ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
December 2021 • Vol. XXIV

Solubility of CeraSeal Compared to MTA-Fillapex and Adseal

Omnia Saber [1], Medhat Taha [2], Tarek M. Elsewify [3].

Abstract

Background: A successful endodontic treatment depends on several factors; however the most important objective is to achieve a tridimensional RC obturation to provide optimal coronal and apical seal, and entomb the remaining bacteria.

Aim of the Study: to evaluate the solubility of a newly introduced BC sealer (CeraSeal) compared to those of MTA-Fillapex, and Adseal.

Materials and Methods: Twenty-four sealer discs were prepared and incubated until complete setting of the sealers. The discs were divided into three groups according to the sealer's type and then weighed using a precision balance to 0.0001 g. Then they were immersed in HBSS at 37°C. At 1, 7-, 14-, 21-, and 27-days intervals, the discs were removed from the containers and dried, reweighed, and then re-immersed in a new HBSS. Solubility was calculated as percentage of mass loss. Results were tabulated and statistically analyzed.

Results: there was a statistically significant difference in the solubility of the three sealers with MTA-Fillapex always showing the highest solubility except after 24 hours where CeraSeal had higher solubility. All sealers showed progressively increasing dissolution over time reaching maximum solubility values at day (27). Both MTA-Fillapex and CeraSeal had solubility values which exceeded that recommended by the ISO specification No. 6876:2012 (i.e., 3%).

Conclusion: Resin-based sealers outperformed CSBSs in terms of solubility dentin. CSBSs' solubility violated the set range by the ISO specification NO. 6876:2012 (3% mass fraction).

1B.D,S, AinShams University
2 Prof. of Endodontics, Faculty of Dentistry, Ain Shams University
3 Assoc. Prof. of Endodontics, Faculty of Dentistry, Ain Shams University

Introduction

In endodontic obturation, the use of a thermoplastic core filling material, such as gutta-percha (GP), in conjunction with an endodontic sealer is considered conventional. Because of its good physical and biological features, gutta-percha (GP) is frequently utilized, but its lack of adhesiveness and flow necessitates the use of endodontic sealers[1].
Endodontic sealants should flow and fill the gaps between the dentinal wall and the GP core, as well as the accessory canals, and bond to both the GP and the dentin. The root filling's sealing ability is determined by the sealer's bonding to dentin and resistance to breakdown by bodily fluids. Endodontic sealants should be biocompatible because they will be in contact with living tissues for a long time[2].

Because sealer dissolution might jeopardize the overall quality of the root canal therapy, endodontic sealers should have low solubility. The degradation of root canal sealers may release chemical substances that cause inflammatory changes in the periapical tissue[3][4]. Furthermore, root canal sealers should have a low solubility rate to retain sealing ability and/or resist reinfection caused by gaps between root canals and filling materials[5].
In general, epoxy resin-based root canal sealers, which are regarded the gold standard sealers, have a low solubility, as defined by ISO 6876:2012 and ANSI/ADA 57:2000 criteria[6][7]. Adseal (Meta Biomed Co, Cheongju, Korea) is one of the epoxy resin-based sealers. It is supplied as 13.5g dual syringe. It has good sealing ability[8] and bonding to dentin[5], fast setting with suitable working time[9] and has good radiopacity. This sealer is simple to mix. It has no effect on tooth color[10] and does not disintegrate in bodily fluids[11].

Bioceramics (BCs) are a type of endodontic material that is primarily made up of synthetic tricalcium silicate.[12] Endodontics originally used bioceramic-based materials in the 1990s as retrograde filling materials, then as root repair cements and root canal sealers (RCS).[13] Bioceramic materials have physico-chemical and biological properties that make them ideal for endodontic treatments. Within the biological milieu, bioceramics are non-toxic, biocompatible, dimensionally, and chemically stable.[14] The hydraulic and hydration capabilities of bioceramics have sparked the most interest since their introduction.[12]

MTA-Fillapex (Angelus, Londrina, Brazil). is the first generation of paste MTA-containing root canal sealer which is based on salicylate resin and other resinous components.[15] It is supplied as a 4 g dual syringe with automixing tips for intra-canal application. After mixing it consists of Salicylate resin, diluting resin, natural resin, calcium tungstate, bismuth oxide, nanoparticulate silica, pigments and MTA[16]. It has alkaline pH, antibacterial activity[17], and showed suitable physical properties to be used as an endodontic sealer.[18] , yet it has been shown to irritate subcutaneous connective tissue[19] and bone structure[20].
CeraSeal (Meta Biomed Co, Cheongju, Korea), a newly developed premixed calcium silicate-based sealer. It comes in the form of a single premixed syringe containing Tricalcium silicate, Dicalcium silicate, Tricalcium aluminate, Zirconium oxide, and a thickening agent[21]. It possesses "exceptional stability," according to the developers. They also claim that it has superior sealing capabilities.[22]

Microorganisms from treated and filled root canals (RC) leak into the periapical tissues, causing most endodontically treated teeth to fail[23]. The most important goal of root canal therapy (RCT) is to construct a fluid-tight seal along the length of the RC system to promote tissue healing, minimize microleakage and reinfection, and encase any microorganisms that may remain after cleaning and shaping[24].
CeraSeal has a small number of research to back up its manufacturer’s claims. As a result, the goal of this study was to compare CeraSeal's solubility to that of MTA-Fillapex and Adseal, which served as a control. The null hypothesis was that there would be no significant difference in solubility between the tested sealers.

