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ORIGINAL ARTICLE

Computer-aided system for measuring the mandibular cortical width on dental panoramic radiographs in identifying postmenopausal women with low bone mineral density

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Abstract *Introduction:* Mandibular inferior cortical width manually measured on dental panoramic radiographs may be useful for identifying postmenopausal women with low skeletal bone mineral density (BMD). Automatic measurement of cortical width may enable us to identify a large number of postmenopausal women with suspected low skeletal BMD. The purposes of this study were to develop a computer-aided system for measuring mandibular cortical width on dental panoramic radiographs and clarify the diagnostic efficacy of this system. *Methods:* Panoramic radiographs of 100 postmenopausal women who had had BMD assessments of the lumbar spine and the femoral neck were used in this study. Experienced oral radiologist determined the position of the mental foramen on 100 digitized dental panoramic radiographs. After determination of the mental foramen, mandibular cortical width below the mental foramen was measured automatically with a computer-aided system by identifying the area of interest, enhancing the original image, determining inner and outer margins of the cortex, and selecting an appropriate point. Cortical width measured by this system was compared with BMD of the lumbar spine and the femoral neck. *Results:* There were statistically significant correlation between cortical width measured by the computer-aided system and spinal BMD (r=0.50) and femoral neck BMD (r=0.54). These correlations were similar with those between cortical width by manual measurement and skeletal BMD. Sensitivity and specificity for identifying postmenopausal women with low spinal BMD by the computer-aided system were about 88.0% and about 58.7%, respectively. Those for identifying postmenopausal women with low femoral neck BMD by this system were about 87.5% and about 56.3%, respectively. *Conclusion:* Our results suggest that our computer-aided system may be useful for identifying postmenopausal women with low skeletal BMD.

Keywords Computer-aided · Mandible · Menopause · Osteoporosis · Panoramic radiograph

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Introduction

Osteoporotic fractures are a health burden worldwide, resulting in reduction of physical activity, increased risk of mortality, and incremental medical cost. Since incidence rates of osteoporotic hip fracture increase exponentially with aging, this demographic change alone should cause the number of hip fractures worldwide to rise from about 1.3 million in 1990 to an estimated 4.5 million in 2050 [1]. The U.S. Surgeon General's report recently states that by 2020, half of all Americans over 50 will have weak bones if individuals at risk, doctors, health systems, and policy-makers take no immediate action [2]. Since bone fragility is mainly dependent on skeletal bone mass or bone mineral density (BMD), several types of equipment have been developed to assess skeletal BMD and predict fracture risk from osteoporosis. BMD at the lumbar spine and femoral neck are typically assessed using dual-energy X-ray absorptiometry (DXA); however, availability of DXA equipment is still too limited to identify a large segment of individuals with undetected osteoporosis [3]. Furthermore, it is likely that individuals with a high risk of osteoporosis, especially postmenopausal women, may not visit medical professionals to take BMD assessment if they have no symptoms or are uninformed about osteoporosis.

Postmenopausal women may have greater opportunity to visit dentists for treatment of dental caries and periodontal disease than to visit medical professionals for diagnosis of osteoporosis. A large number of dental panoramic radiographs were taken for diagnosis of teeth and jaws in general dental practice. Since several studies have pointed out that mandibular inferior cortical width below the mental foramen, which is manually measured on dental panoramic radiographs, may be useful for identifying postmenopausal women with low skeletal BMD or osteoporosis [4–11], dentists may be able to identify postmenopausal women with suspected low skeletal BMD or osteoporosis by incidental finding on dental panoramic radiographs without additional cost and refer them to medical professionals for BMD assessment. However, it is not practical to measure cortical width manually on dental panoramic radiographs for identifying postmenopausal women with low skeletal BMD. The automatic measurement of cortical width on dental panoramic radiographs may enable us to identify a large number of postmenopausal women with low skeletal BMD. It is possible that an automatic measurement system on digital dental panoramic radiography, which has recently spread around the world [12], might be used for mass screening of low skeletal BMD or osteoporosis in the future.

