Cervical thickness of the mandibular alveolar process and skeletal bone mineral density

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Much effort has been devoted to finding methods for detecting individuals with low bone mass and risk of osteoporotic fractures. The aim of the present study was to investigate whether there is a relationship between the thickness of the alveolar process and the bone mineral density (BMD) of the distal forearm. In 24 women (38–65 years), the BMD of the distal forearm, obtained by dual X-ray absorptiometry, was correlated to the *difference* between two measures of the thickness of the mandibular alveolar process in the region of the first premolar. A highly significant correlation ($r = 0.95$, $P < 0.001$) was found. The method was cross-validated by using the equation obtained from the linear regression analysis above to predict BMD in two other groups. In both groups, the correlation betweeen the measured BMD of the forearm and the predicted BMD was highly significant ($r = 0.91$, $P < 0.001$). The interdental thickness between the canine and the second incisor was also correlated to BMD, but with lower predictive value ($r = 0.67$, $P < 0.001$). Measurements of the mandibular alveolar process can be used as one of several parameters to predict skeletal bone density. □ *Mandible morphology; osteoporosis; postmenopausal; prediction*

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Osteoporosis is a disease characterized by a decrease in bone mass and deterioration in bone microarchitecture. It leads to a greater risk of fracture of the forearm, spine and hip of elderly women and men, with all the negative consequences for the individual and society. It is important to detect osteoporosis before the development of secondary complications in order to maintain the quality of life of elderly subjects. Low bone mineral density is an important factor when determining fracture risk. Nowadays, skeletal bone mineral density (BMD) is mostly measured by SXA (single X-ray absorptiometry) and DXA (dual X-ray absorptiometry). A site which is often used for BMD measurements is the distal forearm, which consists of 87% cortical bone and 13% trabecular bone (1). Similar proportions have been found in the dentate premolar region of the mandible (2). Analyses carried out by von Wowern (3) and Klemetti et al. (4) have shown that bone mass in the mandible corresponds well with bone mass in the cortical bones of the skeleton, such as the forearm bones. Furthermore, Kribbs et al. (5) have found a correlation between the bone mass of the mandibular alveolar process in the region mesial of the first molar and the radial bone mineral content. Animal experimental studies have shown that there is a direct relation between the thickness of the alveolar process and its radiologically measured bone mass (6). Thus, a relation could exist between the bucco-lingual thickness of the mandibular alveolar process and the bone mass in the forearm of human individuals.

The purpose of the present study was to develop a method to predict the bone mineral density of the distal forearm in dentate postmenopausal women by measuring the bucco-lingual dimensions of the mandibular alveolar process.

Materials and methods

Subjects

Three groups of peri- and postmenopausal women were studied. One group was used to develop a method with a good coefficient of reliability and a high correlation to BMD. In order to make a cross-validation, this method was later used in 2 other groups to evaluate whether the skeletal bone density (the forearm) could be predicted by measurements of the alveolar process. The patients in the 3 groups had no deepened pockets in the premolar region. All but 1 patient had an intact crestal lamina dura and an apparently healthy gingiva. There was no history of dental trauma or orthodontic treatment, which could have affected the bone and the roots.

Group A consisted of 24 women with a mean age of 50 years (range 38–65), all of them registered with the public dental service (Folktandvården Tullen, Borås, Sweden). The criterion for participation was that the subjects were dentate individuals with at least 2 mandibular premolars on one side. Exclusion criteria were torus mandibularis, extreme gingival recession, advanced periodontal disease and major malposition. Twenty-three subjects had all 4 mandibular premolars and 17 subjects had all the mandibular molars. Four were smokers, 4 were under hormone replacement therapy, 2 patients had had a hysterectomy with ovarian conservation, and 1 patient had been operated on for cancer.

Group B included 24 women, also patients registered with the public dental service. The group had the same criterion for participation as group A. The mean age was 52.5 years (range 40–67). Six were smokers, 7 had hormone replacement therapy, 2 patients had had a hysterectomy with ovarian conservation, and 1 patient had had both ovaries removed. One patient had been operated on for cancer. The members of both groups A and B had been asked to participate when they underwent their annual oral examination.

