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Alberto Marçal Batista

ACURÁCIA DO ESCANEAMENTO DE CONDUTOS RADICULARES EM DIFERENTES PROFUNDIDADES: UMA ANÁLISE DE CINCO SCANNERS INTRAORAIS

Governador Valadares
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Dissertação apresentada ao Programa de Pós-Graduação em Ciências Aplicadas à Saúde, da Universidade Federal de Juiz de Fora, Campus Governador Valadares, como requisito parcial à obtenção do título de Mestre em Ciências Aplicadas à Saúde, área de concentração Biociências.

Orientador: Prof. Dr. Rodrigo Furtado de Carvalho

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Alberto Marçal Batista

Acurácia do escaneamento de condutos radiculares em diferentes profundidades*: uma análise de cinco scanners intraorais.*

Dissertação apresentada ao Programa de pós graduação em Ciências Aplicadas a Saúde da Universidade Federal de Juiz de Fora como requisito parcial à obtenção do título de Mestre em Ciências Aplicadas a Saúde. Área de concentração: Biociências.

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BANCA EXAMINADORA

Prof. Dr. Rodrigo Furtado de Carvalho - Orientador
Universidade Federal de Juiz de Fora

Prof. Dr. Cleidiel Aparecido Lemos
Universidade Federal de Juiz de Fora

Prof. Dr. César Dalmolin Bergoli
Universidade Federal de Pelotas

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RESUMO

Objetivo: Avaliar a acurácia e a veracidade do escaneamento intraoral de dentes bovinos unirradiculares enfraquecidos em diferentes profundidades do canal (6, 9, 12 e 15 mm), comparando os volumes obtidos por escâneres intraorais com aqueles determinados por microtomografia computadorizada (micro-CT), considerada o padrão-ouro. **Materiais e métodos:** Quatro dentes bovinos com lúmen apical de até 1,3 mm foram selecionados, submetidos ao tratamento endodôntico e distribuídos aleatoriamente em quatro grupos de acordo com a profundidade do canal (6, 9, 12 e 15 mm). Os espécimes foram enfraquecidos, mantendo-se uma espessura circunferencial de dentina de 2 mm e uma profundidade de 4 mm. Cada amostra foi escaneada dez vezes utilizando cinco escâneres intraorais: Primescan (P), 3Shape (3S), Dexis IS 3700 (D), Straumann Sirios (S) e Straumann Virtuo Vivo (V). Para cada profundidade, foi realizada micro-CT para obtenção do volume real. Os arquivos STL foram importados para o software Meshmixer® para alinhamento e recorte padronizados e, posteriormente, importados para o MeshLab® para análise volumétrica. **Resultados:** Nas profundidades de 6 e 9 mm, todos os escâneres apresentaram valores positivos de ΔV, indicando volumes maiores quando comparados aos obtidos pela micro-CT. Entretanto, na profundidade de 12 mm, os escâneres D, S e V exibiram valores negativos de ΔV. Na profundidade de 15 mm, os escâneres 3S, D, S e V também apresentaram valores negativos de ΔV, indicando maior distorção volumétrica nas regiões mais profundas. **Conclusão:** A profundidade de escaneamento influencia significativamente a acurácia e a veracidade dos escâneres intraorais na digitalização de canais intrarradiculares, com desempenho reduzido em maiores profundidades, mesmo sob condições geométricas favoráveis.

Palavras-chave: Scanner. Micro-CT. Precisão da Medição Dimensional. Odontologia Digital.

ABSTRACT

Purpose: To evaluate the accuracy and trueness of intraoral scanning of weakened single-rooted bovine teeth at different canal depths (6, 9, 12, and 15 mm), comparing the volumes obtained by intraoral scanners with those determined by micro–computed tomography (micro-CT), considered the gold standard. **Materials and methods:** Four bovine teeth with an apical lumen of up to 1.3 mm were selected, subjected to endodontic treatment, and randomly allocated into four groups according to canal depth (6, 9, 12, and 15 mm). The specimens were weakened, maintaining a circumferential dentin thickness of 2 mm and a depth of 4 mm. Each sample was scanned ten times using five intraoral scanners: Primescan (P), 3Shape (3S), Dexis IS 3700 (D), Straumann Sirios (S), and Straumann Virtuo Vivo (V). For each depth, micro-CT was performed to obtain the true volume. The STL files were imported into Meshmixer® for standardized alignment and trimming and subsequently imported into MeshLab® for volumetric analysis. **Results:** At depths of 6 and 9 mm, all scanners showed positive ΔV values, indicating larger volumes compared with micro-CT. However, at a depth of 12 mm, scanners D, S, and V exhibited negative ΔV values. At a depth of 15 mm, scanners 3S, D, S, and V also showed negative ΔV values, indicating greater volumetric distortion in deeper regions. **Conclusion:** Scanning depth significantly influences the accuracy and trueness of intraoral scanners in the digitization of intraradicular canals, with reduced performance at greater depths, even under favorable geometric conditions.

