Impact of cone-beam computed tomography on implant planning and on prediction of implant size

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Abstract: The aim was to investigate the impact of cone-beam computed tomography (CBCT) on implant planning and on prediction of final implant size. Consecutive patients referred for implant treatment were submitted to clinical examination, panoramic (PAN) radiography and a CBCT exam. Initial planning of implant length and width was assessed based on clinical and PAN exams, and final planning, on CBCT exam to complement diagnosis. The actual dimensions of the implants placed during surgery were compared with those obtained during initial and final planning, using the McNemmar test ($p < 0.05$). The final sample comprised 95 implants in 27 patients, distributed over the maxilla and mandible. Agreement in implant length was 50.5% between initial and final planning, and correct prediction of the actual implant length was 40.0% and 69.5%, using PAN and CBCT exams, respectively. Agreement in implant width assessment ranged from 69.5% to 73.7%. A paired comparison of the frequency of changes between initial or final planning and implant placement (McNemmar test) showed greater frequency of changes in initial planning for implant length ($p < 0.001$), but not for implant width ($p = 0.850$). The frequency of changes was not influenced by implant location at any stage of implant planning (chi-square test, $p > 0.05$). It was concluded that CBCT improves the ability of predicting the actual implant length and reduces inaccuracy in surgical dental implant planning.

Descriptors: Dental Implants; Radiography, Panoramic; Cone-beam Computed Tomography.

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Introduction

Successful implant treatment depends on efficient planning. This should include information on height, width, morphology and density of the bone, as well as identification and location of anatomical landmarks in imaging exams. The selection of proper imaging exams should consider clinical variables, like the number of sites, alveolar bone volume and the need for bone grafting, as well as quality, availability and costs of imaging methods, and radiation dose.[1]

Before the late 1980s, conventional radiographic techniques like intraoral, cephalometric and PAN images were accepted as standard methods.[2] However, improvements in sectional imaging techniques led to the recommended use of tomographic methods to investigate potential implant sites. The American Academy of Oral and Maxillofacial Radiology (AAOMR) recently recommended CBCT as the best option.[3]

The introduction of CBCT, in 1998, provided a new form of 3D evaluation,[4] and several studies have shown that CBCT provides high quality,[5] accurate cross-sectional (CS) images[6] with relatively low dose exposure.[7] However, there is little evidence about the diagnostic usefulness of CBCT compared to other methods in planning implant treatment. Thus, this study aimed at investigating the impact of cone-beam computed tomography (CBCT) on implant planning and on prediction of final implant size.

Methodology

Patients

Consecutive patients referred for implant therapy were submitted to clinical and radiographic exams to determine potential implant sites. Adult patients were either partially or fully edentulous, with single and/or multiple edentulous spaces in different regions of the maxilla and mandible. Exclusion criteria included pregnancy, local bone disease or systemic disease with oral repercussions, no requirement for a three-dimensional image exam and indication for bone grafting. The study design was approved by the *Universidade Federal de Goiás* Ethics Committee (protocol no. 200/2009), and all patients signed an informed consent to participate in the study.

Radiographic methods

PAN exams were undertaken according to manufacturer's instructions, using a Cranex Tome Unit (Soredex, Helsinki, Finland), with a magnifying factor of 1.5. The technical parameters were 60–73 kV, 8–10 mA and 15 s. A 15 × 30 cm film cassette was used with a regular Kodak Lanex intensifying screen and Kodak T-MAT G/RA dental film (Eastman Kodak Company, Rochester, USA). All the radiographic film was developed using standardized procedure and completely automatic AT-2000 XR development equipment (Air Techniques, New York, USA) with Kodak RP X-OMAT developer and fixer (Kodak, São Paulo, Brazil).

The CBCT images were acquired using an i-CAT cone beam dental CT scanner (Imaging Sciences International, Hatfield, USA). The technical parameters used were: 120 kVp, 36.12 mA and 40 s. A scan volume of 6 cm was used for the maxilla and mandible, and voxel size was 0.25 × 0.25 × 0.25 mm. The images were created in DICOM format and evaluated by axial, cross-sectional and sagittal reconstructions, with a cutting interval of 1 mm. The prints were made in PDF format, on 14.8 × 21.0 cm Fujicolor Crystal Archive photographic paper (FujiFilm, São Paulo, Brazil) using a Frontier 330 printer (FujiFilm, São Paulo, Brazil).

