Estimation of skeletal bone mineral density by means of the trabecular pattern of the alveolar bone, its interdental thickness, and the bone mass of the mandible

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Objective. We sought to evaluate the use of the alveolar trabecular pattern, the mandibular alveolar bone mass (MABM) measured by photodensitometry, and the interdental alveolar thickness for prediction of the skeletal bone mineral density (BMD).

Study design. MABM and the coarseness of trabeculation were assessed by using periapical radiographs in 80 dentate women. The interdental alveolar thickness was measured on casts, and BMD of the forearm with dual X-ray absorptiometry.

Results. Significant correlations were found between skeletal BMD and MABM ($r = 0.46$, $P < .001$) as well as the coarseness of the trabeculation ($r = 0.62$, $P < .001$). The interdental alveolar thickness improved the correlation between skeletal BMD and MABM ($R^2 = 0.44$, $P < .001$). Age, but not interdental thickness, improved the correlation between the coarseness of trabeculation and skeletal BMD ($R^2 = 0.52$, $P < .001$).

Conclusion. Evaluation of the coarseness of trabeculation of the alveolar bone as seen on intraoral radiographs is a helpful clinical indicator of skeletal BMD and better than densitometric measurements of the alveolar bone. Dense trabeculation is a strong indicator of high BMD, whereas sparse trabeculation may be used to predict low BMD.

(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001;92:346-52)

The rate of osteoporotic fractures has increased in recent decades. It has affected the quality of life of elderly persons, and it has imposed a heavy financial burden on society. There is a close relation between low bone mass and osteoporotic fractures,[1,2] and several techniques have been developed to measure bone mineral density (BMD) both in the appendicular skeleton and in the axial skeleton, but the high costs and the limited availability of the equipment have curtailed their usefulness for screening examinations. Dentists have been investigating mandibular bone for a long time, partly because of the serious consequences of edentulousness but also to develop methods for detecting mandibular osteoporosis.[3] Photodensitometry of periapical and panoramic radiographs has been used to estimate mandibular bone mass,[4-6] but this method has low predictive value for skeletal osteopenia. Advanced methods such as dual X-ray absorptiometry[7] (DXA) and quantitative computed tomography[8,9] have been applied in edentulous areas, and dual-photon absorptiometry[10] even in dentate areas, but the correlation between the mandibular and the skeletal bone values was found to be as low as with photodensitometry. Digital image analysis techniques for quantitating bone mass have been applied to oral digital or digitized radiographs. The use of gray-level values for detecting changes in alveolar bone density is under development.[11-14] These changes may also reflect changes in skeletal BMD.[14] Morphologic image-processing routines use mathematical operators to facilitate the analysis of trabecular width, spacing, geometry, and orientation.[15] In this way, the structure of the trabecular architecture has been studied in vertebra,[15] in the radius,[16] and also on periapical radiographs.[12,17] Furthermore, in vitro studies have used digital subtraction of oral radiographs[18,19] and fractal dimension[20] to detect density changes in simulated osteoporosis. However, up until now, these new techniques have not been fully developed for use in clinical practice.

The mandibular trabecular architecture has been studied in edentulous areas with the help of periapical radiographs[21] and panoramic radiography[22] to evaluate the bone before implant treatment. The method seems to be efficient and simple for clinicians, but whether the trabecular architecture of the mandible is directly related to the BMD of the rest of the body has not been tested.

Previously, the shape and thickness of the mandibular alveolar process was studied on dental casts. A highly significant correlation was found between the shape of the cervical part (expressed as the difference between

Supported by a grant from the FoU-centre in Southern Älvsborg County and the Swedish Medical Research Council (project: 05006).
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Received for publication Jun 23, 2000; returned for revision Aug 3, 2000; accepted for publication Dec 26, 2000.

1079-2104/2001/$35.00 + 0 **7/16/116494**
doi:10.1067/moe.2001.116494

2 buccolingual measures) midbuccally of the first pre molar and the BMD of the forearm. Furthermore, significant correlations were found between the interdental thickness in the premolar, canine, and incisive area of the mandibular alveolar process and the BMD of the forearm.[23] The importance of the dimension of vertebral bodies in the BMD measuring procedure has been stressed by Pors Nielsen et al.[24] When the dimensions of vertebral bodies are not taken into consideration, osteoporosis is overdiagnosed in small persons with thin bones and underdiagnosed in tall persons with bigger bones.[24] The interdental thickness of the alveolar bone, representing the mandibular bone dimension, and the visual classification of the trabecular pattern as described by Lindh et al,[21] as representing the bone structure, could therefore be important parameters when oral variables are used to predict skeletal BMD.

