Automated classification of mandibular cortical bone on dental panoramic radiographs for early detection of osteoporosis

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ABSTRACT

Findings on dental panoramic radiographs (DPRs) have shown that mandibular cortical index (MCI) based on the morphology of mandibular inferior cortex was significantly correlated with osteoporosis. MCI on DPRs can be categorized into one of three groups and has the high potential for identifying patients with osteoporosis. However, most DPRs are used only for diagnosing dental conditions by dentists in their routine clinical work. Moreover, MCI is not generally quantified but assessed subjectively. In this study, we investigated a computer-aided diagnosis (CAD) system that automatically classifies mandibular cortical bone for detection of osteoporotic patients at early stage. First, an inferior border of mandibular bone was detected by use of an active contour method. Second, regions of interest including the cortical bone are extracted and analyzed for its thickness and roughness. Finally, support vector machine (SVM) differentiate cases into three MCI categories by features including the thickness and roughness. Ninety eight DPRs were used to evaluate our proposed scheme. The number of cases classified to Class I, II, and III by a dental radiologist are 56, 25 and 17 cases, respectively. Experimental result based on the leave-one-out cross-validation evaluation showed that the sensitivities for the classes I, II, and III were 94.6%, 57.7% and 94.1%, respectively. Distribution of the groups in the feature space indicates a possibility of MCI quantification by the proposed method. Therefore, our scheme has a potential in identifying osteoporotic patients at an early stage.

Keywords: Dental panoramic radiographs, Osteoporosis, Computer-aided diagnosis, Mandibular cortical bone

1. INTRODUCTION

Osteoporosis is estimated to affect 200 million women worldwide [1]. Osteoporotic fractures represent a huge public health burden and incremental medical costs. Therefore, it is important to detect osteoporosis in its early stage and to treat it before the risk of fracture rises. Studies have shown that the mandibular cortical index (MCI) based on morphology of mandibular cortex on dental panoramic radiographs (DPRs) is significantly correlated with bone mineral density in the hip, lumbar spine, foramen and biochemical markers of bone turnover, so that the MCI assessment is effective for osteoporosis screening. As shown in Fig. 1, MCI is categorized into one of three groups according to the definitions [2]:

Class I: Normal cortex: the endosteal margin of the cortex is even and sharp on both sides.

Class II: Mildly to moderately eroded cortex: the endosteal margin shows semi-lunar defects (lacunar resorption) or appears to form endosteal cortical residues.

Class III: Severely eroded cortex: the cortical layer forms heavy endosteal cortical residues and is clearly porous.

Other studies have indicated mandibular cortical width (MCW) itself is significantly correlated with bone mineral density, and the condition of cortical bone and osteoporotic risk are evaluated by MCW together with bone erosion.

DPRs are used to examine dental diseases in dental clinics over the world. Especially in Japan, more than 10 million DPRs are taken annually in dental clinics [3]. Identifying asymptomatic patients with osteoporosis through dental examinations may bring a supplemental benefit for the patients. However, most DPRs are used only for diagnosing dental con-

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ditions by dentists in their routine clinical work. MCI is generally assessed subjectively and therefore susceptible to intra and inter-reader variabilities. Computer-aided diagnosis (CAD) system that automatically and quantitatively evaluates MCI on DPRs may be useful for dentists to identify asymptomatic patients with osteoporosis at an early stage. We have previously proposed a new screening pathway by cooperation of dentists and the CAD system [4-6]. If any pathologic signs for osteoporosis and arteriosclerotic disease are detected, CAD alerts dentists. After that, the dentists inform patients of the possible risks for systemic diseases. If the patients desire, the dentist will refer them to the medical hospitals. In previous studies, some groups developed a computerized scheme that automatically measures the MCW on DPRs [7-9]. However, not only the thickness but also evaluation of total condition of the cortical bone could improve the osteoporotic risk assessment. In this study, we propose a new method that analyzes the structure of the cortical bones and classifies them into three MCI categories.

Class I *Class II* *Class III*

Fig. 1 Classification of mandibular cortical index (MCI)

2. METHODS

2.1 Outline

The overall flow of our proposed method is illustrated in Fig. 2, and as follows. Canny edge detector and an active contour method are used to extract the mandibular contour in the first step. Next, region of interest (ROI) images including the cortical bone are obtained from both right and left sides of the mandible near the mental foremen. By applying the line-convergence filter [10], linear structure extraction (LSE) images are created. The original ROIs and the LSE images are sent to two analysis sections: thickness and roughness calculation sections. In the roughness calculation section, four features are determined, and one feature is output from the thickness calculation section. Support vector machine (SVM) classifies each case into one of three groups by using the 5 features.

