Reliability of Circumferential Bone Level Assessment around Single Implants in Healed Ridges and Extraction Sockets Using Cone Beam CT

Filiep Raes, DDS, MSc;* Liesbet Renckens, DDS, Msc;† Johan Aps, DDS, MSc, PhD;‡§
Jan Cosyn, DDS, MSc, PhD;¶** Hugo De Bruyn, DDS, Msc, PhD††‡‡

ABSTRACT

Purpose: Cone beam computerized tomography (CBCT) provides three-dimensional information and could absolutely be useful for evaluating circumferential implant bone levels. However, the accuracy and precision of the technique has not been described. The aim of the study was to assess the accuracy and precision of CBCT (i-CAT®, Imaging Sciences International®, Hatfield, PA, USA) using periapical radiographs (PA) as a reference and to evaluate the circumferential bone level on CBCT around immediately loaded single implants placed in healed ridges (CIT, conventional implant treatment) and extraction sockets (IIT, immediate implant placement).

Materials and Methods: PA and CBCT radiographs were obtained from 26 single Astra Tech Osseospeed™ implants (Astra Tech AB, Mölndal, Sweden) 1 year after loading in respectively healed ridges (CIT) or extraction socket (IIT). For accuracy analysis, the three mesial and three distal interproximal levels obtained by CBCT were pooled to enable a comparison with PA. Precision was analyzed by intra- and interexaminer reliability calculation from mesial and distal sites on CBCT. The circumferential bone level considered all eight positions assessed on CBCT.

Results: Accuracy of CBCT was low ($R = 0.325/p = .019$) given the fact that bone level of the total group was 0.70 mm (standard deviation [SD] 0.78, range 0.00–3.20) on PA and 0.23 mm (SD 0.27, 0.00–1.20) on CBCT ($p < .001$) with only 42% of the measurements showing deviation within 0.2 mm. However, intra- and interexaminer reliability were favorable ($R \geq 0.611/p < .001$, ≥83%). The mean circumferential bone level on CBCT was 0.21 mm (SD 0.30) and 0.26 mm (SD 0.18) for IIT and CIT, respectively. The impact of the treatment strategy was not significant.

Conclusion: PA should be the standard technique to assess interproximal bone level but correlates poorly with the CBCT measurements. However, the precision of CBCT was high. CBCT requires further improvements of hardware and/or software. Within the limitations of the study, there is an indication that the buccal bone 1 year after implant treatment is evenly preserved when implants are immediately loaded in extraction sockets or in healed bone.

KEY WORDS: accuracy and precision, circumferential bone level, cone beam CT, single implant

*Clinical assistant, Dental School, Department of Periodontology and Oral Implantology, Faculty of Medicine and Health Sciences, University of Ghent, Ghent, Belgium; †clinical assistant, Dental School, Department of Prosthetic Dentistry, Faculty of Medicine and Health Sciences, University of Ghent, Ghent, Belgium; ‡head of Dental and Maxillofacial Radiology, Ghent University Hospital; §visiting professor at Faculty of Medicine and Health Sciences, University of Ghent, Ghent, Belgium; ¶professor, Dental School, Department of Periodontology and Oral Implantology, Faculty of Medicine and Health Sciences, University of Ghent, Ghent, Belgium; **visiting professor, Dental Medicine, Faculty of Medicine and Pharmacy, Free University of Brussels (VUB), Brussels, Belgium; ††chairman and professor, Dental School, Department of Periodontology and Oral Implantology, Faculty of Medicine and Health Sciences, University of Ghent, Ghent, Belgium; ‡‡visiting professor, Department of Prosthodontics, University of Malmö, Malmö, Sweden

Reprint requests: Dr. Hugo De Bruyn, Department Periodontology and Oral Implantology, Faculty of Medicine and Health Sciences, University of Ghent, De Pintelaan 185 P8, B-9000 Ghent, Belgium; e-mail: hugo.debruyn@ugent.be

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INTRODUCTION

Currently the intraoral periapical radiograph (PA) using the long-cone paralleling technique is considered accurate and reliable for longitudinal assessment of peri-implant bone loss.[1–3] It is a classical method to evaluate implant success based on bone level changes between loading and follow-up.[4] This type of imaging is convenient because it can be done chairside. In addition, costs and radiation dose[5–7] are favorable. However, the limitation of PA is that only two-dimensional images are obtained and as such, only superimposed bone structures in the interproximal areas are visualized. These limitations can be resolved when three-dimensional scanning techniques, i.e., conventional multislice computerized tomography or cone beam computerized tomography (CBCT), are used. CBCT is known as cone beam volumetric tomography, digital volume tomography, or cone beam imaging.[8] Based on the literature regarding periodontal defects on teeth, CBCT was found more reliable than PA[9–11] and CBCT images demonstrated more potential in the morphological description of periodontal bone defects.[12]

A possible drawback of three-dimensional scanning is the higher radiation dose imposed to the patient compared with the two-dimensional imaging technique.[13] The CBCT effective dose varies substantially depending on the device, field of view (FOV) and selected technique factors. Effective dose detriment of CBCT is higher than conventional panoramic imaging and lower than conventional computerized tomography (CT).[14–16] During the last decade, cone beam technology improved steadily and has been successfully introduced for justified clinical applications in dentistry.

In implant dentistry CBCT is frequently used for planning purposes or guided surgery.[17–22] Hitherto, there are few studies available using CBCT to determine the distance between the cemento-enamel junction (CEJ) and the facial bone crest[23] and to measure the thickness of the facial bone wall at different locations apical to the CEJ in the anterior dentition of the maxilla.[24,25] A recent study used CBCT to measure postoperative bone configuration at implants placed in the anterior maxilla.[26] The proportion of bone-to-implant contact (BIC) and the thickness of the buccal bone plate at different locations apical to the neck of the implant were calculated on the labial site in grafted and nongrafted sites. To our knowledge, however, there are no human studies available on the assessment of circumferential bone level around implants in the premaxilla.

The aim of the current study was to assess first the accuracy and precision of CBCT compared with intraoral periapical radiography and second to evaluate the circumferential bone level on CBCT around immediately loaded single implants placed in healed ridges and extraction sockets after 1 year of function. It was hypothesized that the assessment of interproximal bone level on CBCT images is not inferior to periapical radiographs and that circumferential bone level around implants placed in healed bone or in extraction sockets shows an equal pattern.

