INTRODUCTION

The diagnosis of osteoporosis has been carried out mainly by Dual Energy X-ray Absorptiometry (DEXA) and the Quantitative Ultrasound (QUS) method. The QUS was introduced to overcome the radiation problem in the DEXA, which was harmful to human body; however, the QUS has a great defect due to the measurement of a specific spot in the calcaneus. It is usually the calcaneal tuberosity on which measurement of bone density is made on the calcaneus. As calcaneal tuberosity is located in the lower part of the calcaneus, where trabecular bones are mostly distributed and the surface is quite flat, the ultrasonic waves can be transmitted easily compared to other parts of the calcaneus. On the other hand, since other parts of the calcaneus have a big incidence angle in the ultrasonic waves, most of signals are reflected rather than transmitted. Therefore, the ultrasonic waves are severely attenuated and interfered with one another and accurate diagnosis is difficult. Most of the ultrasonic bone density measurements lie in trying to obtain the most accurate diagnosis results as possible by selecting the calcaneal tuberosity area (Han & Rho, 1998).

The most critical points in measuring bone density using ultrasound are the precision and reproducibility of the measurement. They are affected by the location of the measurement area, the posture of the patient measured, the temperature, and the performance of transducer (Brooke-Wavell et al, 1995; Chappard et al, 1999).

Most of the existing bone densitometers apply a fixed spot measurement in restricted bone areas, in which the location of the probe is fixed by the equipment, thus the measurement location varies depending on the foot-laying places, postures of the examinee, and the size of the examinee's foot. Therefore, the measurement values may contain large errors, which reduce the precision and reproducibility of the bone densitometry.

In this study, we obtained an ultrasonic image of bone quality distribution in order to reduce the measurement errors caused by measuring in limited bony sites with QUS, by scanning the whole area of the calcaneus in two dimensions. And we evaluated a new method for selecting the region of interest (ROI) automatically, regardless of different calcaneal shapes of each individual, in order to elevate the reproducibility of measurement.

METHODS

Among the ultrasound parameters used in bone density measurement, in particular, the Speed Of Sound (SOS) and the Broadband Ultrasound Attenuation (BUA) have been measured Lanton, et al, 1984). The SOS parameter takes advantage of the fact that the speed of sound is directly proportional to density. It measures the time taken for the ultrasonic wave transmitted through the bone to arrive. The SOS reflects bone density and elasticity. As for the BUA, a fast Fourier transformation is carried out for the measured ultrasonic signal for changing to a frequency domain. The difference between the spectrum data obtained through water and foot in water was plotted over the entire frequency range. Then, the slope value of the plot between 0.3 and 0.7 MHz was determined as the BUA. The BUA reflects the microstructures of bone such as anisotropy, porosity, and the size of pores. And it is used most widely in ultrasonic measurement of bone density.

The Geometric Index(GI) parameter, introduced newly in this study, embodies the amplitude of ultrasonic signals that are transmitted in bones. It shows the attenuation of ultrasonic signals in the time domain and has a value between 0 and 128. The ultrasonic imaging method used in this study acquires the bone image of the whole calcaneus by moving the ultrasound transducers according to the locus shown in Figure 1 and selects the specific area where the trabecular bone is distributed the most as the ROI and decides the average value of the ultrasonic parameters in this area (Laugier, et al, 1996). This method increases reproducibility as it can always trace a consistent bony site regardless of the location of the foot Lefebvre, et al, 1998; Cheng, et al, 1999; Laugier, et al, 2000).

The system used in this study allows the trasducers to scan the area of 60×60 mm with the resolution of 1×1 mm. Then, it measures the total 3600 ultrasonic signals and acquires the ultrasonic image of the calcaneus. Lastly, it applies an algorithm that can find the ROI location automatically regardless of the location of the examinee's foot and decides the diagnosis value.

