealing ability. No significant statistical difference was observed between the gap dimensions in the three areas for the tested bioceramic materials ($p<0.005$). In the apical region a homogenous layer with extensions intersecting the hybrid layer was observed when the experimental bioceramic sealer was used. In case of teeth filled with commercial sealer, peripheral hybrid extended areas were identified. | The two bioceramic sealers presented similar apical sealing. Gaps were identified in both sealers but also the presence of hybrid layer was identified. |

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| Comparison of apical sealing ability of bioceramic sealer and epoxy resin-based sealer using the fluid filtration technique and scanning electron microscopy *Asawaworarit et al. (2020)* | Evaluate the apical sealing ability of bioceramic (EndoSequence BC Sealer®) and epoxy resin-based (AH Plus®) sealers at 24 h, 7 days and 4 weeks. | Forty two extracted human upper anterior teeth were sectioned to leave the root 15-mm long, then all the roots were instrumented using a set of ProTaper® rotary instruments. Four roots were selected randomly as controls, and the remaining 38 roots were randomly divided into 2 groups of 19 roots each: group 1: EndoSequence BC Sealer® and gutta-percha, and group 2: AH Plus® and gutta-percha using a multiple wave condensation technique. The apical sealing ability of the filled root canal was measured using the fluid filtration method with 200 mmHg (26.67 KPa) above atmospheric pressure at 24 h, 7 days and 4 weeks. Scanning electron microscopy (SEM) was used to assess the adaptation and penetration of the sealers. The apical microleakage between 2 groups was compared using Student's t-test. $P < 0.05$ was considered statistically significant. | EndoSequence BC Sealer® had significantly better sealing ability than AH Plus® at all test periods ($P < 0.001$). SEM showed EndoSequence BC Sealer® had better penetration into dentinal tubules. | Bioceramic sealer could promote proper sealing of root canals obturated with multiple wave condensation. |
| Dentinal Tubule Penetration and Adaptation of Bio-C Sealer and AH-Plus: A Comparative SEM Evaluation *Caceres et al. (2021)* | Compare and evaluate the dentinal tubule penetration and adaptation of a premixed bioceramic sealer and an epoxy-resin based sealer in the three radicular thirds. | 30 wide roots, with single straight canals and totally formed apexes, were endodontically prepared and divided into two groups (n=14) according to the sealer used for root canal filling: AH-Plus (AHP) and Bio-C Sealer (BIOC). Two samples were left as controls. After the canals were filled, the samples were cut and viewed under Scanning Electron Microscopy by taking images to analyse the tubular penetration and adaptation of the sealers. | BIO-C showed significantly higher penetration in dentinal tubules than AHP in the cervical, middle and apical thirds of the root canal ($P<0.05$) and better adaptation to the dentinal tubule walls. | Under the parameters of this study, BIO-C exhibits higher penetration and better adaptation to the dentinal tubules compared to AHP. |

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| Comparison of Sealing Ability of Bioceramic Sealer, AH Plus, and GuttaFlow in Conservatively Prepared Curved Root Canals Obturated with Single-Cone Technique: An In vitro Study ***Kaul et al. (2021)*** | Compare apical sealing ability between bioceramic (BC) sealer, GuttaFlow, and AH Plus. | One hundred and twenty-five curved roots of maxillary and mandibular third molar teeth with fully formed apex were collected for this study. The root canals were cleaned and shaped using a standard single-cone preparation to file at the established working length and divided into five groups of 25 each. Dye leakage was carried out. Group A: with GP, using EndoSequence BC sealer with conventional with 4% gutta-percha (Brasseler USA, Savannah, Georgia, USA); Group B: with ceramic coated with 4% gutta-percha (Brasseler USA, Savannah, Georgia, USA); Group C: with GP, using AH Plus sealer (Dentsply, De-Trey Konstanz, Germany) with 4% gutta-percha; Group D: with GuttaFlow bioseal (Roeko-Coltène/Whaledent, Langenau, Germany) with 4% Gutta-percha; and Group E is a negative control group. Statistical analysis was done using the Statistical Package for the Social Sciences software and Student's unpaired t-test. | The group AH Plus showed more leakage values than the GuttaFlow group and of two groups of BC sealer and negative control. Student's unpaired t-test disclosed no significant difference ($P < 0.05$) between the groups. | None of the sealers used in the study could completely seal the apical foramen to have a fluid-tight seal. |