Materials and Methods

A. Materials:

Materials Preparation:

- For MTA-Fillapex:

The auto-mixing tip is adapted to the dual syringe and the plunger is pressed to extrude the material on a mixing pad. The dual syringe and the mixing tip ensure equal mixing of the base and catalyst in a 1:1 ratio.

- For CeraSeal:

The material is provided in a premixed syringe through which the sealer is directly applied through the supplied intra-canal tip.

- For Adseal:

The plunger is pressed to extrude the material on a mixing pad. The dual syringe ensures dispensing of the base and catalyst in a 2:1 ratio. The sealer is then mixed with the supplied plastic spatula to gain a homogenous mix.

B. Methods:

i. Sample Preparation:

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference between tested groups regarding solubility; calculation based on the results of a previous study[9]; the predicted sample size (n) was found to be a total of (24) samples (i.e. 8 samples per group). Sample size calculation was performed using G*Power version 3.1.9.7[25]

The solubility was determined based on a modification of the International Standards Organization (ISO) 6876/2012 method[6][26][15][27]. The sample size was a total of twenty-four discs prepared from MTA Fillapex, CeraSeal, and Adseal.

For all discs' preparations (Figure 1), a total of twenty-four polypropylene (PP) rings with 1.5 ± 0.1 mm thickness and an inner diameter of 20 mm were specially prepared according to the ISO specifications. Four PP rings were fixed with sticky glue over a glass plate wrapped with an aluminum foil to facilitate separation of the sealers' discs after setting. Then the sealers were mixed according to the manufacturers' instructions.

For the Adseal group, the rings were filled with the sealer to slight excess avoiding air trapping as much as possible. The tip of a 15 cm piece of dental floss was inserted in the unset cement from one side, allowing the disc to be hung in the solution throughout the experiment. Then another aluminum foil-wrapped glass plate was placed on the top of the filled rings and pressed manually to remove excess sealer and give the discs a flat surface. The assembly, containing four rings, was placed in an incubator 37°C for one week.

For both CeraSeal and MTA-Fillapex, two pieces of moist paper napkins were placed between the rings and the glass plates to accelerate the setting of these bioceramic sealers which require moisture for their setting[28]. Then the rings were filled and the two glass plates were placed as previously described. Then the assembly was carefully placed in zip-locked bag in an incubator at 37°C and 100% humidity for one week.

After one week, sealer's discs were carefully removed from the rings, and any loose particles or residues from the paper napkins were removed. Then each disc was placed in a container. A hole was made in the lid of each container.

i. Sample Classification:

Twenty-four discs were divided into three groups according to the type of sealer used.

Group I, 8 discs with MTA-Fillapex.

Group II, 8 discs with CeraSeal.

Group III, 8 discs with Adseal.

