

A basic study for automatic recognition of osteoporosis using abdominal X-ray CT images

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ABSTRACT

We have developed an algorithm that can be used to distinguish the central part of the vertebral body from an abdominal X-ray CT image and to automatically calculate three measures to diagnose the degree of osteoporosis in a patient. In addition, we examined whether it is possible to use these CT images as an aid in diagnosing osteoporosis. Three measures that were automatically extracted from the central part of a vertebral body in the CT images were compared with the bone mineral density (BMD) values that were obtained from the same vertebral body. We calculated the mean CT number, coefficient of variation, and the first moment of power spectrum in the recognized vertebral body. We judged whether a patient had osteoporosis using the diagnostic criteria for primary osteoporosis (Year 2000 revision, published by the Japanese Society for Bone and Mineral Research). We classified three measures for normal and abnormal groups using the principal component analysis, and the two groups were compared with the results obtained from the diagnostic criteria. As a result, it was found that the algorithm could be used to distinguish the central part of the vertebral body in the CT images and to calculate these measures automatically. When distinguishing whether a patient was osteoporotic or not with the three measures obtained from the CT images, the ratio (sensitivity) usable for diagnosing a patient as osteoporotic was 0.93 (14/15), and the ratio (specificity) usable for diagnosing a patient as normal was 0.64 (7/11). Based on these results, we believe that it is possible to utilize the measures obtained from these CT images to aid in diagnosing osteoporosis.

Keywords: X-ray CT images, automatic recognition, image processing, computer-aided diagnosis, osteoporosis

1. INTRODUCTION

Osteoporosis is on the rise, primarily as a result of menopause and an increasing aging population. This disease is associated with low bone mineral density (BMD). Several methods, such as posteroanterior dual energy X-ray absorptiometry (PA-DXA) and quantitative computed tomography (QCT), have been used as a noninvasive means of measuring BMD.¹⁻³ In Japan, we generally judge whether patients have osteoporosis by using the PA-DXA type BMD measurement equipment.⁴

Recently, we were able to obtain detailed information on a broad area in a short period of time by using a helical (or spiral) CT and a multidetector-row CT.⁵ In general, physicians need information about, and from, the main targets of the X-ray CT examinations that have been requested. For example, the main targets of the chest CT examination include the lung area and mediastinum, and, for most abdominal CT examinations, the liver or spleen. However, good use is not made of information obtained from other targets (for example, the vertebral column) from a single X-ray CT examination. In other words, it is possible that a portion of the information contained in the image is not being used effectively. In order to better help patients, it is crucial to elicit as much information as possible from one examination.

We therefore developed, in this study, an algorithm that can be used to distinguish the central part of the vertebral body from the common CT image, and that can be used to automatically calculate three measures that are used to diagnose osteoporosis. For this purpose, we examined 62 cases, including both males and females. In addition, we report the correlation between the BMD and some of the measures that were calculated, and discuss whether it is possible to use the CT images obtained as an aid in diagnosing osteoporosis. Twenty-six female patients participated. Furthermore, we discuss the potential of the screening examination using the common abdominal X-ray CT examination for diagnosis of osteoporosis.

2. THEORY

1.1. Anatomical features of vertebral column

Figure 1 shows a sagittal image of the vertebral column and three axial images of a vertebra. The vertebral