MATERIALS AND METHODS

Patient Selection

A total of 26 patients who underwent single implant treatment in the context of a previously published study[27] agreed to undergo an additional CBCT radiographic evaluation 1 year after implant therapy in addition to a standardized PA foreseen in the signed study protocol. Fourteen patients were males and 12 were females. Mean age was 43 years (SD 18, range 19–75). Fourteen patients had conventional implant treatment in a healed ridge (CIT) and 12 underwent immediate implant placement in an extraction socket (IIT). Fifteen patients received an Astra Tech Osseospeed™ straight implant (Astra Tech AB, Mölndal, Sweden) (3.5 and 4 mm diameter) and 11 an Astra Tech Osseospeed™ conical implant (4.5 and 5 mm diameter). For details on the surgical procedures and bone level data sorted per treatment strategy, we wish to refer to a previous paper.[27]

The study was conducted in accordance with the Helsinki declaration of 1975 as revised in 2000 and the protocol was approved by the ethical committee of the University Hospital of Ghent (UZ Ghent, n°2004/439).

Periapical Radiography

Periapical radiographs using the long-cone paralleling technique were all made with a Gendex Oralix AC Densomat (Kavo Dental®, Gendex Imaging, Cusona Milanino, Italy – exposure time of 0.2 seconds, at 65 kV and 7.5 mA). A Kodak® E-F speed dental film (Kodak®, Carestream Dental AB, Kista, Sweden) and an X-ray holder (XCP Bite Block, Dentsply® Rinn, Elgin, IL, USA) were used. The latter was individualized with an occlusal resin jig (Tempron®, GC, Aichi, Japan) to standardize

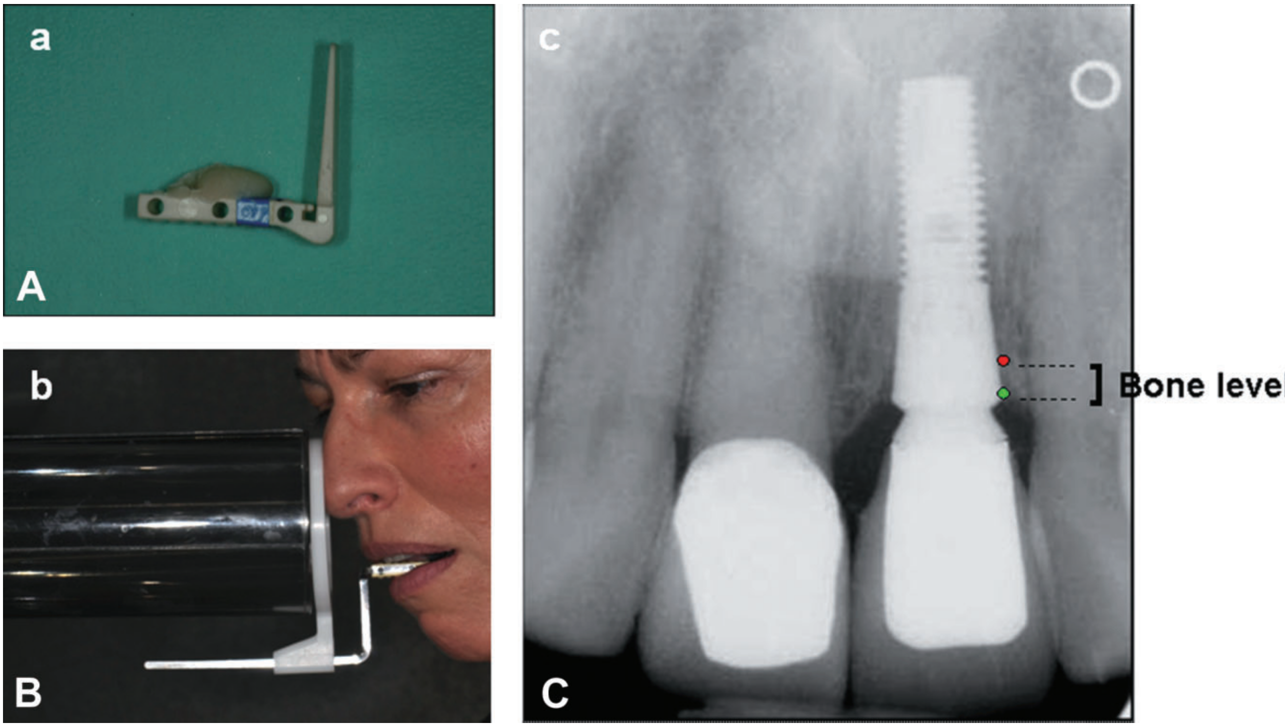

Figure 1 X-ray holder with individual patient's occlusal resin jig (A), and the paralleling Rinn-set and radiographic cone perpendicular to the radiograph (B) in order to obtain clear marking of the implant threads on the standardized periapical radiograph (C). The distance between green and red dot marks the bone level measured on an immediately placed and loaded implant after 1 year.

the angulation and position of the film in relation to the implant and the X-ray beam (Figure 1, A and B). An independent radiologist evaluated all PA radiographs as part of the large study protocol. Marginal bone level defined as the distance from the first BIC to the junction of the roughened microthread and the smooth, beveled implant surface was determined at the mesial and distal aspect of the implant. Measurements were performed to the nearest 0.1 mm under seven times magnification using a magnifying glass and ideal illuminance and dimmed room circumstances (Figure 1C).

Cone Beam CT

A CBCT was made with the Classic i-CAT® apparatus (Imaging Sciences International®, Hatfield, PA, USA) with an amorphous silicon flat panel as detector type and the following set of scanning parameters: 120 kVp, 5 mA, 20 seconds scan time and FOV of 16 cm (width) × 13 cm (height). According to the manufacturer, the i-CAT provides no distortion, a 12-bit gray scale, and a voxel size resolution of 0.2 mm.[28] The acquired and reconstructed three-dimensional volume images were exported and saved as DICOM-files Digital Imaging and Communications in Medicine. The latter were loaded in a specific software program QT Quantitative Tomography 1.0.0.2. (Inspektor Research Systems BV, Amsterdam, The Netherlands). The three-dimensional (X, Y, Z) position of the implant in the dental arch of the patient could be stored by determination of the central point of the apical and coronal part of the implant. Subsequently, the software calculated a three-dimensional rotation and constructed horizontal (XY) planes perpendicular to the long axis of the implant. Four vertical (axial) cross-sectional planes perpendicular to the long axis of the implant were reconstructed (M-D = mesiodistal, B-L = buccolingual, BD-LM = buccodistal-linguomesial, and BM-LD = buccomesial-linguodistal). The axial profile according to the M-D axis was toggled in the right direction (Figure 2A). Using the implant length specifications from the manufacturer, the junction between the roughened microthread and the smooth beveled implant surface can be found (Figure 2B). Finally, the marginal bone level on each side of the implant could be defined at each axial cross section at the first radiographic visible BIC with regard to the reference line indicating the implant junction illustrated on a clinical example of each treatment strategy (Figures 3C and 4C). This resulted in eight circumferential measurements; mesial (M), distal