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| Coronal and apical leakage among five endodontic sealers *Vo et al. (2022)* | Use dye penetration to measure apical and coronal leakage simultaneously in single-canal teeth that had been treated endodontically using a single-cone obturation technique. | One hundred single-canal, extracted human teeth were cleaned and shaped with ProTaper NEXT rotary files to size-X5 (50/.06), then randomly assigned to five sealer groups for single-cone gutta-percha obturation. The teeth were soaked in 0.6% rhodamine B at 37°C for seven days, then the roots were ground mesiodistally and the maximum apical and coronal dye penetration was measured. Differences in leakage among the sealer groups were examined using the Kruskal-Wallis test. Pairwise comparisons were made using the Mann-Whitney test with Bonferroni correction. | The mean values (mm) of dye penetration for AH Plus, Pulp Canal Sealer, NeoSEALER Flo, EndoSequence BC, and Super-Bond RC Sealer were 0.200, 0.300, 0.675, 0.850, and 0.900 apically, whereas 1.675, 2.075, 4.800, 6.500, and 4.125 coronally. Pairwise comparisons showed significant apical differences between AH Plus/Super-Bond RC Sealer ($P = 0.047$) and significant coronal differences between AH Plus/NeoSEALER Flo ($P = 0.001$), AH Plus/EndoSequence BC ($P < 0.01$), AH Plus/Super-Bond RC Sealer ($P < 0.01$), Pulp Canal Sealer/NeoSEALER Flo ($P = 0.010$), Pulp Canal Sealer/EndoSequence BC ($P < 0.01$), and Pulp Canal Sealer/Super-Bond RC Sealer ($P < 0.01$). | Coronal leakage was worse than apical leakage for all sealers. AH Plus exhibited the least leakage apically and coronally; Super-Bond RC Sealer showed the most leakage apically, and EndoSequence BC showed the most leakage coronally. |
| Evaluation of Physicochemical Properties of a New Calcium Silicate–based Sealer, Bio-C Sealer *Zordan-Bronzel et al. (2019)* | Evaluate the physicochemical properties of a new calcium silicate–based sealer (Bio-C Sealer) compared with a cal-cium silicate endodontic sealer (TotalFill BC Sealer) and an epoxy resin sealer (AH Plus). | The setting time and flow were evaluated based on ISO 6876 standard. The pH value was evaluated after different time intervals of storage in deionized water (1, 7, 14, and 21 days). Radiopacity was evaluated by radiographic analysis in millimeters of aluminum. Solubility and volumetric change were evaluated after 30 days of immersion in distilled water. Solubility was assessed by mass loss (%), and volumetric change was evaluated by micro– computed tomographic imaging. | TotalFill BC Sealer and Bio-C Sealer were similar regarding radiopacity, volumetric change, and pH values ($P < 0.05$). Bio-C Sealer presented the shortest setting time and the highest flow and solubility ($P < 0.05$). AH Plus showed the highest radiopacity and the lowest flow, pH, solubility, and volumetric change ($P < 0.05$). | Bio-C Sealer showed a short setting time, alkalinization ability, and adequate flow and radiopacity as well as low volumetric change. However, this sealer had higher solubility than the rates required by ISO 6876 standard. |

