Automatic Assessment of Mandibular Bone Using Support Vector Machine for the Diagnosis of Osteoporosis

M. S. Kavitha, Takio Kurita
Graduate School of Engineering
Hiroshima University
Higashi Hiroshima, Japan
mkkavi14@gmail.com; tkurita@hiroshima-u.ac.jp

Akira Asano
Faculty of Informatics, Kansai University,
Osaka, Japan
a.asano@kansai-u.ac.jp

Akira Taguchi
Department of Oral and Maxillofacial Radiology
Matsumoto Dental University, Nagano, Japan
akiro@po.mdu.ac.jp

Abstract—This study aimed to realize and compare the effectiveness of cortical and trabecular bone measures in a computer-aided system based on support vector machine (SVM) for identifying postmenopausal women with low BMD or osteoporosis. Dental panoramic radiographs of 69 postmenopausal women, as well as bone mineral density (BMD) assessments at the lumbar spine and the femoral neck were used. Average width and variance of continuous measurements of mandibular cortical bone and distribution of average length and angle (direction) of trabecular bone segments on panoramic radiographs were measured by computer-aided systems and used as inputs. The accuracy of the cortical measures using average width and variance was 87% and of the trabecular measures using average length and angle was 65% with RBF kernel-SVM method for diagnosing women with low BMD at the lumbar spine. Likewise, the accuracy of combined cortical and trabecular bone measures was 88%. Our results suggest that the cortical bone measurement is more appropriate than the trabecular bone measurement for triage screening of osteoporosis.

Keywords—osteoporosis; diagnosis; mandible; cortical bone; trabecular bone; support vector machine

I. INTRODUCTION

Osteoporosis and osteoporotic fractures are major causes of morbidity and mortality worldwide. It affects the endosteal cortico-cancellous bone, converting the cortical bone to a more porous cancellous bone structure [1]. The net result is that patients affected by osteoporotic fractures of the hip, wrist and spine generally have a reduced bone mineral density (BMD). It is estimated that over 200 million people worldwide have osteoporosis [2]. It is a major health problem in the Japanese elderly population as well and is estimated to affect approximately 12 million people [3].

In the context of osteoporosis, bone quality encompasses both cortical and trabecular bones architecture. Marked structural changes could be observed in osteoporotic patients in the cortical as well as the trabecular bone. Efforts to increase access to DXA and improve the sensitivity and specificity of osteoporosis risk assessment instruments may help ensure that individuals with osteoporosis are diagnosed early. However, it is likely that a large segment of postmenopausal women with low BMD will not have BMD testing, if they do not have a deep concern of osteoporosis [3]. There are a huge number of dental panoramic radiographs used widely in dental practice for several reasons, and the features of osteoporosis can often be observed in films from affected individuals. Sparse trabecular pattern is a useful predictor in dental clinics to identify more individuals with fracture risk than BMD, especially in the elderly [4]. In fact, special equipment is required to analyze the trabecular bone patterns on intra-oral radiographs, which is a time consuming process. On the other hand, dental X-rays could offer a simple, easy way to detect the bone-thinning disease osteoporosis. Using the image information from these radiographs to detect patients at risk for osteoporosis involves no extra radiation and almost no extra cost. Many investigators demonstrated the cortical width of the mandible as an effective screening tool for identifying postmenopausal women with undetected osteoporosis [5, 6]. It has been shown that cortical bone may have a great impact on bone strength also in regions dominated by trabecular bone, like the vertebra bodies [7]. We have developed two computer aided diagnosis systems in our previous studies, in which the dentists can automatically measure cortical width and trabecular bone pattern change on digitized dental panoramic radiographs rapidly and accurately [8, 9]. However the CAD system using the measures of cortical bone may largely associated than using the trabecular bone pattern in accurate identification of women with low BMD or osteoporosis.
The hypothesis of the present study was that the information of the cortical bone is more appropriate than the trabecular bone pattern on the dental panoramic radiographs for the identification of women at-risk of low BMD or osteoporosis. The panoramic measures of average width and variance of cortical bone and number of distribution of average length and angle of the trabecular bone segments were independently investigated in identifying postmenopausal women with low BMD or osteoporosis in our previous studies. In the present study, the measures of cortical and trabecular bone were used and compared the effectiveness of these in a computer-aided system based on SVM and to evaluate the more appropriate panoramic measure in identifying postmenopausal women with low skeletal BMD.