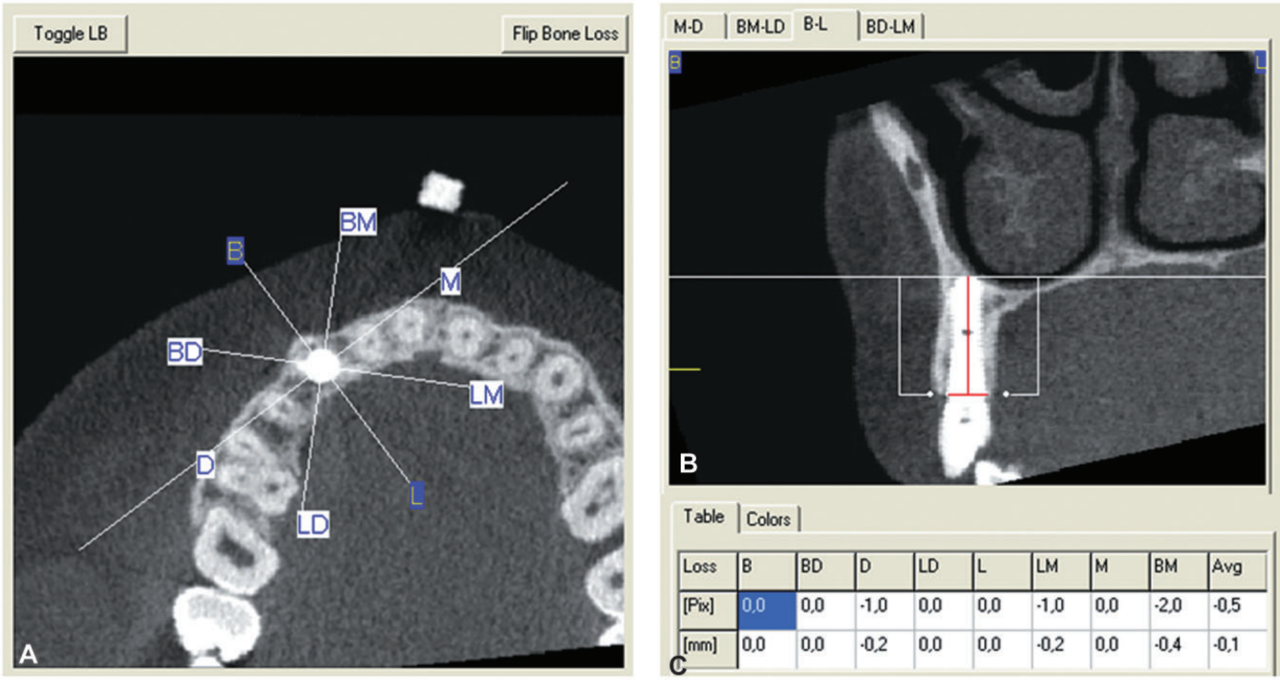

Figure 2 Horizontal and vertical image of converted cone beam computerized tomography DICOM files Digital Imaging and Communications in Medicine with the QT Quantitative Tomography 1.0.0.2 Program® (Inspektor Research Systems BV, Amsterdam, The Netherlands). (A) Four axial planes through the implant's long axis allows eight bone level measurement positions; (B) implant with coronal implant abutment reference line and buccolingual measurement positions; (C) corresponding table of eight absolute level measurements and one value corresponding with the mean circumferential bone level.

(D), buccal (B), lingual (L), buccomesial (BM), linguomesial (LM), buccodistal (BD), linguodistal (LD) resumed in a corresponding table (Figure 2C). No measurements of marginal bone level coronal to the implant junction were assessed on PA and CBCT radiographs.

Considering that the mesial and distal bone height around an implant on a PA is the result of the projection of the total amount of interproximal bone, it was assumed that this would be close to the mean of the three mesial (BM, M, and LM) or three distal (BD, D, and LD) levels as measured on CBCT. These pooled interproximal levels enabled a comparison with the two-dimensional PA considered as a reference. All eight positions on CBCT were used to evaluate the impact of the treatment strategy (IIT vs CIT) and reflected the mean circumferential bone level.

Statistical Analysis

For accuracy and precision analysis, the site was the statistical unit. The accuracy of CBCT was evaluated by comparing pooled mesial and distal CBCT bone levels to mesial and distal bone levels obtained by PA. For this purpose, the Wilcoxon signed ranks test and the Spearman's correlation coefficient were adopted. In addition, the mean difference and percentage agreement within 0.2 mm deviation were calculated. To evaluate the precision of CBCT (intra- and interexaminer reliability), two clinicians (F.R., L.R.) analyzed all images and duplicate analysis was performed by one clinician (F.R.). The aforementioned tests were also used on the mesial and distal sites of CBCT to analyze precision. The impact of the treatment strategy (IIT vs CIT) on the interproximal and circumferential bone level was evaluated by means of the Mann–Whitney *U*-test on patient level. The Friedman test was used to study the impact of the measurement position on circumferential bone level. If a significant difference was found, Wilcoxon signed ranks tests were performed comparing measurements positions two by two. The level of significance was set at 0.05.

