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Influence of stainless-steel orthodontic brackets on the tomographic planning of dental implants: an *ex vivo* study

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Aim: This ex vivo study aimed to assess the influence of stainless-steel orthodontic brackets (SSOB) and the acquisition protocol on linear measurements of bone height and width for the planning of dental implants in inter-bracket regions. **Methods:** Twenty extracted premolar teeth were adapted in artificial sockets on 10 bovine ribs, then adapted into a 3D printed jaw, coated with wax. Cone beam computed tomography (CBCT) scans with and without SSOB were performed using four acquisition protocols, varying the voxel size (280, 200, 125, and 80 μm). Three trained examiners evaluated all 80 CBCT scans, measuring height and width in the center of the simulated edentulous region between the teeth, in the cross-sectional plane. Intra- and inter-examiner reproducibility were assessed using the Intraclass Correlation Coefficient test. Linear measurements were compared using the Bland-Altman method and ANOVA for repeated measures. A significance level of 5% was used. **Results:** Intra- and inter-examiner reproducibility presented excellent reliability for height measurements, while inter-examiner presented moderate and intra-examiner presented moderate to good reliability. The measurements showed a statistically significant difference between the examiners ($p<0.001$), regardless of the voxel size or the presence of SSOB. The Bland-Altman showed discrepancies between -0.18 mm and 1.15 mm in the width measurements. **Conclusion:** The presence of SSOB and the CBCT voxel size do not affect the planning of dental implants in the inter-bracket region.

Keywords: Dental implants. Cone-beam computed tomography. Artifacts. Orthodontic brackets.

Introduction

In implant dentistry, three-dimensional assessment by means of cone beam computed tomography (CBCT) is essential, given the need to assess bone height and width[1,2]. CBCT also allows the assessment of proximity to noble structures, such as the mandibular canal and the maxillary sinus[1,3], reducing the chances of postoperative complications and/or treatment failure. Therefore, the use of CBCT is routinely recommended in the preoperative assessment of dental implant placement[4,5].

However, one of the main limitations of the CBCT exam is the presence of artifacts caused by metallic materials, which are characterized as an error or distortion between the real object and the image, impairing the evaluation of the tomographic image[6,7]. This phenomenon occurs because photons of lower energy are absorbed in the presence of metallic materials, while photons of higher energy are not; therefore, there is a brighter image of the metals, with a certain distortion of the adjacent structures. The impact of the artifact decreases as the region of interest moves away from the metallic object; therefore, a structure immediately adjacent to the metallic object is most affected by this phenomenon, although the image of the contralateral quadrant can also be significantly affected[8].

One of the most commonly used metal devices in Dentistry are stainless-steel orthodontic brackets (SSOBs). Likewise, orthodontic treatment in patients with absent tooth and the indication of dental implants in an inter-bracket region is often necessary to achieve treatment success and meet the patient's expectations, such as the rehabilitation of edentulous spaces after completion of the orthodontic treatment[9]. The intensity of the artifact varies according to the type of material the bracket is made, but the stainless-steel bracket produces more artifacts compared to other orthodontic brackets, reducing the quality of the image[10].

The CBCT acquisition protocol should be selected based on the diagnostic task, and is mainly dictated by the exam spatial resolution, i.e., the voxel size[11,12]: the smaller the voxel size, the greater the degree of image detail, but the greater is the radiation dose for the patient. However, considering that metal jeopardizes CBCT evaluation, it is recommended to select a protocol with the smallest voxel size to improve image assessment[13,14]. Nonetheless, the influence of SSOB on artifacts and the acquisition protocol in the planning of dental implants is not elucidated in the literature. Therefore, the objective of this study was to assess the influence of stainless-steel brackets and the voxel size on linear measurements of bone height and width for the planning of dental implants in inter-bracket regions. The conceptual hypothesis is that there is no significant difference in bone height and thickness measurements, regardless of the presence of SSOBs or voxel size.

Materials ans Methods

Design

This ex vivo laboratory study was approved by the Institution's Research Ethics Committee (protocol number 66998323.0.0000.5346), and all procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Sample

The sample size considered a difference of 2 mm to be detected[15], a significance level of 5%, and a test power of 80%, requiring at least five observation-pairs.

