ISSN 0975-2366
DOI:https://doi.org/10.31838/ijpr/2021.13.04.004

Research Article

Micro CT Analysis of Voids Formation on Root Canal Fillings Using Calcium Silicate Bioceramic-Based Sealers and Ultrasonic Activation

DEWA AYU NYOMAN PUTRI ARTINGSIH[1]*, STEFANI ASTARI DEWI[2], NILAKESUMA DJAUHARIE[1], DWI KAMARATI[2]

[1] Department of Conservative Dentistry, Faculty of Dentistry, Universitas Indonesia
[2]Conservative Dentistry Residency Program, Faculty of Dentistry, Universitas Indonesia
*Corresponding Author:
Email: dewa.ayu61@ui.ac.id
Received: 10.10.21, Revised: 14.11.21, Accepted:06.12.21

ABSTRACT:
Objective: The objective of this study was to analyze the voids formation difference of calcium silicate bioceramic-based sealers and calcium silicate pozzolan-based sealers with ultrasonic activation and without ultrasonic activation by 3D Micro-CT analysis. **Material and Methods**: Thirty-two samples of extracted single root lower premolars were given root canal filling using gutta-percha and calcium silicate-based sealers with or without ultrasonic activation. Void formation on sealers was evaluated by measuring the total voids of the root canal filling with micro-CT analysis. Group 1: calcium silicate-based sealer iRoot® SP (Innovative BioCeramix, Vancouver, Canada) without ultrasonic activation; group 2: calcium silicate-based sealer iRoot® SP (Innovative BioCeramix, Vancouver, Canada) with ultrasonic activation; group 3: calcium silicate pozzolan-based sealer Endoseal® MTA (Maruchi, Wonju, Korea) without ultrasonic activation; and group 4: calcium silicate pozzolan-based sealer Endoseal® MTA (Maruchi, Wonju, Korea) with ultrasonic activation. Statistical analysis used one-way ANOVA and post hoc Bonferroni. **Results**: Ultrasonic activated calcium silicate pozzolan-based sealer group showed the lowest voids formation through micro-CT analysis. Calcium silicate bioceramic pozzolan-based sealers have fewer voids formation significantly ($p<0.05$) compared to calcium silicate bioceramic-based sealers. The ultrasonically activated sealer groups also showed fewer voids formation significantly ($p<0.05$) compared to groups that were not activated by ultrasonic. **Conclusion**: Micro-CT analysis revealed calcium silicate pozzolan-based sealers with ultrasonic activation have the least voids formation on root canal fillings.

Keywords: voids, bioceramic sealer, calcium silicate sealer, calcium silicate pozzolan sealer, ultrasonic, micro-CT

INTRODUCTION:
Under the literature research by Ng et al. (2011), one of the determinants of successful root canal treatment is a dense root canal filling without any voids.[1] The presence of voids in root canal filling has the potential to weaken the structure of obturation material by forming microcracks and causing microleakage, leading to root canal reinfection.[2,3] The most used materials to fill the root canal are gutta-percha and sealer. The ideal sealers, according to Grossman, must have a good density against the root canal wall, be able to bind into dentin, be biocompatible, have an antibacterial effect, be radiopaque, and have good dimensional stability.[4,5] There are several types of sealers that have been produced to improve the quality of root canal filling, including zinc oxide eugenol-based sealer, calcium hydroxide-based sealer, resin-based sealer, and bioceramic sealer.