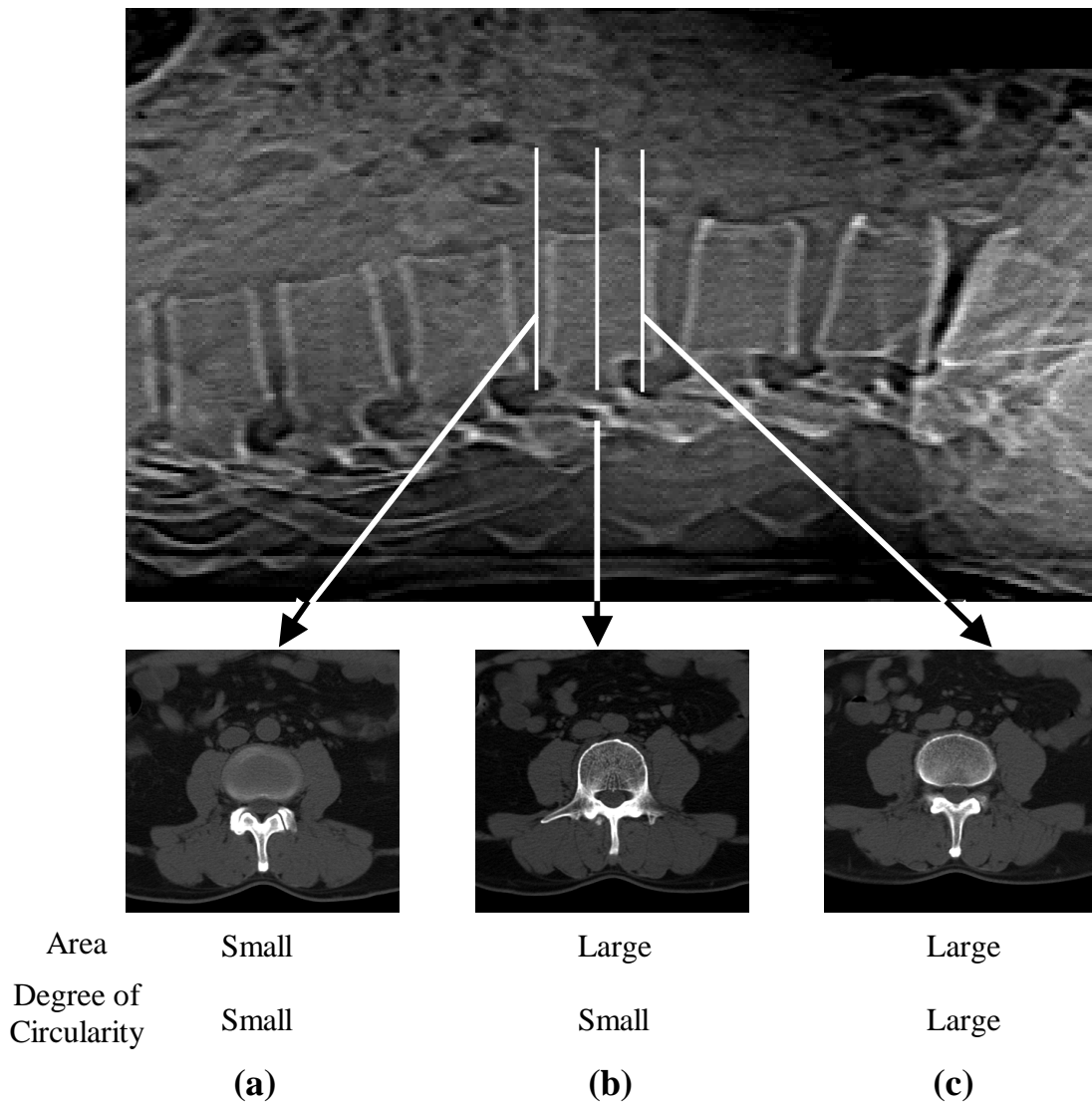


Figure 1. Features of vertebral column and vertebra.

column consists of many intervertebral discs and many vertebrae that overlap each other. In this abdominal X-ray CT examination, the axial images of the vertebra are illustrated in various patterns. For example, in a single image of a vertebra, the lamina of the vertebral arch and the spinous process, along with a part of the intervertebral disc [Figure 1(a)], can be seen. At the central part of the vertebra, the image consists of a vertebral body, costal process, and the spinous process [Figure 1(b)]. An image of a vertebra separated into a vertebral body and a spinous process was obtained at the ends of the vertebra [Figure 1(c)]. By concentrating on the images of the vertebra [Figure 1(a)-(c)], it is possible to see that the area of the spinous process is small in proportion to total image area and that the shape of it is not round [Figure 1(a)]. In Figure 1 (b), it can be seen that the area of the vertebra is large, and that the shape of it is not round, but, in Figure 1(c), the area is large and the shape is round. Using the anatomical features of these various images of the vertebra, it is possible to automatically distinguish the central part of the vertebral body. To that end, we have developed an algorithm that can be used to distinguish the central part of the vertebral body, by calculating the area and degree of circularity of the vertebra. The degree of circularity was calculated by the following equation.