The purposes of this study were to develop a computer-aided system for measuring cortical width of the lower border of the mandible below the mental foramen and to clarify diagnostic efficacy of this system for identifying postmenopausal women with low skeletal BMD.

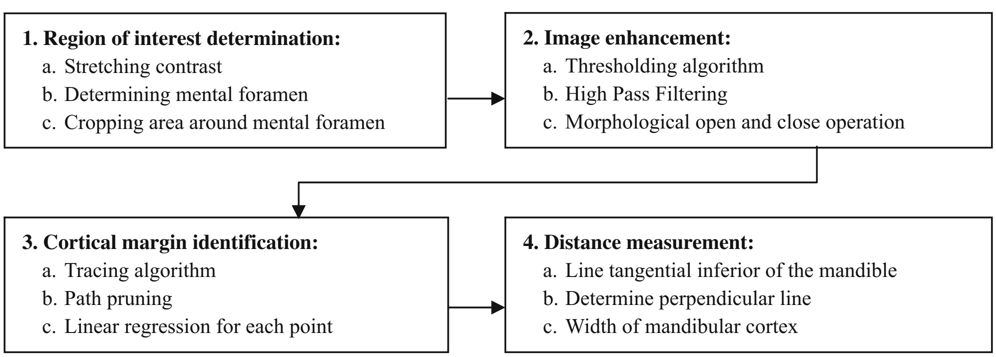
Materials and methods

Subjects and panoramic radiography

Of 531 women who visited our clinic for DXA measurement between 1996 and 2001, 100 postmenopausal women aged 50 years or older with no previous osteoporosis diagnosis (mean 59.6 years; range 50–84 years) were randomly recruited for this study. Panoramic radiography was taken for all subjects with informed consent at the time of DXA measurements of the lumbar spine (L2–L4) and the femoral neck (DPX-alpha, Lunar Co., Madison, WI, USA). None of the subjects had metabolic bone disease (hyperparathyroidism, hypoparathyroidism, Paget's disease, osteomalacia, renal osteodystrophy, or osteogenesis imperfecta), cancers with bone metastasis, or significant renal impairment or were taking medication that affect bone metabolism, such as estrogen. None had a history of smoking, and none had bone-destructive lesions in the mandible. No subject had menstruated for at least 1 year. When using the definition of the Japanese Society for Bone and Mineral research [13], 54 of the 100 women presented normal BMD (BMD more than 80% of Japanese young adult mean), 21 osteopenia (70–80%), and 25 osteoporosis (less than 70%) in the lumbar spine. Forty-seven had normal BMD, 24 osteopenia, and 24 osteoporosis in the femoral neck. Five women did not have DXA of the femoral neck. The rate of women with osteoporosis in the lumbar spine in our study was similar to that (26%) in 1,033 postmenopausal women aged 50 years or older in the Adult Health Study (AHS) cohort in Japan [14].

All panoramic radiographs were obtained with a AZ-3000 (Asahi Co., Kyoto, Japan) at 12 mA and 15 s; kVp varied between 70 and 80. Screens of speed group 200 (HG-M, Fuji Photo film Co., Tokyo, Japan) and film (UR-2, Fuji Photo Film Co., Tokyo, Japan) were used. Appearance of the mandibular inferior cortex was bilaterally clear in the radiographs. All radiographs were digitalized with the resolution of 300 dpi using a flat-bed scanner (ES-8000, Epson, Japan).

Fig. 1 Schematic diagram for the algorithm of measuring cortical width



Development of a computer-aided system for cortical-width measurement

The schematic diagram of the proposed computer-aided system includes identifying the area of interest, enhancing the original image, determining inner and outer margins of the cortex, and selecting an appropriate point at which the width can be measured (Fig. 1). Details of image processing employed in the measurement were explained in our recent study [15]. This system was run on a Pentium 4 (CPU 1.80 GHz) with 1 GB of RAM.

