Accuracy of vertical height measurements on direct digital panoramic radiographs using posterior mandibular implants and metal balls as reference objects

Vazquez, Lydia; Nizamaldin, Y; Combescure, Christophe; Nedir, Rabah; Bischof, Mark; Dohan Ehrenfest, DM; Carrel, Jean-Pierre; Belser, Urs Christophe

How to cite

VAZQUEZ, Lydia et al. Accuracy of vertical height measurements on direct digital panoramic radiographs using posterior mandibular implants and metal balls as reference objects. In: Dento-maxillo-facial radiology, 2013, vol. 42, p. 20110429. doi: 10.1259/dmfr.20110429

This publication URL: https://archive-ouverte.unige.ch/unige:42278
Publication DOI: 10.1259/dmfr.20110429

Dentomaxillofacial Radiology (2013) 42, 20110429

http://dmfr.birjournals.org

RESEARCH

Accuracy of vertical height measurements on direct digital panoramic radiographs using posterior mandibular implants and metal balls as reference objects

L Vazquez*[,1], Y Nizamaldin[1], C Combescure[2], R Nedir[3], M Bischof[3], DM Dohan Ehrenfest[1], J-P Carrel[1] and UC Belser[4]

[1]Department of Oral Surgery, Oral Medicine and Dentomaxillofacial Radiology, School of Dental Medicine, University of Geneva, Geneva, Switzerland; [2]Division of Clinical Epidemiology, Geneva University Hospital, Geneva, Switzerland; [3]Swiss Dental Clinics Group, Ardentis Clinique Dentaire, Vevey, Switzerland; [4]Department of Fixed Prosthodontics and Occlusion, School of Dental Medicine, University of Geneva, Geneva, Switzerland

Objectives: Conventional panoramic radiography, a widely used radiographic examination tool in implant treatment planning, allows evaluation of the available bone height before inserting posterior mandibular implants. Image distortion and vertical magnification due to projection geometry is well described for rotational panoramic radiographs. To assess the accuracy of vertical height measurements on direct digital panoramic radiographs, implants and metal balls positioned in the posterior mandible were used as radio-opaque reference objects. The reproducibility of the measuring method was assessed by the inter- and intraobserver agreements.
Methods: Direct digital panoramic radiographs, performed using a Kodak 8000C (Eastman Kodak Company, Rochester, NY), of 17 partially edentulous patients (10 females, 7 males, mean age 65 years) were selected from an X-ray database gathered during routine clinical evaluation of implant sites. Proprietary software and a mouse-driven calliper were used to measure the radiological length of 25 implants and 18 metal reference balls, positioned in mandibular posterior segments. The distortion ratio (DR) was calculated by dividing the radiological implant length by the implant's real length and the radiological ball height by the ball's real height.
Results: Mean vertical DR was 0.99 for implants and 0.97 for balls, and was unrelated to mandibular sites, side, age, gender or observer. Inter- and intraobserver agreements were acceptable for both reference objects.
Conclusions: Vertical measurements had acceptable accuracy and reproducibility when a software-based calibrated measurement tool was used, confirming that digital panoramic radiography can be reliably utilized to determine the pre-operative implant length in premolar and molar mandibular segments.
Dentomaxillofacial Radiology (2013) **42,** 20110429. doi: 10.1259/dmfr.20110429

Cite this article as: Vazquez L, Nizamaldin Y, Combescure C, Nedir R, Bischof M, Dohan Ehrenfest DM, et al. Accuracy of vertical height measurements on direct digital panoramic radiographs using posterior mandibular implants and metal balls as reference objects. *Dentomaxillofac Radiol* 2013; **42:** 20110429.

Keywords: digital dental radiography; panoramic radiography; dental implant; radiographic magnification

*Correspondence to: Dr Lydia Vazquez, Department of Oral Surgery, Oral Medicine and Dentomaxillofacial Radiology, School of Dental Medicine, University of Geneva, Rue Barthelemy-Menn 19, 1205 Geneva, Switzerland. E-mail: lydia.vazquez@unige.ch
Received 16 December 2011; revised 30 April 2012; accepted 2 May 2012

Introduction

Panoramic radiographs are a widely used standard radiographic examination tool when planning an implant treatment because they are accessible and impart a low radiation dose, while providing the best radiographic survey.[1–5] Furthermore, panoramic radiographs have been reported to be sufficiently reliable to evaluate the available bone height before inserting posterior mandibular implants.[4–6]

Image distortion, due to variations in the degree of magnification in the horizontal and vertical planes, is well described for conventional film-based panoramic radiography.[7–11] As direct digital panoramic machines are not significantly different from conventional panoramic units, the degree of vertical magnification due to projection geometry is similar for digital and conventional rotational panoramic radiographs. Owing to varying magnification, reference objects with known dimensions are required to determine the exact magnification in a particular area.[3,5,9,12–14] On conventional panoramic radiographs, dental implants of known length are easily measured with a sliding calliper to determine the unit's magnification factor.[5] In digital panoramic radiography, magnification can be adjusted with a reference ball calibration method that allows 1:1 image visualization on the screen and the use of software-based measurement tools.[14] With careful radiographic examination, an implant's appropriate length for the intended site can be selected.[14,15] Few studies report on the measurement accuracy and on the distortion or magnification of digital panoramic radiography,[14,16–19] and none, to our knowledge, describes the impact of measurement accuracy on the pre-operative bone height evaluation prior to implant placement in the posterior mandible.

This study aims to assess the accuracy of the vertical height measurement on *post*-operative digital panoramic radiographs using implants in the posterior segment of the mandible as intrabony radio-opaque objects. The vertical distortion obtained from measured implants was compared with the vertical distortion obtained from measured metal balls used as standard extrabony reference objects on *pre*-operative digital panoramic radiographs. The reproducibility of the measuring method was analysed by the inter- and intraobserver agreements. Our hypothesis was that digital panoramic radiographs are sufficiently accurate and reliable to evaluate the available bone height above the mandibular canal.