Group C included 24 healthy perimenopausal women. They were taking part in an investigation of climacteric symptoms. Twenty-four out of 28 invited persons participated in the investigation. They were not registered with the public dental service. This group was homogeneous in age, health and lifestyle. The mean age was 50.5 years (range 47–55). Three of the women were smokers. None of them had had hormone replacement therapy or any other medicine.

The study was approved by the Ethics Committee of Göteborg University, Dnr. S58-95, March 1995.

BMD of the forearm

The BMD was determined in the distal forearm in the non-dominant arm. Both radius and ulna were scanned from the point where the distance between radius and ulna is 8 mm to 24 mm proximal to this point. Two different methods were used to determine BMD: DXA measurements made with Osteometer DTX-200 (7) and SXA measurements made with Osteometer DTX-100 (8). Both systems have an X-ray source located on one side of the forearm and a detector located on the other. During an examination, the source and the detector move synchronously. The X-ray signal registered at the detector is inversely proportional to the amount of bone present. The patients were subjected to a low radiation dose, below 2 mrem during the X-ray scan. The dose to the operator is also low, and no shielding is required. The measurements determined BMD as a percentage and the standard deviation indicates whether the patient has normal values or osteopenia or osteoporosis. The participants in groups A and B got a DXA measurement. Group C got a SXA measurement.

Oral measurements

Thickness of the mandibular alveolar process.—Measurements of the thickness of the mandibular alveolar process were performed on dental casts at different predetermined sites using a dial caliper (Kori-HSL 6871-0201 range 0–15 mm or Kori-HSL 250-00 range 0–10 mm) to estimate the thickness of the bone in the cervical part of the alveolar process, both at the middle of the roots of the teeth (dental alveolar thickness) and between two adjacent teeth (interdental alveolar thickness). *Dental alveolar thickness*:

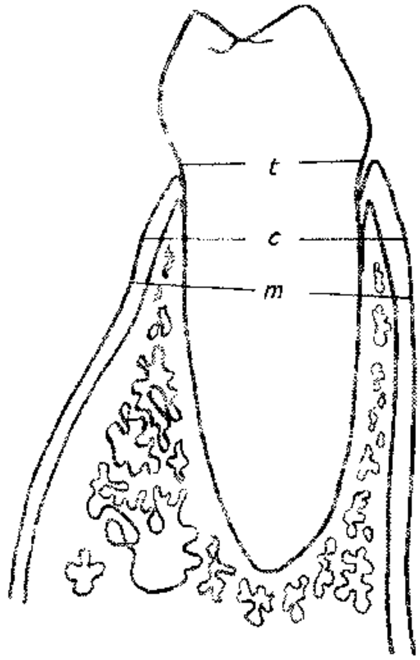

Fig. 1. Dental alveolar thickness. Measure t is the bucco-lingual dimension of the tooth at the cemento-enamel junction. Measure c is the cervical crestal thickness of the alveolar process 2.5 mm midbuccal and 2 mm midlingual apically from the cemento-enamel junction in the attached gingiva. Measure m is the mid-crestal thickness of the alveolar process midbuccally 6 mm from the cemento-enamel border and midlingually 5 mm from the cemento-enamel junction at the muco-gingival junction.