Keywords: Scanner. Micro-CT. Dimensional Measurement Accuracy. Digital dentistry.

SUMÁRIO

1 INTRODUÇÃO

A digitalização intrarradicular, realizada por meio de escâneres intraorais, representa uma inovação significativa no fluxo de trabalho restaurador de dentes tratados endodonticamente, especialmente na obtenção de impressões tridimensionais do espaço do canal radicular para a confecção de pinos personalizados. [1]

Os escaneamentos digitais permitem capturar com precisão a geometria do espaço pós-endodôntico e integrar-se a sistemas CAD/CAM para a produção de pinos e núcleos com ajuste interno superior ao dos pinos pré-fabricados, favorecendo melhor adaptação e potencialmente reduzindo falhas clínicas associadas à desadaptação e a espessuras excessivas de cimento. [1]

Com os avanços da odontologia digital, o uso de escâneres intraorais (IOS) tem sido empregado na confecção de restaurações do tipo “pino e núcleo”, permitindo a captura direta do espaço intrarradicular para o planejamento e a fabricação CAD/CAM de pinos de fibra personalizados, com potencial para maior adaptação biomecânica e precisão de encaixe, conforme demonstrado em relatos de casos clínicos e revisões recentes da literatura. [2]

Essa integração entre materiais fibrosos e tecnologias de escaneamento digital representa uma fronteira promissora na reabilitação protética, embora ainda sejam necessárias evidências clínicas adicionais para a padronização de protocolos e a validação abrangente da acurácia desses métodos em relação às técnicas convencionais. [3]

Entretanto, a acurácia desses sistemas é influenciada pelas condições clínicas e pela técnica operatória, especialmente em áreas de difícil acesso. Nesse contexto, a aplicação dessa tecnologia no escaneamento do espaço intrarradicular surge como uma alternativa promissora para a confecção de pinos e núcleos personalizados, contribuindo para melhor adaptação das restaurações e maior previsibilidade dos procedimentos restauradores.[4]

Além disso, a microtomografia computadorizada (micro-CT) tem sido amplamente empregada na odontologia para a avaliação tridimensional de estruturas dentárias, em virtude de sua elevada resolução volumétrica e de sua capacidade de reconstrução interna detalhada das superfícies anatômicas.[5] Essa técnica tem sido utilizada como padrão-ouro para a geração de modelos tridimensionais de referência, permitindo validar a precisão de outras modalidades de imagem, incluindo o escaneamento intraoral.[6]

Dessa forma, a micro-CT consolida-se como uma ferramenta fundamental em pesquisas odontológicas que demandam avaliação dimensional precisa de tecidos duros, contribuindo para o aprimoramento de métodos diagnósticos e experimentais.[7] A correlação entre micro-CT e escaneamento intraoral fortalece a avaliação da acurácia de modelos tridimensionais digitais utilizados não apenas em pesquisas, mas também em aplicações clínicas avançadas.[8]

2 ARTIGO CIENTÍFICO

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Accuracy of Root Canal Scanning at Different Depths: An Analysis of Five Intraoral Scanners

Alberto Marçal Batista[1*], Flávia de Souza Bastos[2] PhD, Ana Paula Fonseca de Almeida[3] PhD, Ricardo Tadeu Lopes[4] PhD, Guilherme da Rocha Scalzer Lopes[5] PhD, Celso Henrique Najar Rios[6] MSc, Vinicius Hudson Rodrigues Gomes[7], Rodrigo Furtado de Carvalho[8] PhD

1- Master's student in Applied Health Sciences, Federal University of Juiz de Fora – Governador Valadares Campus. E-mail: mbalberto92@gmail.com Orcid: https://orcid.org/0009-0003-1900-9371

2- PhD in Mechanical Engineering, Federal University of Minas Gerais. E-mail: flavia.bastos@ufjf.br Orcid: https://orcid.org/0000-0001-9573-8996

3- PhD in Nuclear Engineering, Federal University of Rio de Janeiro. E-mail: anacamiqui@gmail.com Orcid: https://orcid.org/0000-0003-3624-7091

4- PhD in Nuclear Engineering, Federal University of Rio de Janeiro. E-mail: rlopes@coppe.ufrj.br Orcid: https://orcid.org/0000-0001-7250-824X

