Caio Rodrigo de Oliveira Morábito

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Evaluation of the expression of imaging artifacts of different bioceramic compounds in cone beam computed tomography

Dissertação apresentada à Faculdade de Odontologia da Universidade de Uberlândia, para obtenção do Título de Mestre em Odontologia na Área de Clínica Odontológica Integrada.

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DEDICATÓRIA

Dedico este trabalho aos meus pais, que sempre fazem de tudo para o meu sucesso.

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À Deus, o qual me da forças para sempre continuar.

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SUMÁRIO

Resumo

O objetivo deste estudo foi avaliar a expressão de artefatos tomográficos promovidos por materiais endodônticos biocerâmicos. Para a realização deste estudo, foi fabricado um phantom homogêneo de acrílico com uma abertura cilíndrica central para permitir a inserção dos materiais. Os grupos deste estudo foram divididos de acordo com o material utilizado para preencher o phantom (n=4): a. Grupo controle sem material, b. BIO-C® Repair, c. Biodentine e d. MTA Branco. Três imagens tomográficas de cada phantom foram capturadas usando a tomografia computadorizada de feixe cônico (CBCT) Gendex CB-500 (Gendex Dental Systems, Hatfield, PA, EUA) utilizando os seguintes parâmetros de aquisição: 120 kV, 5 mA, FOV de 8,5x6 cm e voxel de 0,2 mm. As reconstruções axiais utilizadas para análise foram selecionadas manualmente, sendo o ponto de escolha o centro da reconstrução total. Em cada imagem axial escolhida, uma região de interesse (ROI) foi selecionada, cobrindo todo o material. Além disso, oito ROIs com dimensões idênticas à primeira foram posicionadas ao redor da região central. O desvio padrão médio dos valores de escala de cinza para cada material foi calculado agregando-se os valores de desvio padrão das oito ROIs. Observou-se um nível mais alto de artefatos associados aos materiais Bio C Repair e MTA em comparação com os grupos Controle e Biodentine ($p<0,05$). Também foi observado um nível mais alto de artefatos no grupo Biodentine em comparação com o grupo Controle ($p<0,05$). Todos os materiais apresentaram um nível satisfatório de densidade radiográfica ($p<0.05$). Este estudo demonstrou que o material Biodentine produziu uma imagem de CBCT mais homogênea e de melhor qualidade do que os outros materiais testados, o que foi representado pela expressão de menos artefatos na imagem.

Palavras-chave: Artefatos, Endodontia, Tomografia Computadorizada de Feixe Cônico.

Abstract

The objective of this study was to evaluate the expression of tomographic artifacts promoted by bioceramic endodontic materials. To carry out this study, a homogeneous acrylic phantom with a central cylindrical opening was manufactured to allow the insertion of the materials. The groups in this study were assigned according to the material used to fill out the phantom (n=4): a. Control group without material, b. BIO-C ®Repair, c. Biodentine and d. MTA White. Three tomographic images of each phantom were captured using a Gendex CB-500 cone beam computed tomography (CBCT) (Gendex Dental Systems, Hatfield, PA, USA) following acquisition parameters: 120 kV, 5 mA, FOV of 8.5x6 cm, and voxel of 0.2 mm. The axial reconstructions used for analysis were manually selected and the point of choice was the center of the total reconstruction. In each chosen axial image, a region of interest (ROI) was selected, covering the entire material. Additionally, eight ROI with identical dimensions were positioned around the central region. The average standard deviation of the gray scale values for each material was calculated using the standard deviation values of the eight ROI. Higher. The mean standard deviation of the grayscale values for each material was calculated by aggregating the standard deviation values of the eight ROIs. A higher level of artifacts associated with Bio C Repair and MTA materials was observed than the Control and Biodentine groups ($p<0.05$). A higher level of artifacts was also observed in the Biodentine group compared to the Control group ($p<0.05$). All materials presented great radiographic densitity ($p<0.05$). This study demonstrated that the Biodentine material produced a more homogeneous and better quality CBCT image than the other materials tested, which was represented by the expression of fewer artifacts in the image.

Keywords: Artifacts, Endodontics, Cone Beam Computed Tomography.