![Figure 1: Ultrasonic scanning region and its pathway.](image)

ALGORITHM

Figure 2 is the source image of the 60×60 mm GI and BUA maps acquired by ultrasonic scanning and displayed in gray scale. Parts (A) and (B) are the areas where the upper part of the calcaneus and the bottom part of the talus overlap.
Because (A) and (B) are parts where two bones are connected, the shape of the vertical section is complicated and the outline of the surface is uneven and thus, much of the ultrasonic signal is dispersed. Also, as the width of bones in this area is increased, the transmission path of the ultrasonic signal is lengthened, which reduces greatly the strength of transmitted ultrasonic signals. Therefore, the GI value approaches near zero and the extremely low amplitude of the signal obscures the range of the BUA values. Part (C) is where the bottom surface of foot and the floor meet. In the part, the ultrasonic signal becomes weak as it passes the narrow space between the bone and the floor, but the frequency change does not occur greatly. Part (D) is the skin and muscle tissues captured. Part (E) is the center of the calcaneus, and belongs to the ROI. Part (F) is the floor surface.

**Figure 2**: GI and BUA maps of calcaneus

The automatic ROI detection algorithm suggested in this paper adopts the BUA and GI parameters amongst the ultrasonic parameters.

As shown in Figure 3, the configuration of the algorithm consists of 4 stages: the stage to create a map; the stage to obtain bone region; the stage to extract geometric information of the bone; and the stage to find the ROI by using the local minimum evaluation method.

**Figure 3**: Flow chart of automatic ROI algorithm

1. The stage to create the maps of BUA and GI parameters
With regard to the measured ultrasonic signal, each 2-dimensional map was made after filtering, removing noise, and calculating the BUA and GI values through the signal process of the fast Fourier transformation. These processes are shown in Figure 4 in detail.

2. Stage to obtain bone region
In this stage, the regions corresponding to bones and the other regions are separated in the GI and BUA maps in order to extract the bone region, through applying various image-processing techniques.

**Preprocessing stage**
There is a case where data corresponding to excessively high or low noise factors compared to the surrounding data exist in a mixed manner in a BUA map. This phenomenon occurs when an ultrasonic signal at any spot attenuates heavily in the transmission path and only very weak signals are transmitted to the receiver. Also, the phenomenon may occur when the ultrasonic signals are excessively dispersed because of a heavy and rough transmission surface, or when the air bubbles contained in water exist in the ultrasonic wave transmission path.

This study performed the preprocessing stage to avoid fault output due to such noise factors. Median filtering removes impulse noise and a two-dimensional smoothing method makes overall data distribution evenly of the BUA map, so that follow-up operations may not be affected by noise and an exact result may be obtained.

**Figure 4**: All the algorithm steps before bone geometry calculation

**Erosion operation**
The marginal region of the BUA map was filled with zero. The difference between the data corresponding to the bone and the data of the other surrounding tissues and region adjacent to the floor was made great. This operation is the process to remove easily the tissue other than the bone from the image.
Corresponding to the four corners of the map and the outside circle with a radius of 40 mm, in other words, the coordinates (30, 30) and corresponding to the outside of a circle.

In the entire measuring region, the region centering on the bone is calculated.

Exclusion region
In the binary map, when the outline of the bone region is disconnected, not continuously linked, or indicates heavy unevenness, it becomes difficult to precisely judge the region of the bone. The closure algorithm alternatively conducts a dilation and erosion algorithm, removes any non-continuous part, and makes the whole outline smooth.

Removing Insulated Spots
After going through all the above processes, the bone region is obtained and insulated spots may appear in various places on the map, depending on the state of the map. In this process, the insulated spots corresponding to the location inside the bone were filled with 1 by removing these insulated spots and the insulated spots outside were filled with 0, leaving only bone regions in the map.

3. Stage to extract geometric information of the bone

Calculation of outline
In this stage, only the outline part is extracted from the map obtained in the stage to extract the bone region with which the binary data map is made. By carrying out the OR operation with the map that is moved by +2 points horizontally and the map that is moved +2 points vertically, the 2nd map is generated. When conducting the XOR (Exclusive OR) operation with the original map and the generated 2nd map, the outlined map is generated.

Linear interpolation
By conducting linear interpolation on the coordinates (X, Y) of the outlined map data, the overall gradient of the calcaneus is obtained.

Calculation of geometric information of the bone
In this stage, based on the outline information and the gradient of the calcaneus, three straight lines passing through below, or left and right of the bone, shall be obtained and the size of the bone is calculated.