II. MATERIALS AND METHODS

A. Subjects

The Hiroshima University Human Subject Committee approved the study protocol, and dental panoramic radiographs were taken for all the subjects after informed consent was obtained. This study included 69 postmenopausal women as subjects, of whom 40 were allocated to the training of the tool and 29 to its testing. All 69 women underwent BMD of the lumbar spine (L2–L4) and femoral neck by dual-energy X-ray absorptiometry (DPX-alpha; Lunar Co., Madison, WI, USA) at oral radiology clinic at Hiroshima University Hospital between 1996 and 2001. The inclusion criteria were postmenopausal women aged 50 years or older with no previous diagnosis of osteoporosis. The exclusion criteria were subjects who menstruated less than a year, had any metabolic bone disease (hyperparathyroidism, hypoparathyroidism, Paget’s disease, osteomalacia, renal osteodystrophy or osteogenesis imperfecta), had cancer with bone metastasis, had significant renal impairment, had history of taking medication known to affect bone metabolism (e.g. oestrogen), had undergone hysterectomy or oophorectomy, had a history of smoking, had any bone destructive lesion (e.g. malignant tumours or osteomyelitis) in the mandible or had any spinal fracture. Spinal fractures were confirmed semi-quantitatively on lateral radiographs. The subjects were classified as normal (T-score > -1.0), osteopenia (T-score between -1 and -2.5) or osteoporotic (T-score < -2.5) at each skeletal site according to the World Health Organization (WHO) [10] criteria. The Adult Health Study cohort in Japan [11] reported that the cut-off BMD value of osteoporosis in the lumbar spine that was based on the Japanese definition [12] (less than 70%) was similar to that based on the WHO definition (T-score < -2.5 SD); therefore, we used the WHO definition in this study.

B. Dental Panoramic Radiography

All of the panoramic radiographs were obtained by using an AZ-3000 Panoramic Dental X-ray (Asahi Co., Kyoto, Japan) at 12 mA and 15 s; kVp values varied between 70 and 80, and a flat-bed scanner (ES-8000; Epson, Tokyo, Japan) was used to digitize the images at a resolution of 300 dpi. Screens of speed group 200 (HG-M; Fuji Photo Film Co., Tokyo, Japan) and film (UR-2; Fuji Photo Film Co.) were used. One set of duplicate films (MI-Dup; Fuji Photo Film Co.) that were processed with an automatic film processor (Cepros M; Fuji Photo Film Co.) comprised the 100 original panoramic radiographs for the assessment. The appearance of the mandibular inferior cortex was clear bilaterally in the radiographs.

C. Development of Automated System

We have recently developed a computer-aided (CAD) system that continuously measures the mandibular cortical width (MCW) between the upper and lower boundaries of the cortical bone in the region of interest (ROI) on dental panoramic radiographs [8]. The process of measurement of cortical width includes, identifying the region of interest as the right and left cortices as indicated two boxes (Fig. 1), enhance the original image, detect the inner and outer boundaries of the cortex, and finally measure the distance between the boundaries of the cortex at which we can measure the cortical width. In order to determine the direction of the measurements, a second-order polynomial function is fitted to approximate the upper boundary. The cortical width at each point is measured along the tangent line, which is considered to be the smallest distance to the polynomial curve is shown in Fig. 2 on the right (A) and left (B) sides.

Figure 1. Dental panoramic radiograph

Figure 2. Right (A) and left (B) cortical width
osteoporosis. We have also conducted statistical analysis and receiver operating characteristics (ROC) curve analysis, to estimate the CAD system accuracy that precisely measured the cortical width in identifying women with low BMD.

The risk index range corresponding to a sensitivity of approximately 90% was chosen to define the low-risk group [8]. Another CAD system has been developed for automatically measuring the distribution of length and direction of trabecular segments for assessing the trabecular bone pattern of the mandible on dental panoramic radiographs for identifying postmenopausal women with low skeletal BMD or osteoporosis [9]. This system identified that the trabeculae parallel to the roots are reduced more than those perpendicular to the roots by osteoporosis. The reduction of trabecular bone can be identified by the measurement of distribution of length and direction of the trabecular segments based on structural anisotropy and the mechanical properties of trabecular bone [14]. We applied median filter as the pre-processing step to obtain a smooth image. The morphological skeleton of trabeculae and teeth roots is extracted and teeth roots were solely removed from the skeleton image that is achieved by the combinations of mathematical morphological image operations. Otsu’s method was employed to threshold the image. Average filter is applied followed by the traditional thinning algorithm to obtain proper trabecular segments. Finally the length of each segment that is a detected trabecula, and its direction relative to the nearest root in the image were measured as shown in Fig. 3 for the original area of interest (A) extracted trabeculae (B) and segmented trabeculae (C). The number of distributions of average length and angle of the trabecular bone segments has shown the differences of low BMD or osteoporosis from normal BMD.