Implant planning

Initial implant planning was performed by an experienced dental implant surgeon using information from the clinical exam and PAN radiograph. All radiographs were analyzed in standard conditions on a viewing box. An external hexagon template (Neodent, Curitiba, Brazil) with the appropriate magnification factor was superimposed on the radiograph to measure the length and width of each implant (Figure 1). The dimensions of the implants provided by the manufacturer were 7.0, 8.0, 9.0, 11.0, 13.0, 15.0 and 17.0 mm for length, and 3.3, 3.5, 3.75, 4.0, 4.5 and 5.0 mm for width. The length and width of planned implants were recorded at this stage. Immediately after initial planning, CBCT images were added to perform the implant site-specific assessment, and initial planning was reevaluated (final planning) by the same dental implant surgeon (Figure 2). The template with the real size of the implants was used to conduct the final planning. The implant dimensions were recorded, either maintaining or modifying the initial planning dimensions.

Implant treatment

Using the information obtained in the preoperative planning, the implants were placed according to the conventional two-stage surgical protocol. After surgery for implant placement, length and width of implants placed were recorded.

Data analysis

Frequency analysis was used to describe the characteristics of both patients and implants, as well

Figure 1 - A: PAN radiograph; **B:** Transparent template superimposed on the radiograph.

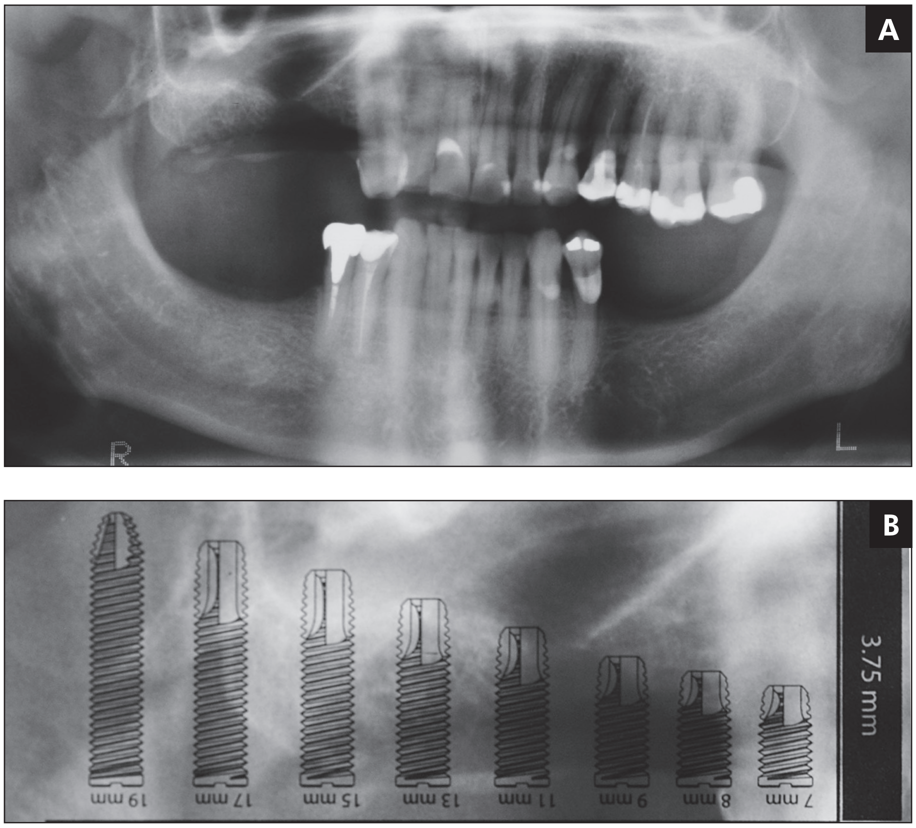
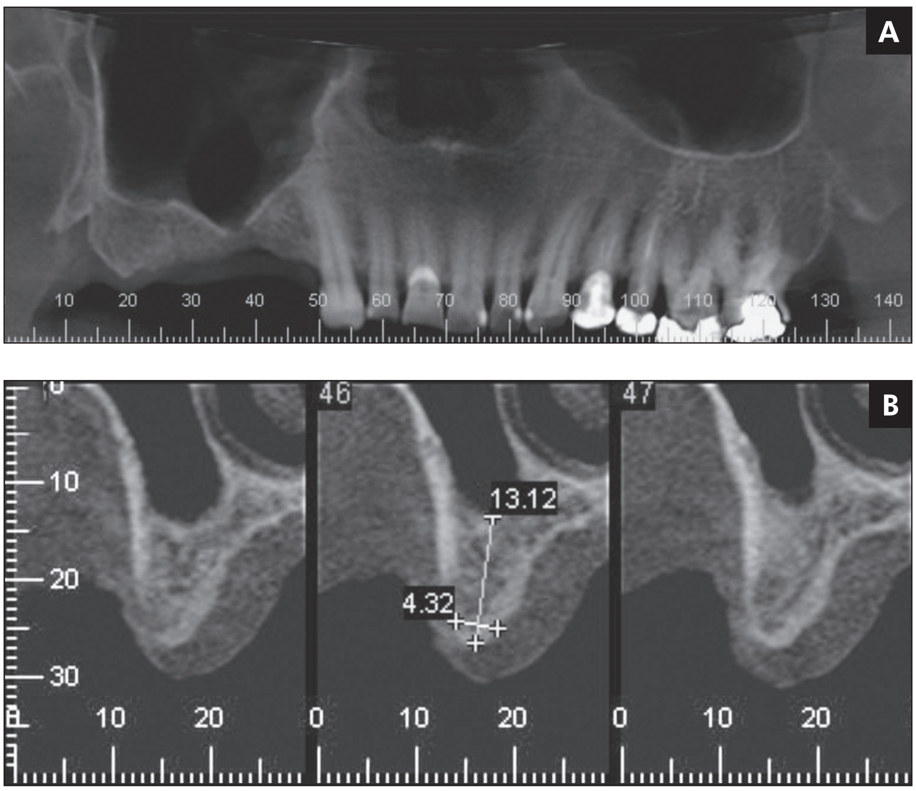