$$\text{Degree of circularity} = 4\pi \frac{\text{Area of vertebra}}{(\text{Perimeter of vertebra})^2} \quad (1)$$

For example, the degree of circularity is a small value (0.418) when the image of the vertebra appears as shown Figure 1(a), but the degree of circularity becomes a large value (0.788) when the image appears as shown in Figure 1(c).

1.2. Diagnostic criteria for primary osteoporosis: year 2000 revision⁴

The diagnostic criteria for primary osteoporosis were proposed by the Japanese Society for Bone and Mineral Research in 2000 (Table 1). The patients were classified into three groups according to the diagnostic criteria on the basis of the BMD in the lumbar spine, as obtained using a PA-DXA examination. The purposes of our study were to distinguish the central part of the vertebral body from a routine abdominal CT examination, and to predict whether a patient was osteoporotic or not with the measures obtained from these CT images. Therefore, in this study, all patients were classified independent of the presence of a fragility fracture.

Table 1. Diagnostic criteria for primary osteoporosis (adapted from year 2000 revision)⁴

I. With fragility fracture ^a	
II. Without fragility fracture	
Classification	Bone mineral density (BMD) ^b
Normal	80% of YAM* or higher
Decreased bone mass (Osteopenia)	70%-80% of YAM
Osteoporosis	Less than 70% of YAM

^aA fragility fracture is a nontraumatic bone fracture that is caused by slight external force to a bone with a low BMD (a BMD less than 80% of YAM).

^bBone mineral density usually refers to lumbar BMD. However, when the measurement is inappropriate because of such reasons as spinal deformity, the femoral neck BMD should be used. When measurement at that site is difficult, the BMD of the radius, second metacarpal bone, or calcaneus will be used.

*YAM: young adult mean (age, 20-44 years)

3. MATERIAL AND METHODS

There were 62 cases (30 males and 32 females), ranging in age from 35 - 86 years (average age: 62.8). We divided the 62 cases into two data sets (18 in the training group and 44 in the test group). The abdominal region contained in the third lumbar vertebra was scanned using spiral CT equipment (CT-W950SR: Hitachi). The tube voltage was 120 kV. The field of view (FOV) and matrix size were 250 mm and 512 x 512 pixels, respectively. The slice thickness was 5 mm, and the movement distance of the table was 5 mm/rotation. It was recalculated so that the reconstruction interval became a minimum unit (1 mm). We then made about 50 images of transverse sections. The island images were selected by threshold processing of each original image. To evaluate whether the CT image included the lumbar vertebral body or not, measures of the area and degree of circularity were used for the determination in each image. A region of interest (ROI: 32x32 pixels) was set up automatically in the recognized images. The threshold values of the two measures were determined by processing the training group, and the test group was processed with the algorithm that determined the threshold values. Figure 2 shows a schematic diagram of the automatic system.

We judged whether each female patient had osteoporosis or not by using the diagnostic criteria (only data on females was available). We calculated the mean CT number, coefficient of variation, and the first moment of the power spectrum in the recognized vertebral body. There were 26 female patients, with an age range of 35 – 79 years (average age: 61.3). Some patients had more than one CT examination, resulting in a total of 32 X-ray CT examinations. Four of the patients had two examinations, and one of the patients had three. BMD measurements with PA-DXA and with lateral DXA (L-DXA) were made with a model QDR-4500 densitometer (Hologic) for the same patients. We classified the three measures obtained from the CT images for the normal and abnormal groups using a principal component analysis, and the results obtained from the diagnosis criteria for the two groups were then compared.