Ten bovine rib blocks were used to simulate the mandibular bone[16]. Two artificial sockets were created in each block, as well as a mandibular canal, using a long spherical drill (Harte, Ribeirão Preto, Brazil). In total, 20 extracted human premolar teeth were adapted to the artificial sockets and fixed with wax, with a space of 10 mm between them. The ten rib-teeth specimens were adapted to a 3D printed jaw surrounded by a 15 mm layer of wax 7 (Asfer, São Caetano do Sul, Brazil) to simulate soft tissues (Figure 1)[17].

Figure 1. Bovine rib with extracted human premolars adapted to a 3D printed jaw surrounded by a 15 mm layer of wax 7

Image acquisition

CBCT scans were performed with and without SSOBs, varying the voxel size (280, 200, 125, and 80 µm). The tomographic images were acquired on the KaVo OP 3D tomographic device (Fábrica KaVo do Brasil Ind. Com. Ltda and KaVo Imagem Distribution Center, Nobel Biocare and Kerr, SC, Brazil – 95 kV, 2-12.5 mA), using four acquisition protocols: (a) Low dose resolution – exposure time: 1.2 seconds, voxel: 280 µm, mAs: 3.8, FOV: 50x50 mm, Kv: 90; (b) Standard resolution – exposure time: 2.3 seconds, voxel: 200 µm, mAs: 18.4, FOV: 50x50 mm, Kv: 90; (c) High resolution – exposure time: 6.1 seconds, voxel: 125 µm, mAs: 38.4, FOV: 50x50 mm, Kv: 90;

(d) Endo resolution – exposure time: 8.7 seconds, voxel: 85 µm, mAs: 54.8, FOV: 50x50 mm, Kv: 90. The test group was composed of teeth with SSOBs (Morelli Ortodontia, Sorocaba, Brazil) attached, whereas the control group was composed of teeth without any metallic bracket.

Image evaluation

The images were exported in DICOM format and evaluated using the OnDemand3D software (KaVo Dental GmbH Biberach, Riß, Germany) by three examiners previously trained. The examiners were composed of 1 Master student and 2 PhD students in Oral Radiology. The training consisted of 1 hour of expository-dialogue class to determine the concepts studied and learn the reference points used in order to perform the measurements in the software. The reference standard for comparing results was obtained by measurements of images acquired using the "Endo resolution" without brackets, performed by a DMFR specialist experienced with CBCT assessment and implant planning.

Before the evaluations, one examiner traced all the panoramic curves and selected the central cross-sectional image in the edentulous region in order to avoid measurement bias in the software. Linear measurements were performed in the selected cross-sectional image, using the "ruler" tool of the OnDemand3D software to determine the width and height measurements. The width was measured between the buccal and the lingual cortical bones, 1 mm below the bone crest. The height measurement was performed using the "tape measure" tool, the first point placed on the bone crest, the second point 1 mm below the bone crest (region of the width measurement), and the third point on the roof of the mandibular canal (Figure 2).

