ORIGINAL RESEARCH

Influence of Three-dimensional Imaging on Implant Treatment Planning: Implant Diameter and Length

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ABSTRACT

Aim: To investigate the influence of the radiographic modalities panoramic radiography (PR) and cone beam computed tomography (CBCT) on selection of implant length and diameter.

Materials and methods: Potential implant sites (59 sites, 40 patients) with available PRs and CBCTs were selected from the databases of two University dental schools. Six experienced clinicians were asked to select the appropriate implant length and diameter based on PR and CBCT. Results were compared with the actual surgical procedure and intra- /interrater agreement was calculated using Cohen's kappa.

Results: On average, greater implant length was more often planned based on PR (24.2 *vs* 8.8% with CBCT), while wider implants were generally more frequently planned based on CBCTs (19.9 *vs* 29.7% with PR). Implant treatment planning based on PR and on CBCT images was equal in 50 to 67%. Compared with the actual surgery, CBCT revealed a higher agreement (46% for implant length), while for PR, 34.4% equal implant length was observed.

Conclusion: The radiographic modality used for implant treatment planning affects implant selection.

Clinical significance: The CBCT scans are advantageous for choosing the appropriate implant dimension. Caution should be exercised when selecting implant length planned from PR.

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INTRODUCTION

Panoramic radiography is the standard two-dimensional (2D) imaging technique applied prior to any surgical procedure in dentistry.[1,2] During the last two decades three-dimensional (3D) imaging, particularly CBCT, has been established to visualize potential implant sites in more detail. While both methods are deemed to be accurate for implant treatment planning, differences exist with respect to visualization, effective dose, costs, and availability of the apparatus.[3-7] Magnification rates and distortion of PR may lead to difficulties in measuring bone height and width. A safety margin of 2 mm has been established for dental implants to ensure integrity of adjacent anatomical structures.[8] The CBCT offers a more detailed visualization, e.g., of the mandibular canal,[9] and a reduced safety zone of 1.7 mm to this nerve structure has been recommended.[10] If implants are requested in areas with a potential high risk of damaging vital structures or with deficient bone morphologies, implant guidelines indicate 3D imaging with CBCT scans for more detailed information.[6,11]

The benefit of diagnostic imaging for the patient has been discussed and graded in six levels, i.e., the efficacy of imaging methods.[12] While levels 1 to 3 are related to technical quality, diagnostic accuracy efficacy, and "diagnostic thinking efficacy," level 4 assesses the effect on the treatment plan. Levels 5 and 6 measure the effect on patient outcomes, and, finally, the analysis of societal

costs. Most studies about implant treatment planning remain on levels 1 or 2.[13] Recent studies reported about level three and documented a difference of implant treatment planning based on 2D and 3D images.[14-17] Providing more detailed bone height measurements in CBCT, bone augmentation was more accurately predicted from CBCT compared with PR.[16] The potential effect of 3D visualization on implant selection in relation to the surgical protocol has not yet been evaluated.

The aim of the current study was to examine the effect of different imaging modalities (PR *vs* CBCT) on the selection of implant dimensions (implant length and diameter) in terms of diagnostic thinking efficacy (level 3).

MATERIALS AND METHODS

Study Sample

Records of 40 patients (24 women and 16 men, mean age 49 years, 19–78 years) requesting single tooth implants in an edentulous space were selected from two clinics (Departments for Oral Surgery, Basel, Switzerland, and Mainz, Germany). The study was approved by the Ethics Research Committee of the University of Basel Switzerland (EK: 245/12). Patients' records included preoperative digital PRs and a CBCT scan from the intended implant site. The PRs and CBCT scans were available to the respective surgeon before implant placement. Records on the implant dimensions (length and diameter) used during the actual surgery existed as inclusion criteria. A total of 59 implant sites in the premolar or molar region of the upper (n = 27) and lower (n = 32) jaw were included.