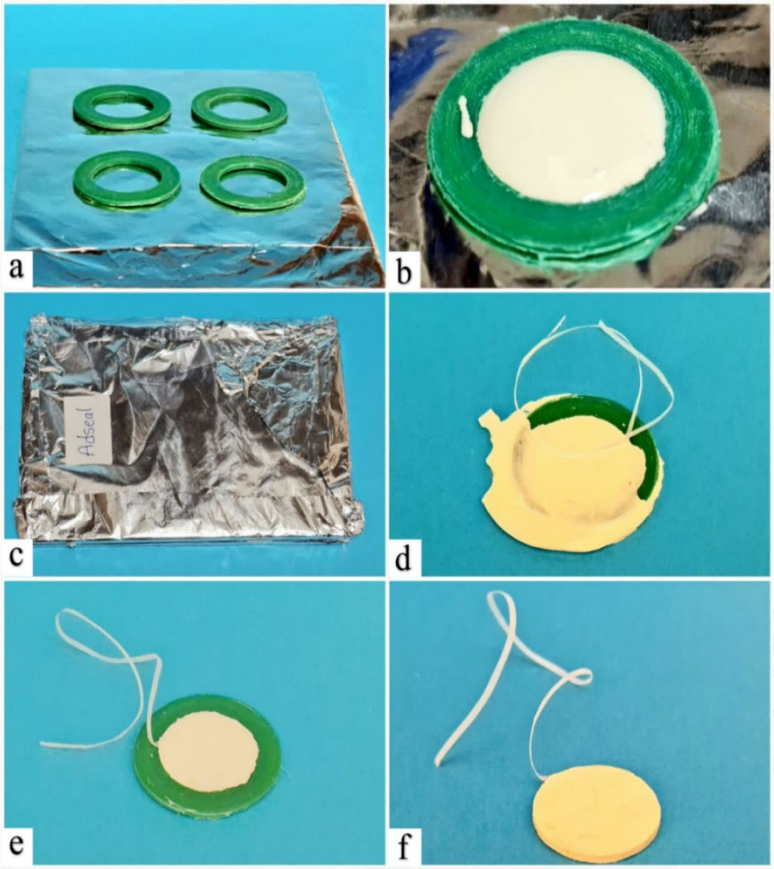

Figure 1: Adseal discs preparation a. The PP rings were placed over an aluminum foil-wrapped glass plate. b. The sealer was mixed according to the manufacturers' instructions then the rings were filled with the sealer to slight excess avoiding air trapping as much as possible. c. The tip of a 15 cm piece of dental floss was inserted in the unset cement from one side then another aluminum foil-wrapped glass plate was placed on the top of the filled rings and pressed manually. d. the ring with the set material after one week incubation at 37°C. e. excess material was scrapped-off of the margins of the ring using sharp lancet. f. The discs were carefully removed from the rings

ii. Method of Evaluation:

Each disc was held by the dental floss and weighed (accuracy 0.0001 g); 3 times, with its floss thread, before the immersion of the samples. The average reading was recorded as the initial dry weight (IDW) of the disc. Each plastic container was filled with 50 ml of Hanks Balanced Salt Solution (HBSS). Then each disc was hung vertically in its container, care was taken to avoid contact of the disc with the inner surface of the container (Figure 2, a and b). Then the containers were placed in the incubator (at 37°C). The discs were then dried and reweighed after 24 hours of immersion and with one week interval afterwards up to 27 days

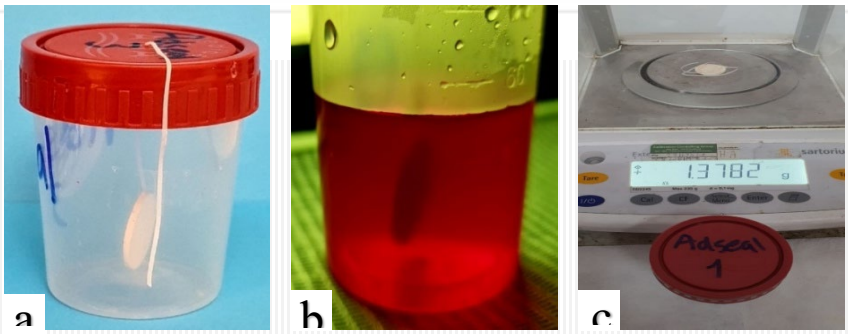

Figure 2: a. Hanging of the discs from the floss without touching the walls of the container. b. The plastic container filled with 50 ml HBSS and the sample hanged in it. c. Weighing of the sample placing it and the floss in the center of the precision balance.

At days 1, 7, 14, 21, and 27 of immersion, the discs were removed from the container, washed under tap water to remove loose debris of decomposition[29][30], dried inside a drying oven containing silica gel at 60°C until the weight was stable (which took four days). Then the discs were placed in a desiccator having silica gel for an hour to cool-down. Then each disc was weighed 3 times, with its floss thread (Figure 2, c), and the average reading was recorded in 0.0001 g as the final dry weight (FDW) of each day. Any specimen that showed signs of disintegration was discarded and replaced. All weightings and drying of samples were carried out in the Central Lab Unit at Ain Shams University.

Solubility was evaluated by means of mass loss. Mass loss was expressed as a percentage of the original mass. The percentage of solubility was calculated each time for each disc according to the following formula:

$$Solubility\ (\%) = \frac{IDW - FDW}{IDW} \times 100$$

iii. Statistical analysis:

Categorical data were presented as frequency and percentage values and were analyzed using fisher's exact test. Numerical data were presented as mean and standard deviation (SD) values. They were explored for normality by checking the data distribution, and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data showed parametric distribution so one-way ANOVA followed by Tukey's post hoc test was used for intergroup comparisons and repeated measures ANOVA followed by Bonferroni post hoc test was used for intragroup comparisons. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with R statistical analysis software version 4.1.2 for Windows[31].

Results

i. Effect of sealer type:

Mean, Standard deviation (*SD*) values of solubility (%) for different types of sealers were presented in **Table 1 and figure 3**

Table 1: Mean, Standard deviation (*SD*) values of solubility (%) for different types of sealers

Solubility (%) (mean ± *SD*)			*p*-value
MTA Fillapex	**CeraSeal**	**Adseal**	
16.15 ± 7.39^{A}	6.09 ± 0.99^{B}	0.50 ± 0.28^{C}	< 0.001*

Different superscript letters indicate a statistically significant difference within the same horizontal row *; significant ($p \leq 0.05$) ns; non-significant ($p > 0.05$)