Calcium silicate bioceramic sealer is the latest technology and shows good bioactivity properties, which are not found in epoxy resin-based sealers, the current gold standard. However, voids are still present due to a lack of flow, manipulation, and application of the sealer.[3,6,7] Premixed calcium silicate sealers have been packed in syringes and injection tips so they are not susceptible to powder and liquid ratio errors, facilitating application to the root canal. This method has been proven to reduce the voids.[8]
Premixed calcium silicate pozzolan-based sealer (CSBPS) and ultrasonic activation can reduce the voids formation of the root canal filling. The pozzolan reaction results in a sealer with better flow and faster hardening time, which, when combined with ultrasonic activation, will reduce the formation of voids and improve the quality of the root canal filling.[9] The user manual of Endoseal® MTA, a premixed CSBPS, suggests the

use of ultrasonic activation to minimize the formation of voids in the root canal filling, as proven effective by the research of Hwang et al. (2015) and Kim et al. (2018) [8,10] In addition, Chandrasekhar et al. (2016) also proved that a combination of premixed calcium silicate-based sealer (CSBS) with ultrasonic activation results in a better filling outcome.[11] However since there have been few studies comparing the voids of various types of premixed CSBSs with ultrasonic activation on the root canal using three-dimensional micro-CT technology, this study strives to fill this gap in the research to prove the quality of root canal fillings performed with those sealers and methods.

MATERIALS AND METHODS:

Thirty-two extracted teeth of first mandibular premolars were constituted in this study. This study's protocol was approved by the Ethical Committee of the Faculty of Dentistry Universitas Indonesia (no.136/ethical approval/FKGUI/IX/2019, No. Protocol: 051451219). A single-rooted tooth without curve canal, caries, root resorption, or root fractures were the inclusion criteria of this study. The teeth morphology was investigated by conventional radiography. Before the experiment, the coronal surface of the teeth was observed with an operating microscope. Only teeth with circular canals were included in the standardized procedure. Then, every tooth crown was cut from the cementoenamel junction to assure 12mm root length. [12]

Root canal instrumentation was using a #10 K-File (Dentsply-Maillefer; Tulsa, OK, USA) and working length was measured 0.5 mm to the apex. ProTaper NEXT files then used (Dentsply-Maillefer; Ballaigues, Switzerland) until X3 with an X-Smart electronic endomotor (Dentsply-Maillefer) at 250 rpm. Irrigation during the instrumentations using 2 mL of 2.5% NaOCl. After instrumentation, the canal was rinsed by an 17% EDTA for 1 minute and final rinse with 5 mL of distilled water. Paper points (Gapadent Co, Ltd; Tianjin, China) were used to dry the canal. Finally, the subject is randomly divided into four groups (n = 8).[12]

Group 1 received CSBS iRoot® SP (Innovative BioCeramix, Vancouver, Canada) without ultrasonic activation, and Group 2 received CSBS the same as group 1 but with ultrasonic activation. The premixed sealer with disposable canal tip inserted into the canal. The cone was applied slowly using master GP cones (ProTaper NEXT Gutta Percha) which showed good apical tug back. At the canal orifice level, the excess cone was trimmed off and no additional cones were used.

Group 3 received CSBPS Endoseal® MTA (Maruchi, Wonju, Korea) without ultrasonic activation, and Group 4 received CSPBS the same as group 3 but with ultrasonic activation. The ultrasonic tip (StartX #3, Dentsply-Maillefer) attached to an ultrasonic device (P-5 Newtron XS; Satelec, Mount Laurel, NJ) and the power was set to ''8''. The sealer was applied first with the disposable canal tip to the root canal and then the ultrasonic vibration was applied to the cotton pliers that was holding the gutta percha cone 20 mm from the tip for 2-3 seconds while inserted to its working length. Finally, excess cones are cut at the level of the orifice. After the obturation process, the roots were stored at 37°C with 100% humidity to ensure that the filler material had been set.[12]

All the obturated roots were scanned with the μ-CT machine (Bruker Skyscan 1172; Kontich, Belgium). The system was set to 100 kVp, 100 mA, beam hardening correction of 40%, and 13.47 μm pixel size. Before the scanning process began, the detector was calibrated. This process purpose to minimize ring artifacts. All samples were rotated 360° with 5 minutes integration time. The time needed is approximately 2 hours for the scanning process. Softwares were used to evaluate and size the void, which was CTAn and NRecon (Bruker SkyScan; Kontich, Belgium). This study was using a modified algorithm to set axial 2D (1,000 × 1,000 pixels) images. Ring artifact correction and smoothing were set to zero. The manufacturer's recommended limits for contrast were used. Finally, 1,023 cross-sectional images captured, reconstructed to set the 2D slices.[12]