RESULTS

CBCT versus Periapical Radiographs

To evaluate accuracy, each of the three mesial (BM, M, and LM) and three distal (BD, D, and LD) CBCT measurements were pooled in order to be able to compare

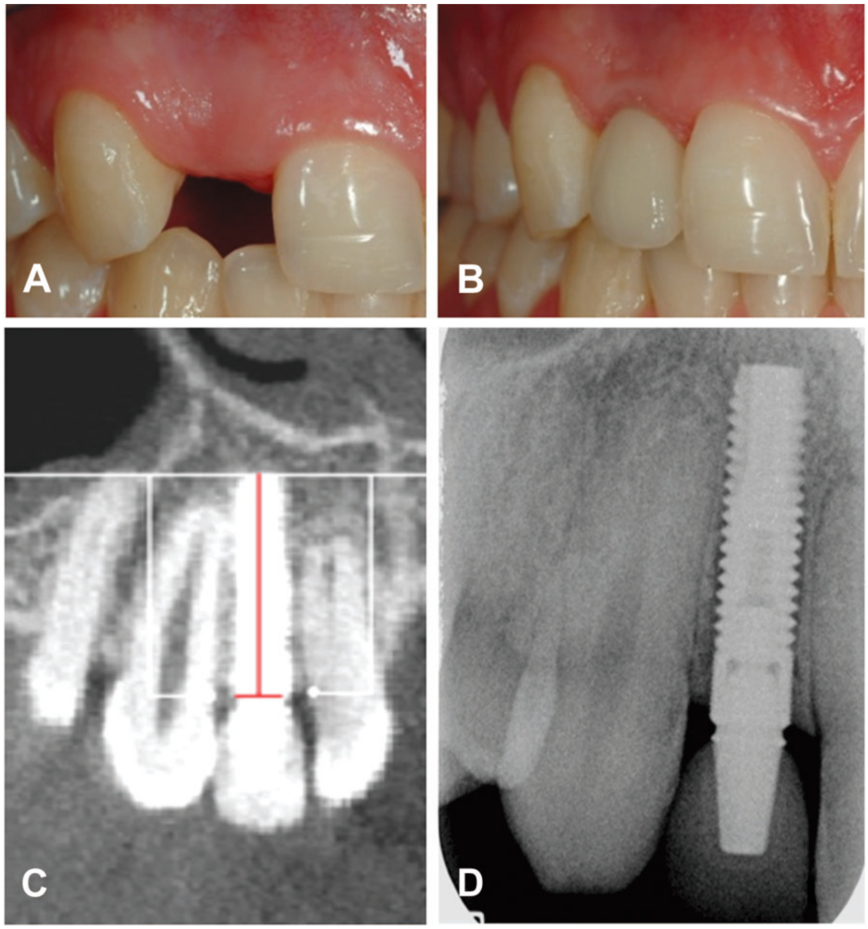

Figure 3 Clinical case of healed bone group with pretreatment (A); final crown after 1 year (B); mesiodistal view of QT Quantitative Tomography conversion and measurement of both positions (C); and periapical radiograph after 1 year (D).

with the mesial and distal values obtained by PA radiographs. Mean bone level after 1 year of function was 0.70 mm (SD 0.78, range 0.00–3.20) on PA and 0.23 mm (SD 0.27, range 0.00–1.20) on CBCT. The disparity was highly significant ($p < .001$) demonstrating that CBCT systematically underrated bone level as assessed on PA. A mean difference of 0.47 mm (SD 0.73, range –0.47–3.13) was observed between PA and CBCT. The lack of proper concordance was also shown by a low Spearman's correlation coefficient ($R = 0.325$, $p = .019$) and the fact that agreement within 0.2 mm deviation was found in only 42% of the sites.

Precision of CBCT Measurements

Table 1 shows details on the intra- and interexaminer reliability of CBCT measurements for bone level evaluation. The mean intraexaminer difference was 0.006 mm (SD 0.087, range –0.204–0.201) with a high Spearman's correlation coefficient ($R = 0.945$, $p < .001$) and the mean interexaminer difference was 0.063 mm (SD 0.333, range –0.602–1.604) with a moderate Spearman's correlation coefficient ($R = 0.611$, $p < .001$). The percentage of agreement within 0.2 mm was 100% and 83%, respectively.

PA and Circumferential Measurements per Treatment Strategy

The PA measurements of the mesial and distal bone levels were 0.56 mm (SD 0.75, range 0.00–2.20) and 0.89 mm (SD 0.78, range 0.00–2.40) for IIT and 0.56 mm (SD 0.86, range 0.00–3.20) and 0.80 mm (SD 0.75, range 0.00–3.10) for CIT, respectively. There was no statistical significant difference between both treatment modalities for the mesial ($p = .851$) and distal ($p = .757$) side. To evaluate the impact of treatment strategy (IIT vs CIT), all CBCT data relating to the eight aforementioned positions were used. Results of these circumferential measurements on CBCT are shown in

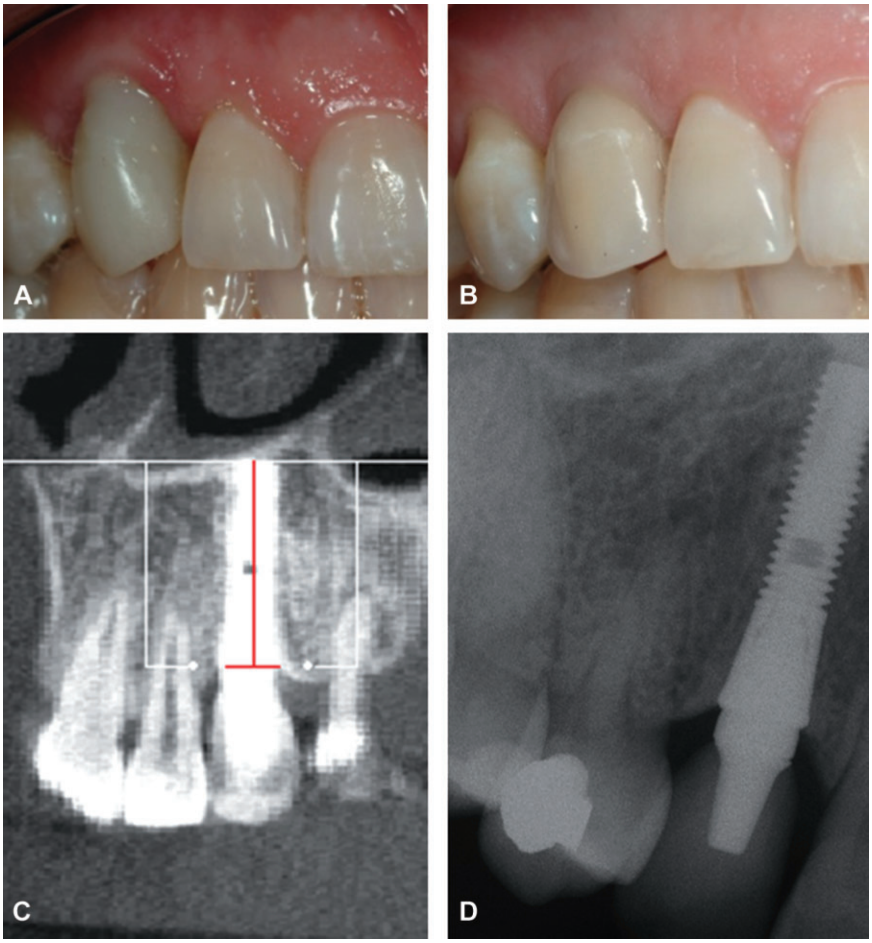

Figure 4 Clinical case of immediate implant therapy with pretreatment (A); final crown after 1 year (B); mesiodistal view of QT Quantitative Tomography conversion and measurement of both positions (C); and periapical radiograph after 1 year (D).