5- Postdoctoral researcher in Prosthodontics, São Paulo State University (UNESP). E-mail: guilherme.scalzer@unesp.br Orcid: https://orcid.org/0000-0003-4322-5309

6- Master's degree in Oral and Maxillofacial Surgery, Universidade Camilo Castelo Branco. E-mail: celsohnrios@hotmail.com Orcid: https://orcid.org/0009-0000-4555-8145

7- Bachelor's degree in Dentistry, Pontifícia Universidade Católica. E-mail: viniciushudsonodontologia@gmail.com Orcid: https://orcid.org/0009-0009-0944-0786

8- PhD in Prosthodontics and Restorative Dentistry, Universidade Estadual Paulista – Faculdade de Odontologia de São José dos Campos. E-mail: rodrigo.carvalho@ufjf.br. Orcid: https://orcid.org/0000-0002-8271-8571

Corresponding: Rodrigo Furtado de Carvalho

Address: Campus Universitário, Rua José Lourenço Kelmer, s/n - São Pedro, Juiz de Fora – MG.

ZIP: 36036-900

Phone: (32) 2102-3911 E-mail: rodrigo.carvalho@ufjf.br.

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Abstract

Purpose: To evaluate the accuracy and trueness of intraoral scanning of weakened single-rooted bovine teeth at different canal depths (6, 9, 12, and 15 mm), comparing the volumes obtained by intraoral scanners with those determined by micro–computed tomography (micro-CT), considered the gold standard. **Materials and methods:** Four bovine teeth with an apical lumen of up to 1.3 mm were selected, subjected to endodontic treatment, and randomly allocated into four groups according to canal depth (6, 9, 12, and 15 mm). The specimens were weakened, maintaining a circumferential dentin thickness of 2 mm and a depth of 4 mm. Each sample was scanned ten times using five intraoral scanners: Primescan (P), 3Shape (3S), Dexis IS 3700 (D), Straumann Sirios (S), and Straumann Virtuo Vivo (V). For each depth, micro-CT was performed to obtain the true volume. The STL files were imported into Meshmixer® for standardized alignment and trimming and subsequently imported into MeshLab® for volumetric analysis. **Results:** At depths of 6 and 9 mm, all scanners showed positive ΔV values, indicating larger volumes compared with micro-CT. However, at a depth of 12 mm, scanners D, S, and V exhibited negative ΔV values. At a depth of 15 mm, scanners 3S, D, S, and V also showed negative ΔV values, indicating greater volumetric distortion in deeper regions. **Conclusion:** Scanning depth significantly influences the accuracy and trueness of intraoral scanners in the digitization of intraradicular canals, with reduced performance at greater depths, even under favorable geometric conditions.

Key words Scanner, micro-CT, Dimensional Measurement Accuracy, Digital dentistry.

Introduction

The restoration of endodontically treated teeth remains a relevant clinical challenge in restorative dentistry, since these teeth frequently present significant loss of dental structure resulting from extensive carious processes, trauma, or the endodontic access itself.[1,2] This compromised structural condition requires restorative solutions that provide adequate retention, mechanical resistance, and clinical predictability.

With the advancement of digital technologies, a significant increase in the accuracy, reproducibility, and efficiency of restorative workflows has been observed. Initially, the application of CAD/CAM systems for the fabrication of fiber posts was limited to the digitization of gypsum models obtained from conventional impressions. However, the evolution of these technologies enabled the implementation of fully digital workflows, expanding control over the planning and manufacturing stages and, consequently, clinical predictability.[3]

In this context, CAD/CAM-milled posts have emerged as a promising alternative to conventional systems. In endodontically treated teeth with severe weakening of the dental structure and extensive root canal preparation, the use of customized intraradicular posts—manufactured by CAD/CAM milling or adapted to the canal—is indicated when coronal retention with prefabricated posts is not satisfactory. The close adaptation to the root canal walls reduces cement layer thickness and voids, improving stress distribution and potentially increasing fracture resistance, especially in indirect restorations.[4]

The fabrication of posts with better adaptation to the root canal allows a reduction in the thickness of the cement line, a factor associated with a decreased risk of failures, such as displacement of the intraradicular retainer,[5,6] in addition to favoring the retention of the restorative complex.[7,8]

Intraoral scanners (IOS) are devices used to obtain direct optical impressions in dentistry, representing a digital alternative to conventional impression techniques.[9] These systems project light sources, such as laser or structured light, onto the dental arches and prepared structures, enabling the acquisition of three-dimensional models through different optical principles, including triangulation, confocal imaging, and active wavefront sampling.[3,10]