Image Acquisition

The PRs were acquired with two different machines: Cranex D (Soredex, Tuusula, Finland) or Orthophos XG (Sirona Dental Systems GmbH, Bensheim, Germany). The CBCT scans were made either with the Accuitomo 80 (J Morita Corp., Kyoto, Japan) with a voxel size of 0.125 mm or with the 3D Exam (Kavo Dental, Biberach, Germany) with a voxel size of 0.2 mm. All images were exported as DICOM files in their natural resolution, and subsequently imported to the Osirix-DICOM-Viewer (www.osirix-viewer.com).[16]

Observers and Observation Process

Six observers, experienced in dental implantology (five oral surgeons, one specialist in prosthodontics), were recruited to analyze the cases. Prior to the evaluation and planning process, the observers were calibrated with respect to the applications and features of the DICOM-Viewer. All 2D and 3D images were presented on a computer screen (size 1680 × 1050, Intel HD Graphics 3000 384 MB) in full volume size and with the option to change all possible setting options (adjusting the contrast, scrolling through the volume, etc.). The screen was calibrated with a software program (Dental Q, Luxor Display Q, IBA Dosimetry, Schwarzenbruck, Germany). All images were presented in a DICOM-Viewer (Osirix, v.4.1.2.). During the entire viewing period, the study supervisor (D.C.D.) recorded the observers' results and guided them through the analyzing process.[13] A total of 80 images (40 PR and 40 CBCT scans) were evaluated twice (one repetition) by each observer (Figs 1 and 2). While evaluation

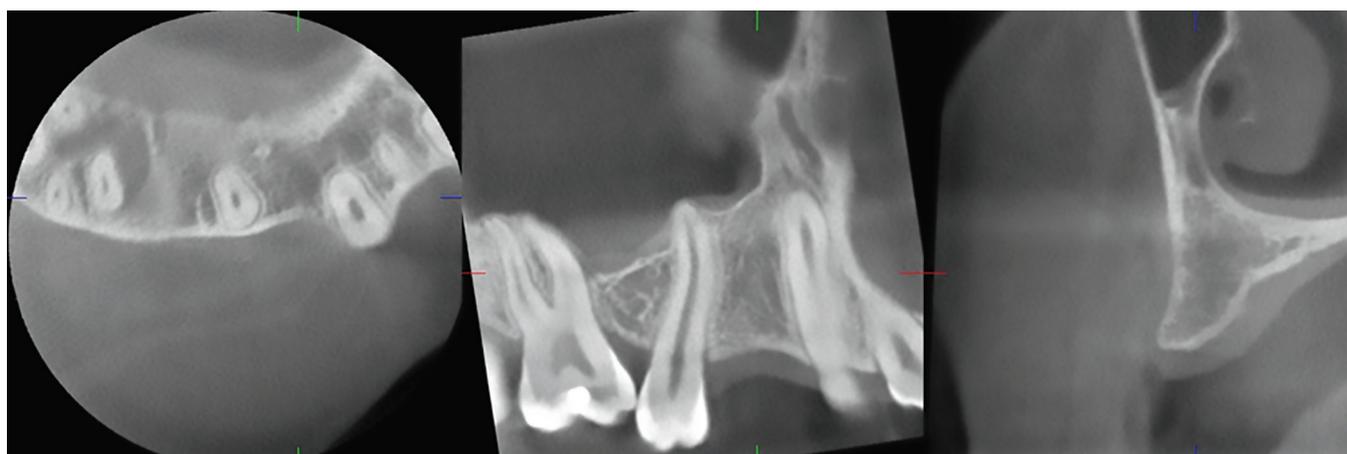**Fig. 1:** Panoramic radiograph for implant planning area 14

Fig. 2: Cone beam computed tomography image for implant planning area 14

Table 1: Analysis of implant selection based on PRs and CBCT

Procedure	Jaw	PR planning "longer/wider"	Diameter not defined on PR	CBCT planning "longer/wider"	Diameter not defined on CBCT	Both equally	p-value*
Implant length	Maxilla n = 324	19.8% (64)	0	10.5% (34)	0	69.8% (226)	0.134
	Mandible n = 384	27.9% (107)	0	7.3% (28)	0	64.8% (249)	0.001
	Both jaws n = 708	24.2% (171)	0	8.8% (62)	0	67.1% (475)	0
Implant diameter	Maxilla n = 324	13.6% (24)	148	34.1% (60)	0	52.3% (92)	0.625
	Mandible n = 384	25.1% (54)	169	26.0% (56)	0	48.8% (105)	0.002
	Both jaws n = 708	19.9% (78)	317	29.7% (116)	0	50.4% (197)	0.092