![Figure 3. The original area of interest (A), extracted trabeculae (B), and segmented trabeculae (C)](image)

D. Support Vector Machine

In this study, we treat osteoporosis detection as a two-class pattern classification problem. We apply this classifier to refer these two classes as women with low BMD or osteoporosis and normal BMD. The SVM classifier seeks the separating hyperplane that produces the largest separation margin [15]. In the sets in which the data points are not linearly separable in the input space, a nonlinear transformation is used to map the data vector \( \mathbf{x} \) into a high-dimensional space (called feature space). It uses a kernel function in which the nonlinear mapping is applied.

The discriminant function in an SVM classifier has the following form:

\[
f(x) = \text{sgn} \left( \sum_{i=1}^{m} \alpha_i y_i K(x_i, x) + b \right)
\]

Where \( K(x_i, x) \) is the kernel function, \( x_i \) is a support vector determined from training data, \( m \) is the number of support vector, \( y_i \) is the class indicator associated with each \( x \) and \( \alpha_i \) are constants also determined from training.

E. Design of SVM Classifier for Osteoporosis Detection

1) Input Feature Vector

We applied SVM on our separate and combined datasets for classifications using average width and variance of continuous cortical bone measurements and number of distributions of average length and angle results of the trabecular bone segments between women with low BMD or osteoporosis and normal skeletal BMD is shown in Fig. 4. These features, have distribution that shown difference between normal BMD and osteoporosis.

2) SVM Kernel Functions

The efficacy of the SVM-based classification is dependent on the type of kernel used, we explored the use of various commonly used kernels such as linear, sigmoid, polynomial and the Radial basis function (RBF) on our datasets. We chose the RBF kernel because it was found to be the most effective in terms of the high accuracy in the detection and performance of the diagnostic system.

![Figure 4. Flow chart of the support vector machine system](image)

Which is expressed as:

\[
K(x_i, x_j) = \exp \left( -\frac{||x_i - x_j||^2}{2\gamma^2} \right)
\]

Two parameters are required to optimize the RBF kernel of the SVM classifier where, \( \gamma > 0 \) is a constant that defines the kernel width and \( C \), the regularization parameter.
3) SVM Training

In the training set, the data was classified into two groups labeled as “osteoporosis” group and “healthy” group that corresponded to positive and negative examples for SVM training. The aim is to classify the panoramic measures into one of the defined groups. We have processed 40 training sets and classify 29 test sets. The SVM algorithm classifies the positive and negative examples by training a classifier that uses a kernel function to map the input samples onto a high-dimensional space that best differentiates the two classes with a maximal margin and a minimal error. The support vectors and other parameters in the decision function \( f(x) \) in (1) are determined maximizing the following:

\[
\sum_{i=1}^{N} \alpha_i - \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \alpha_i \alpha_j y_i y_j K(x_i \cdot x_j)
\]  

subject to the following constraints:

(i) \[ \sum_{i=1}^{N} \alpha_i y_i = 0, \]

(ii) \[ 0 \leq \alpha_i \leq C \text{ for } i = 1, 2, \ldots, N, \]

Where, \( N \) is the total number of training samples, \( C \) is a positive regularization parameter that controls the tradeoff between complexity of the machine and the allowed classification error.

F. Statistical Analysis

We have derived four input variables from dental panoramic radiographs taken from 69 postmenopausal women and one output variable (normal or osteoporosis) according to the result of skeletal BMD assessment. We have chosen to use the RBF as the kernel function because it was shown to perform well on our datasets for classifications using average width and variance of cortical bone measures, average length and angle of the trabecular bone segments results between women with low BMD (BMD T-score of \(-1.0\) or less) and normal skeletal BMD. In this work, the cortical bone measures of average cortical width and variance results and the trabecular bone segments measures of average length and angle results were separately compared with the lumbar spine BMD and femoral neck BMD. These four panoramic measures are combined as average cortical width, variance, average trabecular segment length and angle of the measurements were compared with the lumbar spine BMD and femoral neck BMD. Quadratic programming was used to optimize the combination of parameters and found to yield better classification results at \( \gamma = 2 \) and \( C = 1 \). Smaller values were used to avoid reproducing noise and avoid over-fitting to the data samples that were used in the training procedure. The RBF parameter and weighting factors were determined by experimentation on the training samples. We employed a data analysis framework written in Matlab, which incorporates freely available SVM tools for Matlab that were implemented [16], to perform classification. To provide an indication of the overall performance of the model, sensitivity and specificity were calculated. Positive predictive value, negative predictive value, accuracy and likelihood ratio for a positive risk result were also evaluated. To ensure the consistency of this system, the experiment has been repeated five times separately using different members of training and test sets having different compositions from those of the other experiment. The average of these five different compositions of classification performance was evaluated. The accuracy of the classifications of 10 randomly selected subjects for dental panoramic radiographs measured twice in one-month interval by the same examiner, so as to confirm the consistency of measurement in identifying women with low BMD.