Figure 2 - A: CBCT PAN reconstruction; **B:** Bone measurement in the implant site.



as the distribution of changes between the different planning stages and the implants. Agreement between implant dimensions during preoperative planning stages (initial and final) and placed implant dimensions was tested using the McNemmar test, a non-parametric test for two related dichotomous variables. The chi-square test was used to compare the agreement frequencies among the different maxilla and mandible regions. The significance level was set at $p < 0.05$.

Results

Twenty-seven patients were selected, 10 male and 17 female, between 21 and 70 years of age. The study included 95 implant sites in 37 edentulous areas. Implant distribution by patient, extension of edentulous area and position is shown in Table 1.

Table 2 shows the frequency of changes in length and width, their direction and magnitude, according to the treatment stage. Direction and magnitude of the changes was measured from −4 to +4, in which each score represents one step higher or lower in the available implant length or width dimensions.

Regarding length, the dimensions considered in final planning did not change in 69.5% of cases, in comparison with those found during surgery. At this stage, the number of cases with smaller dimensions was almost the same as that with larger dimensions. In contrast, comparing the dimensions in initial planning to those found during surgery, only 40% of cases remained unchanged, and the number of smaller dimensions was higher than the number of larger dimensions. The comparisons between initial and final planning show a 49.5% rate of change.

Regarding width, the number of changes between the stages was similar. The difference was related to the kind of change. The number of smaller and larger dimensions was almost equal between initial planning and surgery. However, the width decreased

Table 1 - Distribution of implants.

No. of implants per patient	n	%
1 – 2	12	44.5%
3 – 4	6	22.2%
5 – 6	6	22.2%
7 or more	3	11.1%
No. of implants per edentulous area		
1	16	43.3%
2	8	21.6%
3	2	5.4%
4 or more	11	29.7%
Implant position		
Incisive	22	23.2%
Canine	26	27.3%
Premolar	28	29.5%
Molar	19	20.0%
Implant region		
Anterior maxilla	34	35.7%
Posterior maxilla	27	28.4%
Anterior mandible	14	14.7%
Posterior mandible	20	21.2%

Table 2 - Descriptive distribution of implant length and width changes at different implant planning and placement stages.