The use of intraoral or desktop scanners associated with CAD/CAM systems has enabled the milling of customized structures from digital designs, using esthetic materials and optimizing laboratory processes.[11] This advancement allowed faster and more precise fabrication of monoblock restorations capable of adapting to the anatomy of the root canal,[12,13] providing clinical benefits such as greater retention and increased fracture resistance.[7-9]

The quality of intraoral digitization is fundamental for the success of digital workflows and is mainly evaluated by the parameters of precision and trueness. Studies have shown that digital impressions obtained by IOS present satisfactory clinical performance in intraradicular preparations with depths between 6 and 8 mm; however, as preparation depth increases, a progressive reduction in accuracy is observed, demonstrating limitations in the reproduction of deeper regions.[14,15]

Furthermore, micro-computed tomography (micro-CT) is widely employed as a reference method for the evaluation of the accuracy of intraradicular structures, as it allows precise measurements of volume, surface area, and root canal geometry, in addition to detailed three-dimensional reconstruction.[12]

Thus, the present study aims to evaluate the precision and trueness of intraradicular canal scanning at different depths, analyzing the impact of depth on the quality of digital acquisition.

Materials and Methods

Selection and Preparation of the Sample

Four extracted bovine incisor teeth, with an apical lumen of up to 1.3 mm, were prepared and stored in distilled water. The bovine teeth were supplied by a slaughterhouse.

Division and Randomization of Groups

The teeth were randomly divided into four groups according to the depth of root canal preparation:

Group 1: Removal of 6 mm of the root canal filling

Group 2: Removal of 9 mm of the root canal filling

Group 3: Removal of 12 mm of the root canal filling

Group 4: Removal of 15 mm of the root canal filling

Below is a flowchart of the study methodology (Figure 1).

Endodontic treatment

Root canal irrigation was performed with 2 mL of 2.5% sodium hypochlorite (Ciclo Farma, Serrana, São Paulo, Brazil). K-type files #10 (Dentsply Maillefer, Ballaigues, Switzerland) were introduced to the apical region to measure the tooth length (TL), which was considered the working length (WL). The apical limit of instrumentation and obturation was defined as 0.0 mm (WL = TL). Manual instruments were used in the canal. Subsequently, the root canals were irrigated with 17% ethylenediaminetetraacetic acid (EDTA) (Biodinâmica Química e Farmacêutica Ltda, Ibiporã, Brazil) for 1 min under agitation with a K-15 handle, irrigated with 2 mL of 2.5% sodium hypochlorite, and dried with paper points.[16]

For obturation, AH Plus sealer (Dentsply Maillefer) was used. Insertion of the main gutta-percha cone coated with sealer along the working length and accessory cones (Dentsply Maillefer, Ballaigues, Switzerland) soaked in sealer was performed. A NiTi spreader (Dentsply Maillefer, Ballaigues, Switzerland) was used to provide adequate space for the accessory cones. This process was repeated until complete filling of the canal. Excess gutta-percha was removed with heat and compacted with an appropriate plugger (Odous de Deus, Belo Horizonte, Brazil).[16]

Removal of gutta-percha

After the sealer setting, the coronal third of the root canal gutta-percha was removed with Gates-Glidden burs, and the material was removed using ProFile 0.06 taper instruments (Dentsply Maillefer, Ballaigues, Switzerland) with instrument sizes of 6, 9, 12, and 15 mm in a sequence from the cementoenamel junction downward at a speed of 600 rpm and a torque of 2.4 Ncm.[17]

4.5 Sample inclusion

Each specimen was embedded in autopolymerizing acrylic resin (Artigos Odontológicos Clássico, São Paulo, Brazil), according to the manufacturer's recommendations, in PVC tubes. The axis of the intraradicular preparation was aligned with the long axis of the tube used for specimen mounting.[18]

4.6 Root weakening protocols

A diamond bur (KG Sorensen, Maillefer) mounted on a straight handpiece with constant irrigation was used for root weakening, maintaining a circumferential dentin thickness of 2 mm and a depth of 4 mm.[19] Drill 2 of the White Post DC system (FGM) was used to prepare depths of 6, 9, 12, and 15 mm. The teeth were irrigated with 2.5% sodium hypochlorite.