Table 2 and Figure 5. The mean circumferential bone level was 0.21 mm (SD 0.30, range 0.03–1.08) for IIT and 0.26 mm (SD 0.18, range 0.05–0.60) for CIT. The disparity was not significant ($p = .067$). In fact, only one of the eight positions showed a slight statistical significant difference between the treatment groups. With respect to within group differences, there were no significant differences between the eight individual positions for implants installed in extraction sockets ($p = .122$) or healed ridges ($p = .499$).

DISCUSSION

PA radiography is an accurate and reliable technique for evaluating peri-implant bone level;[1,29,30] however, it also has disadvantages including deformation, overlapping of anatomical structures, and focus problems reducing the image quality.[31] The incorrect angulation of the X-ray beam toward the implant can cause distortion and projection geometry problems.[32] To overcome this, care was taken to have the X-ray beam perpendicular to the implant and the film. Furthermore, to compensate for overlapping and focus problems of PA, the CBCT data from three sites per proximal surface were pooled and compared with the interproximal data of PA.

PA has the limitation that the marginal bone level can only be evaluated interproximally because of its two-dimensionality and as a result, information relating to the buccal and lingual or palatal site of the implant is lacking. CBCT provides three-dimensional images and consequently additional information in comparison with the two-dimensional PA radiographs. The possibility of measuring circumferential peri-implant bone level using CBCT is especially of interest if one wants to assess soft or hard tissue changes when immediate placement of implants or bone grafts are involved in the treatment. This understanding may lead to clinical guidelines to improve the aesthetic outcome after immediate implant placement. Additionally reentry procedures, to evaluate bone around implants, can be avoided. It was reported by Grimard and colleagues[9] that CBCT is a proper technique for assessing regenerative therapy outcomes, hereby obviating surgical reentry.

The present study has also the limitation that no CBCT three-dimensional scans were taken at baseline and no comparison can be made between baseline and 1 year of function. This was merely because of ethical reasons and because of the fact that the presurgical selection was also based on three-dimensional imaging with CBCT. In this case the as low as reasonably achievable[33] principle of radiation protection was applied. One should keep in mind that the radiation dose of CBCT is approximately five times lower than for a conventional CT[14–16] but equivalent to the dose of a full-mouth series of 18–22 PA and four to 15 times a standard dental panoramic radiograph. The effective dose of a panoramic radiography is varying from 2.7 to 23 micro-Sieverts (μSv), depending on the unit used.[14,34–42] In the present study, CBCT images were obtained with the Classic i-CAT® unit whereby the actual dose with a medium FOV (16 × 13 cm) is 69 μSv calculated according to the International Commission on Radiological Protection 2007 recommendations.[7,43] As a comparison, a roundtrip airplane flight from Paris to Tokyo exposes passengers to an effective dose of 139 μSv.[28,44,45] In the interest of the patient, the best balance "benefit image quality" versus "radiation dose" was applied.[46]

Several studies showed that the alveolar bone defects can be identified on CBCT and the measurement accuracy is high[9,10,47] with a measurement error of 1.4% compared with direct bone measurements on cadaver mandibles.[48] The voxel size resolution of the i-CAT® used for the present study was 0.2 mm. A recent study indicated that using a voxel size of 0.2 mm instead of 0.3 mm or higher gives a better resolution of the obtained images.[8] Ballrick and colleagues[49] showed that the CBCT machine (i-CAT) has clinically accurate measurements and an acceptable spatial resolution (i.e., the ability to separate two objects in close proximity in the image).

Based on the results of this study, CBCT does not seem to be an accurate method to evaluate marginal bone level around implants because bone level was on average 0.47 mm underestimated compared with PA. Only 42% of the sites showed agreement within 0.2 mm, which is rather low. A high range for PA data was

TABLE 1 Intra- and Interexaminer Reproducibility of the CBCT* Measurements

	CBCT(1) $n = 52$			CBCT(2) $n = 52$			Difference CBCT(1)/CBCT(2)			Wilcoxon signed ranks test	Spearman's correlation	% agreement within 0.2 mm
	Mean (mm)	SD	Range	Mean (mm)	SD	Range	Mean (mm)	SD	Range			
Intra	0.18	0.27	0.00–1.20	0.19	0.27	0.00–1.20	0.006	0.087	−0.20–0.20	$P = 0.579$	R = 0.945 ($p < 0.001$)	52/52 (100%)
Inter	0.18	0.27	0.00–1.20	0.25	0.43	0.00–2.40	0.063	0.333	−0.60–1.60	$P = 0.301$	R = 0.611 ($p < 0.001$)	43/52 (83%)

*Interproximal mesial and distal CBCT bone levels.
CBCT = cone beam computed tomography; Intra = intraexaminer; Inter = interexaminer; CBCT (1)/intra + inter = first measurement examiner one; CBCT (2)/intra = second measurement examiner one; CBCT (2)/inter = measurement examiner two; SD = standard deviation.

TABLE 2 Impact of Treatment Strategy on Bone Level after 1 Year Sorted for the Eight Locations on Cone Beam Computed Tomography

	Treatment Strategy						
	Immediate Implant Therapy (n = 12)			Conventional Implant Therapy (n = 14)			Mann–Whitney
Position	Mean (mm)	SD	Range	Mean (mm)	SD	Range	*U*- test *p* value
Buccal	0.16	0.21	0.00–0.60	0.20	0.22	0.00–0.80	0.595
Buccodistal	0.10	0.29	0.00–1.00	0.25	0.28	0.00–1.00	0.046*
Distal	0.10	0.23	0.00–0.80	0.23	0.34	0.00–1.20	0.193
Linguodistal	0.30	0.55	0.00–1.80	0.35	0.31	0.00–1.00	0.193
Lingual	0.35	0.55	0.00–1.40	0.27	0.31	0.00–0.80	0.820
Linguomesial	0.22	0.42	0.00–1.40	0.25	0.21	0.00–0.60	0.297
Mesial	0.17	0.30	0.00–1.00	0.22	0.19	0.00–0.60	0.252
Buccomesial	0.24	0.26	0.00–0.80	0.29	0.36	0.00–1.00	0.980
Circumferential	0.21	0.30	0.03–1.08	0.26	0.18	0.05–0.60	0.067

*Statistically significant difference between groups.
SD = standard deviation.

observed, which clearly surpassed the range that was found for CBCT data. This could be a reflection of true bone variation assuming that the PA evaluation was accurate. However, this observation could also reflect inaccuracy of PA radiographs for bone level evaluation.