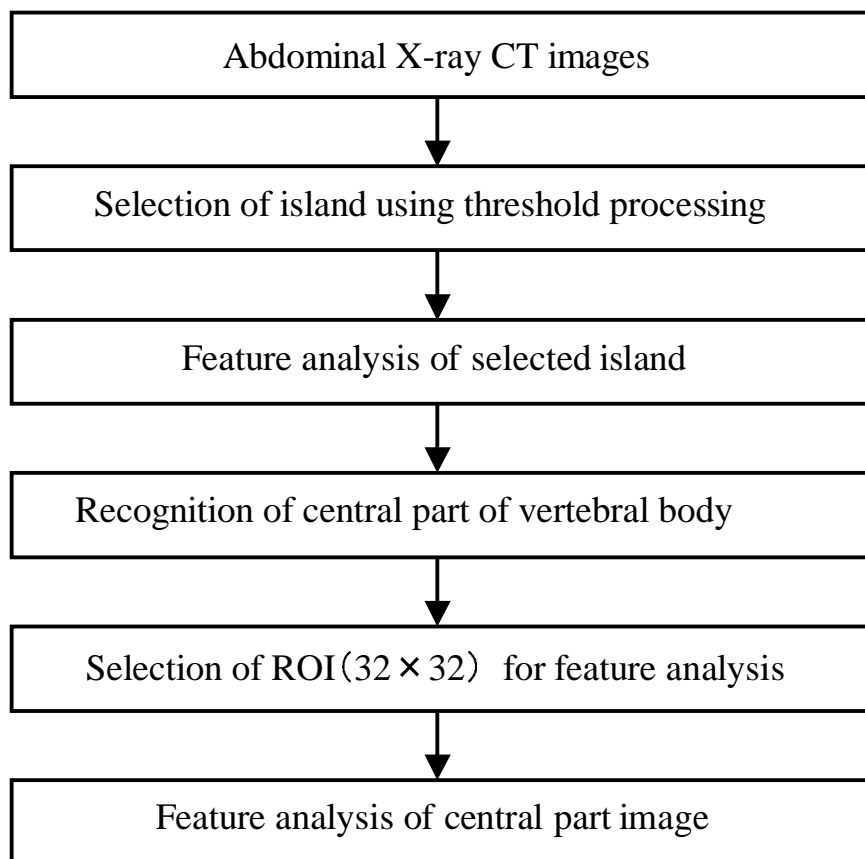


Figure 2. Schematic diagram of the automatic system.

4. RESULTS

Figure 3 shows the relationship between the degree of circularity and area for the training group. The horizontal axis is the island area, and vertical axis the degree of island circularity. The island images were distributed into three regions. In the first region, the values of both measures are small (intervertebral disc). The second region shows that the values of both measures are larger than the first region's values (side part of the vertebra), and the third region indicates that the area is largest, but that the degree of circularity is smaller than the second region (central part of the vertebra). The region in which the symbol * is shown in Figure 3 indicates 1 centimeter taken from the center of the vertebral body perpendicular to the human body axis. The threshold values of the two measures were derived from Figure 3 (area: 1842.7 mm², degree of circularity: 0.431). We were able to use the algorithm to distinguish the central part of the vertebral body in the 62 cases and to calculate these measures automatically.