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| The effect of obturation techniques on the push-out bond strength of a premixed bioceramic root canal sealer<br><br>*Al-Hiyasat et al. (2019)* | Evaluate the effect of obturation techniques on the push-out bond strength of a premixed bioceramic (TotalFill BC) root canal sealer to root canal dentin surface | The palatal root canal of sixty extracted human maxillary first premolar were prepared with Mtwo rotary system, teeth were divided into two groups; according to the sealer to be obturated with; TotalFill BC sealer and AH Plus sealer. Each group was then divided into three subgroups (n = 10) according to the ob- turation technique; cold lateral compaction, single cone, and warm vertical compaction. After obturation teeth were stored in an incubator for two weeks. Three slices of 1.5 mm thickness were then obtained from each root. Bond strength of obturation materials to root dentine was measured using push-out test by universal testing machine. Data were analyzed using ANOVA followed by Tukey's test. Mode of failure was determined by optical microscope examination. | The push-out bond strength of TotalFill BC sealer was significantly higher than that of AH Plus sealer ($P < 0.001$). The obturation technique had no significant effect on the bond strength of TotalFill. While the bond strength of AH Plus was significantly affected, warm vertical compaction and single cone groups displayed lower bond strength than cold lateral compaction group ($P < 0.05$). Mixed mode of failure was most predominant in all groups. | TotalFill BC sealer showed a higher push-out bond strength than AH Plus sealer, and the obturation technique significantly affected AH Plus sealer but not the TotalFill.<br>*Clinical Significance:* Warm vertical compaction significantly reduced the bond strength of the resin based AH Plus sealer compared to cold lateral compaction, but this was not significant with the bioceramic TotalFill BC sealer. Single cone technique could be used with bioceramic sealer which make the obturation faster and easier. |
| Retreatability of three calcium silicate-containing sealers and one epoxy resin-based root canal sealer with four different root canal instruments<br><br>*Donnermeyer et al. (2017)* | Compare the retreatability of three calcium silicate-containing sealers (BioRoot RCS, MTA Fillapex, Endo C.P.M.) and an epoxy resin-based sealer (AH Plus) with different root canal instruments (Hedström files, Reciproc R40, Mtwo retreatment file R 25/.05 + Mtwo 40/.06, and F6 SkyTaper) concerning sealer remnants and retreatment time. | Root canals of 192 teeth were instru- mented with Reciproc R40. All root canals were obturated using the single-cone technique with Reciproc R40 gutta- percha and one of the sealers (n = 48 per sealer). Two months later, retreatment was performed using one of the mentioned instruments (n = 12 per instrument and sealer). The roots were split longitudinally, and both halves were investigated using light microscopy. The percentage of sealer remnants covering the root canal wall was evaluated using the software ImageJ. The time required for retreatment was recorded. Statistical analysis was performed using two-way ANOVA and Student-Newman-Keuls post hoc test. | Regarding the percentage of root canal filling remnants as well as retreatment time, two-way ANOVA indicated that the results were significantly affected by the sealer ($p < 0.001$) and by the instrument used ($p < 0.05$). Overall, the use of AH Plus was associated with significantly more remnants compared to all other sealers ($p < 0.001$) and F6 SkyTaper instruments allowed significantly faster retreatment than the other instruments ($p < 0.05$). | The retreatability of calcium silicate-containing sealers was better compared to AH Plus as less sealer remnants and shorter retreatment times were observed. Retreatment with engine-driven NiTi instruments was superior compared to hand instrumentation. |

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| Micro Push-out Bond Strength and Bioactivity Analysis of a Bioceramic Root Canal Sealer<br><br>*Carvalho et al. (2017)* | Evaluate the bioactivity of BC Sealer and its micro push-out bond strength to dentin compared to AH-Plus (AH) sealer. | To perform the micro push-out test, 24 root canals of mandibular premolars were instrumented and divided into two groups ($n$=12). Each root was cut into 4 slices and lumens of the canals were filled with the sealers and submitted to micro push-out test. Failure mode was assessed using SEM. Bioactivity of BC sealer was investigated with scanning electron microscopy/energy-dispersive X-ray (SEM/EDS) and X-ray diffraction (XRD). Bioactivity assessments were reported descriptively. Bond strength data were analyzed by parametric $t$- test ($\alpha$=5%). | In micro push-out test AH had higher bond strength mean values (16.29 MPa) than BC sealer (9.48 MPa) ($P$<0.05). Both groups had low amount of adhesive failure. SEM showed the presence of a mineral precipitate after 30 days and EDS analysis showed that those precipitates have high proportion of Ca. XRD showed peaks of crystalline phases of calcium carbonate compatible with the bioactivity. | BC sealer showed indications of bioactivity and lower bond strength to dentine compared to AH. |

# 5. Discussion

The literature review of this study compares the root canal sealing ability in endodontics of two types of cements: bioceramic and resin-based (considered as Gold Standard). Generally, the authors agree that the main qualities of root cements are good tubular penetration depth, good apical sealing, good biocompatibility, not be soluble, prevention of bacterial invasion and able to do easy retreatment.