The aim of the present study was to test whether the coarseness of the alveolar trabecular pattern, the interdental thickness of the mandibular alveolar process, and mandibular alveolar bone mass could be used to estimate the BMD of the skeleton in dentate women.

MATERIAL AND METHODS

Subjects

Eighty women with a mean age of 47 years (range 20-78 years) volunteered to participate in a study when they underwent their annual oral examination. These women represented all female patients in the age group visiting the public dental service during a 6-month period of collecting material. Among the total of 90 women treated, 4 premenopausal patients and 6 women more than 70 years old did not want to participate in the investigation. The criterion for participation was that the subjects were dentate adult women with at least the first mandibular premolar present bilaterally, being in occlusion with the antagonist and without pathologic signs. Of the 80 women, 19 were smokers, 13 were on hormone replacement therapy, and 4 had had a hysterectomy (2 of them without ovarian conservation, the third had 1 ovary left, and the fourth had both ovaries left). The individuals had no deepened pockets in the premolar region. All persons had an intact crestal lamina dura in the radiographed area and clinically healthy gingiva.

The study was approved by the Ethical Committee of Göteborg University.

BMD of the forearm

The BMD was determined in the distal forearm of the nondominant arm.[25] Both the radius and ulna were scanned by means of DXA (Osteometer DTX-200; Osteometer, Rödovre, Denmark), starting from the point at which the distance between the radius and the ulna was 8 mm and ending 24 mm more proximal to this point. The measurements determined BMD in gram mineral per centimeter squared and as a percentage (100% signified the mean value of women of the reference age, ie, 40 years), and the SD (T-score) indicated whether the patient had normal values (within 1 SD from the mean), osteopenia (between 1 and 2.5 SD from the mean, which corresponds with a BMD of between 70% and 88% of the mean BMD of women of the reference age), or osteoporosis (more than 2.5 SD below the mean, which corresponds with BMD lower than 70%).

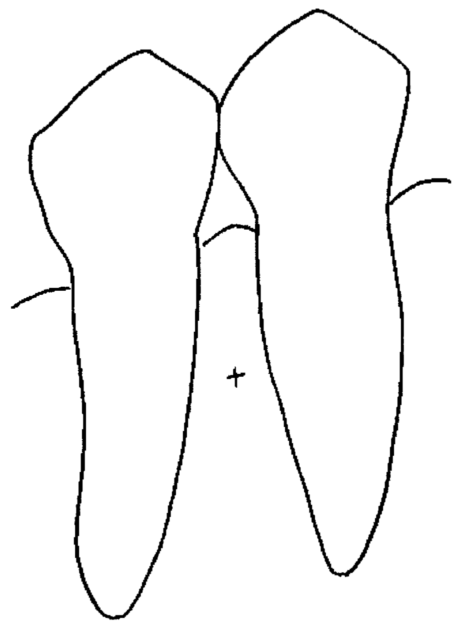

Fig 1. The location between the mandibular premolars for measuring buccolingual thickness of the cervical part of the alveolar process (interdental thickness) on casts and optical density on periapical radiographs, 6 mm apically from estimated cementoenamel junction.

Interdental alveolar thickness

The thickness of the mandibular alveolar process was measured on dental casts with a dial caliper (Kori-HSL 6871-0201 [range, 0-15 mm] or Kori-HSL 250-00 [range, 0-10 mm]; Kori Seiki MFG Co Ltd, Tokyo, Japan). The buccolingual thickness of the cervical part of the alveolar process was measured 6 mm apically from the estimated cementoenamel junction (Fig 1). The measurements were made distally of the first premolar at the right side of the mandible. In 9 cases, the first molar was missing, and in 4 cases the second premolar was missing, but it was estimated that the dimension of the alveolar process was not changed because of the extraction.