Introduction

Despite the high success rates of endodontic treatment, a considerable portion of treated teeth may exhibit persistent or recurrent lesions, which can be associated with inadequate sealing of the root canal system or the ineffectiveness of medications and filling materials in controlling infections or promoting periapical tissue repair (Karamifar et al. 2020; Coşar et al. 2022). The use of bioceramic materials, which enhance the success of treating teeth with pulp involvement, has been proposed as an advancement in endodontic treatment (Ferreira et al. 2019; Coşar et al. 2022). These materials exhibit characteristics such as biocompatibility, effective root canal sealing, stimulation of tissue regeneration, and mechanical resistance of dental tissues (Prati & Gandolfi 2015; Ferreira et al. 2019; Benetti et al. 2019). Thus, the introduction of new bioceramic materials represents a promising opportunity to enhance the effectiveness and durability of endodontic treatments (Camilleri 2015; Ferreira et al. 2019).

An important aspect of endodontic treatment is the ability to accurately assess the sealing provided by the material used to fill the root canal system (Benetti *et al*., 2019). X-rays have been proposed for this purpose, however, this method of analysis has significant limitations inherent to its two-dimensionality, such as overlapping structures, lack of image depth, and possible geometric distortions that hinder the accurate interpretation of these exams (Coşar *et al*., 2022). In contrast, tomographic examinations, more specifically cone beam computed tomography (CBCT), by providing high-resolution three-dimensional images, allow a more detailed and accurate analysis of the conditions of the root canals and the performance of the filling materials, facilitating the diagnosis, planning, and monitoring of endodontic treatment (Fox *et al*., 2018; Queiroz *et al*., 2018).

A difficulty in the tomographic evaluation of sealing materials of root canal systems is the occurrence of imaging artifacts (Celikten *et al*., 2019). Such artifacts occur due to the density of these materials, which are influenced by their chemical composition, causing different materials to present different levels of artifact formation (Celikten *et al*., 2019; Rabelo *et al*., 2021). Specifically, the presence of high-density materials, such as those used in root fillings, can introduce beam hardening artifacts into the images. These artifacts occur when X-rays of different energies are unevenly absorbed when passing

through dense materials, resulting in distortions such as dark areas and banding that compromise image quality and make diagnostic interpretation difficult (Fox *et al*., 2018).

In this sense, it is essential that endodontic materials generate the least possible amount of artifacts in tomographic images, since these imperfections or errors in the image can obscure or distort structures, making it difficult to evaluate the region of interest, making it difficult to diagnose, plan and preserve endodontic treatment (Fox *et al*., 2018; Celikten *et al*., 2019; Rabelo *et al*., 2021), which, consequently, impairs the professional's ability to perform an accurate and effective assessment (Durack & Patel, 2012; Estrela *et al*., 2020). Therefore, minimizing the presence of artifacts is essential to ensure the acquisition of high-quality images that are useful for the different phases of endodontic therapy (Rabelo *et al*., 2021).

By analyzing the occurrence and extent of artifacts in tomographic images generated by different materials, it is possible to identify the characteristics of each one, as well as possible limitations and advantages for each material, providing valuable data on its performance compared to traditional materials. Thus, this study proposes to evaluate the expression of artifacts of bioceramic endodontic materials and compare them with each other, using CBCT images. The null hypothesis is that there is no significant difference in the expression of imaging artifacts in cone beam computed tomography (CBCT) between the different bioceramic materials tested (BIO-C®Repair, Biodentine, MTA White).

Materials and Methods

Sample preparation and groups

To carry out this study, a homogeneous acrylic phantom (diameter of 10.0 cm × height of 4.0 cm) with a central cylindrical opening (diameter of 0.5 cm × height of 0.5 cm) was manufactured (Torno e Fresa Fernandes LTDA, Uberlândia, Minas Gerais, Brazil). The opening was designed for the insertion and accommodation of the materials under study. This filling was done with three different bioceramic materials, which generated the four different groups studied in the study (n=4): a. control group (without filling), b. BIO-C®Repair (Angelus, Londrina, Brazil), c. Biodentine (Septodont, Santa Catarina, Brazil) and d. MTA White (Angelus, Londrina, Brazil).