## 5.1. Bioceramic cement

Bioceramic cements have only recently been introduced into endodontics. They are composed of tricalcium and dicalcium silicates, calcium phosphates, calcium hydroxide, and zirconium oxide as a radiopacifier. (7,8)

MTA (Mineral Trioxide Aggregate) was one of the first bioceramics used in dentistry, particularly in direct or indirect pulp capping. This material can release Ca2+ ions to promote chemical adhesion with dentinal tubules (tag-like structure). The new bioceramics (Table 2), in contact with saline solution, also release calcium to form a calcium phosphate interface (apatite) with root dental wall. (9–11)

In 2018, Arikalta et al. showed in their study that there was no significant difference in the seal penetration depth of the two bioceramic cements studied: MTA Plus® (192.54 ± SD 55.16 μm) and BioRoot® RCS (221.00 ± SD 59.37 μm), at apical root levels (p>0.05). However, the interface gaps were significantly larger with MTA Plus® and especially apical (10.94 ± SD 1.45 μm). (11)

Zordan-Bronzel et al. observed that Bio-C® Sealer has a high flow rate (31.2 mm ± 1.3 and 868.4 mm2 ± 34.9), which is very important because it allows the cement to penetrate irregularities in the canals. TotalFill® BC cement also has a good flow rate but less than Bio-C® Sealer. (10)

However, bioceramic cements are soluble (which is a disadvantage), indeed, they showed that Bio-C® Sealer has a high solubility (17.9 % mass loss) ±2.5). This solubility can be explained by the release of OH- and Ca2+. These results confirm that bioceramic cements allow an alkalinization of the medium, with TotalFill® BC, after one day, the average pH was 10.38 (± 0.19) – antimicrobial effect. (10)

Bueno et al., in 2016, demonstrated the biocompatibility and biomineralisation of bioceramic cements, Smartpaste Bio®. Indeed, they induce a moderate inflammation that diminishes after a few days, and they induce only a thin fibrosis capsule. Biomineralization is shown by Von Kossa staining and polarized light, birefringent granulations can be seen (but they decrease with time, Figure 2). Bioceramic cement is like calcium hydroxide cement such as Sealapex® in terms of biomineralization. (7)

To conclude this section, we can say that the advantages of bioceramic cements are multiple. Indeed, they are bioactive, biocompatible, allow biomineralization, and have a high penetration rate into the dentinal tubules. However, they are soluble in contact with physiological fluids. (7,10,12)

## 5.2.Resin-based sealer

Resin-based cements are widely used for root canal sealing in endodontics. In this study, we found that there are two types of resin cements: epoxy and methacrylate (Table 2). An epoxy resin-based cement, AH-Plus®, has been considered the Gold-Standard for some years, as it has good adaptation and adhesion strength and low polymerization shrinkage.(12,13)

In their study, Zordan-Bronzel et al. showed that AH-Plus® has excellent radio opacity (9.2 mmAl ± 0.5) but has very low solubility (0.2% mass loss ± 0.4) due to the strong bonds of the resin with the tooth structure. However, it has a moderate flow (21.3 mm ± 1.1 and 409.2 mm2 ± 108.6). (10)

Bueno et al., in 2016, showed that the epoxy resin-based cement, Acroseal®, also has biocompatibility, as they showed that the rate of inflammation induced by the cement is moderate and decreases over time. On the other hand, this cement does not induce any mineralization, unlike bioceramic cements. (7)