Region of interest determination

Since automatic detection of the mental foramen of the mandible is difficult, the examiner assisted in determining the position of the mental foramen on each original digitized panoramic image. The images, however, suffered with low contrast and domination of dark color in the area around the mental foramen. Therefore, we stretched the appropriate range of intensity value corresponding to the area. Since the original panoramic radiograph had very high resolution, we picked an area of interest for saving the computation time. This area involved the lower border of the mandibular cortex below the mental foramen that the examiner had already determined. Since the examiner determined the mental foramen on both sides, two areas of interest were obtained (Fig. 2).

Image enhancement

Since the boundary of each object was not sharp, we removed all areas that were considered background and applied enhancement processes to the remaining objects. Thresholding, which assigns a pixel to one class if its gray level is greater than a specified threshold and otherwise assigns it to the other class, is the most common method for separating objects from background. All pixel values outside the 10% and 90% percentiles in the histogram were ignored because pixel gray level less than 10% corresponded to the variation illumination of the background while gray levels above 90% corresponded to the teeth and label text attached to each image. These outliers were simply forced to either 0 or 255, depending upon which side of the range they lay on.

We employed a thresholding algorithm that we recently proposed to classify image pixels into one of two classes, i.e., objects and background, where the threshold is determined based on intra- and interclass variance of the pixel values [16]. This algorithm generated binary images of the determined area of interest (Fig. 3a,b). Multiplying this binary image and the image processed as above removed the background and preserved all gray levels considered as objects.

We applied average filter as low-pass filter to the original image and subtracted this low-frequency image from the original image to obtain the image containing only high frequencies. This step was applied to the image, which no longer had background illumination variation. Therefore,

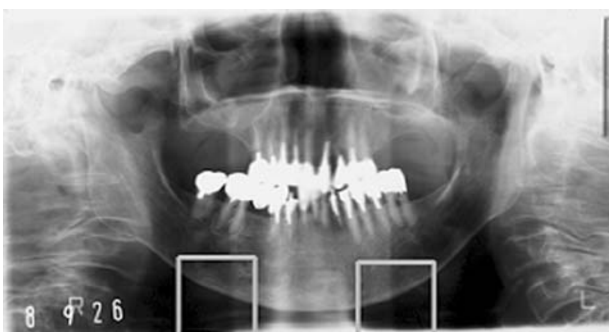


Fig. 2 *Two boxes* correspond to the area below the mental foramen on the left and the right sides of the mandible on digitized dental panoramic radiographs