Stage	Overall cases of smaller dimension	−4	−3	−2	−1	Unchanged	+1	+2	+3	+4	Overall cases of larger dimension
Length											
Initial → Final planning	29 (30.5%)	-	3	6	20	48 (50.5%)	12	3	3	-	18 (19.0%)
Initial planning → Surgery	35 (36.8%)	1	3	5	26	38 (40.0%)	11	6	1	4	22 (23.2%)
Final planning → Surgery	14 (14.7%)	-	2	4	8	66 (69.5%)	6	5	3	1	15 (15.8%)
Width											
Initial → Final planning	21 (22.1%)	-	-	2	19	66 (69.5%)	7	-	1	-	8 (8.4%)
Initial planning → Surgery	13 (13.7%)	-	-	2	11	68 (71.6%)	11	2	1	-	14 (14.7%)
Final planning → Surgery	5 (5.3%)	-	-	-	5	70 (73.7%)	19	1	-	-	20 (20.1%)

Table 3- Frequency of sites with and without implant length and width changes, in initial and final planning, compared to dimensions of implants inserted at surgery.

Implant length		Initial planning → Surgery: Without changes	Initial planning → Surgery: With changes	Total
Final planning ↓ Surgery	Without changes	33	33	66
	With changes	5	24	29
	Total	38	57	95
		$p < 0.001$		
Implant width		**Without changes**	**With changes**	**Total**
Final planning ↓ Surgery	Without changes	55	15	70
	With changes	13	12	25
	Total	68	27	95
		$p = 0.850$		

Implant site location (maxilla or mandible, anterior or posterior) had no influence on the agreement percentage of length or width at the different planning and implant placement stages ($p > 0.05$).

more frequently between initial and final planning, and increased between final planning and surgery.

Cross-tabulation of the agreement between implant length at surgery and in early stages of planning (initial and final) showed that the number of sites with changes in initial planning (33 out of 95) was significantly greater than in final planning (5 out of 95), as compared with the real dimensions of the inserted implants. This led to a p value < 0.001 (McNemmar test), showing that there were significant differences in implant length when planning with or without CBCT (Table 3).

Agreement analysis revealed that the number of sites with changes in width between both planning stages was almost the same. This led to a p value of 0.850 (McNemmar test), showing that there were no significant differences in implant width when planning with or without CBCT (Table 3).

Discussion

Clinically, implant planning is a result of combining the radiographic information of different types of images. This study assesses future implant sites using PAN radiography versus PAN combined with CBCT imaging.

The study shows that CBCT increases the accuracy of treatment planning in predicting implant length defined at surgery. The agreement in predicting the implant length was 40.0% in initial versus 69.5% in final planning, hence a 29.5% increase in agreement after considering the CBCT exam. In about half of the cases (50.5%), implant length remained unchanged after considering CBCT evaluation together with initial planning to conclude final planning. When disagreement occurred, there was a great frequency of negative scores in measuring the difference between initial and final planning (30.5% negative versus 19.0% positive), and between initial planning and surgery (36.8% negative versus 23.2% positive), suggesting that implant length in initial planning tends to be overestimated, versus implant planning with CBCT evaluation and actual implant placement. This could be attributed to the tendency to overestimate the available bone for implant placement in PAN radiography,[8,9] leading to greater risk of injury to adjacent anatomic structures, like the submandibular gland or the inferior alveolar nerve.

The proportion of cases where implant width remained unchanged ranged from 69.5% (from initial to final planning) to 73.7% (from final planning to surgery). The limited benefit of using CBCT to detect implant width and the high levels of correct prediction at both initial (71.6%) and final planning (73.7%) stages must be viewed with some latitude, especially because cases with poor bone dimensions —in which a CBCT exam would be essential[10]—

were previously excluded from the study sample. When disagreement occurred, implant width was frequently overestimated in initial versus final planning (22.1 negative versus 8.4% positive). In contrast, implant width was more frequently underestimated in final planning, compared to the actual width at implant placement (5.3% negative versus 20.1% positive).

