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Osteoporosis and the general dental practitioner: reliability of some digital dental radiological measures

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Abstract – *Objectives:* Dental radiographs are relatively inexpensive and are regularly made of a large fraction of the adult population; therefore, they represent an enormous potential as a screening tool for osteoporosis. Monitoring the population by means of dual X-ray absorptiometry (DXA), which is currently the most accepted method for diagnosing osteoporosis, involves enormous costs and facilities. In previous studies, it was shown that the radiographic trabecular pattern shows correlations with the bone mineral density (BMD) as measured by DXA. The objective of this study was to assess the reproducibility of the quantitative analysis of the trabecular pattern on dental radiographs. *Methods:* Six regions of interest were selected manually on three digital radiographic images of 20 women. This process was performed 10 times resulting in 1200 image samples. For each image sample 26 parameters were measured. The reliability of the parameters was evaluated by means of Cronbach's alpha. *Results:* Of the values of Cronbach's alpha 83% is at least 0.9 and 99% is at least 0.8. *Conclusions:* The measurements of the parameters used in this study are very reproducible. Therefore, the manual selection of the regions of interest does not introduce large amounts of noise. The imaging parameters potentially offer an accurate tool for the prediction of BMD values.

Key words: BMD prediction; dental radiographs; osteoporosis; reliability; trabecular pattern

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Panoramic and intraoral radiographs are common diagnostic tools in dentistry today. Although the radiographs are primarily made for dental diagnosis, they may provide other useful information as well. Thus, dental radiographs showing mandibular or maxillary bone may also be used for the diagnosis of bone-related diseases. Osteoporosis is a bone-related disease with increasing prevalence due to increasing age of the population. Because dental radiographs are relatively inexpensive and already being made regularly of a large fraction of the adult population in many societies, they represent an enormous potential as a screening tool for osteoporosis. The general dental practitioner might fulfill the same role with respect to osteoporosis as with other diseases in the oral region, for example, oral cancer (1). By recognizing the disease in its early phase and referring the patient to a specialist, the dentist could help the patient greatly to increase the chances for a cure and a normal life, and help society to control the financial burden that is associated with osteoporosis.

According to an international consensus, osteoporosis is a systemic skeletal disease characterized by low bone mass and decay of bone microarchitecture resulting in increased bone fragility (2–4). In modern society, osteoporosis is one of the most common disorders in elderly people, affecting more than 75 million people in Europe, Japan, and the USA, causing more than 2.3 million

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fractures annually in Europe and the USA alone (4). Osteoporotic fractures occur in 40% of the cases at the spine, 20% at the hip, another 20% at the wrist, and the remaining cases occur at upperarm, rib, ankle, pelvis, or elsewhere (3). In white women, the risk of developing osteoporotic fractures of spine, hip, or wrist after the age of 50 years is estimated as 40–50%, similar to that for coronary heart disease (5, 6). Only one-third of the patients surviving a hip fracture regain their original level of function (5). Postmenopausal women using antiresorptive drugs obtain a 5–10% increase in bone mineral density (BMD), which reduces the risk of osteoporotic fractures by approximately 50% (7–10).

The currently most accepted method for measuring bone mass is Dual X-ray Absorptiometry (DXA or DEXA) at the lumbar spine, forearm, heel or total body (11). As osteoporosis is a slowly progressing disease with annual bone loss of 1–5%, diagnostic tools need to be precise. The accuracy error of DXA techniques is 3–15% and the precision error is 1–3% (11–14). Referring all postmenopausal women to medical clinics for annual BMD testing would involve enormous amounts of costs and facilities. Therefore, there is a need for alternative methods that can be used on a large scale to monitor the skeletal status and to detect early signs of osteoporosis so as to select individuals for further BMD testing and possible treatment.