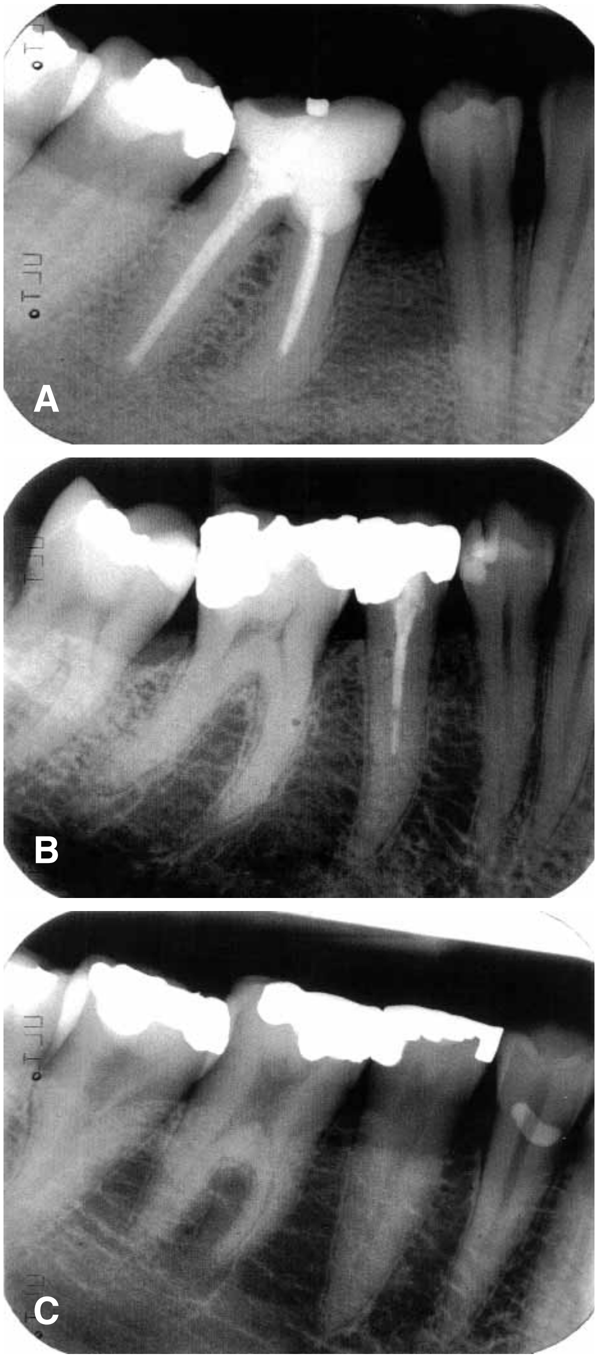

Fig 2. Reference images presenting trabecular pattern as dense trabeculation **(A)**, alternating dense and sparse trabeculation **(B)**, and sparse trabeculation **(C)**.

Apical radiographs

A periapical radiograph (Kodak Ultra-Speed DF-58; Eastman Kodak, Rochester, NY) of tooth 44 was obtained by using a standardized paralleling technique. The dental X-ray apparatus was a long-cone Gendex Oralix 65S (Gendex Corp, Milwaukee, Wis). The exposure time was kept the same for all individuals. After the intraoral exposure, a reference radiograph of an aluminum step-wedge was taken in the absence of the patient by using the same apparatus and the same exposure time. The aluminum step-wedge was placed directly on the film, which was placed on a 10-cm–thick acrylic plate to avoid background interference. The radiographed step-wedge comprised 10 steps (3-13 mm in thickness). It was used to assess mandibular alveolar bone mass (MABM). The intraoral, the reference, and an unexposed radiograph were developed together in an automatic processing machine (Dent-X Model 410, Stamford, Conn). The unexposed radiograph was used to control the quality of the developing procedure.

Table I. Age and number in groups of patients with normal BMD (≥88%), osteopenia (88% > BMD > 70%), and osteoporosis (BMD ≤ 70%)

	Normal	*Osteopenia*	*Osteoporosis*
Numbers (%)	40 (50%)	28 (35%)	12 (15%)
Mean age (SD)	41.6 (9.7)	51.6 (13.2)	55.9 (13.5)
Age range (y)	20-57	22-78	26-73

Mandibular alveolar bone mass. A physicist measured the optical density of the exposed and processed radiographs with a densitometer with an aperture of approximately 2 mm (Macbeth TD-500; Macbeth Division of Kollmorgen Co, Newburgh, NY). The optical density of the premolar radiograph was assessed in 2 ways: (1) as a mean of the optical density of the alveolar bone at 6 locations, 3 along each side of the root of the first premolar and (2) as the optical density of the alveolar bone at a location corresponding to the previously described measuring area on the dental casts (Fig 1). The optical density of each step of the step-wedges was measured on the reference radiograph, and the values were plotted against the corresponding thickness of aluminum. The curve obtained provided the corresponding aluminum equivalents (Al eq) to the measured optical density of the alveolar bone. In this way, an indication of the MABM was obtained. No consideration was given to the varying amount of soft tissue in front of the bone.