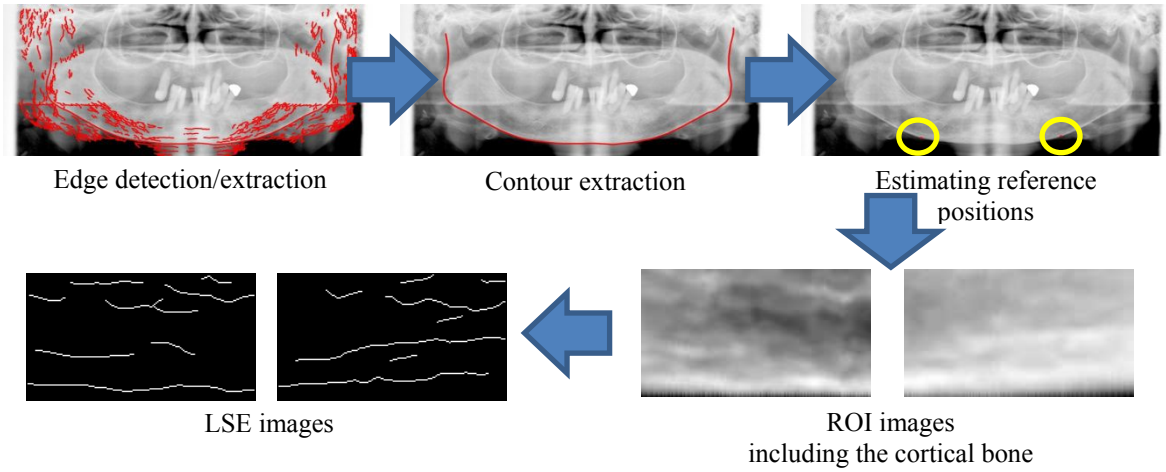

Fig. 2 Overview of our proposed method for classifying MCI

2.2 Roughness calculation section

This section utilizes original ROI images and LSE images. The overall procedures of this section are illustrated in Fig. 3. The cortical bone region is divided into two regions of normal cortical bone and eroded cortical bone by analysis of profiles in ROI images and a lowermost line in LSE images. The region of normal cortical bone is the area of no bone resorption, and the region of eroded cortical bone is the area with linear structures appearing to form endosteal cortical residues by bone resorption. Finally, four features such as the areas of two regions and lengths of the line elements are determined using LSE images with two divided regions.