Image acquisition

Following the methodology applied by Nejaim *et al*. (2018), three tomographic images of each phantom with the material inserts were captured using a Gendex CB-500 CT scanner (Gendex Dental Systems, Hatfield, PA, USA) using the following acquisition parameters: 120 kV, 5 mA, 8.5x6 cm Field Of View (FOV) and 0.2 mm voxel. The values stipulated for FOV and voxel were the lowest possible. In addition, three images were obtained from a control group (intact phantom, without filling of the central hole). The volumetric data obtained were reconstructed and exported in a Digital Imaging and Communications in Medicine (DICOM) file.

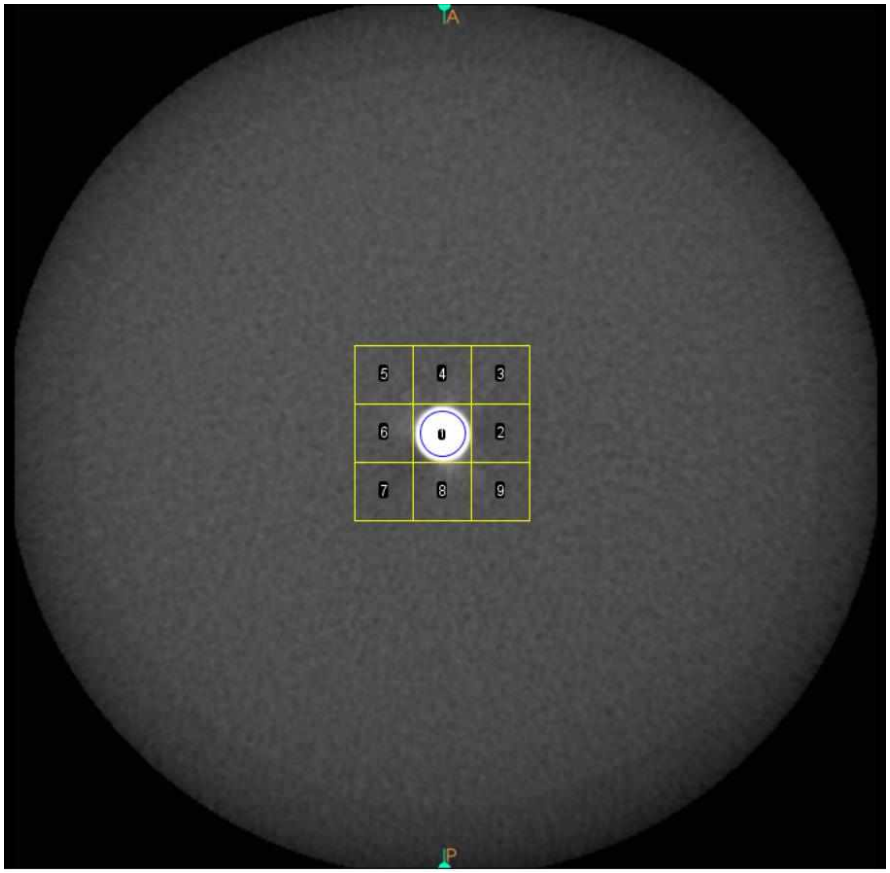


Figure 1 Tomography image of the phantom with the regions of interest (ROI) defined for artifact analysis.

Image analysis

Initially, the DICOM files were imported into the CS3D software (version 7; Carestream Health, Rochester, NY, USA) to select the images to be evaluated for the presence of the artifacts. The axial reconstructions to be used for analysis were manually selected and the point of choice was the center of the image, at half the height of the central cylinder, for all samples, in a standardized manner.

The selected axial reconstructions were saved in TIFF format and exported to Image J software, version 1.51i (National Institutes of Health, Bethesda, MD). In each image obtained, the management tool was used to delineate a region of interest (ROI) measuring 52x52 pixels, covering the entire material. In addition, eight ROIs with identical dimensions to the first were positioned around the central area (Figure 1). The "measure" function was used to obtain the standard deviation of the grayscale values for each ROI. The mean standard deviation of the grayscale values for each material was calculated by adding the standard deviation values of the eight ROIs and dividing by 8. This procedure was repeated in each of the three images of the four study groups. The final average was obtained by calculating the average of the three acquisitions (Queiroz *et al*., 2018). A single examiner, blinded to the types of treatment and previously calibrated as to the analyses, performed the method described above in a quiet environment with reduced lighting. To assess intra-examiner agreement, the assessment was repeated in 50% of the sample after a 30-day interval.