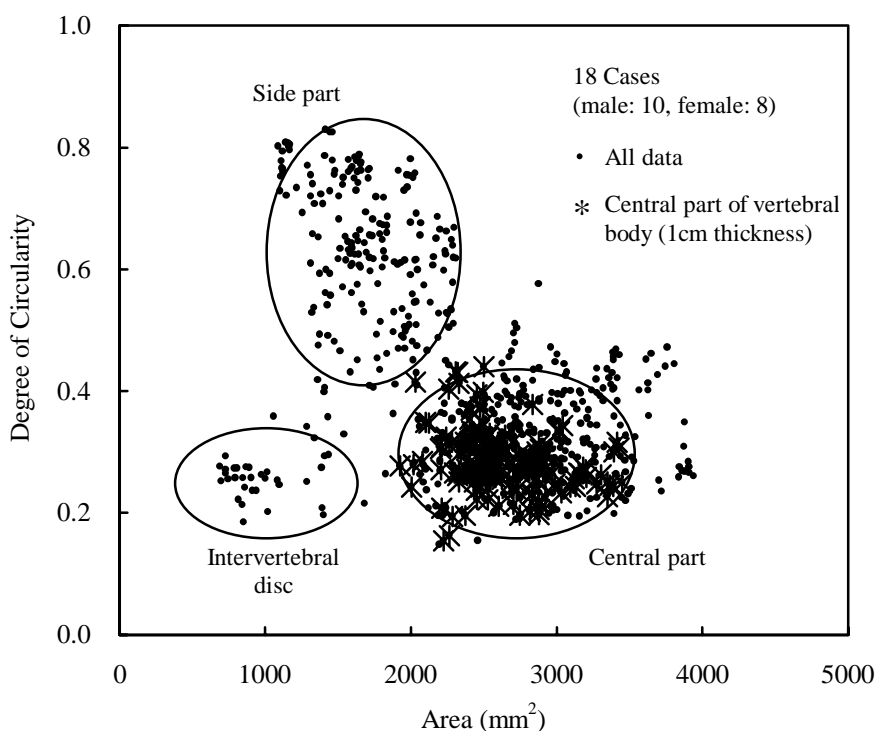
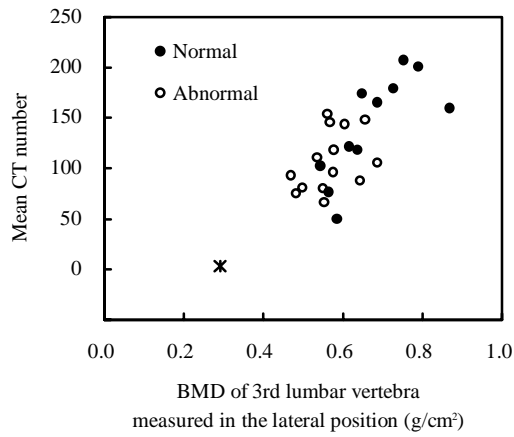
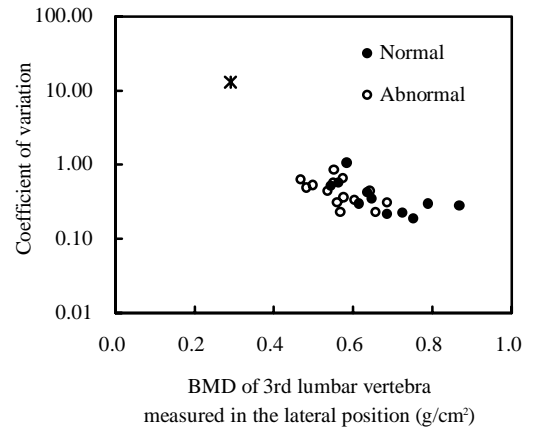


Figure 3. Relationship between degree of circularity and area in the training group.