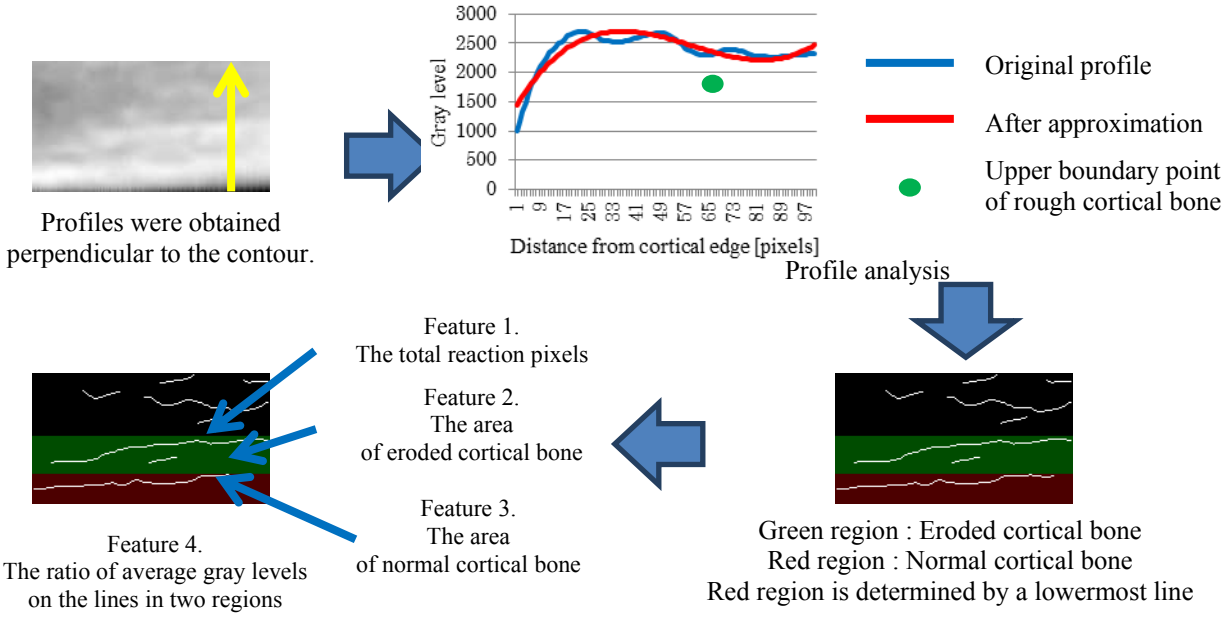

Fig. 3 Overview of roughness calculation section

2.3 Thickness calculation section

The overall procedures of this section are illustrated in Fig. 4. For the purpose of MCI classification, the MCW of our interest is the thickness of normal cortical bone. The endosteal cortical residues caused by bone resorption appear in LSE images. Therefore, measurement excluding porous cortex is possible by using LSE images. For reducing the effect of measurement positions, measurements are made at 3 points each in the right and left ROIs. The points where boundary of eroded and normal cortical bone regions is most clear are selected on the basis of the grayscale profiles in ROI images. Finally, MCW was determined on the basis of the grayscale profile in the original ROIs.

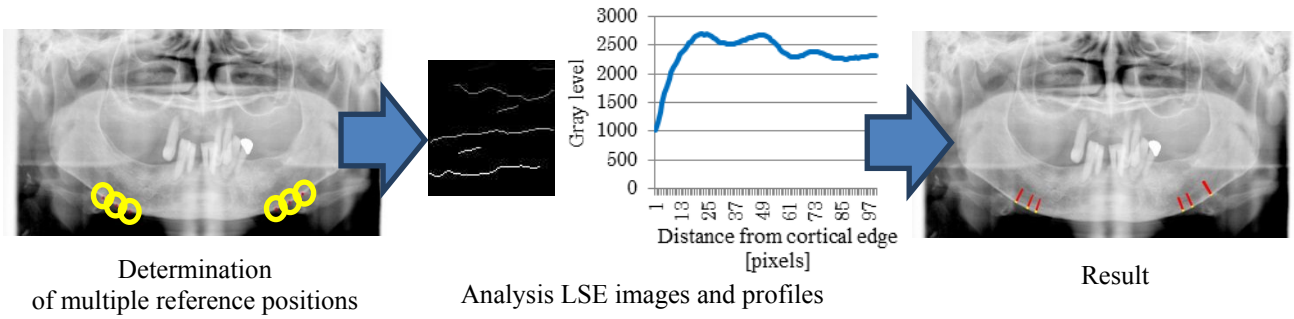

Fig. 4 Overview of thickness calculation section

3. MATERIALS

Ninety eight DPRs were used to evaluate our proposed scheme. Number of cases classified to Class I, II, and III by an expert dental radiologist according to the definitions of MCI are 56, 25 and 17cases, respectively. Furthermore, because of subjective nature of MCI classification, the dental radiologist selected typical cases for each group (Table 1): non typical cases are those that could be considered near the borderline of two classes. The images are in Digital Imaging and Communications in Medicine (DICOM) format with 1,420 × 2,920 pixels, 0.1mm pixel resolution, and 12-bits grayscale.

Table 1 Contents of cases

MCI	Number of cases (Typical cases)
Class Ⅰ	56 (34)
Class Ⅱ	25 (12)
Class Ⅲ	17 (17)
Total	98 (63)

4. RESULTS

Experimental result based on the leave-one-out cross-validation evaluations showed that the categorical sensitivities for the classes I, II, and III were 94.6%, 57.7% and 94.1%, respectively. For the typical cases, the sensitivities were 97.1%, 83.3%, and 94.1%, respectively. Relationship between the classifications by the dental radiologist and the proposed scheme for all cases and the typical cases are shown in Tables 2 and 3, respectively. The purpose of the proposed scheme is to establish a new screening pathway by informing patients with a possible risk. Therefore, class II and III cases are considered positive, whereas class I cases are considered negative. As a result, the sensitivity and specificity were 79.1% and 94.6%, respectively. For the typical cases, the sensitivity and specificity were 96.6% and 97.1%, respectively. In addition, principal component analysis (PCA) was applied to the feature space of 5-dimensions to reduce it to 2-dimensional space. In this space, a transition of the distribution can be observed from the typical class I cases to typical class III cases in the scatter plot (Fig. 5). The transition of the distribution indicates the changes in MCI by osteoporotic progression.