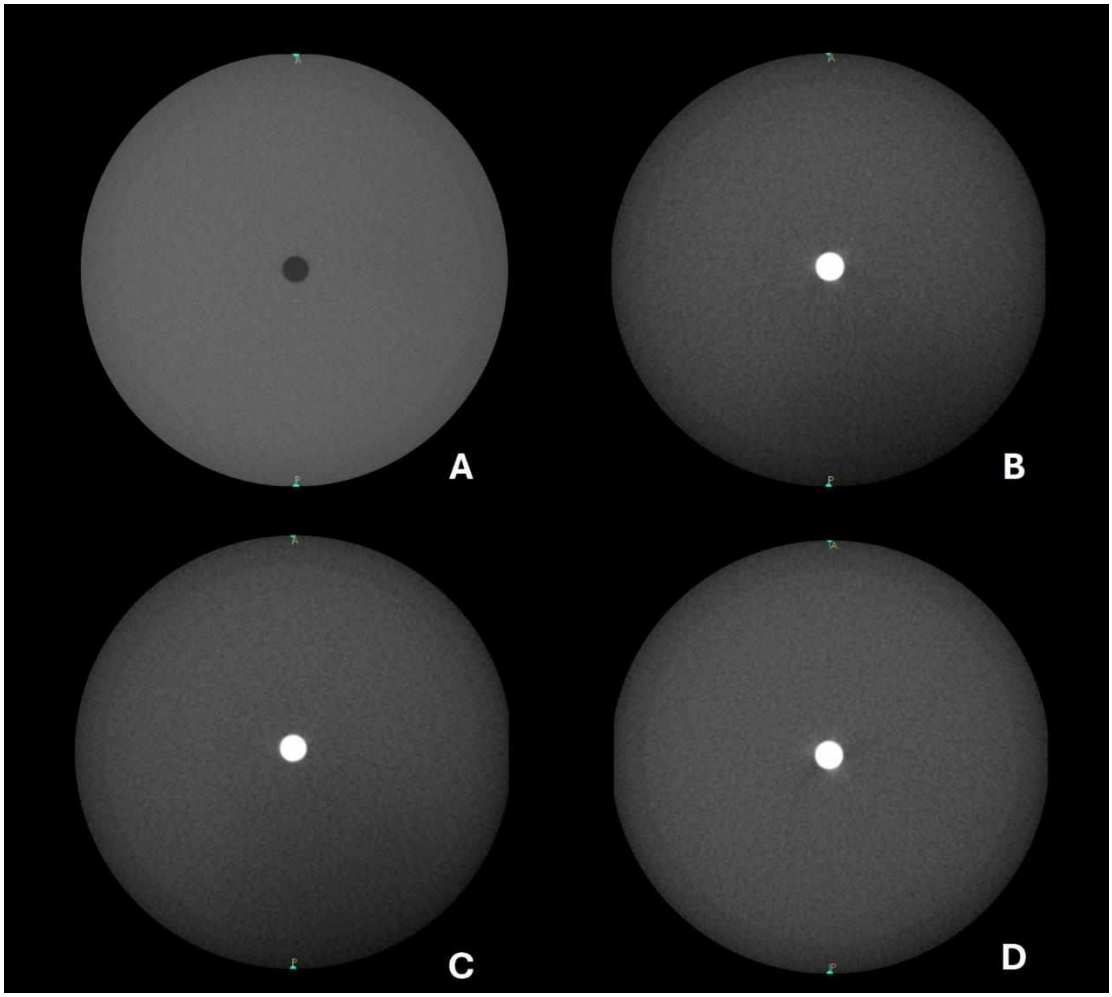


Figure 2 Images of the groups evaluated in this study: A) Control, B) Bio C Repair; C) Biodentine; D) MTA. A greater expression of artifacts can be observed in images B and D.

