Clin Oral Invest (2007) 11:225–229
DOI 10.1007/s00784-007-0107-2

ORIGINAL ARTICLE

Bone density measurements in intra-oral radiographs

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Received: 10 October 2006 / Accepted: 26 January 2007 / Published online: 15 February 2007

Abstract Jaw bone density measurements are applicable in many clinical situations to assess bone tissue. To be able to implement research findings in clinical reality, tools must be simple and low cost. Intra-oral radiographs including a reference material perform well as a densitometric tool. However, the inclusion of a reference material, usually in the form of a metal wedge, is an additional burden for the dentist. The aim of this study was to evaluate whether a reference step wedge is required for accurate densitometric results. Dual energy X-ray absorptiometry measurements and densitometric measurements on intra-oral radiographs using a custom-made software were performed on bone samples from the premolar region of the mandible. Observer agreement of bone density expressed as grey value was high. The correlation between mandibular bone mineral density and the densitometric values on intra-oral radiographs was substantially higher when the aluminium step wedge was included. The Wilcoxon test revealed no significant difference between the density measurements using nine or three steps of the Al reference wedge. Density determination of grey value and mm Aleq thickness value both have good intra- and inter-observer agreement. However, jaw bone densitometry is far more accurate when including a reference wedge.

Keywords Bone density · Jaw bone · DXA · Intra-oral radiograph · Aluminium wedge

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Introduction

Assessment of jaw bone density may be considered as useful or even necessary in many clinical situations to asses bone tissue. Applications include diagnostics of oral and/or systemic diseases, implant planning, therapeutic evaluation and follow-up. In this perspective, most research has been focused on the prediction of low skeletal bone density from oral radiographs [4, 14, 21, 22]. Jaw bone density assessment can be based on intra-oral radiographs [23, 24], panoramic radiographs [6, 13], medical, cone beam and micro-computed tomography [1, 18, 19], dual energy X-ray absorptiometry (DXA) [3, 5], magnetic resonance imaging [2] and quantitative ultrasound (QUS) [17].

If research findings in this field are to be clinically applied, there is a need for a widespread, low cost, user- and patient-friendly tool for bone density evaluation. Furthermore, the tool needs to be accurate and the measurements precise and reproducible. As mentioned above, many techniques for jaw bone density measurements exist and are used clinically and/or experimentally [21, 22].

It is not an easy task to select from these the ultimate tool for large-scale jaw bone density analysis.

Intra-oral radiographs do live up to most requirements of the tool we are in search of. They are commonly used, at a low cost and easy to obtain. Various methods of analysis, both complex and simple, can be applied to intra-oral radiographs: fractal analysis [8], the classification of the trabecular pattern [15], or densitometry [11, 12]. The focus of the current study is densitometry, which might be useful for osteoporosis screening, but also for bone site evaluation before implant placement and to evaluate therapy involving bone. To be able to obtain comparable results in densitometry, it is useful to include a reference material in the radiograph. The aluminium step wedge is frequently used in bone density research because the absorption and scatter properties are similar to those of bone [20]. Therefore, a comparison can be made between the density produced on the radiograph by the wedge and that produced by the bone. To include a step wedge on an intra-oral film is an additional burden for the dentist. To accommodate the step wedge, image space must be sacrificed on the already small receptor. Furthermore, patients might experience more discomfort, having an additional object to bite on or keep steady. Therefore, the aim of this study was to evaluate whether a reference step wedge is required for accurate densitometric results.

Materials and methods

Thirty-two dried bone samples from the premolar region of the mandible were used in this study. The samples were obtained from adult cadavers from the department of anatomy (Faculty of Medicine, KU Leuven, Belgium) with ethical approval.

DXA measurements were made with a fan beam Hologic QDR-4500a® (Hologic, Bedford, MA, USA; Fig. 1), calibrated daily in accordance with the manufacturer's recommendations. The regional high-resolution mode of the small animal scan protocol (scan field 5.0 [width]×7.4 [height] cm^2, line spacing and point resolution 0.0311 cm) was used. The specimens were positioned on a plexi support (thickness=2.0 cm). All DXA measurements and analysis (Subregion Hi-Res V8.26 h) were performed by the same technician. The jaw bone mineral density (BMD) as measured by the DXA scan was used as the gold standard.

