INTRODUCTION

There are two factors that affect adolescent growth: hereditary and environmental. Hereditary factor accounts for about 30% of the growth, and environment factor contributes to the rest of it[1]. Among environment factors, the secretion of growth hormone affects most directly the growth, allowing the bone to grow longitudinally. The growth interruption means the lack of growth plate that is essential for the bone to grow longitudinally. This growth interruption emerges during the second growth of adolescence, when sex hormone reduces secretion of growth hormone and causes the fusion of growth plate in cartilage of each joint to make the growth plate closed. Increase in sex hormone by antagonism against growth hormone leads to decrease in growth hormone that stops the growth.

Some of methods have been suggested to predict the growth toward longitudinal direction of bone[2]. The most popular method is to analyze the opening degree of growth plate using X-ray image. However, it is difficult to estimate periodically and repeatedly the growth with X-ray that has radiation problem[3][4]. As alternative can be used the diagnosis of growth by estimating bone age. It can estimate bone age by checking when each long bone(ex, femur, tibia) closes, how the number of carpals changes, or bone density[5-7]. Another new method is the combination of two ways; analysis of the opening degree of growth plate using X-ray image and estimation of bone age by measuring bone density[8][9]. Lately, the estimation of bone age with bone density by using harmless ultrasound has been applied as a means of periodical and repetitive measurement of the diagnosis of growth[10-12].

The purpose of this study is to suggest a new imaging method for the diagnosis of growth and verify its validation for growth plate in calcaneus by the use of ultrasound that can offer bone quality images.

METHODS

For analyzing the opening degree of growth plate, ultrasonic bone quality parameters and ultrasonic image of calcaneus were acquired on 269 male/female children (7~ 16 years old). Calcaneus consists of cancellous bone, that makes it easier to measure calcaneus with ultrasound. With the existing ultrasonic method, it is difficult to measure the bone density consistently, because only a specific point can be measured, causing errors due to the mislocation of measurement. In this study, therefore, we adopted the way to image the distribution of bone quality in calcaneus with ultrasound. Figure 1 shows the distribution of bone quality acquired by scanning the specific sites of calcaneus. The scanning area was 60×60 mm, resolution of each axes was 1 mm and the number measured was 3600 pixel. We reconstructed the images by utilizing the technique that measured Broadband Ultrasonic Attenuation (BUA) changes into color tone by color bar of black and white (BUA ranging from 30dB/MHz to 150dB/MHz) with the fixed pixel value.

![Figure 1: Principle of BUA image reconstruction](image1)

A new imaging analysis algorithm was applied to detect automatically the size of growth plate in ultrasonic images. This approach is derived from the fact that BUA changes rapidly near the growth plate. Firstly, we binarized and repeatedly eroded the image of bone quality, and extracted the outer shape of calcaneus. Then we calculated the outer three lines with the method of least square, and identified a central axis of calcaneus. Figure 2 shows the process for extracting the outer shape of bone quality and identifying the central axis of calcaneus from analysis of ultrasonic image.

![Figure 2: Ultrasonic image analysis (detection of the outer shape and definition of a central axis of calcaneus)](image2)

From the relation of identified outside of calcaneus to the central axis, we drew perpendicularly a line as long as the diameter of region of interest (ROI) along the central axis. For deciding ROI, we selected a local minimum point of BUA near protuberance of calcaneus where the correct value of bone density can be obtained and there is little signal attenuation, because this site is generally flat. Figure 3 shows ultrasonic image with ROI positioned correctly.

We profiled the BUA mean value of segment of each line from the distance of the central and then analyzed the relation of the profile and the growth plate.
In the ROI detection algorithm for growth plate by ultrasonic parameter, ROI and the information on the outline and incline of foot were obtained from the ultrasonic parameter acquired by scanning the specific area of each heel. Secondly, we got profile of BUA mean value from central point of ROI to bottom of image in perpendicularly bone incline by a gap of 1 mm. Thirdly, we detected profile at region of the growth plate neighborhood by search of pattern and got 2 maximum points from the detected profile. Then we calculated the area between the profile and the line connecting the two maximum values. Figure 4 shows principle for detecting growth plate. Finally, we analyzed position and size for detecting growth plate using one minimum and two maximum points at the growth plate neighborhood as an ultrasonic parameter profile.

Figure 4 shows principle for detecting growth plate

Through these processes, we could analyze the correlation for the opening degree of the growth plate among each joints, compare X-ray with ultrasonic image of calcaneus, and verify the correlation of the ultrasonic diagnosis of growth plate in calcaneus with X-ray diagnosis of knee, the most popular method for diagnosis of children’s growth plate. The FCF5000 (Fuji, Japan) and KXO-30R (Toshiba, Japan) were used for X-ray image analysis.

RESULTS AND DISCUSSION

Figure 6 shows the image of bone quality distribution acquired from ultrasonic scanning. We could appropriately evaluate the opening degree of growth plate from the image of bone quality distribution in calcaneus. In the case of the growth plate opening, the opening degree was different depending on the growing degree of each child.

Figure 6: Ultrasonic images of growth plate in calcaneus
Figure 6 also shows that although all of growth plate of 7 and 9 year-old children were open, the opening degree of their growth plates were different each other. As individual gets older, the image of his growth plate changes from being closed into closed state, showing that individual grows only during the specific period. Furthermore, the growth interruption indicates the disappearance of the growth plate that can be confirmed by the image of closed growth plate, showing that the growth cannot continue any longer.