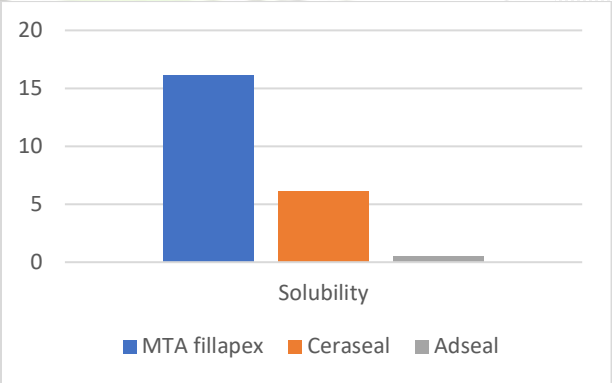

Figure 3: Bar chart showing average solubility (%) for different types of sealers

ii. Effect of sealer type within each measurement time:

Mean, Standard deviation (*SD*) values of solubility (%) for different types of sealers within each measurement time were presented in **Table 2**

Table 2: Mean, Standard deviation (SD) values of solubility (%) for different types of sealers within each measurement time.

Measurement time	Solubility (%) (mean ± *SD*)			*p*-value
	MTA Fillapex	CeraSeal	Adseal	
Day (1)	4.91 ± 0.56^{A}	5.27 ± 0.84^{A}	0.12 ± 0.01^{B}	< 0.001*
Day (7)	12.08 ± 2.08^{A}	5.58 ± 0.89^{B}	0.32 ± 0.05^{C}	< 0.001*
Day (14)	17.42 ± 1.89^{A}	6.07 ± 1.00^{B}	0.50 ± 0.07^{C}	< 0.001*
Day (21)	21.64 ± 1.43^{A}	6.73 ± 0.81^{B}	0.73 ± 0.10^{C}	< 0.001*
Day (27)	24.71 ± 2.26^{A}	6.82 ± 0.78^{B}	0.84 ± 0.12^{C}	< 0.001*

Different superscript letters indicate a statistically significant difference within the same horizontal row *; significant ($p \leq 0.05$) ns; non-significant ($p > 0.05$)

iii. Effect of measurement time within each sealer:

Mean, Standard deviation (*SD*) values of solubility (%) for different measurement times within each sealer were presented in **Figure 4.**

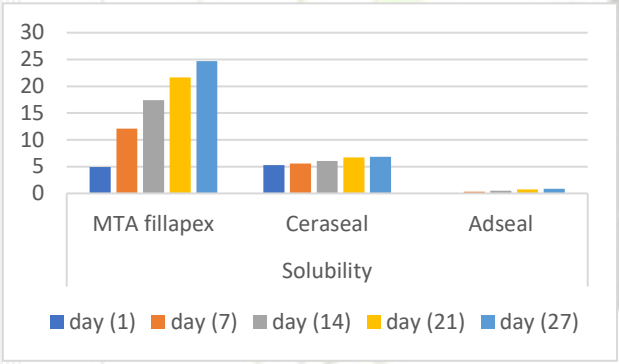

Figure 4: Bar chart showing average solubility (%) for different measurement times within each sealer

Discussion

Endodontic treatment effectiveness is dependent on multiple factors, including RC system shaping, cleaning, and a 3D RC obturation that can produce an excellent coronal seal, limit apical leakage, and encase any remaining bacteria[32][24]. This three-dimensional obturation could be achieved by mixing GP with a sealer, which functions as a binding agent between GP and the RC's dentin. The RC's long-standing bacteria-tight sealing relies mostly on the sealer's integrity, rather than the core material[33]

Dicalcium and tricalcium silicate cements (e.g., mineral trioxide aggregate [MTA]) were originally used in dentistry to treat lateral root perforations and retrograde root-end fillings[34]. Calcium silicate–based RCSs were created because they are highly biocompatible and bioactive. MTA Fillapex was the first MTA-containing sealant. MTA Fillapex is a salicylate resin made up of 13.2% hardened MTA particles, silica fillers, and bismuth(III) oxide as a contrast medium.

The clinical behaviour and handling of endodontic sealer changes are better understood thanks to preliminary laboratory studies of newly created endodontic sealers[35]. CeraSeal, a novel hydraulic calcium silicate-based sealant, was introduced. There is currently insufficient data on the CeraSeal root canal sealer's filling capabilities, physical qualities, and antibacterial activity. Instead, López-Garcia et al. (2020)[36]. investigated the biocompatibility, bioactivity, and ion release of CS sealer. As a result, the goal of this study was to investigate and compare the solubility of CS to MTA-Fillapex and Adseal (a gold standard Epoxy resin-based sealer).

The current study's null hypothesis was that there would be no significant difference in sealer solubility. However, it was rejected since the data revealed a considerable variation in solubility across the tested sealers.

The methodology used in this study was a modification of that proposed by ISO and previously reported by various authors[26][15][27]. It is based on the evaluation of the specimen's loss of mass prior to and after1, 7, 14, 21, and 27 days of immersion in HBSS[37]. For better understanding of what will be the result of sealers's contact with body fluid, the solubility testing was made in HBSS[38].