4. The stage to find the ROI
According to the sequence shown in Figure 5, the central spot location of the ROI is obtained by conducting a local minimum evaluation algorithm with regard to the spots obtained inside the bone region.

Calculation of the polygon of the border in the bone region
Border polygon of bone is generated from three straight lines passing through the outline of bone by using geometrical information on the calcaneus.

Exclusion region
In the entire measuring region, the region centering on the coordinates (30, 30) and corresponding to the outside of a circle with a radius of 40 mm, in other words, the coordinates corresponding to the four corners of the map and the outside of the border polygon are excluded from the central spot candidate of the ROI, which is the goal to be obtained. In this section, it is difficult for the ROI to be placed when the ultrasonic signal is frequently distorted, since it is very weak or interrupted, even if the location of the foot is placed normally; and, this makes it difficult to expect a precise result in the next stage.

Evaluation of the local minimum in the bone region
The evaluation of the local minimum is the method that compares relative size to the surrounding values in the central part of the region, which has been restricted to a certain size. This method is to find a cave-in shape of the region when viewing a three-dimension GI map, since the size of the central part value is lower than the surrounding values in the GI map, recomposed with the 128 GI values.

Figure 5: Flow chart of ROI detection algorithm

Figure 6 shows the local minimum evaluation values of the spots, which are remote from the distance of Re for one spot (X, Y). In this case, as the value of Re changes from 3 to 12, the evaluation is repeated. Evaluation of the local minimum values is conducted in the following order (see Figure 5).

1. Obtain the average of the region given by Re.
2. Obtain the number of spots that have larger values than the average and make it the evaluation value.
3. After adding the cumulative averages obtained in the above process, repeat the process of 1 and 2 by changing the Re value. In this case, the Re values range from 3 to 12.
4. Determine the ultimately-added values as the evaluation value of spot (X, Y).
5. Among the evaluation values of each spot, select the smallest value as the coordinate of the central spot of the ROI.

The experimental equipment consists of scanning system and the computer system that can drive the scanning device, measure ultrasonic signals, and conduct an automatic ROI and diagnosis algorithm.
EXPERIMENTAL SETUP

Two ultrasonic probes with 500kHz central frequency were placed in the water tank facing each other. Then, the foothold was placed in the tank to maintain proper posture when putting the foot there. Thin plastic plates were placed on both sides of the foothold to diminish the effect caused by attenuation of ultrasonic signals in order that the ultrasonic wave could penetrate. The equipment is designed for water to be supplied within the foothold via solenoid valves and a pump during measurement. The ultrasonic sensor is composed for two stepping motors and ball screw tool crossed at a right angle, so that the sensor can move on the two-dimensional plane of the X and Y axes by orthogonal coordinates.

RESULTS AND DISCUSSION

The automatic detecting algorithm of the ROI for an accurate measurement was developed from the ultrasound image method that was introduced in order to supplement the disadvantages of the existing ultrasonic bone densitometry using a fixed-spot method. An automatic ROI detecting algorithm was implemented in order to reflect anatomical shapes of diagnostic regions that vary according to the individual. Clinical experiments on 305 women age 22~88 (Mean ± SD) were performed in to evaluate the applicability of the automatic ROI detecting algorithm. As a result of clinical experiments, satisfactory reliability was obtained.

Figures 8 (a)–(d) display the process that detects bone regions from a reconstructed bone quality image by using the BUA values obtained through measurement. Figure 8 (a) represents the results of applying the erosion operation into an original image and it is the preprocessing stage for binary operation. Figure 8 (b) shows the binary results into B/W images based on a threshold obtained from a gray level classified by pixels of the entire image. As shown in the Figure 8 (b), two black spots exist on the tuberosity of the calcaneus and the lower part of the inner side of the calcaneus, and one white spot is shown on the right bottom part of the image. This represents that the distinction between the inside and outside of bones is not completely made and the discontinuity part exists as well. Therefore, entire outlines are to be clearly distinguished by removing discontinuous parts through repetition of the erosion and expansion operations in order to accomplish a smooth extraction as in Figure 8 (C). Figure 8 (d) displays the last stage to extract the bone region, showing the extracted image of complete bone regions by removing isolated points of black spots and a white spot.