4.7 Micro-CT

The teeth were then scanned using a Skyscan 1173 high-resolution micro-CT system (Skyscan; Kartuizersweg 3B) at 95 kV and 85 mA with a resolution of 14.5 µm, using a 0.25-mm-thick aluminum filter. The generated images were processed and reconstructed using software (Skyscan CT Analyzer; Bruker Corp) for measurement of the volumes of the intraradicular preparations.[20]

Scanning

The scanners were calibrated by an experienced operator strictly following all room temperature and lighting protocols recommended by the manufacturers. [11,21] Five intraoral scanners were evaluated at four depths (6, 9, 12, and 15 mm): Primescan (P); 3Shape (3S); Dexis IS 3700 (D); Straumann Sirios (S); Straumann Virtuo Vivo (V). Each specimen was scanned 10 times. For each depth, a micro-computed tomography (micro-CT) scan was performed and used as the gold standard for determining the true volume. Volume variation (ΔV) was obtained by subtracting each of the 10 volume measurements performed by each scanner from the volume measured by micro-CT at the respective depth. Thus, for each scanner*depth combination, 10 individual differences (scanner − micro-CT) were generated, which constituted the values used in the analysis. All scans were performed by the same operator.

Image processing

All digitized data (n = 10 for each specimen) were exported from the proprietary software of each intraoral scanner in STL (Standard Tessellation Language) format. The STL files were imported into Meshmixer® (Autodesk, USA), where the three-dimensional meshes underwent visual inspection, alignment, and standardized trimming. Trimming was performed using cutting planes defined perpendicular to the long axis of the specimen, in order to isolate the region of interest and form three-dimensional blocks corresponding to the different analyzed depths.

After trimming, the models were exported again in STL format and imported into MeshLab® (Visual Computing Lab, Italy) for volumetric analysis. In MeshLab, the closed-mesh volume calculation function was applied, ensuring beforehand that the models presented continuous and defect-free surfaces (watertight). The intracanal volume, expressed in cubic millimeters (mm^3), was then obtained for each sample and evaluated depth, as shown in figure 2.

Statistical analysis

The variable ΔV (volume variation) was evaluated for normal distribution and homogeneity of variances. Normality was confirmed by the Shapiro–Wilk test ($p = 0.546$); however, homogeneity of variances was not met according to the Bartlett (p=011). Factorial Analysis of Variance (two-way ANOVA) and Tukey's post hoc test were used to compare volume changes, considering the interaction between the scanners (3S, D, P, and SV) and the different depths (6, 9, 12, and 15), adopting a significance level of $\alpha < 0.05$.

Results

It was observed that at depths of 6 and 9 mm, all scanners showed positive ΔV values, indicating larger volumes compared with micro-CT. However, at the depth of 12 mm, scanners D, S, and V started to show negative ΔV values, and at the depth of 15 mm, the same was observed for scanners 3S, D, S, and V (which may indicate a loss of accuracy). (Figure X; if the figure is used, include the post hoc letters, or Table X). There was a significant interaction between scanner and depth ($F(12,180) = 219$, $p < 0.001$; $\eta^2p = 0.936$), and the multiple comparisons are presented in Table 1.

Discussion

The results of the present study demonstrated that the depth of the scanned area exerts a significant impact on the precision and accuracy of intraoral scanners, corroborating previous evidence that IOS performance depends on both the depth and the geometric characteristics of the intraradicular preparation. Studies on intracavitary restorations have shown that greater depths are associated with significant reductions in the precision and trueness of the digital models generated by IOS, reinforcing that the spatial dimension of the area to be digitized is a critical factor for the fidelity of the captured surfaces.[22]

Image acquisition technologies vary significantly among the tested scanners, which may explain part of the differences observed in ΔV. Primescan (P) uses technology based on dynamic pattern projection combined with high-frequency analysis and advanced optical processing, allowing the acquisition of multiple images simultaneously and a higher data density, which may explain its more stable performance at greater scanning depths. The 3Shape (3S) employs confocal technology, widely validated in the literature, which shows good accuracy at moderate depths but may suffer loss of accuracy as preparation depth increases due to limitations in capturing deep and narrow surfaces.[23,24]

Dexis IS 3700 (D) uses structured light scanning technology, which may be more sensitive to changes in angulation and depth, justifying the greater volumetric variations observed at the deepest levels evaluated. Similarly, the Straumann Sirios (S) and Straumann Virtuo Vivo (V) scanners are based on optical projection and three-dimensional reconstruction systems that, although showing good clinical performance in superficial scans, may present limitations in capturing deep intrarradicular regions, resulting in a progressive increase in ΔV as scanning depth increases.[23]

Previous studies had already pointed out limitations of IOS in deep scanning Kanduti et al.[18] reported that intraoral scanners are able to accurately read up to 4 mm of the intraradicular preparation and that, in preparations up to 10 mm, they can produce retainers with accuracy comparable to the indirect technique. Similarly Elter et al.[25] observed that the depth of the scanned space affected the trueness of Primescan, indicating that when the post depth was less than 14 mm and the minimum canal diameter was 2.2 mm, the scanner could be safely used for the digital impression of the post-and-core structure, simplifying the clinical procedure.