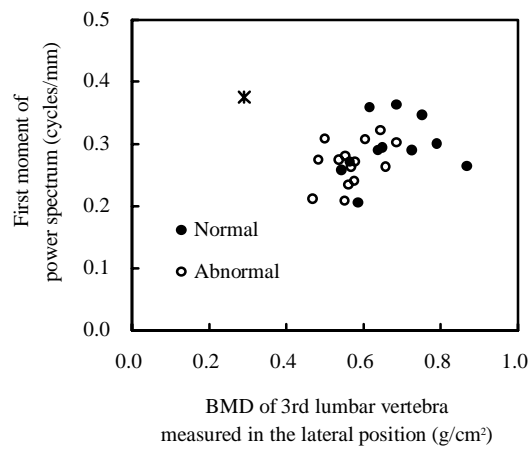
The variations of the BMD obtained from the PA-DXA were 0.49 – 1.18 g/cm² and those obtained from the L-DXA were 0.29 - 0.87 g/cm². Therefore, eleven patients were classified as normal, five patients were rated as osteopenic, and ten patients were recognized as osteoporotic using the diagnostic criteria. The mean CT numbers were 3.32 - 206.52 HU, the coefficients of variation were 0.19 - 12.98, and the first moments of power spectrum were 0.21 - 0.38 cycle/mm in the ROI for 26 female patients. Figures 4(a)–(c) illustrate the relationship between three measures (mean CT number, coefficient of variation, and the first moment of the power spectrum) and the BMDs obtained from the L-DXA. Figure 5 shows the result of the analysis of the three measures obtained from the CT images, in which we used the principal component analysis. The open points in Figure 5 indicate the abnormal cases (osteopenia and osteoporosis), and the solid points show the normal cases. The threshold values of the two principal components were judged from Figure 5 (horizontal axis: 0.72, vertical axis: 0.97). When we applied these threshold values to all female patients, the ratio (sensitivity) usable for diagnosing a patient as osteoporotic was 0.93 (14/15), and the ratio (specificity) usable for diagnosing a patient as normal was 0.64 (7/11).



(a)



(b)



(c)

Figure 4. Relationship between three measures and BMDs.
 (a): mean CT number
 (b): coefficient of variation
 (coefficient of variation = standard deviation / mean CT number)
 (c): first moment of power spectrum

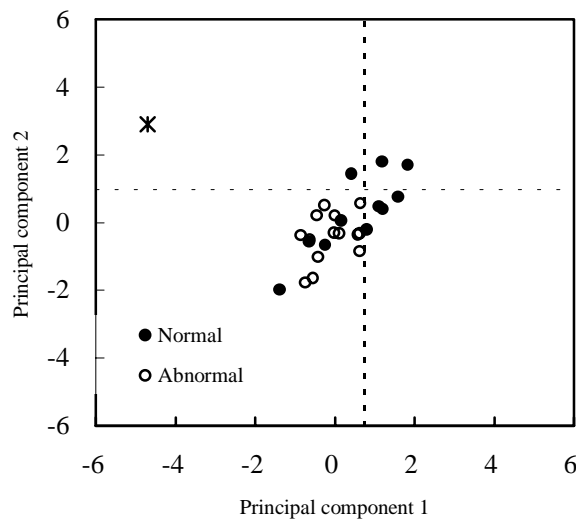


Figure 5. Result of principal component analysis.

5. DISCUSSION

The concept of our study was to obtain more useful information about parts of the body that are not the main targets in abdominal X-ray CT examinations. We have concretely shown that we can use the measures obtained from CT images to aid in making a diagnosis of osteoporosis. An earlier study investigated the diagnostic sensitivity of PA-DXA, L-DXA, and QCT.³ Another study proposed a risk score that separately assessed BMD and the structural parameters for spongy and cortical bone and aggregated them into a single diagnostic parameter.⁶ The concept of these studies was to diagnose osteoporosis or fracture risks with the QCT and/or DXA, but these concepts are different from ours. Other studies have been conducted showing that a diagnosis of osteoporosis could be made by using a chest X-ray CT image, which was taken for other diagnostic purposes.^{7,8} The concepts of these papers and of our study are similar, but we believe that the reliability of these papers is different from ours. For example, Nakayama et al. investigated the CT numbers of the central part of the thoracic vertebral bodies to support a diagnosis of osteoporosis.⁷ However it was not clear that the CT number reflected the condition of osteoporosis, because they did not check the relationship between the CT number and BMD of the same patient. Shiomi et al. discussed an algorithm to automatically extract the values of the central part of the thoracic vertebral bodies, and in this paper, the CT numbers and BMD were compared.⁸ However, the CT numbers and the BMD were obtained from different positions (CT: thoracic vertebral body, BMD: calcaneus). In our study, we compared the CT numbers and BMD from the same position (lumbar vertebral body). Therefore, we believe that the accuracy of our study is higher than of those reported above.