Figures 9 (a) and (b) demonstrate the process to extract the bone's geometric information from the bone region image which was extracted through the preprocessing stage.
**Figure 9**: Calculation of contour and bone geometry
As Figure 9 (a) shows the results of the XOR (Exclusive OR) operation performed on the extracted bone region image map and on the secondary image map achieved through shifting by pixel in the direction of the x and y axes, we can see that the bone contour is extracted as a white continuous line. Figure 9 (b) represents the results of geometric information from the extracted bone contour. It shows the center axis of the bone that was attained from three straight lines that pass under or left/right of the bones.

Figures 10 (a) and (b) demonstrate a bone quality image that was reconstructed by the use of GI or BUA values obtained through clinical experiments. Among these, Figure 10 (c) displays the results of applying bone region extraction and the geometric information extract-algorithm for images of two subjects selected randomly. It shows that the bone geometric information to extract ROI, regardless of bone size and shape, especially extraction of the bone center axis, was well attained. Comparing Figures 10 (a) and (b) with 9 (c), the image in Figure 10 (c), which was attained through various image processes, becomes a little bit smaller than that in Figure 10 (a) and (b), but it does not affect the information on the bone center axis. The bone center axis was calculated by employing 305 clinical experimental subjects and then the ROI was set up. The results were displayed on the bone quality. As the result of the examination, the ROI was accurately placed in 295 people that showed 98.3% accuracy.

**Figure 10**: Examples of bone geometry detection
Figures 11 (a) and (b) represent bone quality images on which the ROI is placed. The Figure 11 (a) shows that the calcaneal tuberosity is located near the central point of the image, while Figure 11 (b) is the image to illustrate the ROI detected in the case that the calcaneal tuberosity is located far from the center of the image in which the foot was located differently from the general cases. As shown in the Figure 11 (b), it is confirmed that the ROI is well placed regardless of the location of the calcaneal tuberosity on the image and that the ROI extract method applying the algorithm is effective.

**Figure 11**: Results of ROI detection algorithm
Figure 12 displays GI and BUA images of some of 10 subjects for whom the detection was not carried out successfully. This is the case for aged women in which overall bone quality is degraded. Therefore, the general features of calcaneal tuberosity by GI or BUA values did not appear. It is considered that the contour of the bones was wrongly extracted or there was a failure to determine the minimum value after the contour extraction.

This is due to the fact that GI values that exceed maximum value were shown frequently in the regions other than in calcaneal tuberosity, in the case of aged patients, due to the limitation of the input voltage level in A/D transformation and fixation of measured gain in the ultrasonic receiver of the bone densitometry that was used for measurement. This could be overcome through real-time adjustment of the gain value of the receiver upon the ultrasound measurement. Further
research is required on aged people from whom the ROI was not perfectly detected.

(a) Age 79

(b) Age 82

(c) Age 75

Figure 12: Examples of incorrect ROI detection

Figure 13 is the graph to analyze the correlation between age and the BUA average value obtained at the ROI location from 295 people out of 395 subjects (excluding 10 people from which ROI was not successfully detected). The linear correlation between age and BUA was highly significant $r=0.85$ ($p<0.0001$). Thus, we verified that the newly introduced automatic ROI detection method in this study provided reliable results by reflecting anatomical shape of calcaneus.

**SUMMARY**

In this study, we suggested an automatic detection method of ROI as one of the means to implement a method to evaluate bone quality accurately by the use of ultrasonic image. The ROI detection method consists of the stages to obtain the image map, to extract the bone region, to extract the bone's geometrical information, and to search the ROI based on the measured data analysis. In order to evaluate the applicability of automatic ROI detecting algorithm for bone density measurement, we performed clinical examinations on 305 female subjects with age 22 ~ 88 (Mean ± SD). Ultrasonic images of 295 subjects out of 305 were confirmed to be accurate. This confirms the high precision (98.3%) of the ROI automatic detection.

Furthermore, the reliability of measurement results was confirmed by analyzing the correlation between age and the BUA, the ultrasonic bone density parameter. Therefore, it is possible to acquire accurate diagnosis of osteoporosis and to improve reproducibility of measurement by introducing a new ROI detecting method.

**REFERENCES**