Figure 7 shows the comparison of the opening period of growth plate in each joint. As shown in Figure 7, the opening degree of growth plate was clearly confirmed in the three cases, the open, the being closed, and the closed in the upper proximal tibia, the carpals of phalanges, and the end of calcaneus. As a result, it was found that the opening degree of growth plate on X-ray images appeared to be highly correlated in each joint. Furthermore, it was also found that the opening degree of growth plate by X-ray image was highly correlated with that by ultrasonic image of calcaneus.

**Figure 7**: The comparison of correlation between X-ray image at each site and ultrasonic image in calcaneus.

Table 1 shows the relationship of opening degree of growth plate between X-ray and ultrasonic images in the three cases; the open, the being closed, and the closed. The opening degree of growth plate of each joint by X-ray image was highly correlated with one another. And the ultrasonic image of growth plate in calcaneus was also highly associated with the X-ray image.

**Figure 8**: Calcaneal images obtained by ultrasound (left) and X-ray (right) methods, showing growth plate open in the case of 8 years old female (a) and (b), and growth plate being closed in the case of 14 years old male (c) and (d).

Figure 8 shows the images of growth plate size obtained by X-ray and ultrasound in calcaneus. While images (a) and (c) were obtained by the detection algorithm of growth plate by ultrasound, images (b) and (d) were obtained by X-ray. For analyzing the actual measurement of X-ray image, we calculated the measured magnification of X-ray image to set up a phantom and measured the size of growth plate under the same condition (Collimator fixed to be 1m high). Then we defined a central axis of calcaneus by the same way as the measurement of growth plate size with ultrasonic image, and measured the distance of growth plate. As shown in image (a), in the case of a 8-year-old girl with the growth plate opening, the profile drawn by ultrasonic imaging analysis had two maximum values on the central axis of calcaneus. The distance between the two maximum values was 5mm, therefore the size of growth plate was 5mm. In image (b), the size of growth plate acquired by the actual measurement of X-ray image was 5.5mm.

Figure 8 (c) and (d) show the ultrasonic and X-ray images of a 14-year-old boy, with his growth plate being closed. Image (c) shows that the boy’s profile had two maximum values on the central axis of calcaneus, and the distance between those values was 2mm. As a result, the size of growth plate was 2

<table>
<thead>
<tr>
<th>Opening degree of growth plate</th>
<th>X-ray Image</th>
<th>Ultrasonic Image</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proximal Tibia</td>
<td>Calcaneus</td>
</tr>
<tr>
<td>Open</td>
<td>128 persons</td>
<td>124 persons</td>
</tr>
<tr>
<td>Being closed</td>
<td>103 persons</td>
<td>110 persons</td>
</tr>
<tr>
<td>Closed</td>
<td>38 persons</td>
<td>35 persons</td>
</tr>
</tbody>
</table>

Table 1: Comparison of the opening degree of growth plate between X-ray and ultrasonic images.
mm. In image (d), the size of growth plate was 1.6mm with the same way used above. The growth plate image by X-ray was slightly different from that by ultrasound, but the size of growth plate was similar.

Figure 9 shows that the size of growth plate measured by X-ray is closely related with that by ultrasound ($r=0.95$, $p<0.0001$).

Generally, there used to be measurement errors in X-ray image of growth plate by different operators. Ultrasonic method makes it easy to measure automatically the size of growth plate, because it applies the same algorithm to individual with analysis of ultrasonic image. Therefore, without the subjectivity of operator, ultrasound leads to the more accurate analysis.

In the study, the average size (mean±SD) of growth plate by X-ray images was $1.47±1.12$mm in the proximal tibia and $3.39±1.43$mm in the calcaneus. And the size of growth plate in calcaneus acquired by ultrasonic images was 4.18±1.46mm. As a result, the size of children's growth plate by ultrasonic image was 1.2 times as big as one by X-ray. It might be due to the fact that dispersion of ultrasonic signals came from the boundary of growth plate and bone. In processing ultrasonic signals, while, in the time domain, amplitude between the growth plate and bone, and the outside of bone and bone changes rapidly, in the frequency domain its bandwidth tends to be narrow. Thus, the size of children's growth plate in calcaneus may be bigger, due to ultrasonic dispersion by superposition of bone along the direction of ultrasonic propagation. Nevertheless, it is a significant discovery that the image of growth plate can be obtained by ultrasound harmless to human body. It is expected that if more efforts to improve the quality of ultrasonic image are made, ultrasound may replace X-ray for diagnosis of children's growth.

**SUMMARY**

The purpose of this study was to suggest a systematic and scientific method for measurement of children's growth development, in which the accuracy of existing diagnosis method has not been concretely examined yet.

The most popular method for diagnosis of children's growth is to analyze the opening degree of growth plate in each joint by X-ray image. However, X-ray method has some disadvantages; it is impossible to measure the diagnosis of growth periodically and repeatedly due to the radiation problem. Hence, this study introduced a profile analysis and the algorithm of analyzing the image of growth plate with the BUA of calcaneus, to verify the possibility of alternative ultrasonic method harmless to human body.

We obtained the images of growth plate in proximal tibiae, phalanges, and calcanei of 269 children (7~16 years old) with X-ray. And the image of growth plate in calcanei was also obtained from those children with ultrasound. The results showed that the time of the opening degree of growth plate in each joint was almost consistent between X-ray and ultrasonic images.

Also, the images of growth plate measured by X-ray and ultrasound showed the high correlation. Therefore, it is expected that the algorithm of ultrasonic profile analysis introduced in this study can replace the existing X-ray method to measure the growth plate correctly.

**REFERENCES**