A reference phantom that consists of some mineral equivalent contents is used to reduce errors that occur in the QCT examination, which are due to machine drift.¹ The machine drift has been attributed to several factors, such as X-ray tube aging, detector drift, and difference of application to calculate the CT image. We studied the intra- and inter-equipment variations in the mean CT numbers of a vertebral body for six X-ray CT equipment.⁹ A lower torso phantom and the CaCO₃ calibration phantom were used. As a result, an intra-equipment variation of 1.9% (coefficient of variation: CV) for the mean CT numbers was obtained in the X-ray CT equipment. Using CaCO₃ reference lines, we obtained the mineral contents of the vertebral body. The intra-equipment variation for the mineral contents was 2.2% (CV). We determined that both variations were almost the same, and suggested that the CT numbers that were not calibrated by the reference phantom can be used to estimate osteoporosis.

The features used in this study to pinpoint the central part of the vertebral body were the degree of circularity and the island area. For this reason, we were able to determine the quantity of anatomical information of the vertebral column. As a result, it was possible to distinguish the central part of the vertebral body in all 62 cases using two simple features. There are other methods that can be used to extract the vertebral body. For example, histograms that correspond to the parts of the vertebral column in each axial chest X-ray CT image can be adopted to detect the space between the thoracic vertebral bodies.⁸ This method is based on the fact that the space between the vertebral bodies is parallel to the axial images. However, there is some possibility that the space between the vertebral bodies is not parallel to the axial images in the lumbar vertebra. Although the 62 subjects in this study included cases in which the space was not parallel to the axial image, it was still possible to use the algorithm to extract significant vertebral body values. Therefore, we believe that our method is effective in the quantitative extraction of the vertebral column.

We classified three measures (mean CT number, coefficient of variation, and first moment of power spectrum) for normal and abnormal groups with the principal component analysis. As a result, 14 (sensitivity: 0.93) of the 15 patients were diagnosed correctly as osteoporotic, and seven (specificity: 0.64) of eleven patients were recognized correctly as normal cases. To improve the accuracy of diagnosis, more examinations will be conducted in the future. In one patient (symbol * in Figure 5) we were unable to estimate whether or not the patient had osteoporosis using our algorithm, because this patient was classified as an abnormal case in the horizontal component, but was not recognized in the vertical component. The horizontal component was regarded as the height and variability of the CT number, and the vertical component was regarded as the roughness of the spongy structure. Thus, this case was evaluated as having an abnormal quantity of mineral content, but the quality of spongy bone was normal. This patient had the lowest mean CT number (3.32 HU) and the highest coefficient of variation (12.98). Figures 4(a) and (b) indicated that these data were clearly abnormal (Symbol *). However, the first moment of power spectrum showed that this patient did not have osteoporosis [Figure 4(c)]. Therefore, we need to investigate an analytical method that can be used for special cases such as this.

In this study, the specificity was 0.64 (7/11). Four of the original normal patients that our algorithm classified as abnormal cases obtained a BMD value of 80.2% on the L-DXA, while the seven other normal patients obtained a value of 100%. However, the mean BMD of the original 15 abnormal patients was 75.7% in comparison with the seven

normal patients evaluated as 100% on the L-DXA. There is a possibility that these four patients were actually abnormal cases. The disease that is close to a borderline should be detected when a screening examination is done. However, we would like to refine our algorithm in order to improve the accuracy with which it can be used to diagnose osteoporosis in a screening examination.

6. CONCLUSIONS

Using our algorithm, it was possible to distinguish the central part of the vertebral body in all 62 cases. In addition, we examined whether it was possible to use the CT images obtained to aid in making a diagnosis of osteoporosis. We found that 14 (sensitivity: 0.93) of the 15 patients were diagnosed correctly as osteoporotic, and seven patients (specificity: 0.64) of eleven were recognized correctly as normal cases. Therefore, we believe that, by using this algorithm, we may be able to obtain more effective information about other parts of the body, which are not the main targets in common body CT examinations.

7. ACKNOWLEDGEMENT

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