The finding of the systematic underestimation of CBCT may also be a reflection of the difficulties encountered by the examiners in identifying the BIC on CBCT images. An in vivo study investigated the accuracy of CBCT compared with light microscopy with regard to the assessment of the cortical bone thickness adjacent to dental implants.[8] When thin cortical bone was present adjacent to dental implants, the resolution of the CBCT was insufficient in comparison with light microscopy. Especially in case of thin buccal bone, CBCT images were deemed unreliable, which is in line with a recent human study.[26] A recent mini pig study[50] investigated bone density measurements around implants on PA and CBCT compared with histology. No match was found between both radiographic techniques and histology. These observations may relate to the disturbed or impaired image quality by the presence of extremely dense structures (i.e., dental implants and amalgam fillings), which result in artifacts caused by beam hardening. When photons of an X-ray beam pass through an object with strong X-ray absorption such as the metal structures of dental implants, the low-energy photons are absorbed in preference to the higher energy photons, which results in beam-hardening artifacts in these areas.[51–57] To elucidate which method is closest to reality, one should undertake a reentry study. Feasibility of this approach was for ethical and aesthetical reasons not an option in the present study. Nevertheless, the hypothesis that the assessment of interproximal bone level on CBCT images is not inferior to periapical radiographs was rejected.

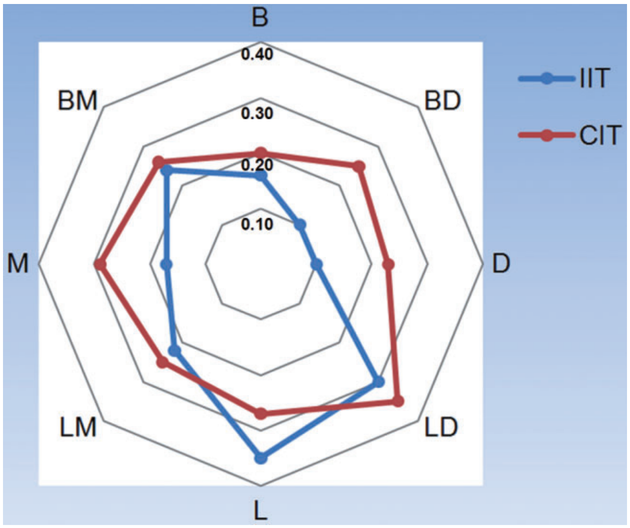

Figure 5 Web diagram of the mean circumferential bone level on cone beam CT after 1 year of loading per treatment strategy. CIT = conventional implant therapy; IIT = Immediate implant therapy; B = bucco; BM = buccomesial; BD = buccodistal; M = mesio; D = distal; LM = linguomesial; L = lingual; LD = linguodistal.

A limitation of the present study is the fact that the evaluation of PA radiographs was performed only once by one examiner while the CBCT images were interpreted by two examiners at different time points. A study by Gröndahl and colleagues[32] determined the intra- and interexaminer variability of PA in radiographic interproximal bone level assessment. Results showed a small interexaminer variation of 0.14 mm with the intraexaminer variation of 0.08 mm as its largest component. Furthermore, they found that the only variable with a significant effect in the intraexaminer variation was the number of radiographs of each fixture, which was confirmed in a study by Pikner.[58] They also concluded that the measurement reliability can be improved by letting one examiner or preferable more make several, independent readings. However, it was not the aim of the present study to evaluate the intra- and interexaminer agreement for PA but only for CBCT.

In contrast to the data on accuracy, CBCT showed acceptable precision (reproducibility) for the evaluation of marginal bone level with 100% of the sites showing an intraexaminer agreement within 0.2 mm and 83% interexaminer agreement with 0.006 and 0.063 mm, respectively, as maximum difference. Hence, it is worthwhile to compare the impact of the surgical treatment strategy on the circumferential peri-implant bone level, despite the uncertainty regarding the true measurements. For both treatments IIT and CIT, circumferential bone level after 1 year of function was preserved with a mean of 0.21 mm and 0.26 mm from the reference point, respectively. Hence, the second hypothesis of the study was withheld. The buccal bone level is close to the coronal site of the implant (see Figure 5), This may be related to the fact that the implants were positioned lingually leaving at least 2 mm buccal bone thickness.[59] Cardaropoli and colleagues[60] revealed that this safety zone is essential if one wants to avoid buccal bone dehiscence and consecutive soft tissue recessions. Keeping in mind that a buccal safety zone was observed, it may be hypothesized that the CBCT error of buccal and lingual sites are within acceptable range because remaining bone thickness is sufficient. This assumption is confirmed by the fact that no measurements were refuted in the analysis and the high reproducibility of the CBCT data. The preservation of the buccal bone further explains why the mean recession is limited to 0.12 mm (SD 0.78) after 1 year of function compared with baseline as reported previously.[27] The importance of the presence of the buccal bone at the implants and the impact on the aesthetic outcome was shown in a recent prospective study, which evaluated the three-dimensional marginal bone level around implants 5–15 years after loading.[61] There were significant correlations between the clinical parameters gingival recession and width of keratinized mucosa on the one hand and bone loss on the other hand.

Another limitation is the presence of artifacts on CBCT three-dimensional scans. However, new technologies appear in a very fast pace on the market, whereby high effort is made to improve and refine the hardware[54,56] and software.[54–56,62–65]

CONCLUSION

Periapical radiographs are still the standard technique to evaluate peri-implant bone levels and CBCT correlates poorly with interproximal bone level measured on PA. The reproducibility of CBCT is satisfying but hardware and/or software needs to be improved especially in the presence of image-distorting dense implants. Within the limitations of the study, there is an indication that the buccal bone level 1 year after implant therapy is evenly preserved when implants were immediately loaded in extraction sockets or in healed bone.