Obturated root canals was measured for the analysis 3D volumetric visualizations and calculations. New cross-sectional image constructed from 256 cross-sectional TIFF images (interval, 0,5 mm) from the apex to coronal section. Voids that were detected at 2D slices were visualized on a thin-film transistor (TFT) medical monitor was based on the recently reported study protocol.[13] One evaluator who can use the software's magnification and specifications examined all images and was not familiar about root filling techniques.[12]

The original grayscale Gaussian lowpass filter was processing the image and after that, the volume was measured. A segmentation procedure under the same software accomplished to withdraw dentin from the sealer, gutta-percha, and voids. Next, binarization process was then applied by processing gray level constitute imposed into black and white images.[12] A region

of interest (ROI) thorough the entire object was then selected for the measurement of void volumes from the apex to coronal of the roots. (Fig. 1)
Correlations between groups were tested using a one-way ANOVA test with Bonferroni correction to assess differences between groups. Analysis of this study using SPSS software (ver. 20; Chicago, IL, USA). An AP value of less than 0.05 was considered to indicate statistical significance.

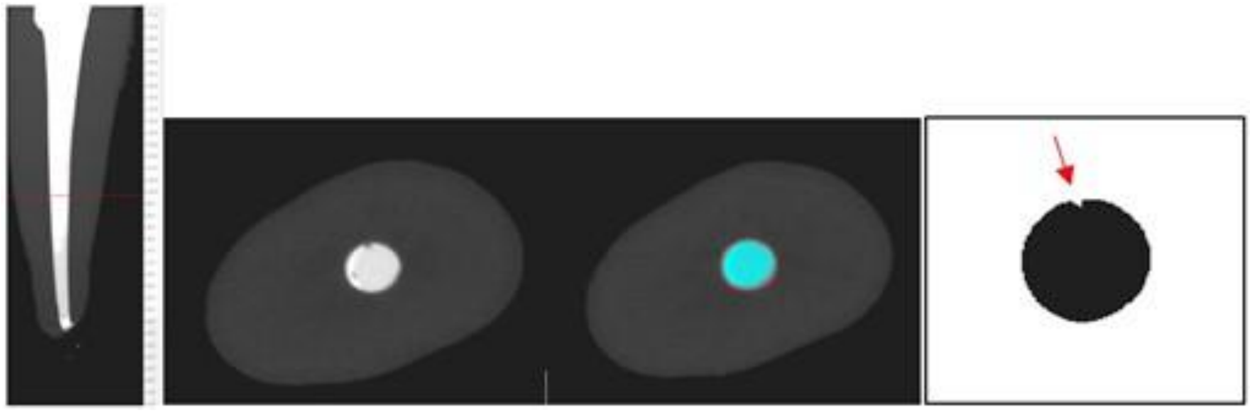

Fig.1: Representation of micro-CT scan results viewed using CTAn software. The results of scanning with segmentation in the middle 1/3 of the root canal (a; b), determined region of interest (ROI) (c), carried out the process of binarization into black and white drawing and obtained voids images (red arrows) (d).

RESULTS:

Table 1:The mean and standard deviation analysis of void root canal filling percentages (%) between CSBSs with and without ultrasonic activation

Sealers	Non-Ultrasonic Activated	Ultrasonic Activated
Calsium Silicate	Group 1 (n= 8) 4.960 ± 2.11[a]	Group 3 (n= 8) 1.989 ± 0,799[b]
Calsium Silicate Pozzolan	Group 2 (n= 8) 1.309 ± 0.67[b]	Group 4 (n= 8) 0.306 ± 0,277[b]

Means and standard deviations data. Different letters mean statistical differences between the groups ($P < 0.05$).