Intra-oral radiographs were obtained from all samples with the Prostyle Intra (Planmeca, Helsinki, Finland). Exposure parameters were 8 mA, 60 kV and 0.08 s. The Vistascan® phosphor plate technique was used for image recording (Dürr Dental, Bietigheim-Bissingen, Germany). A box was designed to standardize the projection geometry.

Fig. 1 DXA scanner with bone sample on plexi

An aluminium step wedge was placed on the X-ray receiver, next to but not in contact with the bone sample (Fig. 2). The wedge consisted of nine steps, each increasing the height with 1.3 mm. After scanning the phosphor plates, a noise filter was applied (DBSwin software®, Dürr Dental).


Fig. 2 Radiograph resulting from experimental set-up

The radiographs were exported to a custom made software, previously described [16]. In this software, first, the wedge must be identified by the operator on the radiographic image. Mean grey value and millimeter aluminium equivalent (mm Aleq) for each step are calculated. Then, a region of interest must be selected. For the current study, the region consisted of the entire bone sample. Of this region, the mean mm Aleq was calculated. Two observers performed the analysis twice. First, the aluminium step wedge was used as a reference, and the results were expressed as mm Aleq. For the second measurement, radiographic density was the only reference, and the results were expressed as grey values. One observer repeated all measurements. To determine how few steps would be necessary to maintain accuracy, ten samples were used. The stepwedge was identified as having nine, then eight, seven, etc. steps visible on the radiograph. As such, each sample was measured nine times.

Statistical analysis

Medical Statistical Software Medcalc® (Mariakerke, Belgium) was used for statistical analysis. Inter- and intra-observer variability was assessed with Passing and Bablock regression. The correlation coefficient for the DXA measurements and the measurements on intra-oral radiographs was calculated. Afterwards, the difference in predicting the areal BMD as measured by DXA was assessed for measurements with and without the aluminium reference wedge. To obtain information on the number of steps, necessary to maintain accuracy, the Wilcoxon test was used. Bonferroni correction was performed to maintain an overall significance level of 0.05.

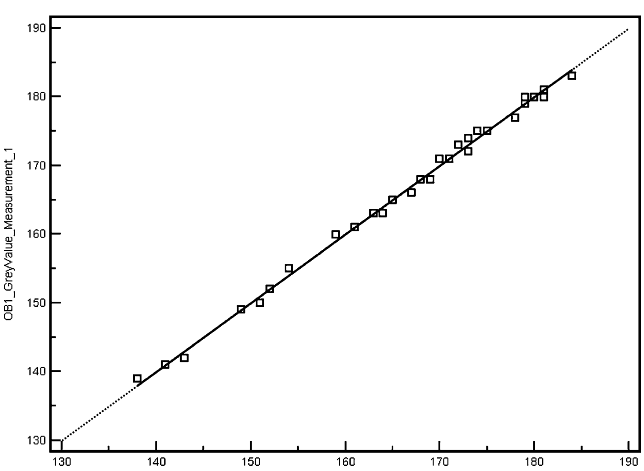

Fig. 3 Passing and Bablock regression for intra-observer variability of bone density expressed as *grey value* (*OB1* observer 1). Ninety-five percent confidence interval (CI) is invisible because of its proximity to the regression line