Statistical Analysis

This study evaluated the artifacts in tomographic techniques that occurred around different root canal filling materials (Control, Bio C Repair, Biodentine, and MTA) as well as assessed the density of these materials. After applying the Shapiro-Wilk normality test, it was observed that the generated data followed a normal distribution. Consequently, the parametric one-way ANOVA test was used for inferential data analysis. The statistical analysis of this study was performed using GraphPad Prism 9 software (San Diego, CA, USA). All tests were conducted at a 95% confidence level.

Results

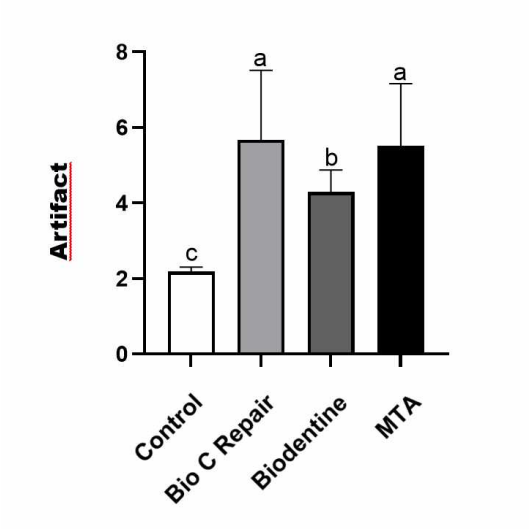
The evaluator presented an adequate level of reproducibility in his analyses (r = 0.99), and the value obtained was interpreted as almost perfect reproducibility. The mean and standard deviation data from this analysis are shown in table 1 and figure 3 below. It is important to note that higher values of grayscale indicate a greater expression of artifacts and a reduced image quality, so a higher level of artifacts associated with the Bio C Repair and MTA materials was observed than the Control and Biodentine groups ($p<0.05$). A higher level of artifacts was also observed in the Biodentine group compared to the Control group ($p<0.05$).

Table 1: Mean and standard deviation data from the analysis of artifacts observed in the study groups.

Group	Mean ± standard deviation
Control	2.18 ± 011^{c}
Bio C Repair	5.67 ± 1.84^{a}
Biodentine	4.29 ± 0.58^{b}
MTA	5.51 ± 1.64^{a}

Different letters represent different statistically significant levels between the groups. $p<0.05$ One-way ANOVA test complemented by Tukey's test

Figure 3: Mean and standard deviation data from the analysis of artifacts observed in the groups.



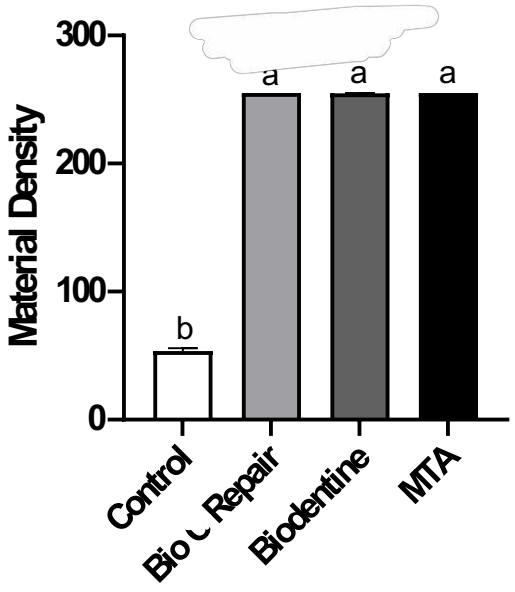
Different letters represent statistically significant differences between groups. p<0.05 One -way ANOVA test followed by Tukey's test.

Table 2 presents the mean and standard deviation data for the density analysis observed in the tomography for different root filling materials compared to the control group. The results indicate that there were no differences in the densities of the different materials and that all materials had higher densities than the control ($p<0.05$). The mean and standard deviation data from this analysis are presented in Table and Figure 4. The control group presented the lowest mean density (53.69 ± 2.06), significantly lower than all the filling material groups. All tested materials presented statistically similar mean densities, indicating high radiopacity of these materials (Camilleri 2015; Benetti et al. 2019. These results suggest that all the tested materials have great performance in terms of radiographic density.