Osteoporosis being a systemic skeletal disease will also affect bone density and bone structure in the jaws. Articles describing the use of dental radiographs for diagnosing osteoporosis are given in several reviews (15–17). Reduced bone mass of the jaws of osteoporotic subjects has been reported (18–22). Mandibular cortical width and shape have been studied in relation to osteoporosis (20, 23–26). Alveolar ridge height has been studied as well (27). With respect to the structure of the trabecular pattern on dental radiographs some studies have explored the use of fractal dimension as a predictive parameter for osteoporosis (24, 28). Extensive morphologic analysis of the trabecular pattern on dental radiographs in relation to osteoporosis is also described (29, 30). The correlations between osteoporosis and radiological measurements in dental radiographs are comparable with those reported for commonly used clinical screening instruments for osteoporosis such as the Osteoporosis Self-assessment Tool or the Simple Calculated Osteoporosis Risk Estimation with area under receiver operating characteristics (ROC) of about 0.8. However, most researchers conclude that these correlations do not yet enable the clinical use of dental radiographs for screening of osteoporosis (15–17, 20, 29, 30).

In 2003, the European Union granted a research project of five European Universities at Amsterdam, Athens, Leuven, Malmö and Manchester. This project, named Osteodent, investigated the diagnostic validity of dental radiography techniques for identifying osteoporotic patients. The overall aim of the research project was to find methods which the dentist can use to assess the osteoporotic status of patients by means of dental radiographs, possibly combined with other clinical information. More specifically, the goals of the project were to investigate up to what extent the BMD of the lumbar spine and femoral neck can be predicted by characteristics of dental radiographs. One of the techniques used is a quantitative analysis of the radiographic trabecular pattern as shown on dental intraoral and panoramic radiographs. This technique has been described in detail before (31, 32). In the project, 671 women in the age range of 39–71 years were recruited and their osteoporotic status was determined by measuring BMD at the lumbar spine and left femoral neck. Their dental status was assessed by means of a dental panoramic radiograph and intraoral radiographs of the upper right and the lower right premolar region. In order to find out the precision with which BMD can be predicted by means of parameters that are measured on the radiographs it is useful to know how reliable the measurement procedures are and how much noise they contain. Therefore, the purpose of the present study was to determine the reliability or amount of noise in the quantitative trabecular parameters that are measured on panoramic and intraoral dental radiographs.

Materials and methods

This study focuses on radiographs of women recruited by the University Hospitals in Athens, Leuven, Malmö and Manchester on behalf of the Osteodent project. In the project, 671 women were recruited in the University Hospitals and the surrounding areas. They were assigned numbers according to the date of investigation. With help of these numbers five women from each University Center were selected at random resulting in a random selection of 20 women. From each woman three radiographs were available, a panoramic radiograph, an intraoral radiograph of the right premolar region of the upper jaw, and an intraoral radiograph of the right premolar region of the lower jaw.

The panoramic radiographs were made with a Planmeca Promax device (64–66 kV) (Planmeca Oy, Helsinki, Finland), a Planmeca Proline XC (66–68 kV) (Planmeca Oy), a Soredex Cranex Tome (70 kV) (Soredex, Helsinki, Finland), and a Soredex Cranex 3+ (69 kV) (Soredex). The Soredex Cranex Tome used photostimulable phosphor plates which were scanned with a resolution of 200 pixels per inch. The other panoramic devices used conventional filmcassettes which were scanned with a resolution of 641 pixels per inch which was lowered to 200 pixels per inch before making measurements. The intraoral radiographs were made with three Planmeca Prostyle Intra devices (60–63 kV) (Planmeca Oy), and one Siemens Heliodent MD (60 kV) (Sirona, Bensheim, Germany). The intraoral radiographs depicted the upper right and lower right premolar region on conventional films which were scanned at a resolution of 300 pixels per inch.

For each radiograph two regions of interest were selected manually. On the panoramic radiograph, the regions of interest were chosen in the right half of the mandible. One region was located below the molars and the premolars if present, and the other region was located in the ramus (Fig. 1). Taking two different regions enables estimating the relevance of the location. On each intraoral radiograph, the first region of interest was chosen preferably between the roots of a premolar and a molar, and it contained only radiographic trabecular pattern. The second region included the first region completely as well as some parts of the adjacent roots if present (Figs 2 and 3). Taking the second region enveloping the first enables evaluating the effect of the presence of roots (or non-trabecular tissue) in the region of interest.