Three bucco-lingual dimensions were measured (Fig. 1). Measure c was made at a location 2.5 mm midbuccal and 2 mm midlingual apically from the estimated level of the cemento-enamel junction. This measure denotes the cervical crestal thickness of the alveolar process. Measure m was taken midbuccally 6 mm and midlingually 5 mm from the estimated level of the cemento-enamel junction. This measure denotes the mid-crestal thickness of the cervical part of the alveolar process. Measure t was the bucco-lingual dimension of the tooth at the estimated level of the cemento-enamel junction. All measures were in mm. The mean values of each pair of symmetrical teeth were calculated. *Cervical crestal bone mass:* The difference $c - t$ was used as an indicator of the amount of bone that surrounds the root at the level of c. *Mid-crestal bone mass*: The difference $m - t$ was used as an indicator of the amount of bone that surrounds the root at the level of m. *The cervical alveolar shape:* The difference $m - c$ between the upper and lower thickness denotes the shape of the cervical alveolar process. When the value of m was smaller than c, the alveolar process converged towards the basal part (Fig. 2A). When m was larger than c, the alveolar process diverged from the crest to the basal part (Fig. 2B). *Interdental alveolar thickness:* The bucco-lingual thickness of the cervical part of the alveolar process between adjacent teeth was measured 6 mm from the alveolar crest corresponding to measure *m*. In group A, all the defined measurements evaluating the dental and interdental alveolar thickness were performed for all teeth. Concerning dental alveolar thickness, only measures of one premolar were performed in groups B and C. The standard tooth was 44, but in subjects with interfering frenula or malposition the contralateral tooth was chosen. Concerning interdental alveolar thickness, only measures between the canines and the second incisors were performed in groups B and C.

Thickness of maxillary alveolar process.—The dental alveolar thickness. The cervical crestal thickness was taken 4 mm from the cemento-enamel junction at the middle of each tooth (*c*), and the *mid-crestal thickness* was measured at a level of 7 mm more apically from the cemento-enamel junction (*m*). Measures *c* and *m* were taken with a caliper (Inox 6006-0100). The bucco-lingual dimension of each tooth (*t*) was measured with a dial caliper (Kori-HSL 6871-0201 range 0–15 mm). The mean values of all three measures were calculated for each tooth pair. *The interdental alveolar thickness* was taken at the same level as *m*. Only the subjects in group A were measured in the maxilla.

Questionnaire

All women were interviewed about lifestyle factors, medical and dental story.

Statistical methods

In group A, the Pearson correlation coefficient (r) was used to assess the amount of agreement between BMD and the alveolar measures (mean value of the 2 sides of the mandible and the maxilla) in order to develop a method for predicting BMD. Furthermore, regression analyses of BMD were performed on the 3 bucco-lingual dimensions of the alveolar process (tooth 44), the cervical alveolar shape ($m - c$), the cervical crestal bone mass ($c - t$) and the mid-crestal bone mass ($m - t$). This time the value of only one side was used in order to obtain the value that best represented the subject and the value least influenced by torus mandibularis, gingival recession, frenula and malposition because of extraction or crowding. A paired t test was performed between the cervical alveolar shape corresponding to tooth 44 and tooth 34 to evaluate if there was any significant difference in size. A cross-validation was performed by using the results from the regression analysis of BMD on the cervical alveolar shape ($m - c$) in group A for predicting BMD of the forearm in groups B and C. The predicted BMD and the corresponding observed BMD of the radius were correlated by linear regression analyses.

Reliability of measurements

Duplicate measurements were performed on all teeth in the mandible and on the second premolar and first molar in the maxilla regarding measure *a*. 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 two measurements. The reliability was calculated according to a method proposed by Houston (9): $1 - S_e^2 / S_i^2$(S^2_i is the total variance of the measurement). For measure *c*, the best reliability was obtained for the first and second premolars (99% and 98% in the mandible, 94% in the maxilla) and the lowest reliability for the molars (86% in the mandible and 63% in the maxilla). Duplicate measurements were then performed of *c* and *m* on tooth 44 in 20 casts at an interval of 1 week, and the error of the method for *c*, *m* and $m - c$ was calculated. For measure *c*, the result was $S_e = 0.06$ mm, for *m* 0.06 mm and for $m - c$ 0.05 mm. The corresponding reliability for these 3 values was 99%. Similarly, duplicate measurements of 20 casts were performed for the interdental thickness between the canine and the second incisor. The error of the method was 0.09 mm and the reliability 97%.