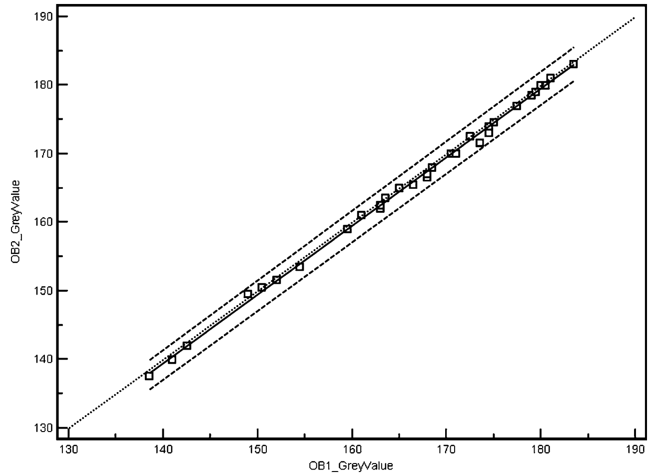

Fig. 4 Passing and Bablock regression for inter-observer variability of bone density expressed as *grey value* (*OB1* observer 1, *OB2* observer 2). The *striped line* is the 95% CI

Results

Intra- and inter-observer variability

Repeatability of the method using the aluminium step wedge as a reference for bone density measurements was previously reported [16] and proven to be excellent.

For the method without a reference wedge, neither for intra-observer nor for inter-observer data, a significant deviation from linearity was found ($p>0.10$) and agreement was high as visualised in Figs. 3 and 4.

Densitometric measurements

Data description

The BMD as measured by the DXA of the mandibular bone samples ranged from 0.528 to 0.820 g/cm^2, with a mean of 0.661 g/cm^2 and standard deviation of 0.079 g/cm^2. A normal distribution of mandibular BMD was accepted by D'Agostino-Pearson test for normal distribution.

Table 1 Pearson correlation coefficients for BMD as measured with DXA and radiographic bone density expressed as grey value and mm Aleq

		BMD (g/cm^2)
Grey value	Correlation coefficient	0.653
	Significance level *P*	0.0001
	N	32
mm Aleq	Correlation coefficient	0.893
	Significance level *P*	0.0000
	N	32

Prediction of BMD

Table 1 shows the correlation of DXA results and density measurements on intra-oral radiographs with (mm Aleq) and without (GreyValue) a reference wedge. The correlation between mandibular BMD and the densitometric values on intra-oral radiographs was substantially higher when the aluminium step wedge was included. Regression results confirmed that the gold standard was much better predicted when the wedge was included than without the wedge (Table 2, Fig. 5).

Number of steps

The Wilcoxon test revealed no significant difference between the density measurements using nine to three steps. With the use of two steps, it was impossible to calculate the mm Aleq (error report). The correlation between a 3-step aluminium wedge (i.c. first three steps) and the mandibular BMD was 0.84 ($p<0.05$).

Discussion

A tool for jaw bone densitometry on intra-oral radiographs, using an aluminium step wedge as a reference, was previously proven to have good intra- and inter-observer repeatability [16]. Using grey values for bone density measurements within the same custom software has now also proven to be a reproducible method.

Although a correlation does exist between the mere grey value and the DXA results, it is far less strong than the correlation between mm Aleq value and the DXA results. Moreover, when performing linear regression, only 43% of BMD variation is explained by grey values, in contrast to the 80% explained by aluminium equivalent values. Therefore, we conclude that jaw bone density assessment based on grey values, even with a brightness correction, is not an acceptable measure.

DXA was chosen as a gold standard, because it was found to be a good reference in several studies concerning jaw BMD [3, 10]. An aluminium wedge was used because of its similar absorption and scatter properties of bone [20] and previous applications in similar research [7]. Other suggested materials are hydroxyapatite and barium sulfate [24]. Nickel was also used as a reference material in oral research context [9]. The use of materials with a higher atomic number, such as nickel, might avoid the inclusion of the rather thick aluminium wedge when taking intra-oral