*p-value relates to difference between methods related to invasiveness of planning

of each radiograph was conducted without time limits, the evaluation time of one session was restricted to 1.5 hours to avoid excessive observer fatigue. Four sessions were required by each observer. Sessions were separated by a minimum period of two weeks to ensure that observers were not recalling their initial decisions.

Planning Implant Dimensions

The observers were asked to evaluate the images at the given implant sites including neighboring structures, and to measure the maximum bone height (in mm) to plan the implant dimensions.[16] Observers were informed about the (global) magnification factor provided by the manufacturers for PR, i.e., for the Cranex D 1:1.25, and for the Orthophos XG, 1:1.19. Applying these global magnification factors, the readings of the observers were subsequently corrected.

Observers were asked to select one of the following options for implant length:
- No implant possible
- 6 mm implant length
- 8 mm implant length
- 10 mm implant length
- 12 mm implant length

In addition, implant diameter was determined from CBCT using the following options:
- No implant possible
- Implant planning not evaluable
- 3.3 mm implant diameter
- 4.1 mm implant diameter
- 4.8 mm implant diameter

At the stage of designing this study, it was assumed that it would not be reasonable to estimate an implant diameter solely based on PR due to the unreliable horizontal magnification in PRs. During conduct of the study, several observers (yet not all of them) still provided diameter estimations on PRs. Since these data were now available for some cases, this information was included in the analysis. This explains the reduced number of cases for this specific parameter.

Data Processing and Statistical Analysis

The number of disagreements between CBCT and PR for the outcomes (selected implant length and diameter) was reported with counts and percentages (Table 1). Any deviations between the two imaging methods or in comparison with the surgical procedure were considered as "more invasive" as soon as a longer and/or wider implant dimension was planned. Correspondingly, a treatment plan was graded as "less invasive," when smaller implant dimensions were planned, or "equal" with concurring plans or decisions. Ratings with no planning were excluded. To accommodate for potential pooled data, the most frequent values (mode) of implant length and diameter were determined for each site and imaging method. The modes of different methods (PR and CBCT) were compared using McNemar-Bowker test or the Wilcoxon signed-rank test for paired data. Prior to testing, categories with few entries were merged as appropriate. Further, the outcomes (implant length and diameter) based on PR or CBCT were compared with the actually conducted surgical procedure and displayed with counts and percentages (Fig. 3 and Table 2).

In a first analysis, the implant parameter of the actual surgical procedure was compared with both imaging methods. All data were considered to calculate the modes of the imaging methods (PR and CBCT), which were compared with the conducted surgical procedure and categorized into "equal" and "nonequal." Secondly, the "invasiveness" of the methods (CBCT and PR) was

Fig. 3: Panoramic radiograph after surgical procedure in area 14 inserted implant at the location of the first maxillary premolar right with 10 mm length and 4.1 mm diameter

Table 2: Implant length planned on PR or CBCT compared with the conducted surgical procedure

	Equal to surgery	Longer	Shorter
Maxilla (n = 312)			
PR	28.9% (90)*	53.8% (168)**	17.3% (54)
CBCT	42.6% (133)	41.7% (130)	15.7% (49)
*p = 0.134; **p = 0.134			
Mandible (n = 360)			
PR	39.2% (141)*	46.1% (166)**	14.7% (53)
CBCT	48.9% (176)	33.6% (121)	17.5 % (63)
*p = 0.006; **p = 0.008C			
Both jaws (n = 672)			
PR	34.4% (231)*	49.7% (334)**	15.9% (107)
CBCT	46.0% (309)	37.4% (251)	16.6% (112)
*p = 0.001; **p = 0.001			

*Comparison of imaging method (PR and CBCT based) with surgery; **Comparison of more invasive PR planning with more invasive CBCT planning

analyzed in comparison with the conducted surgical procedure and categorized into "equal," "longer/wider," and "shorter/narrower." Ratings with no planning were not considered to calculate the modes.