Chen et al. have shown that methacrylate resin-based cements such as RealSeal® SE allow greater penetration into the dentinal tubules, due to its low viscosity and high flow. It is a self-etch and hydrophilic cement.(3)

Despite all the advantages we have seen, resin cements have some limitations. Resin cements are hydrophobic, which may prevent them from penetrating and adhering well to poorly dried dentinal tubules and gutta-percha. In addition, the presence of resin nanoparticles in their composition may prevent deep and more homogeneous penetration, the polimerization contraction of resin cements can create lack of adhesion at root canals.(13,14)

After having detailed the main advantages and disadvantages of the two types of cements analysed in this study: resin-based and bioceramic. It is important to compare their effectiveness through the analysis of the selected articles.

*Table 2 - Different trade names of bioceramic cement and resin-based sealer in articles.*

| Bioceramics cement | Resin-based sealer |
|---|---|
| TotalFill® BC<br>EndoSequence® BC<br>iRoot® SP<br>Smartpaste Bio®<br>Bio-C® Sealer<br>BioRoot® RCS<br>MTA Fillapex®<br>Endo C.P.M. ®<br>Nex MTA®<br>MTAmix ®<br>NeoSEALER® Flo<br>MTA® Plus | AH-Plus® (epoxy)<br>Acroseal® (epoxy)<br>RealSeal® SE (metacrylate)<br>Zirmix® (epoxy)<br>Super-Bond® RC Sealer (metacrylate) |

## 5.3.Comparison of bioceramic and resin-based cement

There are several factors that contribute to optimizing excellent adhesion of the obturator cone, cements, and the dentinal walls of the canal. Indeed, instrumentation of the canal with different file systems, but also irrigation of the canal with strict protocols and good drying of the canals are very important.

Most authors use a common irrigation protocol in their study. During instrumentation, they used a 2.5% sodium hypochlorite (NaOCl) solution as irrigante between each file pass. The last step consists of irrigating with a chelating agent, ethylenediaminetetraacetic acid (EDTA, 15-17%, 3 to 5 mL), which will allow the removal of the Smear Layer which can be used as a substrate for bacteria and will also allow the chelation of $Ca^{2+}$ ions. It will therefore prevent the obstruction of the dentinal tubules by the elimination of the Smear Layer (Figure 3) to have a better penetration of the sealing cements.

Finally, before drying and sealing the canals, the canals will be irrigated again with a 2.5% NaOCl solution. Drying with a paper cone will also be very important to allow proper curing of the cements.

### 5.3.1. Tubular penetration depth

In Romania, Chisnoiu et al. developed an experimental bioceramic cement and compared its sealing ability to TotalFill® BC. They observed that there was no significant difference in the size of the gaps formed in all areas of the canal. However, TotalFill® BC formed larger gaps apically (27.45 μm ± 18.94) and the experimental cement in the middle part of the canal (28.73 μm ± 17.02).(15)

Chen et al., in 2017 observed that resin-based cements (RealSeal® SE and AH-Plus®) and bioceramic cements (iRoot® SP) have good penetration into the dentinal tubules. The depth of penetration into the dentinal tubules of the methacrylate resin cement system, Resilion/RealSeal® SE, is significantly greater along the entire length of the canal (coronal: 114.10 μm, middle: 42.82 μm, apical: 31.93 μm), than that of the Ah-Plus® and iRoot® SP cements. The iRoot® SP bioceramic cement seems to have a better penetration into the tubules, especially apically, compared to the epoxy resin-based cement, AH-Plus®, but this difference is not significant.(3)

Caceres et al. agree that bioceramic cements have better penetration into the dentinal tubules than the epoxy resin-based cement, AH Plus®. Indeed, in their study, they observed electron microscope sections of dentinal tubules, and showed that Bio-C® Sealer bioceramic cements have a better tubular penetration, are more homogeneous and uniform, which shows a better adaptation. In addition, they have a significantly higher percentage occupancy of these compared to AH Plus® cement, for example in the middle third it has a percentage occupancy of 1.87% whereas AH Plus® has only 0.70% ($p<0.001$). Vo et al. showed that methacrylate resin cements (SuperBond® SE) and bioceramic cements penetrate deeper than AH Plus® (epoxy resin cement).(14)