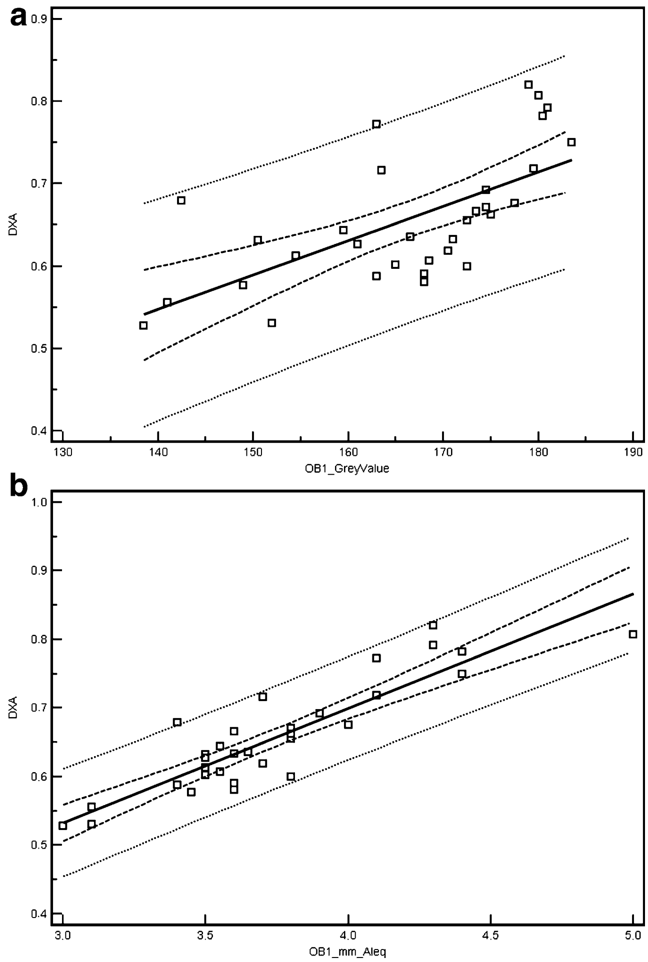

Fig. 5 **a** Linear regression line for *grey values* predicting BMD. The *dotted line* represents the 95% CI, the *striped line* represents the 95% prediction interval. **b** Linear regression line for mm Aleq values predicting BMD. The *dotted line* represents the 95% CI, the *striped line* represents the 95% prediction interval

Table 2 Linear regression analysis for bone density expressed as grey value and mm Aleq

	Regression grey value				Regression mm Aleq			
Dependent Y	DXA				DXA			
Independent X	Grey value				mm Aleq			
R^2		0.4263				0.7978		
Regression equation	$y=-0.0368+0.0042x$				$y=0.0322+0.1670x$			
Parameter	Coefficient	Std. error	T value	P	Coefficient	Std. error	T value	P
Intercept	−0.03681	0.14733	−0.2499	0.8044	0.03222	0.05777	0.5577	0.5812
Slope	0.00417	0.00088	4.7217	0.0001	0.16702	0.01535	10.8812	<0.0001

radiographs. Because space is limited on intra-oral films, exploratory research should first ensure that the scatter does not deform the bone properties. As three steps were sufficient to maintain an accurate bone density measurement, not only thickness, but also length of the wedge could be diminished to a large extend.

To implement the results of this study into clinical practice, it could be considered to build in a reference material in all intra-oral films. This should be a small object, showing a range of densities, possibly including various materials with different absorption properties. Population-based normal density values could then be obtained and used as a starting point for bone mass evaluation, e.g. in preoperative implant planning, bone gain or bone loss because of local and/or systemic diseases or in predicting skeletal bone density. The inclusion of a reference material could also be valuable to the dentist as an instrument for quality control.

Conclusion

Densitometric analysis showed good reproducibility, for the analysis with and without aluminium wedge correction. However, the assessment of bone density was far more accurate with the tool including an aluminium reference wedge. Three steps appear to be sufficient for bone density evaluation.

Further research needs to be performed to develop the most clinically applicable tool for densitometry on intra-oral radiographs.

Acknowledgements This work was supported by a research and technological development project grant from the European Commission FP5 'Quality of Life and Management of Living Resources' (QLK6-2002-02243). Grateful acknowledgement is given to Herman Borghs from the department of Bone Metabolic Disease.

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