However, the methodology prescribed by ISO is based on mass of residues produced by the specimens, after evaporation of the distilled water (DW) in which they are immersed. The specimens were weighed to avoid under-estimation of the material going into solution. For example, it has been established that when the residue method is adapted to ZOE cements, eugenol, which is the major constituent of the eluate, is lost by volatilization and hence is not assessed[39].

Since premixed calcium silicate sealers do not set when dry[40], the presence of moisture is essential for their setting. Literature has presented several methods to incorporate moisture and help setting of materials that require moisture to initiate their setting. In Schafer et al. (2003)[41], sealers mixing was done using tap water-moistened spatula. . In Zhou et al. (2013)[28] and Filho et al. (2017)[42], two pieces of wet cloth were placed between the molds and the glass plates. In Urban et al. (2018)[38], the entire setting was submerged in physiological solution for 48 hours. In Elyassi et al. (2019)[43], a specific amount of water, 0.02 ml, were added to the mixture.

The current study followed Zhou et al· [28] and Filho et al. [42] methodology to set the sealers through placement of wet napkins prepared by dipping the napkins into water and then towel-dry them so that they are no more dripping water and then placing them between the sealers' molds and the glass plates.

It is important to mention that the standardized test procedures for solubility recommend soaking of the materials in solution only after complete setting (or at least 70% of the initial setting). Nevertheless, this situation is impossible to be attained clinically because the materials are immediately placed into contact with fluids. As a result, the solubility values in a clinical situation are probably higher than the ones found in in-vitro trials[44].

In the current study, MTA Fillapex was significantly more soluble in HBSS than CeraSeal at immersion times longer than 24 hours, and Adseal at all immersion periods.

Both MTA Fillapex and CeraSeal presented significantly high solubility after 1, 7, 14, 21, and 27 days in HBSS. The solubility of RCS should not exceed 3% mass fraction when stored in water according to the ISO specification number 6876:2012 for "Materials used for permanent root canal sealer"[6]. Only Adseal solubility met the ISO criteria. The solubility of both MTA Fillapex and CeraSeal was significantly higher than 3%.

Solubility is considered deleterious for a sealer. It could be responsible for creating gaps between the sealer material and the RC dentin, causing loss of the sealing ability and creating a pathway for microorganisms leading to reinfection of periapical tissues[45]. Moreover, Sealer disintegration in the surrounding tissues can produce inflammatory and cytotoxic reactions[46] However, the higher solubility of Calcium silicate-based sealers (CSBSs) indicates high levels of Ca^{2+} ions release. Di- and Tri-calcium silicates produces calcium hydroxide on hydration which, in turn, further dissociates into Ca^{2+} and OH^- ions in solution[47].

Although no previous studies have compared the Ca^{2+} ions release properties of MTA Fillapex with that of CeraSeal, recent studies[48][36] evaluated their ion release properties in comparison to other calcium silicate cements. MTA Fillapex showed maximum mean for concentration of Ca^{2+} ions released from MTA Fillapex at day 1 was 105.37 ppm. While the study of CS

showed the mean for concentration of Ca^{2+} ions released at day 7 was 261.87 ppm. More studies are needed to compare both sealers under same conditions.

High Ca^{2+} ions release is an expression of bioactivity and possible formation of cementum at the apical foramen which is considered a biological seal that prevents percolation of exudates into the RC[36][49]. Further future studies should determine the equilibrium point between solubility and bioactivity.

Although CeraSeal showed higher ion release and longer setting time than MTA Fillapex, the current study found its solubility values to be less than those of MTA Fillapex at all immersion times except after 24 hours. This could probably be due to high water sorption found in MTA Fillapex[50] and its longer setting time. Previous reports have shown that MTA-Fillapex is unable to set, even after one month[46]. Another possible explanation is the use of HBSS as an immersion medium. According to Gandolfi et al. (2011)[50] and Torres et al. (2019)[51], immersion of calcium silicate based sealers in biological-like saline solutions significantly decrease their solubility compared to solubility in deionized water as ISO recommend when in the presence of ion releasing apatite-forming materials.

The low solubility of Adseal could be attributed to its faster setting time (45 minutes as per the manufacturer) thus lower leaching of ions which might be due to elements being thoroughly incorporated within the matrix during material polymerization and the cross links in its resin polymers which promoted low solubility. Increased solubility observed with Adseal by day 27 can be caused by the breakdown and disintegration of unreacted particles.[47]

Solubility of MTA Fillapex compared to Adseal results obtained in this study were in agreement with previous studies[52][53] reporting MTA Fillapex having solubility values significantly higher than that of Adseal. Several studies have reported high solubility for MTA Fillapex[27][54][55][17][16] which exceeds the acceptable limits set by the ISO specification NO. 6876/2012, corroborating with the results of the current study.

However, other studies[56][52] have found lower solubility values in the range from 0.25% after 28 days of immersion[37] to 4.65% after 6 months of immersion[38]. This could be caused by differences in samples' dimensions, immersion medium type and/or quantity, and whether the samples were demolded or not (reducing the surface area exposed to the immersion solution).