Materials and methods

Patient and radiograph selection

The patients were selected from the custom FileMaker Pro (FileMaker Inc., Santa Clara, CA) software database used to store dental implant records at the Swiss Dental Clinics Group (Vevey, Switzerland). To optimize the analysis and to limit measurement mistakes, only one implant model and length was included: 10 mm long standard diameter solid screw Straumann® implants (Straumann AG, Basel, Switzerland) inserted in the posterior mandible. From this group, only digital post-operative panoramic radiographs with 10 mm long implants and a small 1.5 mm high healing cap were selected (Figure 1). Finally, only pre-operative X-rays, taken with a 5 mm diameter metal ball (fixed with wax to the site intended for implant placement), and post-operative panoramic radiographs with posterior mandibular implants (that matched the pre-operative metal ball sites) were included in the study. Panoramic radiographic examinations were performed with a digital panoramic unit (Kodak 8000C; Eastman Kodak Company, Rochester, NY), either by a dental assistant or a dentist, under everyday clinical conditions. The radiographs were taken according to the manufacturer's specified position for the patient's head, but did not follow a strict, standardized protocol to ensure the patient's precise head position before exposure.

The selection process yielded a total of 25 implants, positioned in the posterior segments of the mandible, of 17 partially edentulous patients (10 females, 7 males; ages 40–84 years, mean age 65 years). 9 (36%) implants were inserted in the premolar region and 16 (64%) in the molar region. 15 implants (60%) were located in the left posterior segment of the mandible and 10 on the right side. 11 subjects had a single implant, 5 had 2 implants and 1 had 4 implants. A total of 18 metal balls (10/17 patients) were measured on their matching pre-operative panoramic radiographs. Three patients had pre-operative panoramic bone height evaluated with a single reference ball and more than one implant

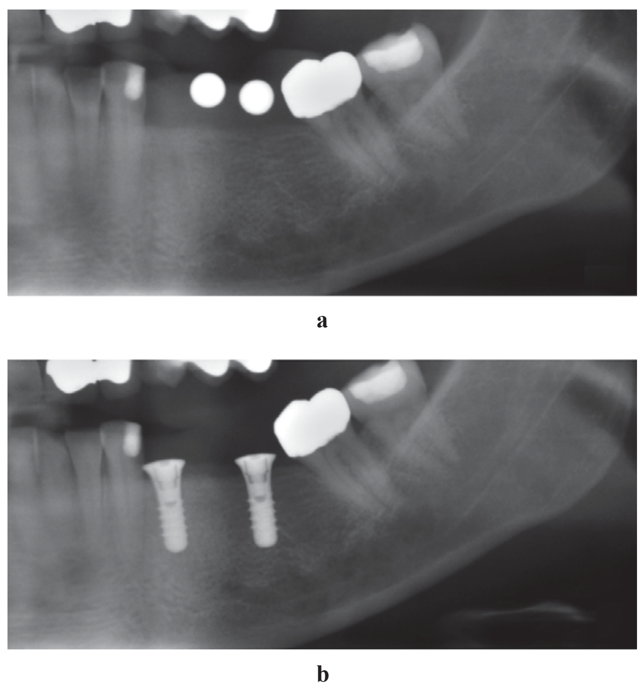

Figure 1 (a) Detail of a pre-operative panoramic radiograph shows two 5 mm diameter reference metal balls in the sites of a second premolar and a first mandibular molar. (b) Post-operative panoramic radiograph of the same patient shows two 10 mm long implants with small 1.5 mm high healing caps. To avoid risk of injury to the mandibular canal, the surgeon inserted an implant in the site of a first premolar and a first molar

inserted in neighbouring sites, six patients had two reference balls and one had three reference balls. 11 (61.1%) reference balls were on the left side and 8 (44.4%) were on molar sites.

The digital panoramic radiographs for this retrospective study were selected from an X-ray database gathered in the course of routine clinical pre-operative and post-operative evaluation of implant sites. No X-rays were taken for the purposes of this study. All radiographs were analysed under standard conditions by one trained oral surgeon experienced in interpreting panoramic radiographs and one observer beginning his training in oral surgery and dentomaxillofacial radiology. Observers had access only to patients' gender and date of birth. Measurements of the metal balls on the pre-operative radiographs, as well as measurements of the implants on the post-operative panoramic radiographs, were done twice at random, 1 week apart, by two independent observers.

Radiological implant and ball length evaluation

In accordance with the manufacturer's instructions, the magnification of digital images was manually scaled with a 5 mm diameter metal ball calibration method when the Kodak 8000C panoramic unit was installed: the computer then automatically generated 1:1 images on the screen. Both observers were calibrated to the measuring technique on the Kodak 8000C proprietary measurement software by measuring, with a mouse-driven calliper, the radiological height of a 5 mm diameter metal ball on a pre-operative panoramic radiograph five times consecutively. On a post-operative radiograph, they defined and agreed upon the upper limit of the healing cap and the most apical point to be measured on a 10 mm long implant, and repeated the vertical measurement of the implant length five times consecutively. The vertical measurements were done along the edge of the implants to obtain the true length of the projected implants as shown by Schulze and d'Hoedt.[20] After the calibration phase, both observers performed a vertical linear measurement of the radiological length of the 25 implants positioned in the premolar and molar mandibular sites. They also used the panoramic unit's software to measure the vertical distance from the topmost to the bottommost margins of the metal balls on the pre-operative digital images.

Statistical analyses

The distortion ratio (DR) was calculated for each implant as follows: radiological implant length/real implant length. The real length of the selected 10 mm long standard Straumann implants, measured from the implant's apex to the top of the small healing cap, is 14.3 mm (a 10 mm long endosseous rough surface, a 2.8 mm long smooth "machined" implant neck, a 1.5 mm high healing cap). As image magnification of the digital panoramic radiographs had been adjusted with a ball calibration, we chose to call this calculated ratio a DR (rather than a magnification factor) as we believe this better describes the distortion of the 1:1 adjusted images. The metal ball DR (radiological ball height/5.0 mm) was calculated for each reference ball in the premolar and molar mandibular sites.