To explore the magnitude of variability of bone height for various random factors, a linear mixed-effects model was computed. The dependent variable was bone height. The parameter raters, imaging method, jaws, and site were treated as independent random factors. No fixed factor, but an overall mean (intercept) was included for each random factor, the variance with standard deviation (SD) was analyzed. Intra- and interrater agreement was calculated using Cohen's kappa. The level of significance was set at $\alpha = 0.05$. All calculations were performed with R 2.15.1.[18]

RESULTS

Comparison of Suggested Implant Length based on PR or CBCT

The suggested implant length according to PR or CBCT did not differ in 67.1% of the sites (Table 1). In 8.8% of the cases, CBCT-based planning yielded a longer implant than planning based on PR. *Vice versa*, PR resulted in 24.2% in longer implants compared with CBCT-based planning. Differences were more pronounced for planning in the mandible ($p = 0.001$) than for the maxilla ($p = 0.134$, Table 1).

Comparison of Suggested Implant Length (based on PR or CBCT) and Conducted Surgical Procedure

A complete agreement between both radiographic methods and the surgical procedure was achieved in

28.3%. While an agreement between treatment plan and surgery was found in 34.4% of the sites planned with PRs, the agreement amounted to 46.0% when planning was based on CBCT scans (Table 2). The PR planning resulted in an overestimated implant length in 49.7% of the cases, while in 15.9% of the sites, implant length was underestimated. For CBCT, an overestimation of the actual implant length was found in 37.4% of the cases, whereas an underestimation was computed for 16.6%. When the results were separated by jaw, a significant difference between planning and surgical procedure was documented in the mandible, but not in the maxilla (Table 2).

Comparison of Suggested Implant Diameter based on PR or CBCT

In 44.8% of the sites, the observers were not able to select an implant diameter based on PR. In 29.7%, CBCT-based planning yielded a wider implant than planning based on PR. Vice versa, PR resulted in 19.9% in a wider implant than based on CBCT. The results were more balanced for the mandibular than for the maxilla (Table 1). While there was no significant difference between the two methods in the maxilla, the suggested treatment plan differed significantly in the mandible ($p < 0.05$).

Comparison of Suggested Implant Diameter (based on PR or CBCT) and Conducted Surgical Procedure

While an agreement with the surgical procedure was found in 24.4% of the sites planned with PR, the agreement amounted to 55.7% when planning was based on CBCT scans (Table 2). Planning on PR underestimated implant diameter in 19.8% of the cases, while an overestimation occurred in 11.0% of the sites. For CBCT, an overestimation of actual implant diameter was found in 25% of the cases, whereas an underestimation was computed in 17.4%.

When the results were separated for the upper and the lower jaw, similar observations were made, except for the planning based on PR for the maxilla. Only 24.4% of the investigated sites showed a similar implant diameter planned on PR and the implant diameter selected during the surgery. In 19.8%, the implant diameter was planned less invasive on PR than conducted during surgery (Table 3).

Agreement within Observers and between Observers

The interrater agreement (between rater) expressed as Cohen's kappa was 0.21 for planning implant length on PR and 0.20 for CBCT planning. For implant diameter, the interrater agreement revealed a kappa value of –0.11

Table 3: Implant diameter planned on PR or CBCT compared with the conducted surgical procedure

	Equal to surgery	Wider	Narrower	Diameter not planned
Maxilla (n = 312)				
PR	22.4% (70)*	10.3% (32)**	21.5% (67)	45.8% (143)
CBCT	51.6% (161)	32.1% (100)	16.3% (51)	
*p = 0.001; **p = 1.000				
Mandible (n = 360)				
PR	26.1% (94)*	11.7% (42)**	18.3% (66)	43.9% (158)
CBCT	59.2% (213)	18.9% (68)	21.6% (79)	
*p < 0.001; **p = 0.008				
Both jaws (n = 672)				
PR	24.4% (164)*	11.0% (74)**	19.8% (133)	44.8% (301)
CBCT	55.7% (374)	25.0% (168)	19.3% (130)	
*p = 0; **p = 0.001				