The influence of root canal depth and diameter was also evidenced by Pinto et al.[26] who recommended shallower scanning depths in narrow canals, attributing this limitation to the difficulty of the light beam in reaching the apical third. In contrast, Oliveira et al.[27] demonstrated that in enlarged root canals, the results related to scanning depth were superior, suggesting that larger diameters favor light penetration and data acquisition in deeper regions. Nevertheless, the progressive increase in scanning depth represents an additional optical challenge, which may justify the greater volumetric changes observed at greater depths in the present study, even under more favorable geometric conditions.

With regard to the specific performance of scanners, several studies have demonstrated advantages of the CEREC Primescan. Negm et al.[28] observed that, regardless of the reference area, Primescan presented more uniform and homogeneous distributions of trueness and precision in color maps when compared with TRIOS 3.

Similarly Keul and Güth[29] demonstrated that Primescan preserves precision and trueness parameters in both in vitro and in vivo environments, with superior accuracy in laboratory tests. These findings corroborate the results of this study, in which scanners with advanced optical acquisition technology showed lower volumetric variation at more complex depths, suggesting that acquisition conditions (laboratory control versus oral cavity) and capture technology significantly influence the quality of digital models.

Similar results were reported by Mourouzis et al.[30], who evaluated the accuracy of different intraoral scanners in the digitization of root canals with a standardized intraradicular depth of approximately 10 mm. Although the authors did not investigate progressive depth variations, Primescan showed the highest accuracy, followed by TRIOS 3 and Omnicam, corroborating the findings of the present study, in which scanners based on more advanced optical technologies demonstrated better performance as scanning geometric complexity increased. Almalki et al.[15] in turn, evaluated the accuracy of direct digital impressions at different post space lengths (6, 8, and 10 mm) and observed that although accuracy was consistent in the coronal and middle thirds, there was a significant reduction in accuracy in the apical third for 10-mm posts, in addition to statistically significant differences among the evaluated IOS.

In the present study, Primescan stood out for presenting more consistent accuracy results at all analyzed depths (6, 9, 12, and 15 mm), with ΔV values closer to those obtained by micro-computed tomography (micro-CT), used as the reference standard. This performance suggests a greater ability of the system to reproduce the geometry of intraradicular canals, even in deeper regions, where the other scanners showed a progressive loss of accuracy. Such behavior may be related to a greater effective depth of field, high capture resolution, and advanced three-dimensional reconstruction algorithms, which contribute to the reduction of errors associated with signal loss, shadowing, and image alignment failures.

In contrast, although the manufacturer of the DEXIS™ IS 3700 declares a depth of field from –2 to 12 mm, the results of this study demonstrated that its reliable performance was restricted to depths of 6 and 9 mm. At depths of 12 and 15 mm, the scanner showed a significant loss of accuracy, being unable to adequately reproduce the geometry of the evaluated canals. This discrepancy between the manufacturer's specifications and the experimentally observed performance may be attributed to limitations inherent to optical capture in deep regions, such as reduced reflected signal, light dispersion, and accumulation of errors during three-dimensional reconstruction.

Similarly, the Straumann Sirios and Straumann Virtuo Vivo scanners showed satisfactory performance only at depths of 6 and 9 mm, with a significant loss of precision and accuracy at 12 and 15 mm, indicating a restriction of the effective scanning zone to intermediate depths in the evaluated context.

Micro-computed tomography (micro-CT), used as the reference standard in this study, is recognized as a conservative, precise, and reliable method for measuring volumes and distances of internal and external dental structures and is widely employed in in vitro dental research.[30] Its high resolution reinforces the reliability of the comparisons performed.

However, this study presents limitations that must be considered. It is an in vitro investigation conducted under controlled conditions, which does not fully reproduce the clinical environment, where factors such as saliva, blood, limitations of intraoral access, patient movement, and variations in lighting may influence the performance of IOS. In addition, the standardization of preparations does not encompass the full anatomical variability observed clinically.

Thus, future studies, preferably in vivo, with greater anatomical diversity, different scanning protocols, and correlation with clinical outcomes, are necessary to expand the understanding of the limits and clinical applicability of intraoral scanners in the fabrication of customized intraradicular posts using digital CAD/CAM workflows.