An intraobserver analysis was made for BMD obtained by DXA: linear regression analysis of values from an automatic procedure and a more individual procedure showed a highly significant correlation ($r = 0.95$, $n = 21$, $P < 0.001$) and the error of standard deviation was $S_e = 4.13\%$. Eleven patients had both DXA and SXA measurements within a week: the linear regression analysis gave a highly significant correlation coefficient ($r = 0.95$, $n = 11$, $P < 0.001$), and the error of the standard deviation was $S_e = 4.96\%$ between SXA and DXA measurements.

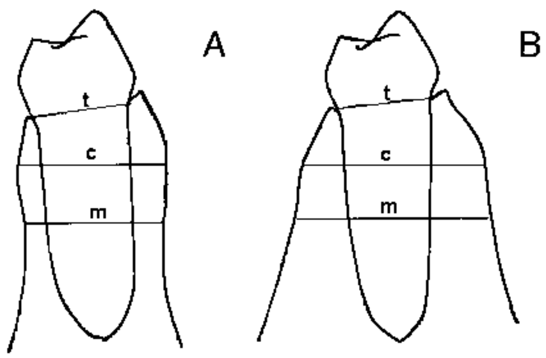

Fig. 2. Cross-section of tooth 44. The cervical alveolar shape ($m - c$) demonstrates the convergence of the cervical part of the alveolar process. When the value of *m* is smaller than *c*, the alveolar process converges towards the basal part (Fig. 2A). When *m* is larger than *c*, the alveolar process diverges from the crest to the basal part (Fig. 2B). *Cervical crestal bone mass:* The difference $c - t$ is an indicator of the amount of bone that surrounds the root at the level of *c*. *Mid-crestal bone mass:* The difference $m - t$ is an indicator of the amount of bone that surrounds the root at the level of *m*.

Results

Development of method

BMD of the forearm.—The mean value of age-related BMD of the forearm in group A was 93% (66–117%). In group B the mean value of BMD was also 93% (74–105%); in group C it was 94% (77–117%).

Questionnaire.—Regression analyses of BMD and different lifestyle factors had no significant correlation in this investigation. Mean BMD for 11 women with hormone replacement therapy was significantly higher than BMD for the remainder of the group (98%). Hysterectomy with or without ovarian conservation did not change mean BMD in this investigation (hormone replacement therapy was applied) nor did smoking.

Thickness of the mandibular alveolar process.—*Dental alveolar thickness.* Cervical crestal thickness (c), mid-crestal thickness (m) and the bucco-lingual dimension of the tooth (t) were measured for all teeth in the mandible. All dimensions gradually increased from the incisors to the molars. Only the dimensions for the canines interrupted the pattern (Fig. 3). A regression analysis of cervical crestal thickness (c) on the bucco-lingual dimension of the tooth (t) gave a highly significant result ($r = 0.90$, $n = 24$, $P < 0.001$). A regression analysis of mid-crestal thickness (m) on the bucco-lingual dimension of the root (t) gave a significant result ($r = 0.74$, $n = 24$, $P < 0.001$), too.

The cervical alveolar shape ($m - c$) demonstrates the convergence of the cervical part of the alveolar process. When the value of m is smaller than c, the alveolar process converges towards the basal part (Fig. 2A). When m is larger than c, the alveolar process diverges from the crest to the basal part (Fig. 2B). For patients with BMD less than 100%, the value of m was lower than the value of c in all cases except 3, and $m - c$ was then mostly negative. For patients with BMD greater than 100%, the value of m was higher than c in all cases except 1. The value $m - c$ was therefore mostly positive. A paired t test between $m - c$ of tooth 44 and $m - c$ of tooth 34 in 20 casts did not reveal any difference between the measurements of the two sides ($P = 0.878$). Similarly, a regression analysis of $m - c$ of tooth 44 versus 34 gave a highly significant result ($r = 0.97$, $n = 20$, $P < 0.001$). *Interdental alveolar bone thickness.* All dimensions gradually increased from the incisors to the molars. Only the dimensions for the canines interrupted the pattern. Regression analyses between dental and corresponding interdental alveolar bone thickness gave a highly significant result ($r = 0.75$ for the first molar and $r > 0.80$ for the rest of the teeth).