The implant and ball DRs were described for each observer and each measurement session using the mean, the standard deviation, the median, and the minimum and maximum values. The distribution of the DRs was represented by box plots. The impact of covariates (patient age and gender, molar or premolar site, right or left side) on the DRs was also investigated. For each observer and each measurement session, the DRs in subgroups were described (for categorical covariates), and a multivariate linear regression model with all covariates was applied and adjusted for each session and each observer. To account for the repeated measurements, a generalized estimating equation linear model with a non-structured working matrix was used. A Bland–Altman analysis analysed the inter- and intra-observer agreements. With a Wilcoxon test for paired data, the absolute error of the implant length measurement was compared with the absolute error of the matching reference ball measurement. The significance level was set at $p = 0.05$ and the statistical analyses were done using S-PLUS 8.0 (Insightful Corp, Seattle, WA).

Results

Accuracy of the implant measurements

The minimum and maximum radiological implant lengths were 13.6 mm and 14.5 mm for Observer 1, and 13.8 mm and 14.3 mm for Observer 2, respectively. The mean radiological implant length was 14.1 mm for each series of measurements, repeated 1 week apart, with the following standard deviations: 0.2 mm for Observer 1 (both sessions) and 0.1 mm for Observer 2 (both sessions). The values of the calculated implant DR ranged from 0.951 to 1.014. For any session and any observer, the means and medians were between 0.98 and 0.99. Details are given in Table 1 and the distribution of the implant DRs is shown in box plots in Figure 2. The distribution of the implant DRs in subgroups is described in Table 2.

Associations between the implant DR and age, gender, molar/premolar site, and the side, adjusted for observers and sessions, were assessed in a multivariate model. The session ($p = 0.26$), age ($p = 0.92$), gender ($p = 0.84$), and the side ($p = 0.10$) were not significantly associated with the implant DR. The DR was significantly lower in premolars than in molars ($p = 0.03$), but the mean difference between the molar DR and the premolar DR was only 0.009, representing 0.9% of the implant's length (0.1 mm), which is clinically insignificant. The observer, however, was significantly associated ($p = 0.03$): Observer 2 had lower DR than

Table 1 Implant DRs and ball DRs

	Implant DRs		*Ball DRs*	
Obs and MS	*Mean (SD)*	*Median (min;max)*	*Mean (SD)*	*Median (min;max)*
Obs1MS1	0.988 (0.011)	0.986 (0.965;1.007)	0.963 (0.034)	0.960 (0.900;1.020)
Obs1MS2	0.987 (0.016)	0.986 (0.951;1.014)	0.970 (0.030)	0.970 (0.900;1.020)
Obs2MS1	0.984 (0.010)	0.986 (0.965;1.000)	0.966 (0.023)	0.960 (0.940;1.000)
Obs2MS2	0.983 (0.008)	0.986 (0.965;1.000)	0.970 (0.020)	0.960 (0.940;1.000)

DRs, distortion ratios; min, minimum; max, maximum; MS, measurement session; Obs, observer; SD, standard deviation.

Observer 1. The mean difference between observers was 0.004, or 0.4% of the implant's length (less than 0.1 mm), which is clinically insignificant. The Bland–Altman analysis (Figure 3) showed acceptable inter- and intraobserver agreements: the differences between both observers and both sessions were close to zero and the limits of agreement were (−0.026;0.029) for Observer 1, (−0.011;0.013) for Observer 2, (−0.014; 0.022) for Session 1 and (−0.028;0.036) for Session 2. The largest difference between observers (Session 2) was 0.04, representing 4% (or 0.5 mm) of the implant length.

Accuracy of the reference ball measurements

The minimum and maximum radiological reference ball heights were 4.5 mm and 5.1 mm for Observer 1, and 4.5 mm and 5.0 mm for Observer 2, respectively. The mean ball height for each series of measurements, repeated 1 week apart, was for Observer 1: 4.8 ± 0.2 mm and 4.9 ± 0.2 mm (Sessions 1 and 2, respectively) and, for Observer 2, 4.8 ± 0.1 mm and 4.9 ± 0.1mm (Sessions 1 and 2, respectively). The values of the ball DR ranged from 0.900 to 1.000. For any session and any observer, the means and medians were between 0.960 and 0.970. Details are given in Table 1 and the