Finally, to conclude this section, Huang et al. showed that there was no statistical difference in the volume of closed pores and the surface of closed pores between bioceramic cements (EndoSequence®) and epoxy resin cements (AH Plus®). However, AH Plus® has a larger volume of closed pores in the apical section (0.151 mm3 versus 0.115 mm3 for EndoSequence®). (16)

### 5.3.2. Bond strength

In this section, only two selected articles mentioned the adhesion strength, especially the push-out adhesion strength. Both studies found contradictory results.

In 2017, Carvalho et al. demonstrated that the average push-out bond strength values of the group of resin-based cements (AH Plus®) are statistically significantly higher than bioceramic cements (EndoSequence®). Indeed, with AH Plus® cement, the bond strength found was 16.29 MPa (± 2.56) whereas the mean value in the bioceramic cement group was 9.48 MPa (± 1.72).(12)

The authors explain this low value for the bioceramic cement group by the fact that, according to the manufacturer, the hardening of EndoSequence® is dependent on the presence of moisture in the dentinal tubules, and therefore it is not necessary to irrigate the canal prior to filling. (12)

In contrast, in 2019, Al-Hiyasat et al. had the opposite results. Indeed, the average push-out bond strength values for all obturation techniques found for bioceramic cements (TotalFill®) were significantly greater than for resin-based cements (AH Plus®), 4.03 MPa ± 1.07 and 3.47 MPa ± 1.00 ($p<0.001$) respectively. The highest result was for cold lateral compaction filling with TotalFill®, 4.21 ± 0.98.(17)

The push-out bond strength is just one aspect of the quality of the filling, another very important aspect of the quality of the filling is the apical leakage, as this will show whether the apical seal is effective or not. (17)

### 5.3.3. Apical sealing

Asawaworarit et al. demonstrated in their study that canal sealing with EndoSequence® Sealer (bioceramic cement) was significantly better than with AH Plus® (epoxy resin cement) over all time periods (after 24 hours, 7 days and 4 weeks). Indeed, for example, after 4 weeks, the bioceramic cement had apical microleakage of 0.288 nL/s at 200 mmHg (± 0.092) while the resin cement had 0.880 nL/s (± 0.188), which is almost three times higher.(18)

The study by Kaul et al. confirmed these results. Indeed, they observed that bioceramic cements had a better sealing capacity than resin-based cements (AH Plus®) and even better than gutta-based cements (GuttaFLow®). Indeed, their experiment showed that there was a dye leakage of 0.89 mm for bioceramic cements whereas for AH Plus® there was a leakage of 1.73 mm. However, these results did not show statistically significant differences. (19)

Yanpiset et al. in 2018 wanted to demonstrate bacterial leakage after different sealants, indeed, they used two types of obturator cone - bioceramic and gutta-percha, and two types of cement - bioceramic (TotalFill®) and resin-based (AH Plus®). One of the main objectives of endodontics is to have a canal that is completely bacteria-tight, Yanpiset et al. wanted to reproduce this mechanism with one of the pathogenic bacteria, Enterococcus faecalis. The conclusion was that there were no significant differences between the different uses of cements or cones in apical bacterial leakage. (20)

Hedge et al. and Aziz et al. used different types of obturator cones in their studies: surrounded by hydrophilic polymers such as C-Points or ProPoints, for example, or the RealSeal® system (based on methacrylate resin). Hedge et al. demonstrated that C-points/ Smart-Paste® Bio (bioceramic cement) and bioceramics impregnated gutta-percha/EndoSequence® combinations provided the superior sealing ability over the lateral condensation technique.(13,21)

Aziz et al. in 2018 also found that the combination of C-Point (single cone) and EndoSequence® bioceramic cement had low apical dye leakage values compared to the other combinations (0.95 mm ± 0.56) but that the difference was not significant, except with the combinations of gutta-percha and EndoSequence® (2.68 mm ± 0.71) and C-Point and MTA Fillapex® (2.61 mm ± 0.71). We can therefore conclude that, in addition to the choice of the cement used, the choice of the type of cone and the obturation technique used (single cone or lateral condensation), are important parameters to be considered. (21)

### 5.3.4. Other parameters

In addition to the sealing and strength capabilities, there are other parameters to consider when choosing the cement to use, such as bacterial resistance and also the possibility of reworking the canal, for example. This last section will present two studies done on these parameters.