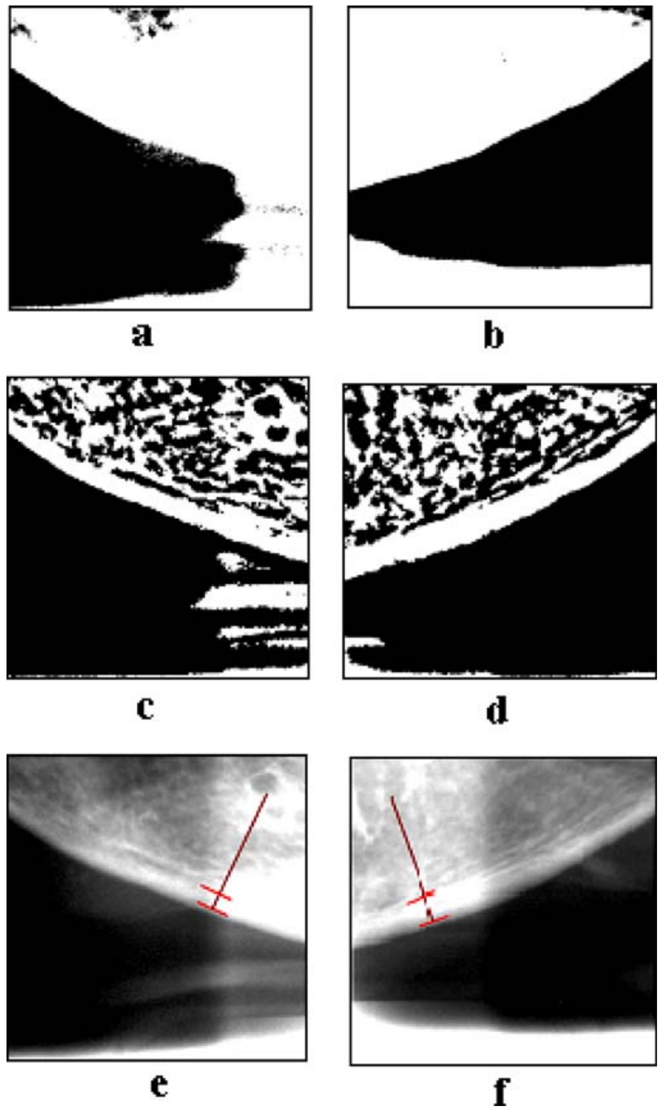


Fig. 3 Images corresponding to the right and the left sides of mandibular cortical bone, respectively, were **a**, **b** for image thresholding result, **c**, **d** for high-pass filtering result, and **e**, **f** for cortical width measurement demonstrations

the high-pass filtering process sharpened the boundary along the cortical bone only because the region of no interest lay adjacent to the cortical bone had been removed. Morphological open and closed operation concluded the enhancement processes by joining small patches that spread out along the cortical bone (Fig. 3c,d).

Cortical margin identification

Some margins appeared even; however, other margins exhibited defects or porousity. In some cases, the margin of the cortex was not clearly deliniated because there were some connections to trabecular bones. Therefore, cortical margin determination needed manual assistance for validating the appropriate margin by choosing two points inside the cortex. Based on these inputs, our tracing algorithm identified outer and inner margins along the cortical bone. Both margins were identified as groups of pixels along the cortex boundary. Since such margins seem connected to some other objects, some margin pixels may be a branch leading to an incorrect path. In this study, we overcame this problem by developing an algorithm for tracing all connected pixels along both margins. The tracing process was carried out on the outerside of the margin and followed by finding the gradient of linear regression at every point along the line. Gradients were used to determine the most appropriate point from which to measure the width.

Criteria used for this selection are the perpendicularity of the line between two gradients, the gradient obtained from the linear regression, and the gradient measured between the mental foramens to the appropriate point. Tracing was also carried out on the inner side of the margin. Moreover, path pruning was applied, which removed any link misleading to the pixels inside the mandible from the margin and preserved all points along the margin. Since we must obtain a line parallel to the long axis of the mandible and tangential to the border of the mandible, we needed to identify such lines as the candidates for this purpose. A regression line was constructed at each point based on gradient value measured at that point.

Distance measurement

The final step involves determining the best point for measurement in the outer side of the margin. Among all the lines parallel to the axis of the mandible and tangential to the border of the mandible, we chose one line where the segment between the mental foramen and the contact point of the line to the outer side was the most perpendicular to the line itself. We needed to choose the counterpart point in the inner margin so as to compute the distance between both points. This point actually represented the intersection between the inner side and the line along the selected point to the mental foramen. Finally, we assigned the Euclidean distance between both points as the cortical width (Fig. 3e,f).

Data analysis

Mean cortical width of both the right and left side was used in this study. Two oral radiologists (AT, TN) independently measured the mandibular cortical width of 20 randomly selected dental panoramic radiographs by using our computer-aided system twice. Intra- and interexaminer agreements were evaluated by Pearson's correlation coefficient. For measurement of one oral radiologist (AT) with 17 years of clinical experience, correlation coefficient was calculated to evaluate the relationship between cortical width measured by the computer-aided system and BMD of the lumbar spine and femoral neck in 100 dental panoramic radiographs. Further, correlation coefficient between manual cortical measurement and skeletal BMD was calculated to estimate whether the cortical width was precisely measured by the computer-aided system in comparison with manual measurement.

For measurements by the oral radiologist (AT), receiver operating characteristics (ROC) curve analyses were used to determine optimal cutoff thresholds of cortical width measured by the computer-aided system and manually measured by a caliper for identifying postmenopausal women with low BMD. The risk index range corresponding to a sensitivity of approximately 90% was chosen to define the low-risk group. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy, and likelihood ratio for a positive risk result for identifying postmenopausal women with low BMD by optimal cutoff thresholds of cortical width determined on ROC analyses were calculated. Data analyses were performed using Statistical Package for the Social Sciences (SPSS; version 8.0; SPSS Inc, Chicago, IL, USA). P values less than 0.05 were considered statistically significant.