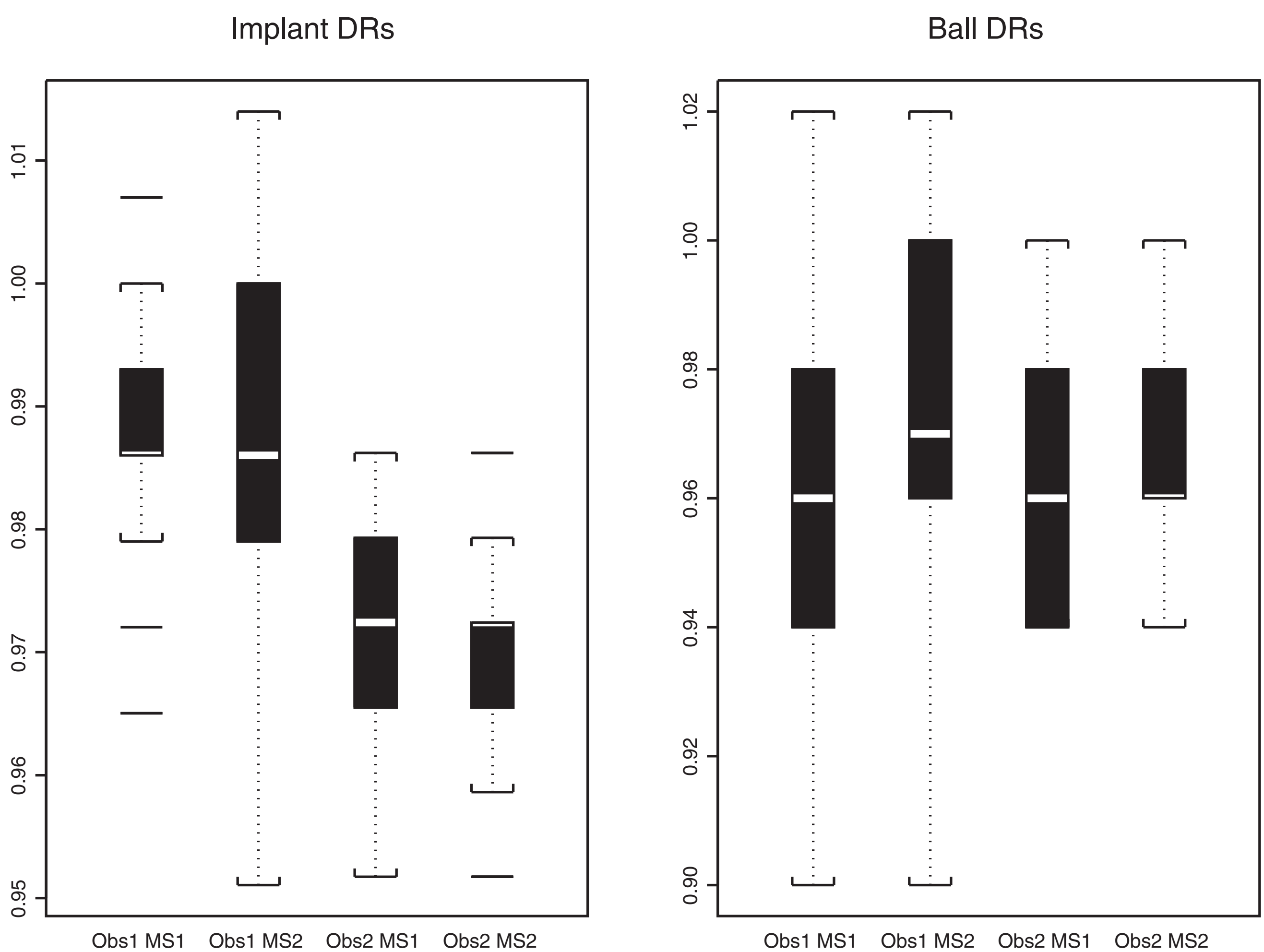

Figure 2 Distribution of the distortion ratios for the implants and balls: the white horizontal line represents the median, the black rectangle the interquartile range, and the lower and upper limits are the minima and maxima, respectively. DRs, distortion ratios; Obs, observer; MS, measurement session

Table 2 Covariates and the implant and ball DRs

Parameters			*Obs1MS1*		*Obs1MS2*		*Obs2MS1*		*Obs2MS2*	
			Mean (SD)	*Median (range)*	*Mean (SD)*	*Median (range)*	*Mean (SD)*	*Median (range)*	*Mean (SD)*	*Median (range)*
Implants	Gender	Male	0.986 (0.013)	0.986 (0.965;1.007)	0.986 (0.019)	0.986 (0.951;1.014)	0.983 (0.011)	0.979 (0.965;1.000)	0.983 (0.010)	0.986 (0.965;1.000)
		Female	0.991 (0.008)	0.986 (0.979;1.007)	0.987 (0.014)	0.986 (0.965;1.014)	0.985 (0.008)	0.986 (0.965;0.993)	0.983 (0.007)	0.986 (0.965;0.993)
	Site	Molars	0.991 (0.009)	0.993 (0.972;1.007)	0.992 (0.012)	0.990 (0.965;1.014)	0.986 (0.009)	0.986 (0.965;1.000)	0.983 (0.007)	0.986 (0.965;1.000)
		Premolars	0.983 (0.013)	0.986 (0.965;1.007)	0.977 (0.018)	0.979 (0.951;1.000)	0.981 (0.010)	0.979 (0.965;0.993)	0.983 (0.011)	0.986 (0.965;1.000)
	Side	Right	0.983 (0.009)	0.986 (0.965;0.993)	0.983 (0.017)	0.986 (0.951;1.000)	0.980 (0.011)	0.979 (0.965;1.000)	0.981 (0.010)	0.983 (0.965;1.000)
		Left	0.992 (0.011)	0.993 (0.965;1.007)	0.989 (0.016)	0.986 (0.958;1.014)	0.987 (0.008)	0.986 (0.972;1.000)	0.984 (0.007)	0.986 (0.972;1.000)
Balls	Gender	Male	0.957 (0.037)	0.940 (0.920;1.020)	0.963 (0.029)	0.970 (0.920;1.000)	0.970 (0.017)	0.960 (0.960;1.000)	0.970 (0.017)	0.960 (0.960;1.000)
		Female	0.967 (0.034)	0.960 (0.900;1.020)	0.973 (0.031)	0.970 (0.900;1.000)	0.963 (0.025)	0.960 (0.940;1.000)	0.970 (0.022)	0.960 (0.940;1.000)
	Site	Molars	0.978 (0.035)	0.980 (0.940;1.020)	0.969 (0.033)	0.980 (0.920;1.000)	0.971 (0.027)	0.980 (0.940;1.000)	0.976 (0.022)	0.980 (0.940;1.000)
		Premolars	0.930 (0.026)	0.930 (0.900;0.960)	0.970 (0.042)	0.970 (0.920;1.020)	0.955 (0.010)	0.960 (0.940;0.960)	0.965 (0.025)	0.960 (0.940;1.000)
	Side	Right	0.968 (0.044)	0.980 (0.900;1.020)	0.976 (0.017)	0.980 (0.960;1.000)	0.960 (0.028)	0.940 (0.940;1.000)	0.964 (0.026)	0.960 (0.940;1.000)
		Left	0.960 (0.039)	0.940 (0.920;1.020)	0.965 (0.042)	0.970 (0.900;1.020)	0.970 (0.021)	0.960 (0.940;1.000)	0.978 (0.020)	0.970 (0.960;1.000)

DRs, distortion ratios; MS, measurement session; Obs, observer; SD, standard deviation.

distribution of the reference ball DRs is shown in box plots in Figure 2. The distribution of the ball DRs in subgroups is described in Table 2.

Associations between the ball DR and age, gender, molar/premolar site, and the jaw side, adjusted for observers and sessions, were assessed in a multivariate model. Observer ($p = 0.73$), session ($p = 0.09$), age ($p = 0.95$), gender ($p = 0.51$), site ($p = 0.90$) and jaw side ($p = 0.75$) were not significantly associated with the ball DR. The Bland–Altman analysis (Figure 4) showed acceptable inter- and intraobserver agreements: the differences between both observers and both sessions were close to zero and the limits of agreement were (−0.074;0.061) for Observer 1, (−0.030;0.021) for Observer 2, (−0.065;0.061) for Session 1 and (−0.069;0.069) for Session 2. The largest difference between both sessions (Observer 1) was 0.074, representing 7.4% (or 0.4 mm) of the vertical ball height, which was similar to the implant's maximal agreement (0.5 mm).