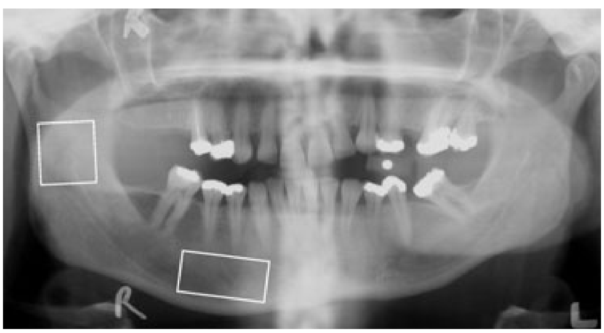

Fig. 1. Panoramic radiograph with region of interest in the front and in the ramus.

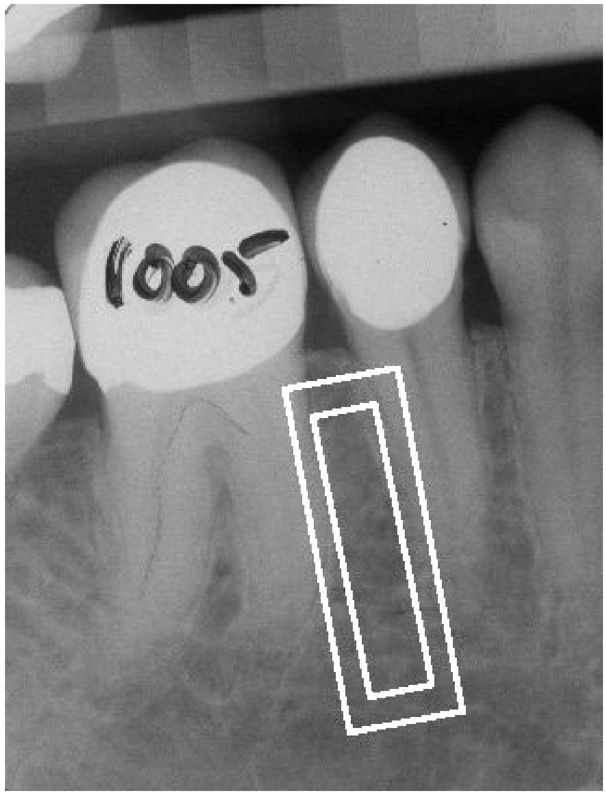

Fig. 2. Intraoral radiograph of lower jaw with inner and outer region of interest.

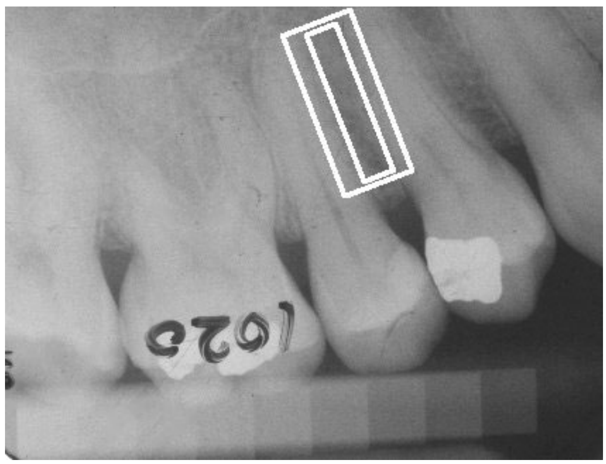

Fig. 3. Intraoral radiograph of upper jaw with inner and outer region of interest.