Thickness of the maxillary alveolar process in group A.—The reliability of measurements of alveolar bone thickness in the lateral segments of the maxilla was not as good as in the mandible. Besides, the rugae area prevented a reasonable measurement in the frontal segment. *Dental alveolar thickness:* The bucco-lingual dimensions of the first molar and of the second premolar were greater than those of the mandible. Similarly, the crestal alveolar thickness dimensions were greater than those of the mandible. *Interdental alveolar bone thickness:* Even in the maxilla the correlation was high between dental and interdental alveolar bone thickness and between the dental alveolar thickness of one tooth and that of adjacent teeth.

Regression analyses between BMD and mandibular cervical thickness.—*Dental alveolar bone thickness.* The linear regression analyses gave far better coefficients of correlation between BMD and measure m (Table 1) than between BMD and measure c, but the best correlation was between BMD and *the cervical alveolar shape* ($m - c$) in the region of the first premolar: $r = 0.90$ when the mean value of $44 - 34$ was used (Table 1), but $r = 0.95$ when only 44 was used. The linear regression analysis of BMD on the cervical alveolar shape ($m - c$) gave the following equation: $y = 23.2x_1 + 97.4$, where y denotes BMD and x_1 denotes ($m - c$). *Mid-crestal bone mass:* Linear regresssion analysis of BMD on ($m - t$) gave a highly significant result ($r = 0.70$, $n = 24$, $P < 0.001$ in the region of the first premolar). *Cervical crestal bone mass.* No statistically significant correlation was found between BMD and ($c - t$). *Interdental alveolar bone thickness.* There was a strong correlation between BMD and interdental thickness between the first premolar and the canine, between the canine and the second incisor and between the incisors (Table 1).

Application of method

Prediction of skeletal bone mineral density.—In order to make a cross-validation, the equation obtained by the linear regression analysis of BMD of the forearm and the cervical alveolar shape ($m - c$) of the first premolar in the mandible: $y = 23.2x_1 + 97.4$ ($r = 0.95$, $n = 24$, $P < 0.001$) was used to estimate BMD in group B and group C. The predicted PMD values were compared to the observed values from the DXA and SXA measurements. Linear regression analysis of predicted BMD versus observed BMD gave a highly significant result ($r = 0.91$, $n = 24$, $P < 0.001$ for group B). In the unselected group C, three individuals were excluded from the group due to the presence of torus and malposition. A highly significant result of regression analysis of predicted BMD versus observed BMD was also found in group C ($r = 0.90$, $n = 21$, $P < 0.001$ for group C).

Discussion

This investigation has shown a strong correlation between the cervical alveolar shape of the mandible and the BMD of the distal forearm of all dentate postmenopausal women studied. Cross-validation showed that the findings obtained from the first group could be applied to 2 other independent groups with strong predictive power. A