Implant absolute error vs *ball absolute error*

Each patient's implant measurements and reference ball measurements were matched with the site (molar/premolar) and the jaw side (left/right). For each session and observer, the absolute error in the measurements of the implants and the balls was assessed. The means and medians of the absolute error for both reference objects, and differences in the absolute error between matched pairs of implants and balls ($n = 13$ pairs of implants/balls), are shown in Table 3. The absolute error between implant length measurements and reference ball measurements was significantly different for Observer 2 at Session 2 ($p = 0.005$).

Discussion

Panoramic radiography is a quick, simple, low-cost and low-dose diagnostic tool.[4] It is widely used as a standard radiographic examination tool in implant treatment,[1–4] and allows evaluation of the available bone height before inserting posterior mandibular implants.[4–6] Taking into account the panoramic unit's magnification factor,[5] and in accordance with the recommendations for implants placed above the inferior alveolar nerve, a safety margin of at least 2 mm between the implant's tip and the mandibular canal is recommended.[4,21] The effective doses of digital panoramic radiographs—calculated according to the International Commission on Radiological Protection 2007 standards (hereafter ICRP 2007), which include weighting of salivary glands—range from 14.2 μSv to 24.3 μSv.[22]

Three-dimensional imaging assesses not only the bone height at the implant site but also the bone thickness. Due to relatively large radiation doses ranging from 474 μSv to 1160 μSv[23] (ICRP 2007), dentomaxillofacial CT is rarely justified for pre-implant

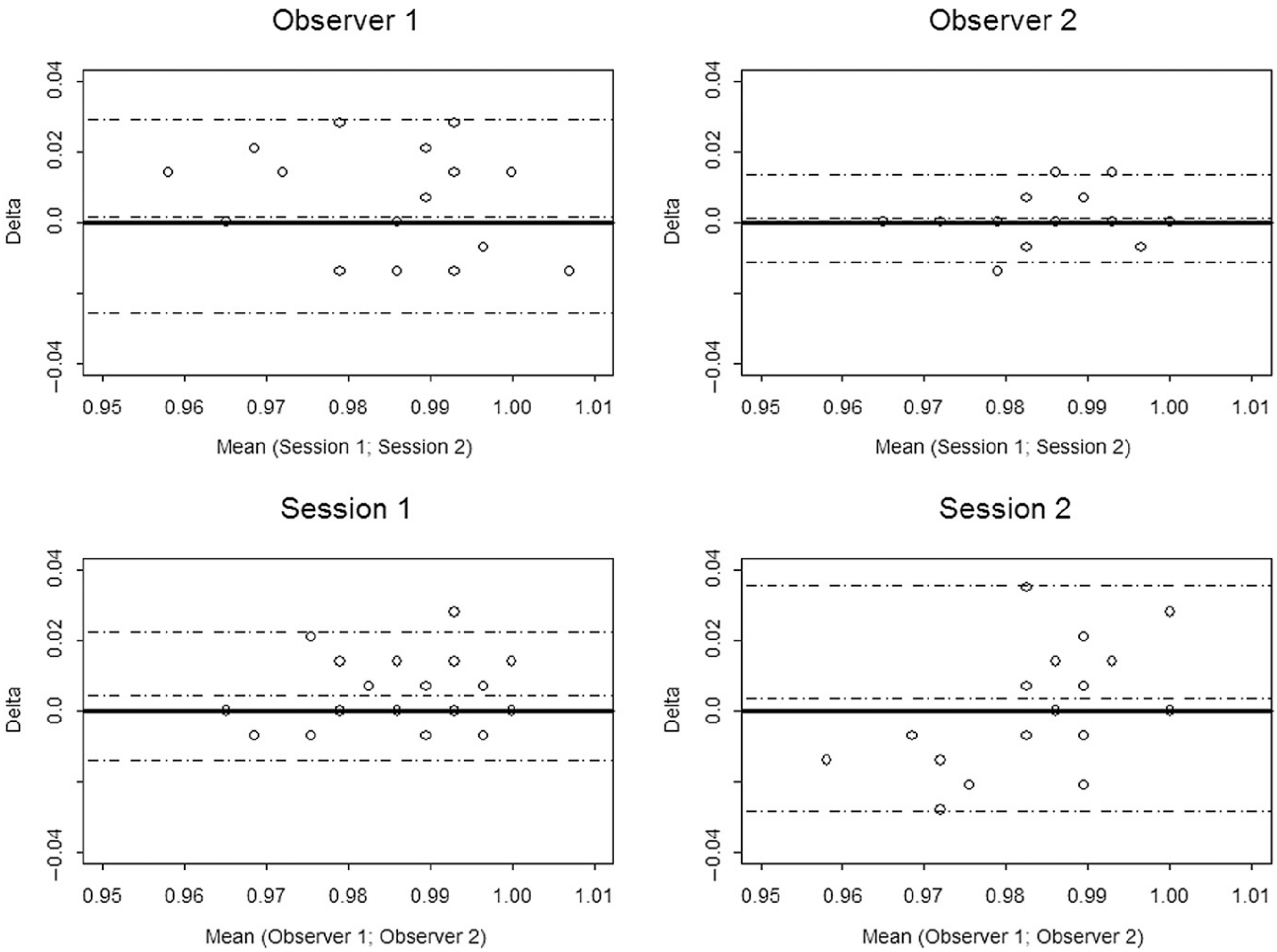

Figure 3 Bland–Altman analysis showing the inter- and intraobserver agreements for the implant distortion ratios

imaging of small edentulous segments.[2,24–26] Cone-beam CT (CBCT) is considered to give less radiation dose than CT, although a wide range of values have been reported; CBCT effective doses range from 13 μSv to 82 μSv[23] (ICRP 2007), and from 27 μSv to 674 μSv[27] (ICRP 2008). CBCT generates reformatted images of panoramic and cross-sectional views of the jaws in real size (1:1).[26,28] But linear measurements on CBCT images differed from linear measurements on dry skulls, cadaver mandibles and geometric objects,[29–31] and thickness measurements of various anatomical sites varied significantly with the CBCT used.[32] Similarly, mandibular canal tracing methods on CBCT images showed differences due to the tracing method used.[33] Moreover, when CBCT images are used to select implants for the posterior mandible, a vertical safety margin of at least 1.7 mm is recommended[33]—this is close to the recommendations for panoramic radiographs.[23]