This study included 95 implants in 27 patients. Some of the implants were placed in the same patients and in the same edentulous space, meaning that some observations are dependent. Although this is a limitation to the data analysis, the large variation between neighboring zones emphasizes the importance of site-specific bone evaluation prior to surgical procedures in implant placement.[11] Moreover, ethical issues reinforce the need to include patients with multiple edentulous spaces.

Previous studies have evaluated changes in implant dimensions between presurgical planning and post-placement using conventional tomography.[12-16] In our study, we found changes in length in about 60% of cases not using CBCT (40% remained unchanged), similar to the results by Schropp *et al.*[13] who found changes in 70% of cases. Ekestubbe and Grondahl[12] detected a 70% agreement in the dimensions of the selected implants, between the planning stages, using conventional tomography and the dimensions at surgery, similar to our results (69.5% agreement for length and 73.7%, for width). The study by Diniz *et al.*[15] found no significant difference in implant dimensions using conventional tomography and/or PAN radiography; however, they did not compare the planning stages with implant placement, which restricts comparison with our study.

In Schropp *et al.*,[16] the selected implant size differed considerably when planned using PAN or CS tomographic images. Regarding width, the implant dimensions changed in 66% of cases, and regarding length, 69%, comparing before-and-after implant planning stages. In the present study, width changed in 69% and length in 55% of cases. However, this is a limited comparison. Although the percentages were not very different, the type of change was indeed. There was a prevalence of shorter implants selected after CBCT analysis, whereas longer implants were planned using conventional CS tomography. This could be due to the different types of exams used.

In relation to the different regions, i.e., maxilla and mandible (posterior or anterior), Hu *et al.*[17] evaluated not only the reliability of the two presurgical preparation methods, PAN radiography and CBCT, but also the surgery stage. The result shows that implant planning can be performed safely using digital PAN radiography for the mandible, but CBCT was recommended for the maxilla. More recently, Correa *et al.*[18] found that implant sizes measured using CS CBCT images were both narrower and shorter than the sizes obtained from digital PAN radiographs and CBCT-PAN views; the difference in width selection could be observed in the upper premolar region, and the difference in length, in the lower molar region. This last study did not include the surgery stage. However, analyses of the implant site locations (maxilla or mandible, anterior or posterior) in this study had no influence on the percentage agreement of length and width in the different stages of planning and implant placement, suggesting that the contribution of CBCT to the prediction of implant dimensions was not related to the location of the implant site; in both studies, CBCT exams led to a safer decision. The region-related differences may be explained by the difference in the specialty and experience of each surgeon.

The results of the present study are in concordance with the AAOMR recommendation. The AAOMR suggests that the radiographic exam of any potential implant site should include CS imaging orthogonal to the site of interest, and determined that CBCT should be considered the imaging modality of choice. The CBCT exam has led to better predictability in surgery, and consequently to a safer treatment modality.

A change in the planned implant dimensions during surgery could be attributed to specific local conditions, like bone density, not assessed in CBCT exams[19] and perceived objectively only during surgery. Direct visualization of the implant site and soft tissue height after surgical incision may also affect the planned implant dimensions, because the implant may have to be inserted more deeply or superficially to achieve better esthetic results.[20] An-other factor associated with the decrease in implant length is alveolar bone ridge thickness. In PAN radiography, an irregular crest leads to overestimated measurement of the available bone detectable in the CBCT image. The surgical procedure may include crestal bone flattening, which decreases the bone height and, consequently, the implant length.[21]

The appropriate preoperative image selection in implantology must consider minimum radiation exposures that result in images of acceptable diagnostic quality. This is known as the ALARA concept (*as low as reasonably achievable*). It is important to stress that professional judgment in choosing the appropriate image may vary according to the skill, experience, knowledge and capacity of each individual. Nonetheless, research results have increasingly established the importance of CBCT analyses in implant planning.

Conclusion

In conclusion, there were significant changes in the length of the selected implants in initial planning versus that of implants placed at surgery, suggesting that CBCT improves the ability to predict the actual implant length, thus reducing inaccuracy in the surgical planning of dental implants.

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