Results

Intraobserver agreement was 86% for the first oral radiologist (AT) and 82% for the second oral radiologist. Interobserver agreement between the two radiologists was 83% at the first observation and 75% at the second observation. In the first oral radiologist's measurement, there was statistically significant correlation between cortical width measured by the computer-aided system and BMD of the lumbar spine (r=0.50, P<0.001) and the femoral neck (r=0.53, P<0.001). These correlations were similar to those between manual cortical measurement and BMD of the lumbar spine (r= 0.52, P<0.001) and the femoral neck (r=0.54, P<0.001).

Area under ROC curve for identifying women with low spinal BMD was 0.834 (95% CI, 0.749–0.918) for manual measurement and 0.777 (95% CI, 0.687–0.866) for the computer-aided system. Area under ROC curve for identifying women with low femoral BMD was 0.831 (95% CI, 0.736–0.926) for manual measurement and 0.803 (95% CI, 0.710–0.896) for the computer-aided system. When the risk-index range corresponding to a sensitivity of approximately 90% was chosen to determine the optimal cutoff threshold in identifying women with low BMD, the cutoff threshold of cortical width was 3.94 mm for manual measurement and 3.09 mm for the computer-aided system at the lumbar spineand 3.91 mm for manual measurement and 3.16 mm for the computer-aided system at the femoral neck (Table 1).

Sensitivity and specificity for identifying women with low spinal BMD were 92.0% and 60.0% for manual measurement and 88.0% and 58.7% for the computer-aided system (Table 2). Sensitivity and specificity for identifying women with low femoral neck BMD were 87.5% and 64.8% for manual measurement and 87.5% and 56.3% for the computer-aided system. There were no significant differences in any diagnostic efficacies between manual measurement and the computer-aided system for identifying women with low BMD at both the lumbar spine and femoral neck.

Discussion

This is the first demonstration comparing correlations between skeletal BMD and mandibular cortical width measured by a computer-aided system on digitized dental panoramic radiographs. These correlations were similar to those between skeletal BMD and cortical width manually measured on dental panoramic radiographs. In comparison with manual measurement, we can easily and quickly measure mandibular cortical width of a large number of dental panoramic radiographs with high reproducibility. Devlin and Horner reported that mandibular cortical width below the mental foramen manually measured on dental panoramic radiographs was significantly correlated with the T scores recorded at the spine (r = 0.514, P<0.01) and femur (r = 0.449, P<0.01) in 74 Caucasian women aged from 43 to 79 years [9]. Our results were almost similar to those of their study. This suggests that mandibular cortical width may be equally used in both Asian and Caucasian postmenopausal women. Day et al. reported the significant association between total hip BMD and metacarpal index (r=0.48, P<0.001), which is the proportion of the cortex on the second metacarpal at its midpoint, in 379 elderly community-dwelling women aged 75 years or more [17]. Correlation between mandibular cortical width measured on dental panoramic radiographs and femoral neck BMD in our study was also similar to that of their study. They concluded that the metacarpal index may be useful assessments of bone mass and fracture risk and is comparable to peripheral assessment of skeletal status by forearm densitometry. This implies the possibility that mandibular cortical measurement, especially automatic measurement by the computer-aided system, may be useful assessments of bone mass and fracture risk because automatic measurement is both reproducible and highly applicable.

Cutoff thresholds of mandibular cortical width measured by the computer-aided system were somewhat lower than those obtained by manual measurement. This discrepancy might be caused by the different perception between human eyes and numerical analysis in interpreting the inner and outer margins of the cortical bone. Even if pixel values linearly increased along a line, the human eyes found a virtual boundary of brightness because of their nonlinearity. On the other hand, threshold estimation by the system was based on statistical optimality of pixel values and did not consider the nonlinearity. Thus, the estimated boundaries were different. This discrepancy can be compensated for by an appropriate calibration.