Observers measuring the same vertical distances on conventional panoramic radiographs may report different results, and there may be a tendency to underestimate the distance from the alveolar crest to the superior border of the mandibular canal.[34] Accurate bone height evaluation above the mandibular canal is essential when planning a posterior implant as insertion of an inadequately long implant can injure the inferior alveolar nerve resulting in permanent hypoesthesia of the lower lip. Machtei et al[35] measured the distance from the apex of a pilot drill to the roof of the inferior alveolar canal on a digital panoramic radiograph (Planmeca Proline XC; Planmeca, Helsinki, Finland; mean 5.18 ± 0.61 mm) and compared it with the readings of an ultrasonic device used to measure the distance from the bottom of the osteotome preparation to the canal (mean 5.26 ± 0.61). They found a strong and highly significant correlation between the two measurement methods, indicating that digital panoramic radiographs have the measurement precision and accuracy required to determine pre-operative implant length for use in the posterior mandible. Kim et al[19] assessed the magnification rates of dental implants on radiographs taken with an Orthopantomograph® digital panoramic unit (Instrumentarium, Tuusula, Finland) and showed that the mean radiological magnification was 1.26 in the mandibular premolar and 1.25 in the mandibular molar

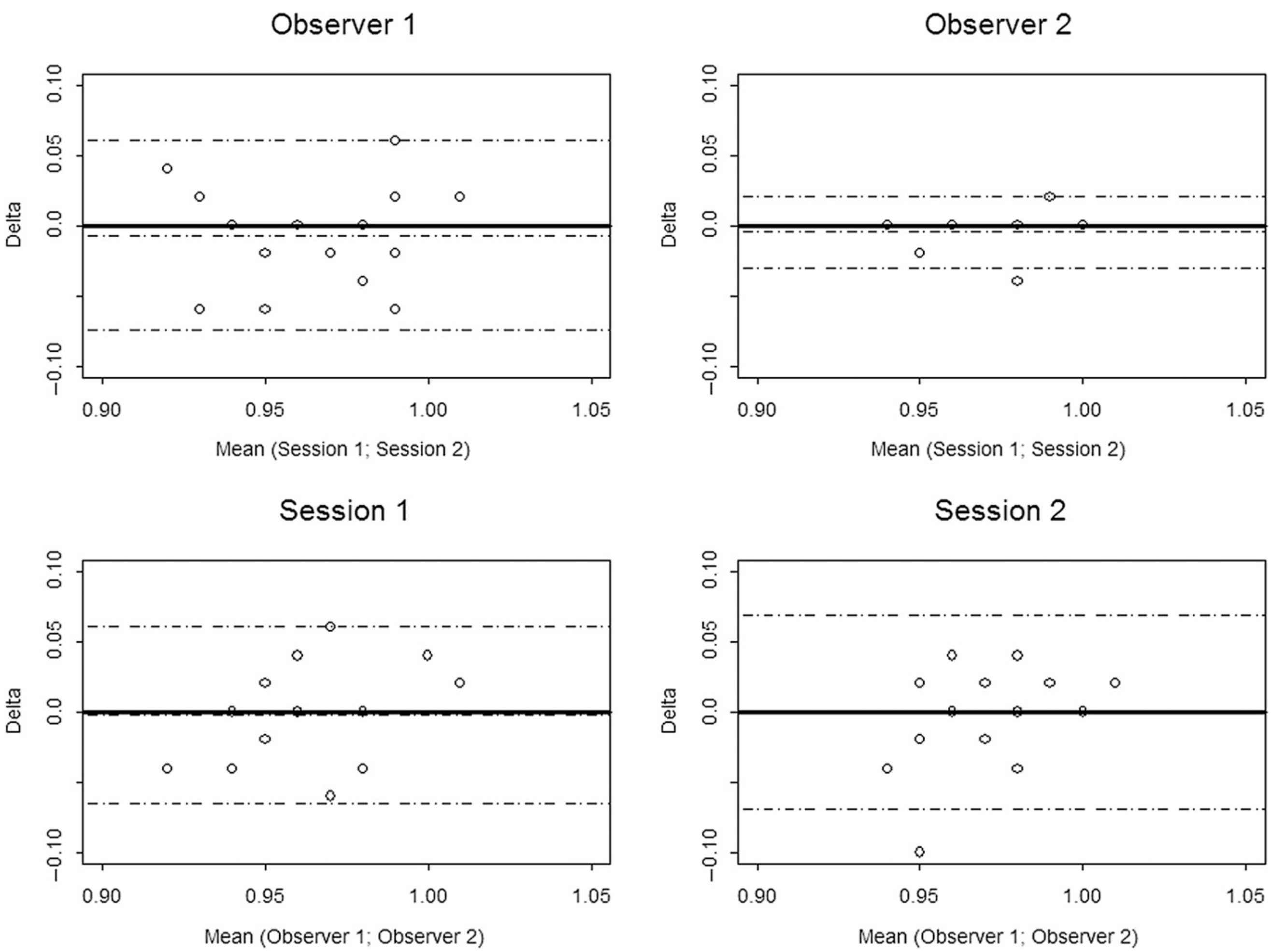

Figure 4 Bland–Altman analysis showing the inter- and intraobserver agreements for the metal ball distortion ratios

region. They concluded that digital panoramic radiography is a simple, effective method for pre-implant evaluation and that vertical assessment can provide accurate information. Park[18] reported that the mean magnification of mandibular implants was 1.31 in the premolar region and 1.27 in the molar region on digital panoramic radiographs taken with a digital Cranex® (Soredex, Helsinki, Finland) and concluded that digital panoramic radiographs were sufficiently accurate to evaluate the available bone height for posterior mandibular implants.