III. RESULTS

The RBF kernel–SVM predictions for the diagnostic classification of postmenopausal women using the cortical bone measures of average width and variance had 93.0% sensitivity and 84.1% specificity on the basis of the lumbar spine BMD and 90.5% sensitivity and 70.1% specificity on the basis of the femoral neck BMD (Table 1). Likewise, using the trabecular bone segments measures of average length and angle had 81.8% sensitivity and 43.6% specificity on the basis of the lumbar spine BMD and 80.0% sensitivity and 37.9% specificity on the basis of the femoral neck BMD. The diagnostic classification of women with SVM using the four combined panoramic measures had 95.6% sensitivity and 83.2% specificity on the basis of the lumbar spine BMD and 91.0% sensitivity and 70.6% specificity on the basis of the femoral neck BMD.

In addition, the mean sensitivity and specificity of the cortical bone measures and the trabecular bone segment measures calculated separately for the combined data of both the lumbar spine and the femoral neck BMD using SVM method, processed five times by interchanging its compositions with different members of training and testing samples were 93.2%, 76.1% and 62.3%, 39.5%, respectively. Likewise, mean sensitivity and specificity of the four combined measures for the combined data of both the lumbar spine and the femoral neck BMD using SVM method, processed five times by interchanging its compositions with different members of training and testing samples were 92.6% and 79.8%, respectively. The average time to complete the classification measurement on a single radiograph using cortical measures and trabecular bone measures separately was 9.0 s and 2.0 min. There were no significant differences in the accuracy of the classifications for 10 randomly selected subjects that were measured twice with one-month interval for the four combined panoramic measures and cortical measures were 89% and 90%, respectively, whereas for the trabecular bone measures it was 69%.

IV. DISCUSSION

The developed CAD system with SVM has shown, as hypothesized, that an eroded cortical bone was associated with a higher diagnostic efficacy, whereas the distribution of the
trabecular bone was related to lower diagnostic efficacy for the identification of women at-risk of osteoporosis. Likewise, there were no significant differences of sensitivity and specificity of our CAD system in both the results of the combined panoramic measures and cortical bone measures for identifying postmenopausal women with low skeletal BMD. It was observed that the information of trabecular bone pattern addition to the cortical bone was not contributing to increase the diagnostic efficacy to identify women with low BMD or osteoporosis.

In our previous study of continuous measurements using the trimmed mean technique [8], which used data for the 50 validation subjects, the sensitivity and specificity were 93.3% and 82.9%, respectively on the basis of the lumbar spine BMD and 92.3% and 75.7%, respectively on the basis of the femoral neck BMD. These clearly indicate that the diagnostic efficacy of our system using the combined panoramic measures and cortical bone measures are almost same with that of the previous system. The practice of measuring MCW below the mental foramen of the mandible has been widely used worldwide [17] simultaneously reported, it to be the most appropriate site for determining MCW.

Several investigators have developed simple decision rules based on a questionnaire, such as the Osteoporosis Screening Tool (OST), to identify women with low skeletal BMD or osteoporosis [18, 19]. The sensitivity of such decision rules in identifying postmenopausal women with osteoporosis ranged from 92–95%, and the specificity ranged from 35–46% [20]. The sensitivity of our CAD system using the information of cortical bone was almost the same, but the specificity was much higher. This is an indirect evidence to support screening for osteoporosis with high influence of cortical bone, which directly reflects the general skeleton. Further, the average time required for the measurement of trabecular bone was much longer than the measurement of cortical bone.