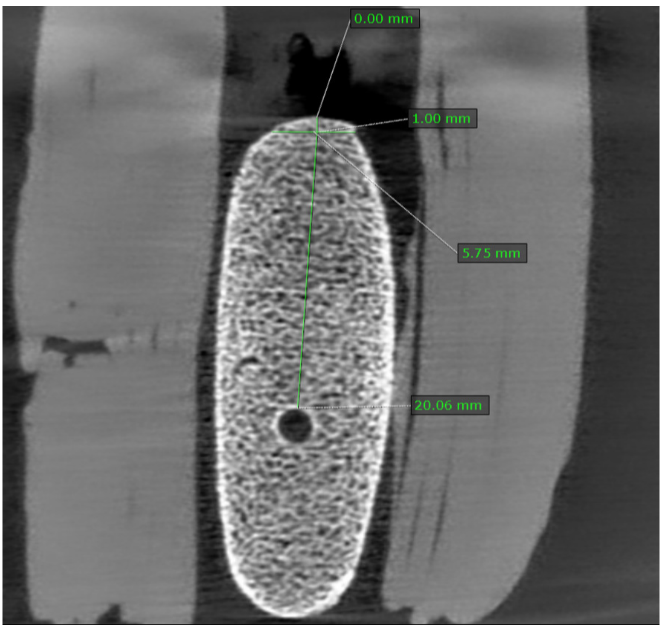

Figure 2. Height and width measurements performed in the cross-sectional plane

Each examiner used the “1x sharpen” filter and was allowed to adjust brightness, contrast, and zoom settings. All evaluations were carried out on an Intel i5 computer (Intel® Core™ i5-3570 CPU @ 3.40GHz) equipped with a 23-inch Dell U2312HMt monitor (Dell Ltda, Eldorado do Sul, Brazil), LED screen with a 1920 X 1080 resolution, located in a windowless room with artificial lighting. Each examiner evaluated all 80 DICOM files, plus 20% of the sample after 1 month to assess intra-examiner reproducibility. All measurements were recorded in an Excel spreadsheet. All evaluations were carried out between July and September/2023.

Statistical analysis

Statistical analyses were performed using the Jamovi software (Open Source Software; General Public License; Version 2.3.17) and Excel (Microsoft Corporation, Redmond, WA), considering a significance level of 0.05.

Intra- and inter-examiner reproducibility were assessed using the Intraclass Correlation Coefficient (ICC) test. The linear measurements obtained by each examiner in each tooth situation (with or without SSOB) and acquisition protocol were compared using ANOVA for repeated measures and Bonferroni post-hoc test. Linear measurements of each examiner were also compared to the reference standard using the Bland and Altman[18] method. This statistical method consists of a scatter plot of two continuous measurements, depicting the mean difference and the 95% confidence interval (CI) for the mean difference (1.96 times the standard deviation). When analyzing the results, it is expected that 95% of the observations stay within this CI and that the CI is appropriate for clinical use. Thus, this method allows for comparing a new approach to the reference method and evaluating clinically relevant differences.

Results

Intra- and inter-examiner reproducibility for height measurements presented values greater than 0.9 in all comparisons (ICC inter-examiner: 0.972 [95%CI 0.959–0.981]; ICC intra-examiner ranged from 0.982 to 0.998 [95%CI 0.950–0.999]). As for width measurements, ICC values showed fair to almost perfect agreement (ICC inter-examiner: 0.514 [95%CI 0.385–0.634]; ICC intra-examiner ranged from 0.739 to 0.972 [95%CI 0.410–0.979]).

Linear measurements showed a statistically significant difference between the examiners ($p<0.001$), but were not influenced by the voxel size or the presence of orthodontic brackets (Table 1).

Table 1. Mean values of height and width measurements for each examiner, according to voxel size and presence or absence of SSOB

Voxel Size	Ex1		Ex2		Ex3	
	Width	Height	Width	Height	Width	Height
280 µm						
Without SSOB	6.04 A	19.8 A	6.74 A	20.1 A	6.90 A	19.7 A
With SSOB	6.03 A	19.9 A	6.84 A	20.1 A	7.20 A	19.7 A

Continue

Continuation						
200 µm						
Without SSOB	5.92 A	19.9 A	6.67 A	20.1 A	7.01 A	19.7 A
With SSOB	5.94 A	19.9 A	6.81 A	19.9 A	6.99 A	19.6 A
125 µm						
Without SSOB	5.88 A	19.9 A	6.63 A	20.1 A	6.89 A	19.8 A
With SSOB	5.96 A	19.8 A	6.67 A	20.1 A	7.01 A	19.7 A
80 µm						
Without SSOB	5.86 A	19.9 A	6.93 A	20.1 A	6.98 A	19.8 A
With SSOB	6.05 A	19.8 A	7.03 A	20.0 A	7.07 A	19.7 A

Ex1, examiner 1; Ex2, examiner 2; Ex3, examiner 3; SSOB, stainless-steel orthodontic bracket. Equal letters following the values correspond to the absence of statistically significant difference.

Tables 2 and 3 show the Bland-Altman plots for the height and width measurements of each examiner compared to the reference standard, depicting the distribution of the measurements performed. The mean difference of the height assessment is close to zero, indicating good precision (Table 2). However, for the width measurements, the results showed a mean difference close to zero in only one of the examiners, as well as wider confidence intervals, with some values greater than 2 mm, which may signal relevant differences in clinical situations (Table 3).