Table 2: Mean and standard deviation data from density analysis observed on CT scans in all groups. Different letters represent different statistically significant levels between the groups. $p<0.05$ One-way ANOVA test.

Group	Mean ± standard deviation
Control	53.69 ± 2.06^{b}
Bio C Repair	255.0 ± 0.00^{a}
Biodentine	255.0 ± 0.00^{a}
MTA	255.0 ± 0.00^{b}

Figure 4: Mean and standard deviation data from density analysis observed on CT scans in all groups. Different letters represent different statistically significant levels between the groups. p<0.05 One-way ANOVA test.



Different letters represent statistically significant differences between groups. p<0.05 One -way ANOVA test followed by Tukey's test.

Discussion

The overall findings of this study indicated that the Bio C Repair and MTA materials had significantly higher levels of artifacts compared to the control group and the Biodentine group. In turn, when compared to the control group, Biodentine presented a greater number of artifacts. These results suggest that the choice of endodontic material can directly impact the quality of the tomographic images obtained, which is crucial for the accurate evaluation of root canal sealing and for the evaluation of the prognosis of endodontic treatment. These findings are in line with previous studies highlighting the significant influence of radiopaque materials on the formation of artifacts on CBCT imaging, which can potentially affect diagnostic accuracy and clinical accuracy (Fox *et al*., 2018; Queiroz *et al*., 2018; Vergaças *et al*., 2021).

The bioceramic cements used in this study are used in endodontics for more complex and challenging cases, including retreatments, perforations sealing, barrier formation in immature apices, invasive resorptions, and revascularizations. They have been shown to be effective in promoting tissue regeneration and sealing root canals, which are essential for the long-term success of endodontic treatment (Benetti *et al*., 2019; Prati & Gandolfi, 2015). In addition, cone beam computed tomography (CBCT) evaluation is recommended to monitor these treatments due to its ability to provide detailed three-dimensional images, allowing for a more accurate analysis of the seal and integrity of the materials (Fox *et al*., 2018; Queiroz *et al*., 2018). However, the occurrence of image artifacts can complicate this assessment (Vergaças *et al*., 2021). Thus, the choice of endodontic material, along with the appropriate use of advanced imaging techniques, is crucial to ensure treatment efficacy and long-term clinical success (Durack & Patel, 2020; Schulze *et al*., 2011).

Biodentine showed a slightly lower mean density but still significantly higher than the control and different from the other materials. These results suggest that Bio C Repair and MTA have superior performance in terms of radiographic density.The possible causes of having more artifacts in the MTA and Bio C Repair groups may be related to the specific composition of these materials. Radiopaque components, such as heavy metal oxides present in these materials, are known to increase the incidence of artifacts in tomographic imaging (Schulze *et al*., 2010; Tanomaru-Filho *et al*., 2017). For example, MTA contains bismuth oxide particles, which are essential for radiopacity but can contribute significantly to artifact formation (Vergaças *et al*., 2021). Preclinical studies show that the presence of bismuth in MTA is associated with a greater expression of artifacts, compromising image quality (Camilleri, 2015; Ferreira *et al*., 2019). The Bio C Repair and Biodentine materials have zirconium oxide as radiopacifiers (Ghilotti *et al*, 2020), however Biodentine has a lower concentration of this radiopacifier and a higher concentration of calcium silicate, which may justify its higher level of distortion compared to Bio C Repair (Ghigloti *et al*., 2020). Alternatives such as the use of radiopacifiers less likely to generate artifacts, such as zirconia-based ones, can be explored to improve the quality of tomographic images (Fox *et al*., 2018). It is essential that future studies examine the detailed composition of these materials and identify the specific agents responsible for the artifacts in order to develop formulations that minimize these unwanted effects.