*Comparison of imaging method (PR and CBCT based) with surgery; **Comparison of more invasive PR-planning with more invasive CBCT-planning

Table 4: Variance analysis of influencing factors affecting bone height

Variability	Variance (SD)
Between modalities	22.57 (4.75)
Between sites	18.35 (4.28)
Within rater	9.10 (3.02)
Between jaws	9.07 (3.01)
Between rater	0.13 (0.35)

Table 5: Observers' evaluation of the case shown in Figures 1 and 2

Observer	Repetition	Implant length in PR (mm)	Implant length in CBCT (mm)	Implant diameter in PR	Implant diameter in CBCT
1	1	10	10	–	4.1
2	1	12	10	4.1	3.3
3	1	12	12	–	4.1
4	1	12	12	–	3.3
5	1	12	10	–	3.3
6	1	12	12	4.1	3.3

Data from first assessment shown. During surgery, an implant with 10 mm length and 4.1 mm diameter was inserted

concerning the planning based on PR *vs* 0.16 for CBCT images. When comparing the two repetitions each observer had conducted, the planned implant length revealed a within-rater Cohen's kappa of 0.71 for PR *vs* 0.54 for CBCT. For implant diameter, the kappa values were 0.26 on PR and 0.56 on CBCT images.

Influence on Selection of Implant Dimensions

According to the linear mixed-effect models, greatest variance in bone height measurements was demonstrated for the type of imaging (PR or CBCT) with variance (± SD) of 22.57 (± 4.7). This was followed by the implant sites (18.35 ± 4.3), while intraobserver agreement, jaw location (maxilla or mandibular), and interrater agreement had minor influence (Table 4).

DISCUSSION

The aim of this level 3 study was to investigate the impact of modality of radiographic imaging on the implant selection during treatment planning. The analysis revealed that greater implant length was planned based on PR, while wider implants were planned based on CBCTs. A higher agreement occurred between CBCT-based planning and the conducted surgical procedure.

In general, implant selection depends on local bone height and width as well as on the intraoperative surgical situation possibly requiring bone augmentation. In the current study, implant dimensions were selected among predefined lengths and widths, and the term "invasive" was related to greater length or width. Comparing implant planning based on the two different imaging methods, implant length was consistent for approximately two-thirds of the investigated sites, while shorter implants were more frequently planned in CBCT compared with PR, which is in agreement with data from the literature.[14,15] Based on PR, implant length was overestimated in approximately half of the cases when compared with the conducted surgical procedure, which indicates a certain risk of overseeing morphological variations, such as buccal concavities in the maxilla or lingual undercuts in the posterior mandible.[19,20] It is well known that panoramic imaging results in distortion and magnification of anatomical structures, and the individual anatomical inclination of the jaw cannot be visualized. Due to these aspects, 2D visualization of bone morphology and anatomical structures in PR is limited, e.g., in the mandible with deficient imaging of the mandibular canal or lingual undercuts (Table 5). Consequently, bone height measurements in PR provide only an estimation of the true height.[21-24]

As the number of diameter estimations based on PRs was low, the current results should be considered as an approximation, which need to be verified in further studies. If implant diameter was determined in PR, it was smaller compared with the planning based on CBCT. In contrast to these results, some studies documented either no differences in planning implant diameter,[14] or planning of narrower implants based on CBCT compared with PR.[15] This discrepancy reflects different treatment strategies either favoring wider implant diameter with the need for bone in certain cases augmentation, or preferring smaller implants to avoid horizontal augmentation procedures.