Conclusion

Scanning depth significantly influences the precision and trueness of intraoral scanners in the digitization of intraradicular canals. Most systems showed reliable performance only up to 9 mm. These findings indicate that the choice of the intraoral scanner should consider limitations related to intraradicular preparation depth, especially in clinical applications involving customized posts fabricated through digital CAD/CAM workflows.

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Figure 1. Mean and standard deviation

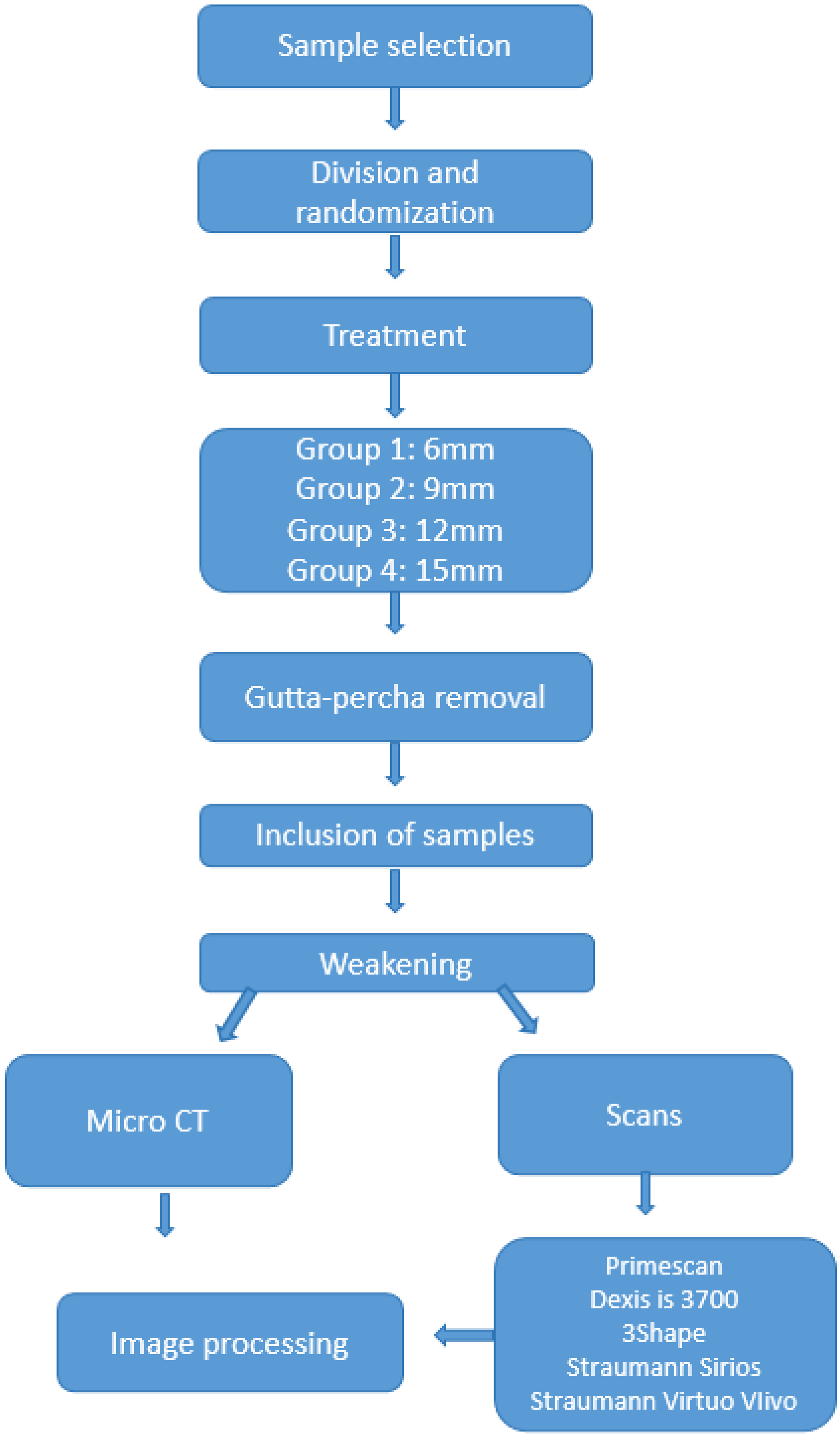


Figure 2. Three-dimensional volumes obtained by different intraoral scanners at increasing depths, compared with micro–computed tomography (micro-CT) images.