The lower expression of artifacts facilitates the visualization of the anatomical structures and the accurate evaluation of the sealing of the material within the root canal. Clinically, this translates into more accurate diagnoses, less chance of errors during treatment planning, and a better ability to monitor the response of periapical tissues to treatment. Superior image quality with the use of Biodentine can therefore improve clinical outcomes and the efficiency of endodontic treatments (Camilleri, 2015; Queiroz *et al*., 2018). Previous studies that evaluated these materials did not compare the formation of artifacts between them (Camilleri, 2015; Vergaças *et al*., 2021; Tanomaru-Filho *et al*., 2017). The present study showed that Biodentine shows a lower tendency to the formation of artifacts. The absence of bismuth (Camilleri 2015; Celikten, *et al*., 2016), the higher concentration of ceramic materials such as calcium silicate (Tanomaru-Filho *et al*., 2017) and lower porosity (Iglecias *et al*., 2017), may justify the findings of this study. In addition, it is worth noting that radiographic properties alone do not indicate the effectiveness of the material in endodontic treatment, however, Tanomaru-Filho *et al*. (2017) also found that Biodentine has low cytotoxicity and high biocompatibility. These studies indicate that Biodentine is not only effective in sealing root canals, but also facilitates better postoperative follow-up, providing greater accuracy in the evaluation of endodontic sealing and contributing to the long-term success of the treatment (Benetti *et al*., 2019; Vergaças *et al*., 2021

The present study, despite its significant contributions, has some limitations. The use of a homogeneous acrylic phantom, even though it is a validated methodology in radiographic analyses, may not completely replicate the actual clinical conditions, which may influence the observed results (Pauwels *et al*., 2011; Oliveira *et al*., 2017). In addition, the analysis of the images was performed by a single examiner, which may introduce bias, despite efforts at calibration and blinding, in addition to the almost perfect reproducibility observed (McGuigan, Duncan & Horner, 2018). In addition, the variability between different brands of CT scanners and reconstruction software may exacerbate or mitigate the presence of these artifacts, highlighting the importance of standardizing imaging protocols and considering these variabilities when interpreting CT results. (Schulze, Berndt & d'Hoedt, 2010; Wahidi *et al.,* 2023). Future studies should address these limitations, including samples that are more representative of actual clinical conditions and the use of multiple examiners to validate results. It would also be beneficial to carry out studies evaluating the expression of artifacts in high-resolution CT

scanners, which are the most suitable for endodontic evaluation. (Iglecias *et al*., 2017; Tanomaru-Filho *et al*., 2017).

Conclusion

This study demonstrated that the Biodentine material produced a more homogeneous and better quality CBCT image than the other materials tested, which was represented by the lower expression of artifacts in the image.

References

Benetti, F., Queiroz, Í. O. de A., Lopes, J. M. de A., Oliveira, S. H. P. de, & Araújo, G. S. (2019). Cytotoxicity, biocompatibility, and biomineralization of a new high-plasticity MTA material. Journal of Endodontics, 43(7), 774-778.

Camilleri, J. (2015). Staining potential of Neo MTA Plus, MTA Plus, and Biodentine used for pulpotomy procedures. Journal of Endodontics, 41(7), 1139-1145.

Celikten, B., Jacobs, R., de Faria Vasconcelos, K., Huang, Y., Shaheen, E., Nicolielo, L. F. P., & Orhan, K. (2019). Comparative evaluation of cone beam CT and micro-CT on blooming artifacts in human teeth filled with bioceramic sealers. Clinical Oral Investigations, 23(8), 3267-3273.

Celikten, B., Uzuntas, C. F., Orhan, A. I., Orhan, K., Tufenkci, P., Kursun, S., & Demiralp, K. Ö. (2016). Evaluation of root canal sealer filling quality using a single-cone technique in oval shaped canals: An in vitro micro-CT study. Scanning, 8, 133-140.

Coşar, Ö., Erdoğan, H., Erdönmez, D., & Akyol, M. E. (2022). The effect of two different root canal sealers on treatment outcome and post-obturation pain. International Endodontic Journal, 55(5), 497-506.

de Oliveira, M. V. L., Wenzel, A., Campos, P. S. F., & Spin-Neto, R. (2017). Quality assurance phantoms for cone beam computed tomography: A systematic literature review. Dentomaxillofacial Radiology, 46(4), 20160329.