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CONFLICT OF INTEREST AND SOURCE OF FUNDING

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REFERENCES

1. De Smet E, Jacobs R, Gijbels F, Naert I. The accuracy and reliability of radiographic methods for the assessment of marginal bone level around oral implants. Dentomaxillofac Radiol 2002; 31:176–181.
2. Wakoh M, Harada T, Otonari T, et al. Reliability of linear distance measurement for dental implant length with standardized periapical radiographs. Bull Tokyo Dent Coll 2006; 47:105–115.
3. Adriaens PA, De Boever J, Vande Velde F. Comparison of intra-oral long-cone paralleling radiographic surveys and orthopantomographs with special reference to the bone height. J Oral Rehabil 1982; 9:355–365.

4. Albrektsson T, Isidor F. Consensus report of session IV. In: Lang NP, Karring T, eds. Proceedings of the 1st European Workshop on Periodontology. London, PA: Quintessence, 1993:365–369.
5. UNSCEAR. UNSCEAR 2008 report to the general assembly, with scientific annexes. *Sources of ionizing radiation United Nations Scientific Committee on the Effects of Atomic Radiation* 2008; I.
6. Little MP, Hoel DG, Molitor J, Boice JD, Wakeford R, Muirhead CR. New models for evaluation of radiation-induced lifetime cancer risk and its uncertainty employed in the UNSCEAR 2006 report. Radiat Res 2008; 169:660–676.
7. Ludlow JB, Davies-Ludlow LE, White SC. Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. J Am Dent Assoc 2008; 139:1237–1243.
8. Razavi T, Palmer RM, Davies J, Wilson R, Palmer PJ. Accuracy of measuring the cortical bone thickness adjacent to dental implants using cone beam computed tomography. Clin Oral Implants Res 2010; 21:718–725.
9. Grimard BA, Hoidal MJ, Mills MP, Mellonig JT, Nummikoski PV, Mealey BL. Comparison of clinical, periapical radiograph, and cone-beam volume tomography measurement techniques for assessing bone level changes following regenerative periodontal therapy. J Periodontol 2009; 80:48–55.
10. Misch KA, Yi ES, Sarment DP. Accuracy of cone beam computed tomography for periodontal defect measurements. J Periodontol 2006; 77:1261–1266.
11. Noujeim M, Prihoda T, Langlais R, Nummikoski P. Evaluation of high-resolution cone beam computed tomography in the detection of simulated interradicular bone lesions. Dentomaxillofac Radiol 2009; 38:156–162.
12. Vandenberghe B, Jacobs R, Yang J. Diagnostic validity (or acuity) of 2D CCD versus 3D CBCT-images for assessing periodontal breakdown. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007; 104:395–401.
13. Roberts JA, Drage NA, Davies J, Thomas DW. Effective dose from cone beam CT examinations in dentistry. Br J Radiol 2009; 82:35–40.
14. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac Radiol 2006; 35:219–226.
15. Chau AC, Fung K. Comparison of radiation dose for implant imaging using conventional spiral tomography, computed tomography, and cone-beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009; 107:559–565.
16. Kau CH, Bozic M, English J, Lee R, Bussa H, Ellis RK. Cone-beam computed tomography of the maxillofacial region – an update. Int J Med Robot 2009; 5:366–380.
17. Arisan V, Karabuda CZ, Ozdemir T. Implant surgery using bone- and mucosa-supported stereolithographic guides in totally edentulous jaws: surgical and post-operative outcomes of computer-aided vs. standard techniques. Clin Oral Implants Res 2010; 21:980–988.
18. Arisan V, Karabuda ZC, Ozdemir T. Accuracy of two stereolithographic guide systems for computer-aided implant placement: a computed tomography-based clinical comparative study. J Periodontol 2010; 81:43–51.
19. Lofthag-Hansen S, Grondahl K, Ekestubbe A. Cone-beam CT for preoperative implant planning in the posterior mandible: visibility of anatomic landmarks. Clin Implant Dent Relat Res 2009; 11:246–255.
20. Chan HL, Misch K, Wang HL. Dental imaging in implant treatment planning. Implant Dent 2010; 19:288–298.
21. Van de Velde T, Sennerby L, De Bruyn H. The clinical and radiographic outcome of implants placed in the posterior maxilla with a guided flapless approach and immediately restored with a provisional rehabilitation: a randomized clinical trial. Clin Oral Implants Res 2010; 21:1223–1233.
22. D'Haese J, Van De Velde T, Komiyama A, Hultin M, De Bruyn H. Accuracy and complications using computer-designed stereolithographic surgical guides for oral rehabilitation by means of dental implants: a review of the literature. Clin Implant Dent Relat Res 2010. DOI: 10.1111/j.1708-8208.2010.00275.x [Epub ahead of print].
23. Januario AL, Duarte WR, Barriviera M, Mesti JC, Araujo MG, Lindhe J. Dimension of the facial bone wall in the anterior maxilla: a cone-beam computed tomography study. Clin Oral Implants Res 2011. DOI: 10.1111/j.1600-0501.2010.02086.x [Epub ahead of print].
24. Braut V, Bornstein MM, Belser U, Buser D. Thickness of the anterior maxillary facial bone wall-a retrospective radiographic study using cone beam computed tomography. Int J Periodontics Restorative Dent 2011; 31:125–131.
25. Nowzari H, Molayem S, Chiu CH, Rich SK. Cone beam computed tomographic measurement of maxillary central incisors to determine prevalence of facial alveolar bone width >/=2 mm. Clin Implant Dent Relat Res 2010. DOI: 10.1111/j.1708-8208.2010.00287.x [Epub ahead of print].
26. Naitoh M, Nabeshima H, Hayashi H, Nakayama T, Kurita K, Ariji E. Postoperative assessment of incisor dental implants using cone-beam computed tomography. J Oral Implantol 2010; 36:377–384.
27. Raes F, Cosyn J, Crommelinck E, Coessens P, De Bruyn H. Immediate and conventional single implant treatment in the anterior maxilla: one-year results of a case series on hard and soft tissue response and aesthetics. J Clin Periodontol 2011; 38:385–394.
28. Palomo JM, Kau CH, Palomo LB, Hans MG. Three-dimensional cone beam computerized tomography in dentistry. Dent Today 2006; 25:132–135.