Several screening tools based on a simple questionnaire have been developed to identify postmenopausal women with low skeletal BMD or osteoporosis, and the validation of these tools have been evaluated in many countries [18–20]. Cook et al. reported that the area under ROC curve for identifying postmenopausal women with low skeletal BMD (BMD T score <−1.0) by some questionnaire-based screening tools ranged from 0.718 to 0.773 in 208 Caucasian postmenopausal women aged 29–87 years [20]. When the risk index range corresponding to a sensitivity of approximately 90% was chosen to define the low-risk group, the specificity of questionnaire-based screening tools ranged from 14% to 38%. The diagnostic efficacy of mandibular cortical width measured by the computer-aided system as well as the manual procedure in our study was better than that of several questionnaire-based screening tools in the study of Cook et al. although the background of subjects was different between our study and theirs.

How do we use this system in general dental practice? General dental practitioners can digitize their dental

Table 1 Number of subjects with normal and low skeletal bone mineral densities (BMD) by mandibular cortical width

	Lumbar spine		Femoral neck	
	Normal	Low BMD	Normal	Low BMD
Cortical width by manual measurement				
≤ Cutoff threshold	30	23	25	21
> Cutoff threshold	45	2	46	3
Cortical width by computer-aided system				
≤ Cutoff threshold	32	22	19	21
> Cutoff threshold	43	3	52	3

Cutoff threshold by manual measurement was 3.94 mm at the lumbar spine and 3.91 mm at the femoral neck
Cutoff threshold by computer-aided system was 3.08 mm at the lumbar spine and 2.69 mm at the femoral neck

Table 2 Diagnostic efficacy of manual and computer-aided automatic measurements of mandibular cortical width in identifying women with low skeletal bone mineral densities (BMD)

	Sensitivity (95% CI)	Specificity (95% CI)	Positive predictive value (95% CI)	Negative predictive value (95% CI)	Accuracy (95% CI)	Likelihood ratio (+) (95% CI)
Lumbar spine						
Manual measurement	92.0 (81.4–100.0)	60.0 (48.9–71.1)	43.4 (30.1–56.7)	95.7 (90.0–100.0)	68.0 (58.9–77.1)	2.3 (1.7–3.1)
Automatic measurement	88.0 (75.3–100.0)	58.7 (47.5–69.8)	41.5 (28.2–54.8)	93.6 (86.6–100.0)	66.0 (56.7–75.3)	2.1 (1.6–2.9)
Femoral neck						
Manual measurement	87.5 (74.3–100.0)	64.8 (53.7–75.9)	45.7 (31.3–60.0)	93.9 (87.2–100.0)	70.5 (61.4–79.7)	2.5 (1.8–3.5)
Automatic measurement	87.5 (74.3–100.0)	56.3 (44.8–67.9)	40.4 (27.0–53.7)	93.0 (85.4–100.0)	64.2 (54.6–73.9)	2.0 (1.5–2.7)

CI confidence interval

panoramic radiographs and send them to some institutions in which mandibular cortical width can be quickly and easily measured for identification of women with low skeletal BMD by our computer-aided system. It is also possible that general dental practitioners can identify women with low skeletal BMD by using digital dental panoramic radiographs with our computer-aided system. Combination of automatic cortical width measurement and automatic cortical shape estimation, reported in our previous study [21], may be more useful for identification of women with low skeletal BMD if these systems are loaded in digital dental panoramic radiographs in the future.

Our computer-aided system has some limitations. Examiners such as dentists have to determine the mental foramen. It is likely that the experience of the examiners may largely influence the determination of the mental foramen, resulting in poor intra- and interexaminer agreement. Automatic determination of the mental foramen would be necessary to maintain good reproducibility around the world. Further, it is possible that superimposition of the hyoid bone may contribute to incomplete cortical width measurement. The robustness of this system would be also necessary to overcome this system limitation.

In conclusion, sensitivity and specificity for identifying postmenopausal women with low spinal BMD by our computer-aided system were about 88.0% and 58.7%, respectively. Those for identifying postmenopausal women with low femoral BMD by this system were about 87.5% and 56.3%, respectively. Our results suggest that our computer-aided system may be useful for identifying postmenopausal women with low skeletal BMD.

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