When the regions of interest had been selected on the 20 panoramic radiographs the selection procedure was repeated the same day until each region of interest had been selected 10 times. No efforts were spent to remember the exact position of the regions. Similarly, when 80 regions of interest on the 40 intraoral radiographs had been selected, the procedure was repeated nine times on the same day. In total, 1200 image samples were taken from 60 radiographs. The average dimensions of the regions of interest were 750×280 and 550×920 pixels for the panoramic radiograph, 50×90 and 70×110 pixels for the intraoral radiograph of the lower jaw, and 40×70 and 70×90 pixels for the intraoral radiograph of the upper jaw. The measurements have been normalized to account for the variation of the size of the regions of interest.

All samples were stored on hard disk and subjected to a sequence of automatic measurement procedures. The measurements were grouped into simple, geometric, topological and directional measurements.

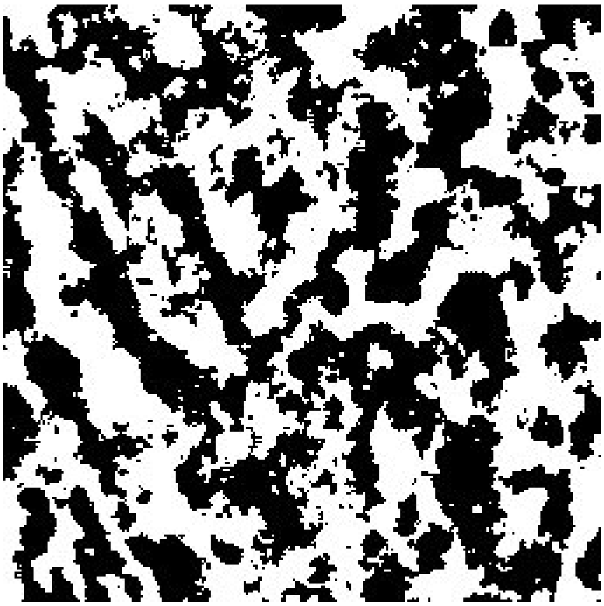

Fig. 4. Binarized version of the region of interest.

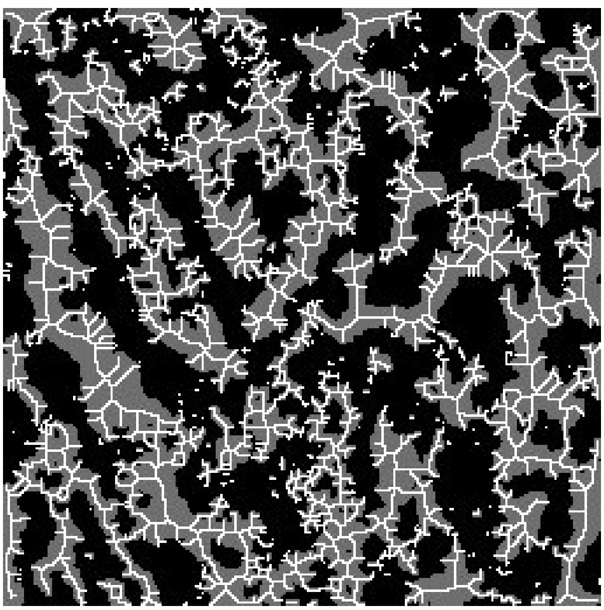

Fig. 5. Wire diagram of the white segments in Fig. 4.

The *simple parameters* were measured on the raw, unfiltered sample and consisted of determining the mean and standard deviation of the gray values in the sample, which represent brightness and contrast of the sample. Because the brightness depends on BMD of the jaw and the exposure, there should exist an inverse relation between the brightness and the BMD of the jaw under the condition that the exposure is kept constant. When osteoporosis reduces the amount of bone mass and compromises the trabecular structure it is speculated that brightness increases and contrast decreases.

To measure the *geometrical parameters* the sample was filtered and segmented to obtain a binarized version of the sample, consisting of black and white

Table 1. Codenames of parameters and their description

Simple parameters of the raw unfiltered sample:

1. MEAN Mean of gray values in the region of interest.
2. STDDEV Standard deviation of gray values in the region of interest.