Up till now only one study evaluated the solubility of CeraSeal, Kharouf et al. (2020)[57]. Such study reported the solubility mean values of CeraSeal as follows: 10.72 ± 2.03 at day (1), 12.61 ± 0.44 at day (7), and 13.92 ± 0.66 at day (14). The mean values found in the current study were significantly lower than the values reported by Kharouf et al. This is possibly due to the different immersion medium used, since Kharouf et al. used DW in which calcium silicate cements have shown higher solubility in as previously mentioned.

Conclusion

Based on the present results, within the circumstances of this in-vitro study, it can be concluded that CSBSs' solubility violated the set range by the ISO specification NO. 6876:2012 (3% mass fraction).

References

[1] L. Kwang-Won, W. Michael C., C. Jean J., and P. David H., "Adhesion of endodontic sealers to dentin and gutta-percha.," *J. Endod.*, vol. 28, no. 10, pp. 684–688, 2002

[2] M. K. Wu, L. W. M. Van Der Sluis, and P. R. Wesselink, "Fluid transport along gutta-percha backfills with and without sealer," *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.*, vol. 97, no. 2, 2004

[3] J. E. Gomes-Filho *et al.*, "Effect of MTA-based sealer on the healing of periapicallesions," *J. Appl. Oral Sci.*, vol. 21, no. 3, p. 235, 2013

[4] E. J. N. L. Silva, M. L. Cardoso, J. P. Rodrigues, G. De-Deus, and T. K. da S. Fidalgo, "Solubility of bioceramic- and epoxy resin-based root canal sealers: A systematic review and meta-analysis," *Aust. Endod. J.*, vol. 47, no. 3, pp. 690–702, Dec. 2021

[5] H. Razmi, B. Bolhari, N. K. Dashti, and M. Fazlyab, "The Effect of Canal Dryness on Bond Strength of Bioceramic and Epoxy-resin Sealers after Irrigation with Sodium Hypochlorite or Chlorhexidine," *Iran. Endod. J.*, vol. 11, no. 2, p. 129, Mar. 2016

[6] "ISO 6876:2012(en), Dentistry — Root canal sealing materials," *Int. Organ. Stand.*, p. 9, 2012 [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:6876:ed-3:v1:en

[7] American National Standards Institute/American Dental Association. ANSI/ADA Specification 57: Endodontic Sealing Material. American National Standards Institute/American Dental Association: Chicago, IL, USA. 2000.

[8] R. Singh, S. Pushpa, D. Arunagiri, A. Sawhny, A. Misra, and R. Sujatha, "The effect of irrigating solutions on the apical sealing ability of MTA Fillapex and Adseal root canal sealers," *J. Dent. Res. Dent. Clin. Dent. Prospects*, vol. 10, no. 4, pp. 251–256, 2016

[9] M. A. Marciano *et al.*, "Physical Properties and Interfacial Adaptation of Three Epoxy Resin – based Sealers," vol. 37, no. 10, 2011

[10] S. T. Savadkouhi, G. R. Fokalaei, M. Afkar, A. N. Shamsabad, and A. Jafari, "Colorimetric Comparison of Tooth Color Change Following the Use of Two Endodontic Sealers: An Ex-Vivo Study," *Winter And Spring*, vol. 33, no. 1, 2021.

[11] "Instructions manual of ADSEAL." https://meta-biomed.com/

[12] S. Drukteinis and J. Camilleri, "Bioceramic Materials for Root Canal Obturation," in *Bioceramic materials in endodontics*, 1st ed., S. Drukteinis and J. Camilleri, Eds. Springer, Cham, 2021, pp. IX, 101.

[13] C. Prati and M. G. Gandolfi, "Calcium silicate bioactive cements: Biological perspectives and clinical applications," *Dent. Mater.*, vol. 31, no. 4, pp. 351–370, Apr. 2015

[14] S. Malhotra, "Bioceramic Technology in Endodontics," *Br. J. Med. Med. Res.*, vol. 4, no. 12, 2014

[15] R. P. Borges *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.*, vol. 45, no. 5, pp. 419–428, 2012

[16] F. Jafari and S. Jafari, "Composition and physicochemical properties of calcium silicate based sealers: A review article," *J. Clin. Exp. Dent.*, vol. 9, no. 10, pp. e1249–e1255, Oct. 2017

[17] N. B. Faria-Júnior, M. Tanomaru-Filho, F. L. C. V. Berbert, and J. M. Guerreiro-Tanomaru, "Antibiofilm activity, pH and solubility of endodontic sealers," *Int. Endod. J.*, vol. 46, no. 8, pp. 755–762, Aug. 2013

[18] R. Pino Vitti *et al.*, "Physical Properties of MTA Fillapex Sealer," *J. Endod.*, vol. 39, pp. 915–918, 2013