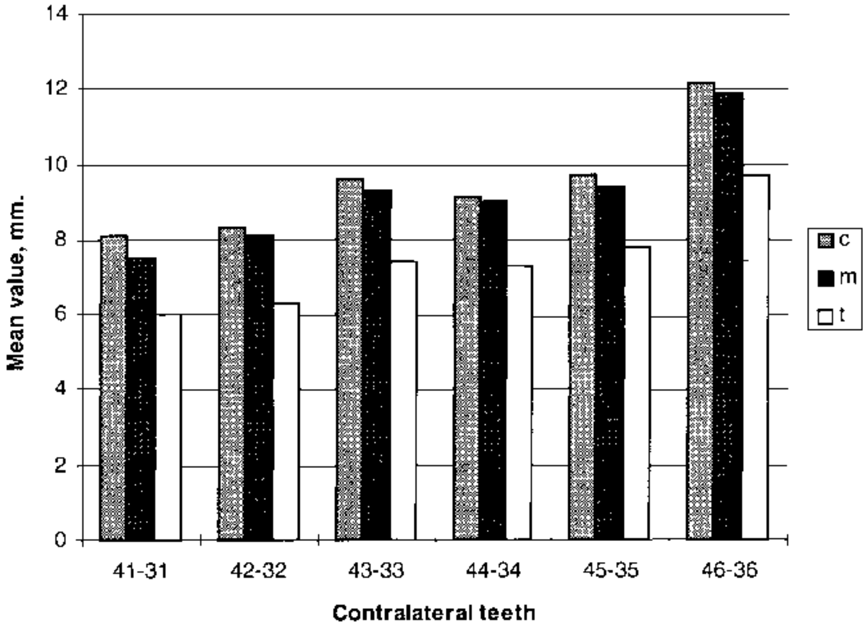

Fig. 3. Dental alveolar thickness in group A. Bucco-lingual measurements of the cervical alveolar process for developing the method. The mean values of contralateral teeth (mm) regarding cervical crestal thickness (*c*) of the alveolar process, mid-crestal thickness (*m*) of the alveolar process and bucco-lingual dimension of the tooth (*t*).

correlation was also found between BMD and the interdental thickness of the mandibular front region. Regardless the cause of osteopenia, secondary causes or lifestyle factors, it seems that our variables can be used.

In animal studies, Bresin et al. (6) have shown that, in rats with decreased masticatory function, the thickness of the molar alveolar process was smaller than that of rats with normal function. In addition, bone quantity and bone quality were poorer in the group with decreased function. In this investigation we also found a highly significant correlation between the thickness of the alveolar process and BMD, but the predictive power was better using the cervical alveolar shape, which demonstrates the convergence of the cervical part of the alveolar process.

The prediction based on cervical alveolar shape has limitations due to torus mandibularis, extreme gingival recession, frenula and major malposition. However, despite these limitations, only 7 persons out of 55 were excluded when forming the 2 groups (A and B). Three individuals were excluded from the unselected group C. The area around the first premolar was better than around other teeth. Use of the cervical alveolar shape and not the thickness was a way to reduce the influence of the bucco-lingual dimension of the root. Aware of the conic form of the root, the measure *t* has been used as indicator on all 3 sites (*t*, *c* and *m*). The proximity of the 3 sites measured ensures that the variations in bucco-lingual root dimension are minor. Furthermore, by taking the difference between 2 measures we also diminished the importance of the gingival thickness as an interfering factor. An advantage of

Table 1. Spearman's correlation coefficients *r* for the relationship between BMD (bone mineral density in the distal forearm, expressed as a percentage of mean BMD of age-related women) and the mean value of dental alveolar thickness (bucco-lingual dimension of the alveolar process 2 mm lingually and 2.5 mm buccally from cervix (*c*) and 5 mm lingually and 6 mm bucally from cervix (*m*) at the middle of the root) for contra-lateral teeth of the mandibular and maxillar alveolar process (group A)

	41–31	42–32	43–33	44–34	45–35	46–36	16–26	15–25
r_c	0.27	0.34	0.41*	0.10	−0.05	−0.08	0.37	0.38
r_m	0.26	0.55**	0.55**	0.45*	0.34	0.07	0.25	0.36
r_{m-c}	0.02	0.49*	0.45*	0.90***	0.69***	0.26	−0.03	−0.04
r_{int}	0.58**	0.62**	0.67***	0.61**	0.52**	0.43*	0.34	0.45*

* p <0.05, ** p <0.01, *** p <0.001.

† *c* = the cervical crestal thickness; *m* = the mid-crestal thickness; *m* − *c* = the cervical alveolar shape; *int* = the interdental alveolar thickness mesially for the teeth mentioned.

this method is that no extra examinations and equipment (panoramic radiographs) were required.