There were significant differences between the four groups. Group 1 had the highest mean of voids root canal filling percentages, while Group 4 had the lowest mean (Table 1). A post hoc test was performed to determine the significance of the differences between groups. The data in Table 2 show that there is a significant difference in the percentage of voids of root canal filling between the CSBS group and the CSBPS group ($P<0.05$), with the mean voids percentage of the CSBPS group lower than the CSBS group. A statistically significant difference in the percentages of voids root canal filling was found between the CSBS group with ultrasonic activation and without ultrasonic activation ($P<0.05$), with the mean voids percentage of the CSBS group that was ultrasonic activated lower than the calcium-based sealer group silicate that was not activated.

DISCUSSION:

Voids in root canal filling have clinical relevance because pores and gaps formed are sufficient for bacterial penetration and its products.[14] Premixed calcium silicate sealers have been packaged in syringes so that they are not susceptible to powder and liquid ratio errors, with injection tips to facilitate application to the root canal, which is proven to reduce the voids of the root canal filling.[8] In recent years, premixed calcium silicate sealer was combined with alumina-silica to trigger a pozzolan reaction, producing a sealer with an effective and hardened flow when exposed to water, resulting in a denser and more cemented sealer. Ultrasonic application has also been proven in several studies to reduce the formation of voids.[9] Voids formed in this study ranged from 0.306% to 4.960%, with open and closed porosity appearing types on all tooth roots from apical to coronal. Closed porosity affects the macroscopic properties of materials, such as density, elasticity, mechanical strength, and thermal conductivity. Open porosity has a direct impact on the penetration of bacterial and bacterial toxins into the dentine, as well as an increase in bacterial adhesion due to the creation of a medium for development.[15]

Some researchers have mentioned that this sealer is recommended for use with lateral cold compaction or the single cone technique due to the influence of temperature on the mechanical properties of the sealer.[15] The faster hardening time of CSBSs also makes it difficult to carry out cold lateral compaction techniques, so the single cone filling technique is still recommended for use in conjunction with CSBSs.[16]

Micro-CT techniques can help overcome some disadvantages of the method commonly used to assess root canal filling because it does not damage specimens, such as SEM and stereomicroscope analysis. Current research shows that micro-CT facilitate the visualization of the root canal obturation as both a single 3D object or an examination of cross-sectional images of roots at each layer. Hence, the volume of root canal obturation by gutta-percha, sealer, and voids can be measured, and the shape and type of voids can be recognized in detail.[18]

From the four groups tested by 3-dimensional Micro-CT analysis, the ultrasonic-activated CSBPS group showed the lowest root canal wall voids compared to the other groups (Table 1). In this study, it was found that the CSBPS had a better density of sealer against the root canal wall with a smaller percentage of voids volume than a CSBS, with statistically significant differences (Table 1). This can be caused by the addition of silica-alumina in calcium silicate sealer so that the pozzolan reaction will occur when in contact with water. The pozzolan reaction is a reaction between small particles of the mineral aggregate alumina silicate (1.5 μm) and calcium silicate hydration products. This reaction will form a strong cement matrix because it can dissolve in water, calcium oxide, and calcium hydroxide to produce an effective flow, lower solubility, and faster hardening time, resulting in a denser and cemented sealer compared to CSBS.[9] This is supported by Lim et al. (2015), which showed Endoseal MTA® has a dimensional change of 2% after experiencing complete hardening within 12 hours compared to iRoot® SP with a dimensional change of 0.2%.19 Small sealer particles also help improve the sealer flow and can fill irregularities of the root canal, filling the voids between gutta-percha and the root canal wall so that the filling gap is very tight. It is also supported that the two sealers have the appropriate flow recommended by ISO 6786/2001, which is above 20mm.[20]