Our hypothesis was that digital panoramic radiographs with 1:1 adjusted images are sufficiently accurate and reliable to evaluate the available bone height above the mandibular canal, as has been shown for conventional panoramic radiographs in prior studies.[4,5] In the present study, we evaluated the measurement accuracy of digital panoramic radiographs using posterior mandibular implants and metal balls as reference objects, and found a good stability in vertical measurements in both groups. The mean radiological implant length was 14.1 ± 0.2 mm and 14.1 ± 0.1 mm (Observers 1 and 2, respectively) for both measurement sessions; the mean radiological ball height was 4.8 ± 0.2 mm and 4.9 ± 0.1 mm (Sessions 1 and 2, respectively) with identical variability for molar and premolar segments. In our view, the modest differences in measurements found in the present study indicate that measurements on a digital panoramic radiograph are sufficiently reliable for clinical application in implant dentistry. Unlike Schulze et al[16] reporting on metal pins and balls, we found no significant differences in the vertical measurements of our reference objects. The mean vertical DR was 0.99 for implants and 0.97 for balls, and was unrelated to the mandibular sites. Analysis of the inter- and intraobserver agreements showed acceptable measurement reproducibility for both reference objects.

Several factors may explain the modest differences in measurements found in our study. One is the choice of reference objects (one implant model and length, and a 5 mm diameter metal ball), which provided homogeneous implant and ball populations, and stable measurement parameters. A second is the use of metal balls and titanium implants, which ensured a sharp radiographic contrast and made it easier for the observers

Table 3 Absolute errors in the measurements of the reference objects, and differences in the absolute errors for implants and balls (n=13 pairs of matching implants and balls)

	Implant absolute error			*Ball absolute error*			*Difference in absolute error*			
Obs and MS	n	*Mean (SD)*	*Median (range)*	n	*Mean (SD)*	*Median (range)*	n	*Mean (SD)*	*Median (range)*	p
Obs1MS1	25	−0.168 (0.160)	−0.200 (−0.500;0.100)	18	−0.183 (0.172)	−0.200 (−0.500;0.100)	13	0.008 (0.222)	0.000 (−0.300;0.300)	0.78
Obs1MS2	25	−0.192 (0.231)	−0.200 (−0.700;0.200)	18	−0.150 (0.150)	−0.150 (−0.500;0.100)	13	−0.038 (0.331)	−0.100 (−0.400;0.700)	0.36
Obs2MS1	25	−0.228 (0.137)	−0.200 (−0.500;0.000)	18	−0.172 (0.113)	−0.200 (−0.300;0.000)	13	−0.054 (0.145)	−0.100 (−0.200;0.200)	0.08
Obs2MS2	25	−0.244 (0.119)	−0.200 (−0.500;0.000)	18	−0.150 (0.099)	−0.200 (−0.300;0.000)	13	−0.115 (0.121)	−0.200 (−0.300;0.100)	0.005

MS, measurement session; Obs, observer; SD, standard deviation.

to determine precise landmarks on the measured objects. Other factors, such as the patient's head position, the observer's experience and attention given to the task of measuring, may also influence measurement accuracy and precision. When measuring posterior mandibular implants on conventional panoramic radiographs, Vazquez et al[5] found that the implant length measurement was sufficiently reliable to evaluate the vertical magnification factor even when the patient's head position was not strictly standardized before exposure and when measurements were taken by observers with different skill levels and experience. We found similar results in the present study on digital panoramic radiographs. The observer's experience had no clinically significant influence on the measurements even though, interestingly, the less experienced observer (Observer 2) had a lower DR than the more experienced observer.

The calibration method is another factor that can impact the accuracy and reproducibility obtained from digital panoramic radiographs. Gotfredsen et al[17] showed that calibration with dedicated software had a greater impact on the anterior and premolar regions than on the molar region. When using panoramic radiographs, adjusting for image size distortion with a reference ball calibration method is an indispensable step in implant treatment planning as it allows a more precise selection of the implant length.[14] When the digital panoramic unit was first installed in the dental clinic, the surgeons, who had worked with conventional panoramic radiographs, now used the 5 mm diameter reference balls to verify that the adjusted 1:1 images were sufficiently reliable for posterior mandibular implant planning. They were soon satisfied and stopped using the reference balls, resulting in a small number of pre-operative digital panoramic radiographs with reference balls found in the database, and limiting the matched implants available for this study. The use of reference metal balls to calibrate magnification has the advantage that the symmetrical shape of the spheres produces radiographic images that are not influenced by projection geometry.[14] Schropp et al[14] measured reference metal balls and showed that the mean calculated magnification factor in digital panoramic radiographs in the vertical plane was 1.27 (range 1.23–1.31) in the premolar region and 1.26 (1.23–1.30) in the molar region. They also found that implant length selection varied with the calibration method used. They compared the values obtained using the standard calibration method (using a 1.25 magnification factor) with the values obtained using the ball calibration method, and showed that a different implant length was selected in approximately 50% of the cases, and that the changes in implant length were greater in the mandibular premolar region than in the molar region. Interestingly, the Straumann implant system was less affected by the calibration method used: changes in implant length were less frequent with that system than with the two other implant systems tested. Our study, using Straumann implants and metal balls as radiopaque references on digital panoramic radiographs, found that these two reference objects had similar and modest distortion in the premolar and molar sites, confirming that digital panoramic radiography is a simple and reliable tool to evaluate the available bone height before inserting posterior mandibular implants.

In conclusion, vertical measurements had acceptable accuracy and reproducibility when a software-based calibrated measurement tool was used, confirming that digital panoramic radiography can be reliably utilized to determine the pre-operative implant length in premolar and molar mandibular segments.

Acknowledgments
The authors thank Dr Nickolay Gaydarov for his valuable help in collecting the data for this study.