Table 2. Bland Altman plots for height measurements compared to the reference standard

Voxel size	**280 µm**		**200 µm**		**125 µm**		**80 µm**	
Examiner	**Mean difference**	**95% CI**	**Mean difference**	**95% CI**	**Mean difference**	**95% CI**	**Mean difference**	**95% CI**
Ex1								
Without SSOB	0.02	-0.43 to 0.48	0.075	-0.35 to 0,5	0.1	-0.43 to 0.64	0.08	-0.33 to 0.50
With SSOB	0.1	-0.32 to 0.52	0.05	-0.21 to 0.32	-0.01	-0.42 to 0.39	0.04	-0.28 to 0.36
Ex2								
Without SSOB	0.29	-0.25 to 0.83	0.27	-0.22 to 0.76	0.28	-0.27 to 0.84	0.34	-0.63 to 1.32
With SSOB	0.26	-0.16 to 0.68	0.11	-0.38 to 0.6	0.33	-0.2 to 0.86	0.24	-0.18 to 0.67
Ex3								
Without SSOB	-0.09	-1.19 to 1	-0.1	-0.89 to 0.68	0	-0.56 to 0.57	0	-0.79 to 0.8
With SSOB	-0.09	-0.95 to 0.77	-0.24	-1.65 to 1.16	-0.1	-0.97 to 0.76	0.24	-0.07 to 0.56

CI, confidence interval; SSOB, stainless-steel orthodontic bracket.

Table 3. Bland Altman plots for width measurements compared to the reference standard

Voxel size	Low		Standard		High		Endo	
Examiner	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI
Ex1								
Without SSOB	-0.01	-1.35 to 1.33	-0.13	-1.20 to 0.95	-0.17	-1.39 to 1.05	-0.18	-1.31 to 0.94
With SSOB	-0.01	-1.09 to 1.06	-0.11	-0.99 to 0.78	-0.09	-1.46 to 1.28	0	-1.23 to 1.23
Ex2								
Without SSOB	0.70	-0.19 to 1.58	0.62	-0.25 to 1.50	0.58	-0.44 to 1.6	0.88	0.18 to 1.58
With SSOB	0.79	-0.09 to 1.68	0.76	-0.01 to 1.54	0.62	-0.48 to 1.72	0.98	-0.7 to 2.66
Ex3								
Without SSOB	0.85	-0.77 to 2.48	0.96	-0.66 to 2.58	0.84	0.07 to 1.61	0.93	-0.68 to 2.54
With SSOB	1.15	-0.38 to 2.69	0.95	-0.94 to 2.83	0.96	-0.81 to 2.73	1.02	-0.23 to 2.27

CI, confidence interval; SSOB, stainless-steel orthodontic bracket.

Discussion

Artifact generation still represents a challenge for CBCT evaluation and clinical decision-making. Therefore, its impact on different clinical scenarios has to be studied so that the best acquisition protocol may be chosen in special situations. The present study evaluated the influence of artifacts caused by SSOBs and four voxel sizes on linear measurements when planning dental implants. According to the findings of this study, the presence of metallic brackets and the different voxel sizes did not influence bone height and width measurements. Thus, the conceptual hypothesis was accepted.

Quantitative analysis has shown that the region adjacent to metallic brackets presents altered gray values in comparison to artifact-free image, which could compromise image evaluation[19,20]. A study showed that metallic devices such as brackets, intra-radicular posts, and dental implants did not compromise CBCT assessment when the metal object was located 5 cm beyond the region of interest; however, when the metallic object was closer to the region of interest, artifacts were observed in 18.4% of the scans[21]. Nonetheless, studies also report that metallic materials may jeopardize image assessment even when located outside the field of view[22,23]. Isman et al.[24] (2020) verified that metallic brackets compromised the diagnosis of caries, especially enamel lesions. In this study, although the brackets were located adjacent to the region of interest for implant planning, their artifact did not affect the linear measurements. This is possibly due to the streak artifacts being located at the level of the dental crowns, where the SSOBs were placed. Thus, as the artifacts most affected the region above the bone crest, the performance of linear measurements was not affected. Another study corroborates this finding, as they also did not find statistically significant differences in measurements as the number of amalgam restorations and stainless-steel crowns increased[25].