Trabeculation. Three periapical radiographs of the right premolar area of the mandible with varying degrees of trabeculation were used as index references (Fig 2) to assess the trabeculation pattern as proposed by Lindh et al.[21] With the help of those radiographs, the trabeculation of the alveolar process was classified as either *sparse* (regarded as a numerical variable with a value of 1), *alternating dense and sparse trabeculation* (numerical value of 2), or *dense* (numerical value of 3). A supplementary evaluation of the trabeculation was also made around the canine and the molars. Furthermore, in the radiographs with alternating dense and sparse trabeculation, small interruptions in the trabecular network (Fig 3), similar to the described condition focal osteoporotic bone marrow defect, were registered whenever they occurred.[26,27]

Fig 3. Radiograph presenting alternating dense and sparse trabeculation with focal osteoporotic bone marrow defect.

Statistical methods

The Pearson correlation coefficient (r) was used to determine the amount of association between variables. Stepwise multiple regression analyses were used to estimate the relationships between skeletal BMD, mandibular alveolar bone mass, age, and interdental thickness. Spearman rank correlation was used when the coarseness of trabeculation was involved. One-way analysis of variance was used to compare the mean BMD of varying degrees of trabeculation.

Reliability of measurements

The interdental alveolar thickness was measured in duplicate on 20 casts (6 months' difference in time). The error of the method was calculated according to Dahlberg's formula:

$$S_e = \sqrt{\frac{\Sigma d^2}{2n}}$$

where d is the difference between the 2 measurements. The reliability was calculated according to a method proposed by Houston[28]: $1 - S_e^2/S_i^2$ (S^2_i is the total variance of the measurement). The error of the method was 0.09 mm and the reliability 97%. The trabeculation was assessed twice in 24 subjects by one observer with an interval of a week. Linear regression analysis between the first and the second assessment was highly significant (r = 0.93, n = 24, P < .001). Similarly, the error of the method and the reliability with respect to the photodensitometric evaluation of the intraoral radiographs were calculated for 20 radiographs. The error of the method was 0.15-mm aluminum equivalents (Al eq), and the reliability was 97%.

An intraobserver analysis was made for BMD obtained by means of DXA: Linear regression analysis of values from an automatic procedure and a more individual procedure showed a highly significant correlation (r = 0.95, n = 21, P < .001), and the error of the method was S_e = 4.13%. Paired t tests between the first and the second evaluations of all methods tested revealed no systematic errors between the 2 occasions.

RESULTS

BMD of the forearm

The mean value of BMD (absolute value) was 0.43 g/cm^2 ± 0.06 g/cm^2 (n = 80). The mean BMD (relative value, to the norms of 40-year-old women) was 86% ± 13% (range, 55%-109%). BMD was highly significantly correlated with age (r = –0.52, P < .001; Table I).

Interdental alveolar bone thickness

The mean interdental alveolar bone thickness 6 mm from the estimated cementoenamel junction (Fig 1) distally of the first premolar was 9.0 mm ± 0.9 mm (80 subjects; range, 7.3-12.0 mm).

Apical radiographs

Mandibular alveolar bone mass. The MABM based on measurements at 6 locations mesial and distal to the root of tooth 44 was 8.3 Al eq ± 1.2 Al eq (range, 5.0-11.0 Al eq). When only one location was measured 6 mm from the cementoenamel junction (Fig 1) distal to 44, the mean MABM was 7.9 Al eq ± 1.2 Al eq (range, 5.0-11.0 Al eq). The MABM measured at one location was slightly better correlated with the skeletal BMD than the MABM measured at 6 locations, and it was therefore used in the regression analyses. When the MABM was correlated separately with the explanatory variables, it was significantly correlated with interdental thickness (r = 0.49, P < .001), skeletal BMD (r = 0.46, P < .001), and age (r < –0.31, P < .01). The skeletal BMD and the interdental thickness of the alveolar process both were highly statistically significant explanatory variables when the MABM was used as a dependent variable in a multiple regression analysis (R^2 = 0.44, P < .001).