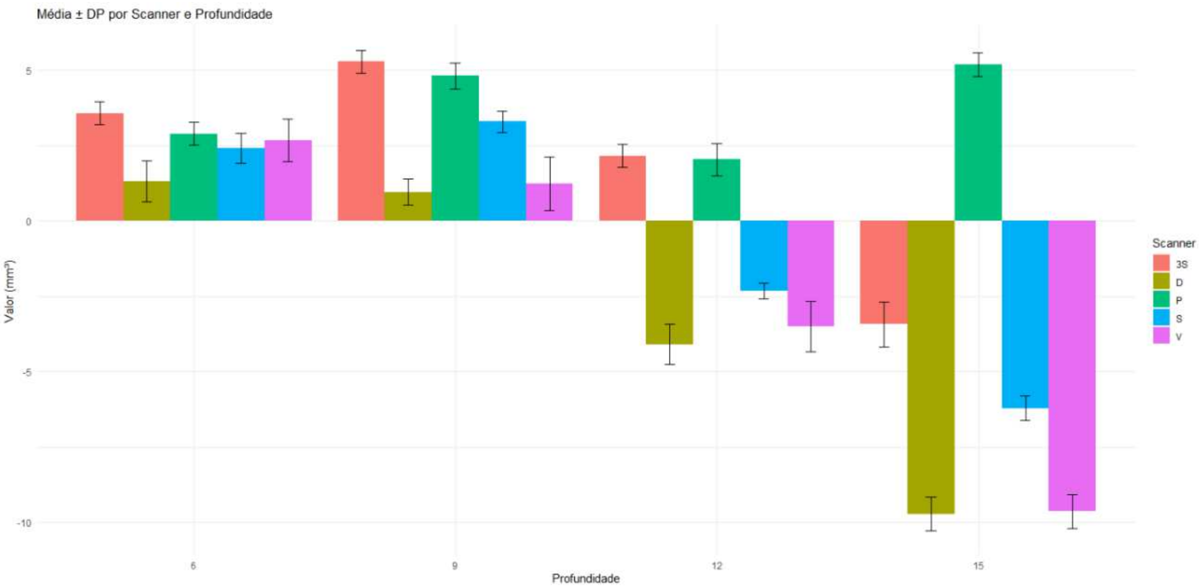
Scanner penetration depth	**6mm**	**9mm**	**12mm**	**15mm**
3Shape				
Strauman				
Dexis				
Sirios				
Primescam				
MicroCT				

Table 1. Mean and standard deviation of volumetric variation (ΔV, mm³) of digital models obtained by different intraoral scanners, evaluated at scanning depths of 6, 9, 12, and 15 mm.

Scaner	**ΔV (mm³)**			
	6mm	9mm	12mm	15mm
3S	3.58 ± 0.387^{Ab}	5.30 ± 0.379^{Aa}	2.17 ± 0.382^{Ac}	-3.44 ± 0.748^{Bd}
D	1.31 ± 0.677^{Ca}	0.954 ± 0.437^{Ca}	-4.10 ± 0.659^{Cb}	-9.74 ± 0.563^{Dc}
P	2.89 ± 0.380^{ABb}	4.82 ± 0.426^{Aa}	2.04 ± 0.534^{Ab}	5.18 ± 0.397^{Aa}
S	2.41 ± 0.489^{Ba}	3.29 ± 0.354^{Ba}	-2.33 ± 0.255^{Bb}	-6.22 ± 0.406^{Cc}
V	2.67 ± 0.710^{Ba}	1.25 ± 0.889^{Cb}	-3.50 ± 0.839^{Cc}	-9.64 ± 0.564^{Dd}

Different lowercase letters indicate significant differences between depths within the same scanner (rows), whereas different uppercase letters indicate significant differences between scanners within the same depth (columns), according to the Tukey post hoc test applied to the ART data ($P < 0.05$).

Figure 3. Mean and standard deviation



3 CONCLUSÃO

A profundidade de escaneamento influenciou significativamente a acuráciaeaveracidade dos escâneres intraorais na digitalização de canais intrarradiculares, commelhor desempenho observado nas menores profundidades (6 e 9 mm) ereduçãoprogressiva da confiabilidade volumétrica em 12 e 15 mm. Emmaioresprofundidades, parte dos escâneres apresentou subestimação volumétricaemaiordistorção geométrica quando comparados aos valores obtidos pela microtomografiacomputadorizada, evidenciando limitações na captura precisa deestruturasintrarradiculares extensas, mesmo sob condições geométricas favoráveis. Essesachados indicam que a profundidade do canal é um fator crítico a ser consideradona aplicação clínica do escaneamento intraoral para confecçãodepinospersonalizados por meio de sistemas CAD/CAM

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