The patient's clinical condition should guide the selection of CBCT acquisition protocol. Studies have shown that the diagnosis of root fractures, peri-implant bone evaluation, and maxillary molars' second mesiobuccal canal detection require a high-resolution scan to improve accuracy[26-28]. In this study, the voxel size did not influence the measurements of bone height and width. This finding corroborates current scientific information, which states that voxel sizes between 300 and 400 μm provide images with sufficient resolution for implant planning[15]. Therefore, an acquisition protocol that exposes the patient to less radiation is indicated.

This study found statistically significant differences among the examiners' linear measurements. Discrepancies regarding linear measurements were already reported in the literature, due to the examiner's experience and skills, and to difficulties of selecting the exact level of the alveolar crest in order to perform the measurement[29]. In order to better evaluate the clinical relevance of the statistically significant differences found, the results were also assessed using the Bland and Altman[18] method. The results showed smaller variations in regards to bone height, yet major discrepancies were found regarding width measurements, with some CI values greater than 2 mm. As clinical practice recommends the use of a 2 mm safety margin[15], the certainty of greater safety in maintaining the integrity of important adjacent anatomical structures, such as the mandibular canal and maxillary sinus, is implied[1,3]. As for width, even though there is an expected error of approximately 2 mm, there are techniques to overcome the buccal or lingual/palatal exposure of implant threads, such as bone regeneration using particulate grafts[30].

To our knowledge, this study was the first to evaluate the influence of artifacts caused by metallic brackets on dental implant planning, as well as the impact of different acquisition protocols on this evaluation. Measurements of bone height and width were carried out by three trained examiners with compatible levels of experience. However, some limitations of this study should be considered. The dental alveoli and the mandibular canal were artificially created, with the latter being more defined when compared to in vivo tomographic images of the mandibular canal, allowing for easier measurement of bone height. Nonetheless, the use of bovine rib blocks to simulate mandibular human bone is a method that has already been used in other studies[16,31,32], as both types of bone are similar in terms of cortical and medullary bone, but it lacks in terms of anatomical reproducibility.

The present study provides valuable insights into the influence of SSOBs and CBCT acquisition protocols on linear measurements of bone height and width for dental implant planning in inter-bracket regions. The robust intra- and inter-examiner reproducibility for height measurements underscores the reliability of the results, irrespective of the presence of SSOBs or voxel size. While width measurements exhibited slightly lower inter-examiner reproducibility, the overall findings suggest that metallic brackets and voxel size do not significantly impact the planning of dental implants in an inter-bracket region, allowing to infer that the recommended acquisition protocol for implant planning in these cases is the one that offers the lowest dose of radiation to the patient. By highlighting the minor impact of SSOBs and voxel size, this research contributes to the optimization of clinical workflows, streamlining the implant planning process, and potentially reducing associated costs, as brackets do not need to be removed before performing a CBCT scan in order to plan dental implants. Overall, these results enhance our understanding of the factors influencing implant planning precision, fostering advancements in clinical practice and ultimately benefiting both practitioners and patients.

In conclusion, the presence of metallic brackets and the CBCT voxel size do not affect the planning of dental implants in the inter-bracket region. Nonetheless, the examiner seems to have an impact on the measurements of bone width.

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Conflicts of interest

The authors report no conflict of interest.

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Data availability

Datasets related to this article will be available upon request to the corresponding author.

Author contributions

Lucas Machado Maracci: Conception of the work; Original draft of the work; Analysis of data for the work; Final approval of the version to be published; Agreement to be accountable for all aspects of the work; **Gabriel Fernandes Barbosa:** Acquisition of data; Drafting the work; Final approval of the version to be published; Agreement to be accountable for all aspects of the work; **Gleica Dal Ongaro Savegnago:** Interpretation of data; Drafting the work; Final approval of the version to be published; Agreement to be accountable for all aspects of the work; **Wislem Miranda De Mello:** Interpretation of data; Critical review; Final approval of the version to be published; Agreement to be accountable for all aspects of the work; **Mariana Marquezan:** Design of the work; Critical Review; Final approval of the version to be published; Agreement to be accountable for all aspects of the work; **Gabriela Salatino Liedke:** Design of the work; Interpretation of data; Critical review; Final approval of the version to be published; Agreement to be accountable for all aspects of the work.

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