Teoh et al. wanted to show the bacterial resistance of different cements. They were able to conclude that new generation calcium hydroxide-based cements (Supercal®) had a higher resistance to bacterial penetration (28 days survival, statistically significant). The cement with the lowest resistance was an epoxy resin-based cement (AH Plus®). However, another epoxy resin cement (Zirmix®) showed better results than a bioceramic type of cement (MTAmix®). (22)

Donnermeyer et al. wanted to evaluate the ability to reprocess canals with different cements by studying the reprocessing time and the cement remaining on the canal walls. They showed that the highest percentage of cement remaining in the canals was in the group of manually reprocessed AH Plus® resin-based cements (28.2%), and the reprocessing time was also significantly longer with AH Plus® cement.(9)

Through this study we were able to see that bioceramic cements had multiple advantages, in most studies they had better tubular penetration, higher bond strength, excellent apical sealing but also they would be easier to reprocess than the resin-based cements. However, the only study on bacterial resistance showed similar or at least non-significant results.

# 6. Conclusion

This integrative systematic review shows many advantages of bioceramic cements over resin-based cements. However, the results are obtained in vitro, so more studies are needed to confirm the following results :

- Bioceramic-based root canal sealers show promising results. On the one hand, discrepancies in the results of these studies reveal that these sealers do not fulfil all of the requirements demanded of the ideal root sealer. The biocompatibility and biomineralization effect of these sealer might avail them for alternative uses in direct pulp capping and root end filling. On the other hand, their solubility in the physiological fluids due to the liberation of $Ca2+$ and $OH-$ can be a disadvantage on a long-term basis.

- Resin-based cements are hydrophobic, which may prevent them from penetrating and adhering well to poorly dried dentinal tubules and gutta-percha as opposed to bioceramic. In addition, the presence of resin nanoparticles in their composition may prevent deep and more homogeneous penetration, the polymerization contraction of resin cements can create lack of adhesion at root canals

- Finally, through these different studies we can conclude that bioceramic sealers had deeper tubular penetration, higher bond strength, excellent apical sealing with chemical adhesion with dentinal tubules (tag-like structure), easier to reprocess if needed compared to the resin-based sealers. The only inconclusive part was on the bacterial resistance, further studies are required.

# 7. References

1. T-J Huang G. Dental pulp and dentin tissue engineering and regeneration: advancement and challenge. Front Biosci. 2011;3(2):788-800.

2. Haute Autorité Santé. Traitement endodontique - Rapport d'évaluation technologique. 2008;

3. Chen H, Zhao X, Qiu Y, Xu D, Cui L, Wu B. The Tubular Penetration Depth and Adaption of Four Sealers: A Scanning Electron Microscopic Study. BioMed Res Int. 2017; 2017:2946524.

4. Vo K, Daniel J, Ahn C, Primus C, Komabayashi T. Coronal and apical leakage among five endodontic sealers. J Oral Sci. 2022;64(1):95–8.

5. Raghavendra S, Jadhav G, Gathani K, Kotadia P. Bioceramics in endodontics - a review. J Istanb Univ Fac Dent. 2017 Nov 17;51(3 Suppl 1):128–37.

6. Al-Haddad A, Che Ab Azziz ZA. Bioceramic-Based Root Canal Sealers: A Review. Int J Biomater. 2016;2016:9753210.

7. Bueno C, Valentim D, Marques V, Gomes-Filho J, Cintra L, Jacinto R, et al. Biocompatibility and biomineralization assessment of bioceramic-, epoxy-, and calcium hydroxide-based sealers. Braz Oral Res. 2016;30(1:S1806-83242016000100267.).