Trabeculation. Twenty-five subjects (31%) had sparse trabeculation and a mean skeletal BMD of 76.6% ± 11.7% (range, 55%-105%). Two subjects of 25 with sparse trabeculation had a normal BMD. Forty-three patients (54%) had alternating sparse and dense trabeculation and a mean skeletal BMD of 88.5% ±

10.6% (range, 62%-108%), 13 patients had osteopenia, and 3 were osteoporotic. Twelve patients (15%) had dense trabeculation and a mean skeletal BMD of 99.3% ± 6.4% (range, 87%-109%), one subject was regarded as having dense trabeculation, although she had slight osteopenia. Analysis of variance showed a significant difference between the mean skeletal BMD in the groups with different degrees of trabeculation.

All radiographs classified as dense had a dense trabeculation not only in the premolar area, but in the canine and the molar areas from the crest to the apical part of the radiograph. Similarly, the radiographs classified as sparse had sparse trabeculation all over the radiographed area. When the radiographs with alternating dense and sparse trabeculation were studied closely, it seemed as if the trabecular network was interrupted in many cases and that small marrow "holes" were created, having the appearance of focal osteoporotic bone marrow defects (Fig 3). Those radiographically translucent lesions appeared mostly in the premolar-molar region, halfway between the crest and the apical area. Eleven women with a mean BMD of 82.9% ± 10.0% (range, 62%-92%) had these translucent lesions, whereas the rest of the group with alternating dense and sparse trabeculation had a mean BMD of 90.4% ± 10.4% (range, 65%-108%). There was a statistically significant difference in mean skeletal BMD between the women with and the women without translucent spots ($P < .05$). Another irregularity in the trabecular system was that the whole area under the molar apices could be deprived of trabeculae. This feature was seen both in patients without osteopenia and in patients with osteopenia.

The coarseness of trabeculation was correlated with skeletal BMD ($r = 0.62$, $P < .001$). The coarseness of trabeculation was not significantly correlated with age, MABM, or interdental thickness. The coarseness of trabeculation and age were both highly statistically significant explanatory variables when skeletal BMD was used as a dependent variable in a multiple regression analysis ($R^2 = 0.52$, $P < .001$).

DISCUSSION

The results of this study showed that the alveolar trabecular pattern may be a useful and simple warning signal in the detection of osteopenia or osteoporosis in a patient. Furthermore, it was found that the interdental thickness is a significant parameter in the relationship between the MABM and the skeletal BMD. The MABM was also correlated statistically with skeletal BMD in a simple linear regression analysis. However, estimating MABM is time-consuming, and the clinical relevance was as little as in previous investigations.[4-6] Horner et al[7] used DXA both in the mandible and in the forearm and found a better correlation, but the DXA technique in the mandible is difficult and expensive—and it can only be used in edentulous areas.

A highly significant correlation between skeletal BMD and the interdental thickness of the mandibular alveolar process was found in an earlier study.[23] In the present investigation, the interdental thickness improved the correlation between mandibular bone mass and skeletal BMD, but it did not seem to affect the coarseness of trabeculation. Dense trabeculation was seen both in subjects with thin alveolar processes and in subjects with broad alveolar processes. The correlation between the skeletal BMD and the shape of the alveolar process has also been studied.[23] The correlation found ($r = 0.91$-0.95, $P < .001$) was highly significant, but it was based on a population of dentate women between 38 years and 67 years with no torus mandibularis. In the present investigation, all ages between 20 years and 78 years were represented and no patients were excluded because of torus mandibularis.

The evaluation of the trabecular network of the alveolar process with the classification proposed by Lindh et al[21] seems to be a quick and simple way to correctly classify the patients with the highest and the lowest skeletal BMD. Dense trabeculation was a very strong indication of high skeletal BMD and high mandibular bone mass. Similarly, sparse trabeculation was a strong indicator of osteopenia. The middle group, with alternating dense and sparse trabeculation, could not be correctly diagnosed only by assessing the trabecular pattern, but the presence of dark spots/interruptions in the trabecular network was a sign of osteopenia that should lead to inclusion of osteoporotic risk factors in the medical history. The risk factors and the close correlation between the mandibular alveolar shape and the skeletal BMD[23] could also be used as tools in the evaluation of patients with alternating dense and sparse trabeculation.

Lindh et al[21] used trained oral specialists with experience in implant treatment to study the trabecular pattern of the mandibular bone in autopsy specimens. The accuracy of their classification compared with the outcome of the total trabecular bone volume measurement was 78% for the radiographs with dense trabeculation, but their agreement was lower for sparse (28%) and for alternating dense and sparse trabeculation (57%). Similarly, the interobserver and intraobserver agreement was higher for dense trabeculation.