Durack, C., & Patel, S. (2012). Cone beam computed tomography in endodontics. Brazilian Dental Journal, 23(3), 179-191.

Estrela, C., Costa, M. V. C., Bueno, M. R., Rabelo, L. E. G., Decurcio, D. A., & Silva, J. A. (2020). Potential of a New Cone-Beam CT Software for Blooming Artifact Reduction. Brazilian Dental Journal, 31(6), 582-588.

Ferreira, N. S., Gollo, E. K. F., Boscato, N., Arias, A., & Silva, E. J. N. L. (2019). Evaluation of the potential of mancha of Neo MTA Plus, MTA Plus, and Biodentine used for pulpotomy procedures. Journal of Endodontics, 45(3), 123-130.

Fox, A. J., Li, H., Dacre, I. T., & Kasper, K. A. (2018). Reducing metal artefact in cone beam CT imaging of equine dentition. Equine Veterinary Journal, 50(5), 655-662.

Ghilotti, J., Sanz, J. L., López-García, S., Guerrero-Gironés, J., Pecci-Lloret, M. P., Lozano, A., Llena, C., Rodríguez-Lozano, F. J., Forner, L., & Spagnuolo, G. (2020). Comparative surface morphology, chemical composition, and cytocompatibility of Bio-C Repair, Biodentine, and ProRoot MTA on hDPCs. Materials, 13(2189).

Iglecias, E. F., Freire, L. G., Candeiro, G. T., dos Santos, M., Antoniazzi, J. H., & Gavini, G. (2017). Presence of voids after continuous wave of condensation and single-cone obturation in mandibular molars: A micro-computed tomography analysis. Journal of Endodontics, 43(4), 638-642.

Karamifar K, Tondari A, Saghiri MA. Endodontic Periapical Lesion: An Overview on the Etiology, Diagnosis and Current Treatment Modalities. Eur Endod J. 2020 Jul 14; 5(2):54-67. doi: 10.14744/eej.2020.42714. PMID: 32766513; PMCID: PMC7398993.

McGuigan, M. B., Duncan, H. F., & Horner, K. (2018). An analysis of effective dose optimization and its impact on image quality and diagnostic efficacy relating to dental cone beam computed tomography (CBCT). Swiss Dental Journal, 128, 297-316.

Pauwels, R., Stamatakis, H., Manousaridis, G., Walker, A., Michielsen, K., Bosmans, H., & Jacobs, R. (2011). Development and applicability of a quality control phantom for dental cone-beam CT. Journal of Applied Clinical Medical Physics, 12(4), 3478.

Prati, C., & Gandolfi, M. G. (2015). Calcium silicate bioactive cements: Biological perspectives and clinical applications. Dental Materials, 31(4), 351-370.

Queiroz, P. M., Santaella, G. M., Groppo, F. C., & Freitas, D. Q. (2018). Metal artifact production and reduction in CBCT with different numbers of basis images. Imaging Science in Dentistry, 48(1), 41-44.

Rabelo, L. E. G., Bueno, M. D. R., Costa, M. V. C. D., de Musis, C. R., Estrela, C. R. A., Guedes, O. A., Gavini, G., & Estrela, C. (2021). Blooming artifact reduction using different cone-beam computed tomography software to analyze endodontically treated teeth with intracanal posts. Computers in Biology and Medicine, 136, 104679.

Schulze, R. K., Berndt, D., & d'Hoedt, B. (2010). On cone-beam computed tomography artifacts induced by titanium implants. Clinical Oral Implants Research, 21(1), 100-107.

Tanomaru-Filho, M., Torres, F. F. E., Bosso-Martelo, R., Chávez-Andrade, G. M., Bonetti-Filho, I., & Guerreiro-Tanomaru, J. M. (2017). A novel model for evaluating the flow of endodontic materials using micro-computed tomography. Journal of Endodontics, 43(5), 796-800.

Vergaças, J., Oliveira, M. L., de Azevedo, A. M., & Machado, F. A. (2021). Marginal gaps and voids of three root-end filling materials: A microcomputed tomographic study. Microscopy Research and Technique, 84(5), 904-911.