[19] C. O. Tavares *et al.*, "Tissue reactions to a new mineral trioxide aggregate-containing endodontic sealer," *J. Endod.*, vol. 39, no. 5, pp. 653–657, May 2013

[20] E. Assmann, D. E. Böttcher, C. B. Hoppe, F. S. Grecca, and P. M. P. Kopper, "Evaluation of bone tissue response to a sealer containing mineral trioxide aggregate," *J. Endod.*, vol. 41, no. 1, pp. 62–66, 2015

[21] H. Oh *et al.*, "Comparison of biocompatibility of calcium silicate-based sealers and epoxy resin-based sealer on human periodontal ligament stem cells," *Materials (Basel).*, vol. 13, no. 22, pp. 1–14, 2020

[22] CeraSeal Pamphlet, 2019. Meta Biomed Co., Ltd. Korea, Republic *2019*. https://www.meta-europe.com

[23] H. Mokhtari *et al.*, "Evaluation of apical leakage in root canals obturated with three

different sealers in presence or absence of smear layer," *Iran. Endod. J.*, vol. 10, no. 2, pp. 131–134, 2015

[24] A. S. Al-Hiyasat and S. A. Alfirjani, "The effect of obturation techniques on the push-out bond strength of a premixed bioceramic root canal sealer," *J. Dent.*, vol. 89, no. March, p. 103169, 2019

[25] F. Faul, E. Erdfelder, A. G. Lang, and A. Buchner, "G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences," *Behavior research methods*, vol. 39, no. 2. Behav Res Methods, pp. 175–191, 2007.

[26] E. S. Lim, Y. B. Park, Y. S. Kwon, W. J. Shon, K. W. Lee, and K. S. Min, "Physical properties and biocompatibility of an injectable calcium-silicate-based root canal sealer: In vitro and in vivo study," *BMC Oral Health*, vol. 15, no. 1, pp. 1–7, 2015

[27] E. J. N. L. Da Silva, T. Accorsi-Mendonça, A. C. Pedrosa, J. M. Granjeiro, and A. A. Zaia, "Long-term cytotoxicity, PH and dissolution rate of AH plus and MTA Fillapex," *Braz. Dent. J.*, vol. 27, no. 4, pp. 419–423, 2016

[28] H. M. Zhou, Y. Shen, W. Zheng, L. Li, Y. F. Zheng, and M. Haapasalo, "Physical properties of 5 root canal sealers," *J. Endod.*, vol. 39, no. 10, pp. 1281–1286, 2013

[29] A. D. Wilson, "Specification Test for the Solubility and Disintegration of Dental Cements: A Critical Evaluation of Its Meaning," *J. Dent. Res.*, vol. 55, no. 5, pp. 721–729, Nov. 1976

[30] R. K. Prüllage, K. Urban, E. Schäfer, and T. Dammaschke, "Material Properties of a Tricalcium Silicate–containing, a Mineral Trioxide Aggregate–containing, and an Epoxy Resin–based Root Canal Sealer," *J. Endod.*, vol. 42, no. 12, pp. 1784–1788, 2016

[31] R. C. Team, "A language and environment for statistical computing," *Computing*, vol. 1. Jan. 01, 2006.

[32] D. Mancino, N. Kharouf, J. Hemmerlé, and Y. Haïkel, "Microscopic and Chemical Assessments of the Filling Ability in Oval-Shaped Root Canals Using Two Different Carrier-Based Filling Techniques," *Eur. J. Dent.*, vol. 13, no. 2, pp. 166–171, 2019

[33] J. WHITWORTH, "Methods of filling root canals: principles and practices," *Endod. Top.*, vol. 12, no. 1, pp. 2–24, Nov. 2005

[34] M. Parirokh and M. Torabinejad, "Calcium Silicate–Based Cements," *Miner. Trioxide Aggreg. Prop. Clin. Appl.*, pp. 281–332, Aug. 2014

[35] A. Ibrahiem Ahmed Mohamed *et al.*, "Evaluation of Setting Time and Solubility of Bio-ceramic Sealer Before and After Mixing with Prednisolone Powder: A Comparative In Vitro Study," *Acta Sci. Dent. Sci.*, vol. 5, pp. 2581–4893, 2021 Accessed: Dec. 02, 2021. [Online]. Available: https://www.drugs.com/dosage/

[36] S. López-García *et al.*, "Cytocompatibility, bioactivity potential, and ion release of three premixed calcium silicate-based sealers," *Clin. Oral Investig.*, vol. 24, no. 5, pp. 1749–1759, 2020

[37] R. P. Vitti *et al.*, "Physical properties of MTA fillapex sealer," *J. Endod.*, vol. 39, no. 7, pp. 915–918, 2013

[38] K. Urban, J. Neuhaus, D. Donnermeyer, E. Schäfer, and T. Dammaschke, "Solubility and pH Value of 3 Different Root Canal Sealers: A Long-term Investigation," *J. Endod.*, vol. 44, no. 11, pp. 1736–1740, 2018