Table 2 Classification results of the dental radiologist and proposal method for all cases

		Dental radiologist		
Proposed scheme		Class Ⅰ	Class Ⅱ	Class Ⅲ
	Class Ⅰ	53 (94.6%)	9 (34.6%)	0 (0%)
	Class Ⅱ	3 (5.4%)	15 (57.7%)	1 (5.9%)
	Class Ⅲ	0 (0%)	2 (7.7%)	16 (94.1%)

Table 3 Classification results of the dental radiologist and proposal method for the typical cases

		Dental radiologist		
Proposed scheme		Class Ⅰ	Class Ⅱ	Class Ⅲ
	Class Ⅰ	33 (97.1%)	1 (8.3%)	0 (0%)
	Class Ⅱ	1 (2.9%)	10 (83.3%)	1 (5.9%)
	Class Ⅲ	0 (0%)	1 (8.3%)	16 (94.1%)

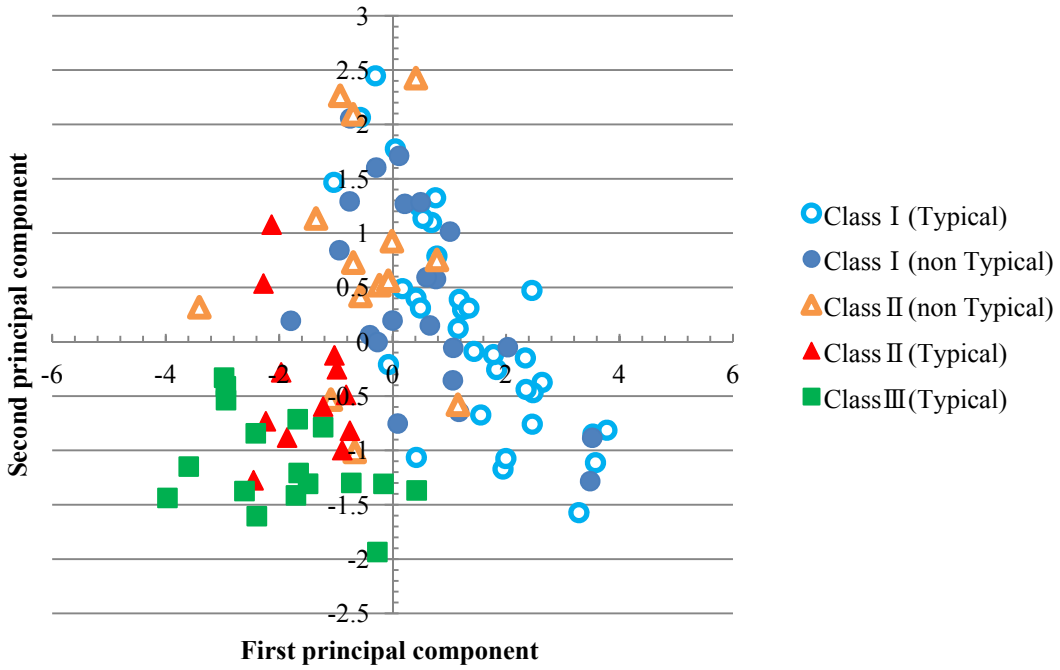

Fig. 5 The distributions of cases with MCI categories in feature space

5. CONCLUSIONS

A computerized scheme that classifies the MCI on DPRs was developed. Experimental result showed that the categorical sensitivities for Class I, II, and III are 94.6%, 57.7% and 94.1%, respectively. When Class II and III are considered positive, the sensitivity and specificity are, 79.1% and 94.6%, respectively. Furthermore, the transition of the distributions with the progressive classes in feature space indicates a possibility of MCI quantification and the usefulness of MCI classification. These results show that our proposed scheme has a potential to identify osteoporotic patients at an early stage.

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