It was also found that ultrasonic activation significantly reduced the voids of CSBS in root canal filling (Table 1). This is consistent with previous studies, which show that ultrasonic activation on root canal filling vibrated through three media, ultrasonic tips, clamp tweezers, and gutta-percha, is significant in helping to reduce voids in CSBSs. Ultrasonic activation at high strength frequencies will create acoustic transmission and cavitation effects that will minimize the formation of voids inside the material, resulting in better adaptation between the sealer and the root canal dentine, the filling of irregularities, and good penetration into the lateral root canals and canals accessories.[21–23] The frequency of ultrasonic vibrations generated from ultrasonic devices (P-5 Newtron XS, Satelec) vary from 28-36kHz and still has a high amplitude.[24] Amplitude is associated to the power of ultrasonic waves and represent the distant between the peak and the average value of the waveform. Amplitude can be deflate when ultrasonic waves flow to substrate when the frequency is consistent, so Kim et al. (2018) used ultrasonic waves across three media, including ultrasonic tips, tweezers, and gutta-percha, so that the actual amplitude of gutta-percha is sufficient to remove trapped air bubbles without affecting the sealer's integrity.[8,25] The ultrasonic activation for 3 seconds as suggested by Pharasos et al. (2014) in the use of calcium silicate-based endodontic sealers is sufficient, so it does not change its mechanical properties.[26]

No significant differences were found in the CSBPS group, which was activated ultrasonically and without ultrasonic activation (Table 1). This is because the CSBPS group without ultrasonic activation in this study has shown a low voids volume, so it does not differ significantly from the ultrasonically activated group. CSBPS with ultrasonic activation still produced the least voids compared to the group without activation. Based on the results of this study, ultrasonic activation through three media—the ultrasonic tip, tweezers, and gutta-percha—can successfully reduce the formation of voids to obtain a better quality of root canal filling.

CONCLUSION

The ultrasonic-activated CSBPS group showed the lowest root canal wall voids compared to the other groups. CSBPS produces lower voids in root canal filling than CSBS. Ultrasonic activation helps to reduce the voids of CSBSs. Root canal filling with CSBPS with ultrasonic activation on a single cone technique can be an alternative in the selection of CSBS and root canal filling techniques.

REFERENCES:

1. Ng YL, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. Int Endod J. 2011 Jul;44(7):583-609.
2. Siqueira JF Jr. Aetiology of root canal treatment failure: why well-treated teeth can fail. Int Endod J. 2001 Jan;34(1):1-10.
3. Ortiz FG, Jimeno EB. Analysis of the porosity of endodontic sealers through micro-computed tomography: A systematic review. J Conserv Dent. 2018 May-Jun;21(3):238-242.
4. Hargreaves K, Berman L. Cohen's Pathways of the Pulp, 11th Edition. 11th ed. St. Louis: Elseveir; 2016. pp465-478.
5. Alaenazi, Mohammed Sulaiman et al. "Contemporary Endodontic Sealers." Journal of Health, Medicine and Nursing 46. 2018; 42-52.
6. Siboni F, Taddei P, Zamparini F, Prati C, Gandolfi MG. Properties of BioRoot RCS, a tricalcium silicate endodontic sealer modified with povidone and polycarboxylate. Int Endod J. 2017;50 Suppl 2:e120-e136.
7. Viapiana R, Moinzadeh AT, Camilleri L, Wesselink PR, Tanomaru Filho M, Camilleri J. 2016. Porosity and sealing ability of root fillings with gutta-percha and BioRoot RCS or AH Plus sealers. Evaluation by three ex vivo methods. Int Endod J. 49 (8):774-782.
8. Kim JA, Hwang YC, Rosa V, Yu MK, Lee KW, Min KS. 2018. Root Canal Filling Quality of a Premixed Calcium Silicate Endodontic Sealer Applied Using Gutta-percha Cone-mediated Ultrasonic Activation. J Endod. 44(1) 133-138.
9. Yoo, Yeon-Jee et al. "Dynamic intratubular biomineralization following root canal obturation with pozzolan-based mineral trioxide aggregate sealer cement." Scanning. 2018; 38(1): 50-6.
10. Hwang JH, Chung J, Na HS, Park E, Kwak S, Kim HC. Comparison of bacterial leakage resistance of various root canal filling materials and methods: Confocal laser-scanning microscope study. Scanning. 2015;37(6):422-428.
11. Chandrasekhar, V. et al. "To Compare the Pursuance of Ultrasonic Activation at Distinct Planes of Endodontic Therapy on Filling Superiority of Different Root Canal Sealers." British journal of medicine and medical research. 2016; 14: 1-9.
12. Celikten B, Uzuntas CF, Orhan AI, Tufenkci P, Misirli M, Demiralp KO, et al. Micro-CT assessment of the sealing ability of three root canal filling techniques. Journal of Oral Science. 2015;57(4):361–6.
13. Moeller L, Wenzel A, Wegge-Larsen AM, Ding M, Kirkevang LL. Quality of root fillings performed with two root filling techniques. An in vitro study using micro-CT. Acta Odontol Scand. 2013;71(3-4):689-696.
14. Huang Y, Celikten B, De Faria Vasconcelos K, et al. Micro-CT and nano-CT analysis of filling quality of three different endodontic sealers. Dentomaxillofacial Radiol. 2017;46(8).
15. Shen, Y., Peng, B., Yang, Y., Ma, J., & Haapasalo, M. What do different tests tell about the mechanical and biological properties of bioceramic materials? Endodontic Topics. 2015; 32:47-85.
16. Bonnaud PA, Ji Q, Coasne B, Pellenq RJM, Van Vliet KJ. Thermodynamics of water confined in porous calcium-silicate-hydrates. Langmuir. 2012;28(31):11422-11432.
17. Kim, H., Young-Jin Kim, S. Nam and Kwon Tae-Yub. "Evaluation of Sealing Effect and Working Time of Root Canal Filling MTA Materials." THE JOURNAL OF THE KOREAN ACADEMY OF PEDTATRIC DENTISTRY. 2016; 43:129-136.
18. Jung, M., Lommel, D., & Klimek, J. The imaging of root canal obturation using micro-CT. International endodontic journal. 2005; 38(9):617-626 .
19. Lim ES, Park YB, Kwon YS, Shon WJ, Lee KW, Min KS. Physical properties and biocompatibility of an injectable calcium-silicate-based root canal sealer: In vitro and in vivo study. BMC Oral Health. 2015;15(1):1-7.
20. Al-Haddad, A.Y., Kutty, M.G., Kasim, N.H., & Aziz, Z.A. Physicochemical Properties of Calcium Phosphate Based Coating on Gutta-Percha Root Canal Filling. International Journal of Polymer Science. 2015; 1-5.
21. Guimarães BM, Amoroso-Silva PA, Alcalde MP, Marciano MA, Bombarda De Andrade F, Hungaro Duarte MA. Influence of ultrasonic activation of 4 root canal sealers on the filling quality. J Endod. 2014;40(7):964-968.
22. Arslan H, Abbas A, Karatas E. Influence of ultrasonic and sonic activation of epoxy-amine resin-based sealer on penetration of sealer into lateral canals. Clin Oral Investig. 2016;20(8):2161-2164.
23. Jiang, S., Zou, T., Li, D., Chang, J., Huang, X., & Zhang, C. Effectiveness of Sonic, Ultrasonic, and Photon-Induced Photoacoustic Streaming Activation of NaOCl on Filling Material Removal Following Retreatment in Oval Canal Anatomy. Photomedicine and laser surgery. 2016; 34(1):3-10 .

24. P5XSFLYER.pdf.
25. Chaudhuri, K. and B. Verma. "Amplitude- and frequency-dependent ultrasonic attenuation in indium-doped tin at 1.3K." Journal of Physics F: Metal Physics. 1982: 12: 3039-3052.
26. Parashos, P., Phoon, A., & Sathorn, C. Effect of Ultrasonication on Physical Properties of Mineral Trioxide Aggregate. BioMed Research International, 2014.