References

1. Dula K, Mini R, van der Stelt PF, Buser D. The radiographic assessment of implant patients: decision-making criteria. *Int J Oral Maxillofac Implants* 2001; **16**: 80–89.
2. Harris D, Buser D, Dula K, Grondahl K, Haris D, Jacobs R, et al. EAO Guidelines for the use of diagnostic imaging in implant dentistry. A consensus workshop organized by the European

Association for Osseointegration in Trinity College Dublin. *Clin Oral Implants Res* 2002; **13**: 566–570.
3. Frei C, Buser D, Dula K. Study on the necessity for cross-section imaging of the posterior mandible for treatment planning of standard cases in implant dentistry. *Clin Oral Implants Res* 2004; **15**: 490–497.
4. Vazquez L, Saulacic N, Belser U, Bernard JP. Efficacy of panoramic radiographs in the preoperative planning of posterior mandibular implants: a prospective clinical study of 1527 consecutively treated patients. *Clin Oral Implants Res* 2008; **19**: 81–85.
5. Vazquez L, Nizam Al Din Y, Belser UC, Combescure C, Bernard JP. Reliability of the vertical magnification factor on panoramic radiographs: clinical implications for posterior mandibular implants. *Clin Oral Impl Res* 2011; **22**: 1420–1425.
6. Tal H, Moses O. A comparison of panoramic radiography with computed tomography in the planning of implant surgery. *Dentomaxillofac Radiol* 1991; **20**: 40–42.
7. Tronje G, Welander U, McDavid WD, Morris CR. Image distortion in rotational panoramic radiography. I. General considerations. *Acta Radiol Diagn (Stockh)* 1981; **22**: 295–299.
8. Tronje G, Eliasson S, Julin P, Welander U. Image distortion in rotational panoramic radiography. II. Vertical distances. *Acta Radiol Diagn (Stockh)* 1981; **22**: 449–455.
9. McDavid WD, Dove SB, Welander U, Tronje G. Dimensional reproduction in direct digital rotational panoramic radiography. *Oral Surg Oral Med Oral Pathol* 1993; **75**: 523–527.
10. Batenburg RH, Stellingsma K, Raghoebar GM, Vissink A. Bone height measurements on panoramic radiographs: the effect of shape and position of edentulous mandibles. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1997; **84**: 430–435.
11. Scarfe WC, Eraso FE, Farman AG. Characteristics of the Orthopantomograph OP 100. *Dentomaxillofac Radiol* 1998; **27**: 51–57.
12. Gomez-Roman G, Lukas D, Beniashvili R, Schulte W. Area-dependent enlargement ratios of panoramic tomography on orthograde patient positioning and its significance for implant dentistry. *Int J Oral Maxillofac Implants* 1999; **14**: 248–257.
13. Stramotas S, Geenty JP, Petocz P, Darendeliler MA. Accuracy of linear and angular measurements on panoramic radiographs taken at various positions in vitro. *Eur J Orthod* 2002; **24**: 43–52.
14. Schropp L, Stavropoulos A, Gotfredsen E, Wenzel A. Calibration of radiographs by a reference metal ball affects preoperative selection of implant size. *Clin Oral Investig* 2009; **13**: 375–381.
15. Nedir R, Bischof M, Briaux JM, Beyer S, Szmukler-Moncler S, Bernard JP. A 7-year life table analysis from a prospective study on ITI implants with special emphasis on the use of short implants. Results from a private practice. *Clin Oral Implants Res* 2004; **15**: 150–157.
16. Schulze R, Krummenauer F, Schalldach F, d'Hoedt B. Precision and accuracy of measurements in digital panoramic radiography. *Dentomaxillofac Radiol* 2000; **29**: 52–56.
17. Gotfredsen E, Schropp L, Wenzel A. Software used to predict implant size from digital panoramic radiographs. *Int Congr Ser* 2005; 1281–1414.
18. Park JB. The evaluation of digital panoramic radiographs taken for implant dentistry in daily practice. *Med Oral Patol Oral Cir Bucal* 2010; **15**: e663–666.
19. Kim YK, Park JY, Kim SG, Kim JS, Kim JD. Magnification rate of digital panoramic radiographs and its effectiveness for preoperative assessment of dental implants. *Dentomaxillofac Radiol* 2011; **40**: 76–83.
20. Schulze R, d'Hoedt B: Mathematical analysis of projection errors in "paralleling technique" with respect to implant geometry. *Clin Oral Implants Res* 2001; **10**: 364–371.
21. Buser D, von Arx T. Surgical procedures in partially edentulous patients with ITI implants. *Clin Oral Implants Res* 2000; **11**: 83–100.
22. 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.
23. Loubele M, Bogaerts R, Van Dijck E, Pauwels R, Vanheusden S, Suetens P, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. *Eur J Radiol* 2009; **71**: 461–468.
24. Bou Serhal C, Jacobs R, Persoons M, Hermans R, van Steenberghe D. The accuracy of spiral tomography to assess bone quantity for the preoperative planning of implants in the posterior maxilla. *Clin Oral Implants Res* 2000; **11**: 242–247.
25. Tyndall DA, Brooks SL. Selection criteria for dental implant site imaging: a position paper of the American Academy of Oral and Maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; **89**: 630–637.
26. Guerrero ME, Jacobs R, Loubele M, Schutyser F, Suetens P, van Steenberghe D. State-of-the-art on cone beam CT imaging for preoperative planning of implant placement. *Clin Oral Investig* 2006; **10**: 1–7.
27. Suomalainen A, Kiljunen T, Kaser Y, Peltola J, Kortesniemi M. Dosimetry and image quality of four dental cone beam computed tomography scanners compared with multislice computed tomography scanners. *Dentomaxillofac Radiol* 2009; **38**: 367–378.
28. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. *J Can Dent Assoc* 2006; **72**: 75–80.
29. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). *Dentomaxillofac Radiol* 2004; **33**: 291–294.
30. 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.
31. Marmulla R, Wortche R, Muhling J, Hassfeld S. Geometric accuracy of the NewTom 9000 Cone Beam CT. *Dentomaxillofac Radiol* 2005; **34**: 28–31.
32. Loubele M, Maes F, Schutyser F, Marchal G, Jacobs R, Suetens P. Assessment of bone segmentation quality of cone-beam CT versus multislice spiral CT: a pilot study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; **102**: 225–234.
33. Gerlach NL, Meijer GJ, Maal TJ, Mulder J, Rangel FA, Borstlap WA, et al. Reproducibility of 3 different tracing methods based on cone beam computed tomography in determining the anatomical position of the mandibular canal. *J Oral Maxillofac Surg* 2012; **68**: 811–817.
34. Lindh C, Petersson A, Klinge B. Measurements of distances related to the mandibular canal in radiographs. *Clin Oral Implants Res* 1995; **6**: 96–103.
35. Machtei EE, Zigdon H, Levin L, Peled M. Novel ultrasonic device to measure the distance from the bottom of the osteotome to various anatomic landmarks. *J Periodontol* 2011; **81**: 1051–1055.