Geometrical parameters of the binarized version of the sample:

3. FRACTL Fractal dimension
4. BAREA Area of black segments
5. WAREA Area of white segments
6. WCIRC Perimeter of white segments
7. BLAKS Number of black segments
8. WITES Number of white segments

Topological parameters of the wire diagram of the white segments

9. WAXIS Length of struts
10. WENDS Number of endpoints
11. WFORK Number of furcations

Topological parameters of the wire diagram of the black segments

12. BAXIS Length of struts
13. BENDS Number of endpoints
14. BFORK Number of furcations

Directional parameters of the binarized version of the sample:

15. LFD 0 orientation along 0°
16. LFD 15 orientation along 15°
17. LFD 30 orientation along 30°
18. LFD 45 orientation along 45°
19. LFD 60 orientation along 60°
20. LFD 75 orientation along 75°
21. LFD 90 orientation along 90°
22. LFD 105 orientation along 105°
23. LFD 120 orientation along 120°
24. LFD 135 orientation along 135°
25. LFD 150 orientation along 150°
26. LFD 165 orientation along 165°

Parameters 4–14 are standardized by division with the area of the region of interest.

segments (Fig. 4). The procedures to obtain the binarized version of the sample have been described previously (31, 33–36). The binarized sample was used to measure the fractal dimension, the combined area of the black segments, the combined area of the white segments, the perimeter of white segments, the number of black segments, and the number of white segments.

For measuring the *topological parameters*, the white segments in the binarized sample were eroded to a wire frame structure (Fig. 5) that was used to measure the total length of struts, the number of endpoints, and the number of furcations. Similarly, the black segments in the binarized version of the sample were eroded to a wire frame structure that was used to measure the total length of struts, the number of endpoints, and the number of furcations. With the exception of fractal dimension the geometrical and topological parameters were standardized by dividing them by the area of the sample. The geometrical and topological parameters were determined because previous studies reported correlations with osteoporosis indices (29, 30, 33, 34, 37).

Finally, the binarized sample (Fig. 4) was used to measure the *directional parameters* consisting of the LFD index of orientation along 12 directions starting with 0°, and then in steps of 15° up to 165°. The method of measuring orientation has been described previously (32, 37–39). Previous studies showed that the directional parameters are less connected to osteoporosis than the geometrical and topological parameters (32, 36, 37). However, these studies were based upon radiographs of the wrist or the hip, and it remains to be seen if this also holds for dental radiographs.

Table 1 lists the code names of the 26 parameters and a brief description. Cronbach's α is used to compute the reliability of the 26 parameters for each of the six regions of interest (40).

Results

Table 2 shows the values of Cronbach's α for each of the 26 parameters and each of the six regions of interest. Of the 156 values of Cronbach's α, two values are between 0.70 and 0.79, 24 are between

Table 2. Cronbach's α for image parameters of six regions of interest: frontal region and ramus region on panoramic radiograph inner and outer region on intraoral radiograph of the upper jaw inner and outer region on intraoral radiograph of the lower jaw