29. Benn DK. Estimating the validity of radiographic measurements of marginal bone height changes around osseointegrated implants. Implant Dent 1992; 1:79–83.
30. Benn DK. A review of the reliability of radiographic measurements in estimating alveolar bone changes. J Clin Periodontol 1990; 17:14–21.
31. Mengel R, Candir M, Shiratori K, Flores-de-Jacoby L. Digital volume tomography in the diagnosis of periodontal defects: an in vitro study on native pig and human mandibles. J Periodontol 2005; 76:665–673.
32. Gröndahl K, Sunden S, Gröndahl HG. Inter- and intraobserver variability in radiographic bone level assessment at Branemark fixtures. Clin Oral Implants Res 1998; 9:243–250.
33. ICRP. Radiation dose to patients from radiopharmaceuticals. Addendum 3 to ICRP publication 53. ICRP publication 106. Approved by the commission in October 2007. Ann ICRP 2008; 38:1–197.
34. Gibbs SJ. Effective dose equivalent and effective dose: comparison for common projections in oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000; 90:538–545.
35. White SC. 1992 assessment of radiation risk from dental radiography. Dentomaxillofac Radiol 1992; 21:118–126.
36. Scarfe WC, Farman AG, Levin MD, Gane D. Essentials of maxillofacial cone beam computed tomography. Alpha Omegan 2010; 103:62–67.
37. Carrafiello G, Dizonno M, Colli V, et al. Comparative study of jaws with multislice computed tomography and cone-beam computed tomography. Radiol Med (Torino) 2010; 115:600–611.
38. Koong B. Cone beam imaging: is this the ultimate imaging modality? Clin Oral Implants Res 2010; 21:1201–1208.
39. Okano T, Matsuo A, Gotoh K, et al. [Estimation of effective dose to salivary glands at examination of the oral and maxillofacial region]. Nippon Hoshasen Gijutsu Gakkai Zasshi 2009; 65:594–602.
40. Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. Am J Orthod Dentofacial Orthop 2008; 133:640.e1–640.e5.
41. Palomo JM, Rao PS, Hans MG. Influence of CBCT exposure conditions on radiation dose. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 105:773–782.
42. Garcia Silva MA, Wolf U, Heinicke F, Grundler K, Visser H, Hirsch E. Effective dosages for recording Veraviewepocs dental panoramic images: analog film, digital, and panoramic scout for CBCT. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 106:571–577.
43. ICRP. The 2007 recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007; 37:1–332.
44. Bagshaw M. Cosmic radiation in commercial aviation. Travel Med Infect Dis 2008; 6:125–127.
45. Beck P, Bottollier JF, Reitz G, Ruhm W, Wissmann F. Cosmic radiation and aircrew exposure. Radiat Prot Dosimetry 2009; 136:231.
46. Loubele M, Jacobs R, Maes F, et al. Image quality vs radiation dose of four cone beam computed tomography scanners. Dentomaxillofac Radiol 2008; 37:309–318.
47. Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac Radiol 2006; 35:410–416.
48. Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A. Accuracy in measurement of distance using limited cone-beam computerized tomography. Int J Oral Maxillofac Implants 2004; 19:228–231.
49. Ballrick JW, Palomo JM, Ruch E, Amberman BD, Hans MG. Image distortion and spatial resolution of a commercially available cone-beam computed tomography machine. Am J Orthod Dentofacial Orthop 2008; 134:573–582.
50. Dos Santos Corpas L, Jacobs R, Quirynen M, Huang Y, Naert I, Duyck J. Peri-implant bone tissue assessment by comparing the outcome of intra-oral radiograph and cone beam computed tomography analyses to the histological standard. Clin Oral Implants Res 2010; 22(5):492–499.
51. Draenert FG, Coppenrath E, Herzog P, Muller S, Mueller-Lisse UG. Beam hardening artefacts occur in dental implant scans with the NewTom cone beam CT but not with the dental 4-row multidetector CT. Dentomaxillofac Radiol 2007; 36:198–203.
52. Lee DW, Choi YS, Park KH, Kim CS, Moon IS. Effect of microthread on the maintenance of marginal bone level: a 3-year prospective study. Clin Oral Implants Res 2007; 18:465–470.
53. Katsumata A, Hirukawa A, Noujeim M, et al. Image artifact in dental cone-beam CT. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006; 101:652–657.
54. Kovacs M, Fejerdy P, Dobo NC. Metal artefact on head and neck cone-beam CT images. Fogorv Sz 2008; 101:171–178.
55. Reitz I, Hesse BM, Nill S, Tucking T, Oelfke U. Enhancement of image quality with a fast iterative scatter and beam hardening correction method for kV CBCT. Z Med Phys 2009; 19:158–172.
56. Schulze RK, Berndt D, d'Hoedt B. On cone-beam computed tomography artifacts induced by titanium implants. Clin Oral Implants Res 2009; 21:100–107.
57. Siewerdsen JH, Jaffray DA. Cone-beam computed tomography with a flat-panel imager: magnitude and effects of x-ray scatter. Med Phys 2001; 28:220–231.
58. Pikner SS. Radiographic follow-up analysis of Branemark dental implants. Swed Dent J Suppl 2008; 194:5–69, 2.
59. Tomasi C, Sanz M, Cecchinato D, et al. Bone dimensional variations at implants placed in fresh extraction sockets: a multilevel multivariate analysis. Clin Oral Implants Res 2010; 21:30–36.

60. Cardaropoli G, Lekholm U, Wennström JL. Tissue alterations at implant-supported single-tooth replacements: a 1-year prospective clinical study. Clin Oral Implants Res 2006; 17:165–171.
61. Kehl M, Swierkot K, Mengel R. Three-dimensional measurement of bone loss at implants in patients with periodontal disease. J Periodontol 2010; 82(5):689–699.
62. Maltz JS, Gangadharan B, Bose S, et al. Algorithm for X-ray scatter, beam-hardening, and beam profile correction in diagnostic (kilovoltage) and treatment (megavoltage) cone beam CT. IEEE Trans Med Imaging 2008; 27:1791–1810.
63. Malusek A, Seger MM, Sandborg M, Alm Carlsson G. Effect of scatter on reconstructed image quality in cone beam computed tomography: evaluation of a scatter-reduction optimisation function. Radiat Prot Dosimetry 2005; 114: 337–340.
64. Zhang Y, Zhang L, Zhu XR, Lee AK, Chambers M, Dong L. Reducing metal artifacts in cone-beam CT images by preprocessing projection data. Int J Radiat Oncol Biol Phys 2007; 67:924–932.
65. Leng S, Zambelli J, Tolakanahalli R, et al. Streaking artifacts reduction in four-dimensional cone-beam computed tomography. Med Phys 2008; 35:4649–4659.