When the trabeculation was assessed as dense or sparse in our investigation, the requirement was that the whole network seen on the premolar radiograph should have the same coarseness of trabeculation, whereas when the trabeculation was assessed as alternating dense and sparse, the network was not regular in coarseness. The most common feature of irregularity was that the network apical to the molars was very sparse or could be missing. Parfitt[29] described this feature as an apparent empty space under the molar roots resembling a cystic area. Often the trabeculae seemed thinner in the whole molar area. von Wowern[30] found this variation in trabecular structure in the mandibular body in 24 autopsy specimens. Another feature of irregularity was small interruptions in the trabecular network, mostly seen interdentally between the premolars and between the second premolar and the first molar. These small holes in the network (Fig 3) were found in the 3 osteoporotic patients; 2 of them had severe risk factors. The finding of interruptions in the trabecular network could be similar to the condition described as *focal osteoporotic bone marrow defects*.[26,27] According to Parfitt,[31] rapid bone loss results in perforation of the trabeculae and larger marrow spaces in trabecular bone, most commonly after menopause. It is therefore not surprising that these larger marrow spaces can be seen in apical radiographs.

Our results are also in line with those of Taguchi et al,[22] who compared the trabecular bone pattern of edentulous mandibles visualized by panoramic radiography with mandibular BMD measured by means of computed tomography. They used a classification that was based on the thickness of the trabeculae. The principal contribution of the present study is found in its evaluation of the trabecular pattern in dentate women who represented the population of female patients treated by the public dental service. Furthermore, in our investigation the trabecular bone pattern was related to the BMD of the forearm, whereas Lindh et al[21] and Taguchi et al[22] related the bone pattern to other mandibular radiographic measurements before implant treatment. We chose bone mass measurement of the forearm because it is a recognized method for estimating the future risk of osteoporosis,[2,32] although other investigators recommend axial measurement with more trabecular bone. The rationale for using forearm measurement as the gold standard in the present investigation is that the distal forearm at the measurement area consists of 87% cortical bone and 13% trabecular bone,[33] and similar proportions are found in the mandibular premolar area.[30]

The main source of errors with radiographs is the development procedure. It is advisable to use digital radiographs to avoid these errors, but they probably do not provide a better result with respect to the evaluation of the coarseness of trabeculation. The trabecular network is not seen better on digital radiographs, as demonstrated by Kullendorff et al,[34] who tested periapical bone lesions both with conventional periapical radiographs and with direct digital imaging of the same area. They found that conventional film radiography performed slightly better with respect to detection of bone lesions than digital radiography.

Hildebolt et al[14] compared the DXA of the radius and the alveolar bone mineral content based on grayscale values from digitized bite-wings of 9 patients. They found a correlation that is similar to ours ($r = 0.5$-0.6). Furthermore, they found that the patients with the highest fracture risk had “the poorest alveolar bone health” and that the patients with the best skeletal BMD had “the best alveolar bone health,” which is in line with our findings, which show that sparse trabeculation was found in patients with the lowest BMD and dense trabeculation was found in patients with the highest skeletal BMD. The radiographs from our study showed that the discriminating area for bone evaluation to detect osteopenia is the apical half of the interdental bone. Periapical radiographs should therefore be more useful than bite-wings. In the future, when direct digital imaging technology is more widespread than it is now, it likely will provide a highly efficient tool for measuring the quantity and quality of the alveolar bone. Until then, a simple evaluation of the coarseness of trabeculation could be useful in the prediction of the risk of fracture.

The loading of the mandibular bone during mastication influences the mandibular bone density both in local and in remote areas.[35] Even if metabolic disturbances are induced, the mechanical load on the bone has a major effect on the development of the trabecular pattern.[36] The functional factor has not been evaluated in the present study, although it may have contributed to the form and structure of the alveolar trabecular pattern. Therefore, further studies are necessary to test the influence of the functional factor with respect to the alveolar trabecular pattern and a given BMD.

In conclusion, this study has shown that the trabecular pattern can be used as a warning signal in the detection of osteopenia or osteoporosis in human patients. We have found that dense trabeculation is a reliable sign of normal BMD, whereas sparse trabeculation indicates osteopenia. Alternating dense and sparse trabeculation was found both in patients with low and in those with normal BMD, but the existence of translucent lesions is a sign of low BMD. The mandibular alveolar bone mass was significantly correlated with the skeletal BMD, and the correlation was improved by adding the interdental alveolar thickness. However, the practical value of this method is less when compared with that of the evaluation of the trabecular pattern as a screening procedure to detect osteopenia and osteoporosis among women.

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