Our findings are supported by those of previous studies. Lindh et al, [21] demonstrated that the degrees of inter- and intra-observer agreement in the visual assessment of the trabecular patterns of the jaws may be expected to be relatively low, because the trabecular pattern of the jaws is more diverse and readily resorbed and/or sclerosed in local inflammation. It was also reported that the trabecular bone of the jaws is likely not appropriate for screening osteoporosis because the need for a specialized computer system to analyze trabecular bone patterns would be incompatible with the basic concept of routine screening for osteoporosis in dental clinics [3]. Arifin et al [22] showed that the combination of cortical bone measures such as width and shape by using fuzzy neural network achieved more superior diagnostic efficacy of 94.5% sensitivity and 64.0% specificity based on lumbar spine BMD and 90.9% sensitivity and 64.7% specificity based on femoral neck BMD. A comparison of our results with those of the previous studies indicate that the measurements of cortical bone using SVM method achieved robust accuracy and more appropriate for detecting women with low BMD compared with the trabecular bone pattern. Several screening tools based on simple questionnaires have been developed to identify postmenopausal women with low skeletal BMD or osteoporosis, and validation of these tools has also been performed in many countries [23]. The sensitivity and specificity of such decision rules in identifying postmenopausal women with osteoporosis ranged from 90% to 92% and 37% to 45%, respectively. This proves that the diagnostic efficacy of our study using cortical bone measurements largely determines the risk of osteoporosis [24] than that of the several questionnaire-based screening tools that were used in the previous studies, although the backgrounds of the subjects were different. The limitations in our study were that the number of subjects was relatively small, and the subjects were relatively healthy postmenopausal women because we used rigid exclusion criteria. The dental panoramic radiographs used in this study were digitized with the resolution of 300 dpi, and CAD system performance needs to be updated with different resolutions of panoramic radiographs.

### Table 1. Diagnostic Efficacy of the SVM Method Using Various Measures for Identifying Women With Low BMD at 95% Confidence Interval (CI). (SE: Sensitivity, SP: Specificity, PPV: Positive Predictive Value, NPV: Negative Predictive Value, AR: Accuracy and LR: Likelihood Ratio)

<table>
<thead>
<tr>
<th>Region</th>
<th>SE</th>
<th>SP</th>
<th>PPV</th>
<th>NPV</th>
<th>Acc.</th>
<th>LR (+)</th>
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</thead>
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<tr>
<td><strong>Average width and variance of cortical bone</strong></td>
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<tr>
<td>Lumbar spine</td>
<td>93.0</td>
<td>84.1</td>
<td>77.9</td>
<td>96.7</td>
<td>87.0</td>
<td>5.6</td>
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<td>(86.9–99.0)</td>
<td>(75.4–100.0)</td>
<td>(68.2–78.7)</td>
<td>(86.9–100.0)</td>
<td>(92.9–94.9)</td>
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<tr>
<td>Femoral neck</td>
<td>90.5</td>
<td>70.1</td>
<td>47.6</td>
<td>96.0</td>
<td>75.0</td>
<td>3.3</td>
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<td>(84.3–97.8)</td>
<td>(59.2–90.0)</td>
<td>(36.8–80.8)</td>
<td>(86.9–90.0)</td>
<td>(64.8–85.2)</td>
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<td><strong>Average length and angle of trabecular bone segments</strong></td>
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<td>Lumbar spine</td>
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<td>46.3</td>
<td>85.9</td>
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<td>(29.5–59.0)</td>
<td>(71.4–76.1)</td>
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<td>41.1</td>
<td>76.6</td>
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<td>(49.5–72.5)</td>
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<td><strong>Combined measures of cortical bone and trabecular bone segments</strong></td>
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<tr>
<td>Lumbar spine</td>
<td>95.6</td>
<td>82.5</td>
<td>81.2</td>
<td>98.6</td>
<td>88.0</td>
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<tr>
<td>Femoral neck</td>
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<td>56.9</td>
<td>96.5</td>
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<td>(44.9–68.3)</td>
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<td>(64.8–85.2)</td>
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### V. Conclusion

The trabecular bone measurement on dental panoramic radiograph is not appropriate for triage screening for osteoporosis, whereas the cortical bone is largely associated in diagnosing high-risk groups with low BMD or osteoporosis. The use of the cortical measures with SVM in this study provided a high degree of consistency and reproducibility in the results for the identification of undetected individuals with low BMD. The encouraging results indicate that cortical bone measures could be more helpful in dental clinics to detect accurately and diagnosing low BMD or osteoporosis earlier and faster than using trabecular bone pattern measures.
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