Data of the current study revealed that CBCT-based implant planning was more congruent with the surgical protocol than the PR planning. These results are in agreement with previous studies documenting that the content and quality of 3D CBCT images were more precise compared with PRs.[9,25] However, implant planning based on CBCT tended to overestimate implant length in more than one-third and implant diameter in 25%. These findings are possibly related to existing differences between the accurate visualization of anatomical structures in CBCT and the real tissues of the intraoperative situs. Even clinical information, which are provided with casts combined with radiographs cannot bridge the discrepancy between images and the actual clinical condition in all cases.[17]

When discussing the adequate indication for imaging techniques, their true benefits and effective dose have to be balanced. As a rough rule-of-thumb, the average effective dose of PR is about 10 times less than the average of effective dose of CBCT scans.[26] A recent meta-analysis[27] computed mean effective doses between 84 μSv (small field of view) and 212 μSv (small field of view). When comparing these values with an average effective dose from PR ranging between 2.7 and 24.3 μSv,[28] the rule-of-thumb relation still appears valid. New technologies with different scanning protocols and especially comparison of equal volume sizes have to be taken into account for future rule-of-thumb relation. In addition to that, the availability of imaging modalities might also influence the choice of methods, even though with meticulous techniques, panoramic imaging can still be useful.[5] Furthermore, both modalities possess a wide range of image quality. The selected voxel were in the sub millimeter range with 0.125 mm for Accuitomo 80 and 0.2 mm for Kavo 3Dexam. The differences in millimeter between the implants with respect to the possible length and/or diameter are larger than the differences in resolution in terms of voxel. Therefore, an influence of the CBCT apparatus seems to be negligible. Further studies are required to address this point. It has to be kept in mind that the radiographic imaging in living subjects is limited to a realistic visualized detail size of 0.5 mm.[29]

Recently, treatment planning was analyzed in questionnaire studies with dental practitioners.[30,31] Both studies showed that there is a great variance regarding the treatment plan selected by a dentist for a given clinical situation. The suggested approach was affected by confounders, such as profession, age or gender. This research indicates that transfer from research to clinical practice may need to be improved and evidence-based guidelines established if possible.[32,33] However, in evidence-based dentistry settings, the experience of the dental practitioner is an important parameter for decision-making.[32] In many cases, the variance between different dentists does not necessarily represent the selection of a right *vs* a wrong approach. It simply reflects clinical reality. Keeping this in mind, the current study was designed and the data regarding variance were provided. Reading panoramic images and planning implants based on PR is a common and routine procedure and dentists are familiar with this method. Reading CBCT scans, even for experienced specialists in implantology, is more challenging. In the current study, the variance of the results concerning CBCT planning was higher compared with the planning based on panoramic images. The interrater agreement (Cohen's kappa: 0.26–0.71)[33] was relatively low, reflecting the great diversity regarding treatment planning of different experienced observers. In a similar study, presurgical implant planning showed an interobserver agreement (kappa) of 0.30 to 0.34.[14] The observer's effect on interpretation of radiographs is a multifactorial procedure with subjective elements affecting the outcome.[34] These aspects are still valid and also count for modern 3D imaging technology. In the current study, six experienced observers were selected, who conducted the challenge of data interpretation in terms of diagnostic efficacy. All images were provided with full-options in changing the settings, which means that each observer could rotate the CBCT volume in her/his appropriate way for implant treatment planning. Six observers represent the process of implant planning more appropriate than just one observer, who might have a personal opinion of implant planning. Implant length and diameter were planned in real cases, with the same records the surgeon had for the entire implantation process.

Since this was a study with the primary focus on treatment planning, in this study, the observers were not able to operate the cases themselves. However, an alternative study design would follow surgeons during the planning phase based on both radiographic methods and observe their actual surgical procedures. However, such a protocol would only consider the planning process of single subjects and thus would preclude a multirater analysis, which is a strength of our study.

CONCLUSION

The results of the current study indicate that bone height measurements in presurgical implant planning are influenced by the imaging modality (PR and CBCT scan). Compared with PR planning, CBCT-based implant planning was closer related to the conducted surgery; however, interindividual differences were also higher.

CLINICAL SIGNIFICANCE

The CBCT scans provided sufficient additional information in the third dimension to facilitate reliable planning of the implant dimension, particularly the implant diameter.

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