	Front	Ramus	Upper Inner	Upper Outer	Lower Inner	Lower Outer	Ref A	Ref B
1. MEAN	1.00	1.00	1.00	1.00	1.00	1.00	–	–
2. STDDEV	0.99	1.00	0.99	0.99	0.98	0.96	–	–
3. FRACTL	0.99	1.00	0.94	0.98	0.95	0.96	–	–
4. BAREA	0.99	0.99	0.93	0.97	0.97	0.96	–	–
5. WAREA	0.99	0.99	0.92	0.91	0.97	0.96	0.33	0.72
6. WCIRC	0.99	0.99	0.93	0.98	0.97	0.97	0.91	0.94
7. BLAKS	0.99	0.99	0.89	0.97	0.90	0.93	0.29	0.87
8. WITES	0.99	0.99	0.92	0.98	0.94	0.95	0.62	0.76
9. WAXIS	0.99	0.99	0.93	0.97	0.96	0.96	0.53	0.93
10. WENDS	0.99	0.99	0.95	0.98	0.96	0.96	0.72	0.88
11. WFORK	0.99	0.99	0.94	0.98	0.95	0.96	0.83	0.93
12. BAXIS	0.99	0.99	0.94	0.97	0.97	0.97	0.66	0.87
13. BENDS	0.99	0.99	0.93	0.98	0.94	0.96	0.69	0.92
14. BFORK	0.99	0.99	0.95	0.98	0.95	0.96	0.78	0.89
15. LFD 0	0.99	0.98	0.77	0.90	0.90	0.93	0.84	0.53
16. LFD 15	0.99	0.99	0.78	0.89	0.87	0.94	0.80	0.48
17. LFD 30	0.99	0.99	0.88	0.93	0.86	0.94	0.51	0.74
18. LFD 45	0.98	1.00	0.91	0.95	0.85	0.91	0.78	0.69
19. LFD 60	0.93	0.99	0.91	0.94	0.88	0.84	0.87	0.69
20. LFD 75	0.87	0.99	0.91	0.90	0.92	0.90	0.91	0.77
21. LFD 90	0.88	0.99	0.92	0.92	0.94	0.94	0.92	0.79
22. LFD 105	0.87	0.99	0.87	0.94	0.93	0.93	0.77	0.71
23. LFD 120	0.90	0.99	0.84	0.94	0.87	0.90	0.75	0.65
24. LFD 135	0.95	0.99	0.87	0.89	0.88	0.88	0.55	0.71
25. LFD 150	0.97	0.99	0.91	0.80	0.87	0.89	0.77	0.70
26. LFD 165	0.98	0.97	0.89	0.90	0.89	0.87	0.93	0.53

For codenames of parameters see Table 1. Ref A: values from Korstjens et al. (41). Ref B: values from Geraets et al. (37).

0.80 and 0.89, and 130 are 0.90 or higher. Most of the parameters yield the lowest value of Cronbach's α for the inner region of interest on the intraoral radiograph of the upper jaw and the highest value of Cronbach's α for the ramus region on the panoramic radiograph.

Conclusions and discussion

For parameters 5–26 in Tables 1 and 2, two previous reports, one on radiographs of the hip, and the other on radiographs of vertebral slices, list the values of Cronbach's α (37, 41). These values have been copied to the two columns of Table 2 marked 'Ref. A' and 'Ref. B'. In the previous reports the area of the region of interest was kept constant, therefore, there was no need to standardize parameters 5–14 as has been carried out in the present report.

Comparison of the values in Table 2 for Cronbach's α of the present study with the values of the previous reports shows that in most cases the values of the present study are higher. Parameter BLAKS (see Table 1, parameter 7) having a value of only 0.29 in the column marked 'Ref. A' is exceeded dramatically by the corresponding value of 0.99 referring to measurements in the front and ramus region of interest on the panoramic radiograph. It seems from these results that intra-oral and panoramic radiographic images are at least as good to determine the trabecular parameters as the previously described images of other skeletal bones. The largest exception is the value for the orientation index LFD 0° of the upper inner region which is 0.07 less than the corresponding values in the column marked 'Ref. A'. The present study estimates the noise that is introduced by the selection of the region of interest. However, both reference studies in Table 2 also include other sources of noise which explains why the reference values are less than the values of the present study. It has been shown that repeated scanning of the same radiograph is the greatest source of noise, at least for the geometrical and topological parameters (41).

Although strict threshold values for Cronbach's α are not provided in the literature, it seems justifiable to conclude that the values in Table 2 are fairly high, because 83% of the values is at least 0.9 and 99% is at least 0.8. The process of selecting the regions of interest manually is somewhat arbitrary; however, the high values of Cronbach's α indicate that only small amounts of noise are introduced by the selection process. This promotes a high precision of the prediction of BMD.

While the current study shows that the proposed trabecular parameters can be measured with a high degree of reproducibility, the next step is to measure the parameters on a larger collection of radiographs and to relate the outcome to BMD values.

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