[39] A. D. Wilson, "Specification Test for the Solubility and Disintegration of Dental Cements: A Critical Evaluation of Its Meaning," *J. Dent. Res.*, vol. 55, no. 5, pp. 721–729, Nov. 1976

[40] M. Xuereb, P. Vella, D. Damidot, C. V. Sammut, and J. Camilleri, "In situ assessment of the setting of tricalcium silicate-based sealers using a dentin pressure model," *J. Endod.*, vol. 41, no. 1, pp. 111–124, 2015

[41] E. Schäfer and T. Zandbiglari, "Solubility of root-canal sealers in water and artificial saliva," *Int. Endod. J.*, vol. 36, no. 10, pp. 660–669, 2003

[42] M. Tanomaru-Filho *et al.*, "Physicochemical Properties and Volumetric Change of Silicone/Bioactive Glass and Calcium Silicate–based Endodontic Sealers," *J. Endod.*, vol. 43, no. 12, pp. 2097–2101, 2017

[43] Y. Elyassi, A. T. Moinzadeh, and C. J. Kleverlaan, "Characterization of Leachates from 6 Root," *J. Endod.*, vol. 45, no. 5, pp. 623–627, 2019

[44] E. A. Bortoluzzi, N. J. Broon, C. M. Bramante, W. T. Felippe, M. Tanomaru Filho, and R. M. Esberard, "The Influence of Calcium Chloride on the Setting Time, Solubility,

Disintegration, and pH of Mineral Trioxide Aggregate and White Portland Cement with a Radiopacifier," *J. Endod.*, vol. 35, no. 4, pp. 550–554, Apr. 2009

[45] M. Colombo *et al.*, "Biological and physico-chemical properties of new root canal sealers," *J. Clin. Exp. Dent.*, vol. 10, no. 2, pp. e120–e126, 2018

[46] J. K. Lee, S. W. Kwak, J. H. Ha, W. C. Lee, and H. C. Kim, "Physicochemical Properties of Epoxy Resin-Based and Bioceramic-Based Root Canal Sealers," *Bioinorg. Chem. Appl.*, vol. 2017, no. 57, pp. 1–9, 2017

[47] J. Camilleri, "Hydration mechanisms of mineral trioxide aggregate," *Int. Endod. J.*, vol. 40, no. 6, pp. 462–470, 2007

[48] R. S. I. Belal *et al.*, "Comparison of calcium and hydroxyl ion release ability and in vivo apatite-forming ability of three bioceramic-containing root canal sealers," *Clin. Oral Investig.*, no. 0123456789, 2021

[49] D. Ricucci, N. M. Grande, G. Plotino, and F. R. Tay, "Histologic Response of Human Pulp and Periapical Tissues to Tricalcium Silicate–based Materials: A Series of Successfully Treated Cases," *J. Endod.*, vol. 46, no. 2, pp. 307–317, Feb. 2020

[50] M. G. Gandolfi, P. Taddei, F. Siboni, E. Modena, G. Ciapetti, and C. Prati, "Development of the foremost light-curable calcium-silicate MTA cement as root-end in oral surgery. Chemical–physical properties, bioactivity and biological behavior," *Dent. Mater.*, vol. 27, no. 7, pp. e134–e157, Jul. 2011

[51] F. F. E. Torres, C. L. Zordan-Bronzel, J. M. Guerreiro-Tanomaru, G. M. Chávez-Andrade, J. C. Pinto, and M. Tanomaru-Filho, "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.*, vol. 53, no. 3, pp. 385–391, Mar. 2020

[52] S. Abu Zeid, H. Y. Edrees, A. A. Mokeem Saleh, and O. S. Alothmani, "Physicochemical Properties of Two Generations of MTA-Based Root Canal Sealers," *Materials (Basel).*, vol. 14, no. 20, p. 5911, 2021

[53] F. C. Lopes *et al.*, "Effect of sonic and ultrasonic activation on physicochemical properties of root canal sealers," *J. Appl. Oral Sci.*, vol. 27, 2019

[54] R. Viapiana, D. L. Flumignan, J. M. Guerreiro-Tanomaru, J. Camilleri, and M. Tanomaru-Filho, "Physicochemical and mechanical properties of zirconium oxide and niobium oxide modified Portland cement-based experimental endodontic sealers," *Int. Endod. J.*, vol. 47, no. 5, pp. 437–448, 2014

[55] P. A. Amoroso-Silva *et al.*, "Microscopic Analysis of the Quality of Obturation and Physical Properties of MTA Fillapex," vol. 1036, no. September, pp. 1031–1036, 2014

[56] Á. H. Borges *et al.*, "Physicochemical properties and surfaces morphologies evaluation of MTA FillApex and AH plus," *Sci. World J.*, vol. 2014, 2014

[57] N. Kharouf *et al.*, "Physicochemical and antibacterial properties of novel, premixed calcium silicate-based sealer compared to powder–liquid bioceramic sealer," *J. Clin. Med.*, vol. 9, no. 10, pp. 1–17, 2020