Other oral variables that may distinguish the osteoporotic patient have been investigated previously. In dentate subjects, Kribbs et al. (10) found a statistical correlation between radius and the cortical thickness at the gonium ($r = 0.46$, $n = 85$, $P < 0.001$). Furthermore, Goldberg et al. (11) found a correlation between the ratio of the radiographic height of the alveolar process to the mandibular height and the bone mineral content of the radius ($r = 0.7$, $n = 17$, $P < 0.005$). Both methods mentioned previously are based on measurements on panoramic radiographs.

This investigation shows that cervical crestal thickness is highly correlated to the bucco-lingual dimension of the tooth. The cervical part of the alveolar process consists mainly of cortical bone ending up cervically at the 'cortical curvature' of the crestal lamina dura. The lower correlation found between the mid-crestal thickness and the bucco-lingual dimension of the tooth indicates that factors other than the tooth dimension determine the thickness of the alveolar process in this region. One of these factors could be BMD being most influential in the mandibular premolar region. The mid-crestal region has relatively more trabecular bone, which is more affected by osteopenia after the menopause. The investigation indicates that the mid-crestal thickness is smaller than the cervical crestal thickness in osteopenic women. It is, however, the same or greater in non-osteopenic women. Since the investigation was cross-sectional, the change in shape that occurred in the mid-crestal area in connection with the menopause in osteopenic women has not been shown, but the high predictive value, based on cervical alveolar shape, does indicate that external changes take place in the alveolar process in women, depending on their BMD level and age.

In previous investigations, the observed alveolar changes have been reduction in crest height and thickness in edentulous individuals (10, 12). To our knowledge, external thickness changes in dentate areas have not been described earlier.

Michaëlsson et al. (13) have shown that weight of over 71 kg is associated with a very low risk of becoming osteopenic compared with women weighing less than 64 kg. Similarly, Klemetti et al. (12) have shown, using the body mass index, that the size of an individual may play an important role in the destiny of the alveolar bone after tooth extraction. The residual ridge in obese subjects was less reduced. A possible explanation is that the jaws of heavy subjects are probably more massive and thicker than the jaws of smaller individuals. Consequently, they have more bone to lose, and the shape will remain stable for a longer period.

Bone loss starts in the third and fourth decade, but the pattern of bone loss differs between cortical and trabecular bone, the cortical bone being less affected (14). Age-related bone loss in trabecular bone leads to thinning (and later perforation) of the trabeculae. Bone loss in cortical bone leads to increased porosity and conversion of the inner third of the cortex to a trabecular-like structure. The result of these changes is a reduction of bone strength (15). Atkinson & Woodhead (16) found that the alveolar cortical bone in the premolar region was more porous with increasing age than its associated mandibular basal bone. Additionally, they found that the density of the buccal alveolar cortex in the incisor and premolar region falls rapidly with age, whereas on the lingual surface it does not. The trend is reversed in the molar area. Such alternating low density indicates an uneven porosity distribution which might explain changes in the cross-sectional shape of the alveolar process with age. Klemetti et al. (4) also found significant correlation between the BMD of the radius and the density of the mandibular buccal cortex.

Kiliaridis et al. (17) found significant differences in bone mass in the alveolar bone of rat molars between groups with different functional demands. Thus function and occlusal loading may be factors that are likely to influence the cervical alveolar shape in regions where the main masticatory performance takes place. This could be one of the underlying reasons for the low correlation found between the measures of the dental alveolar thickness of molars and BMD. Further studies are necessary to investigate the role of these factors in the shape and transverse dimensions of the alveolar process. Even young premenopausal women and male patients in all ages should be investigated to see if the alveolar shape or the interdental thickness could be useful when identifying osteoporotic patients.

Conclusions

The difference between two measures of the thickness of the mandibular alveolar process in the region of the first premolar was highly correlated to the BMD of the forearm in perimenopausal women. Furthermore, there was a strong correlation between the interdental thickness between the second incisor and the canine and the bone mineral density of the forearm. Morphological measurements of the mandibular alveolar process may be useful in future screening procedures for osteoporosis.

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