8. Chisnoiu R, Hrab D, Rotaru D, Păstrav O, Delean A, Moldovan M, et al. Comparative apical sealing evaluation of two bioceramic endodontic sealers. Med Pharm Rep. 2019;92(Suppl No 3):S55–60.

9. Donnermeyer D, Bunne C, Schäfer E, Dammaschke T. Retreatability of three calcium silicate-containing sealers and one epoxy resin-based root canal sealer with four different root canal instruments. Clinical Oral Investigations. 2018 Mar 1;22(2):811–7.

10. Zordan-Bronzel CL, Esteves Torres FF, Tanomaru-Filho M, Chávez-Andrade GM, Bosso-Martelo R, Guerreiro-Tanomaru JM. Evaluation of Physicochemical Properties of a New Calcium Silicate-based Sealer, Bio-C Sealer. J Endod. 2019 Oct 1;45(10):1248–52.

11. Arikatla SK, Chalasani U, Mandava J, Yelisela RK. Interfacial adaptation and penetration depth of bioceramic endodontic sealers. J Conserv Dent. 2018 Jul 1;21(4):373–7.

12. Carvalho CN, Grazziotin-Soares R, de Miranda Candeiro GT, Martinez LG, de Souza JP, Oliveira PS, et al. Micro Push-out Bond Strength and Bioactivity Analysis of a Bioceramic Root Canal Sealer. Iran Endod J. 2017 Jul 2;12(3):343–8.

13. Hegde V, Arora S. Sealing ability of three hydrophilic single-cone obturation systems: An in vitro glucose leakage study. Contemp Clin Dent. 2015 Mar 1;6(Suppl 1):S86–9.

14. C C, MR L, M M, F PB. Dentinal Tubule Penetration and Adaptation of Bio-C Sealer and AH-Plus: A Comparative SEM Evaluation. Eur Endod J. 2021;6(2).

15. Chisnoiu R, Hrab D, Rotaru D, Păstrav O, Delean A, Moldovan M, et al. Comparative apical sealing evaluation of two bioceramic endodontic sealers. Med Pharm Rep. 2019;92(Suppl No 3):S55–60.

16. Huang Y, Orhan K, Celikten B, Orhan AI, Tufenkci P, Sevimay S. Evaluation of the sealing ability of different root canal sealers: a combined SEM and micro-CT study. J Appl Oral Sci. 2018;26.

17. Al-Hiyasat AS, Alfirjani SA. The effect of obturation techniques on the push-out bond strength of a premixed bioceramic root canal sealer. J Dent. 2019 Oct 1;89:103169.

18. Asawaworarit W, Pinyosopon T, Kijsamanmith K. Comparison of apical sealing ability of bioceramic sealer and epoxy resin-based sealer using the fluid filtration technique and scanning electron microscopy. J Dent Sci. 2020 Jun 1;15(2):186–92.

19. Kaul S, Kumar A, Badiyani B, Sukhtankar L, Madhumitha M, Kumar A. Comparison of Sealing Ability of Bioceramic Sealer, AH Plus, and GuttaFlow in Conservatively Prepared Curved Root Canals Obturated with Single-Cone Technique: An In vitro Study. J Pharm Bioallied Sci. 2021 Jun 1;13(Suppl 1):S857–60.

20. Yanpiset K, Banomyong D, Chotvorrarak K, Srisatjaluk RL. Bacterial leakage and micro-computed tomography evaluation in round-shaped canals obturated with bioceramic cone and sealer using matched single cone technique. Restor Dent Endod. 2018;43(3).

21. Mohamed El Sayed MA, al Husseini H. Apical dye leakage of two single-cone root canal core materials (hydrophilic core material and gutta-percha) sealed by different types of endodontic sealers: An in vitro study. J Conserv Dent. 2018;21(2):147.

22. Teoh YY, Athanassiadis B, Walsh LJ. Sealing Ability of Alkaline Endodontic Cements versus Resin Cements. Materials (Basel). 2017 Oct 25;10(11).

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