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Ryuji Nagamine · Yoshinari Hanada · Masakazu Kondo
Shin-ichi Fukumoto · Toshihide Shuto
Yasuharu Nakashima · Go Hirata · Aiko Katayama
Yukihide Iwamoto

Quantification of bone volume on radiographs using NIH Image

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Abstract We attempted to quantify periarticular bone atrophy from radiographs of the proximal phalanx in patients with rheumatoid arthritis (RA) by means of the National Institutes of Health (NIH) Image computer program. The degree of brightness or darkness in four squares, each 20 × 20 pixels, in the right third proximal phalanx was measured using NIH Image, and the mean value of the 400 pixels was defined as the brightness/darkness index (BDI). The BDI was used to express bone volume. The BDI value was set at zero for an area of complete darkness and at 255 for an area of maximum brightness. The mean coefficient of variation in our hospital was 2.28%. The BDI was measured in 54 RA patients and 146 normal volunteers. The mean BDI at the midpoint of the diaphysis was 100 in RA patients and 176 in normal volunteers, while at the medial side of the proximal end it was 75 and 145, respectively. The difference between normal volunteers and RA patients was greatest in younger people. In some young RA patients, the BDI was significantly low at the medial side of the proximal end, clearly demonstrating periarticular bone atrophy. Periarticular bone atrophy can be quantified using the NIH Image computer program.

Key words Radiograph · Rheumatoid arthritis · Bone volume · NIH Image · Computer

Introduction

Osteoporotic change seen on radiographs of patients with rheumatoid arthritis (RA) is an important indicator of RA activity.[1–3] However, few methods have reported the quantitative assessment of bone volume in cancellous bone using simple radiographs of the hands.[4] In this study, the National Institutes of Health (NIH) Image computer program was used to quantify bone volume from radiographs. With NIH Image, the degree of brightness or darkness of any area of a picture can be measured on the computer. An index of the degree of brightness/darkness can then be used to express bone volume. This paper reports on three studies. The first assessed the reliability of the values obtained by means of NIH Image. The second assessed the correlation between the values obtained by NIH Image and bone mineral density (BMD) as ascertained by dual energy X-ray absorptiometry (DEXA). In the third study, periarticular bone atrophy on the radiograph was quantified using the NIH Image program, and the usefulness of this method for evaluating the radiographs of RA patients was assessed.

R. Nagamine (✉) · Y. Hanada · S. Fukumoto · T. Shuto · Y. Nakashima · G. Hirata · A. Katayama · Y. Iwamoto
Department of Orthopaedic Surgery, Postgraduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka, Japan
Tel. +81-92-642-5488; Fax +81-92-642-5507
e-mail: nmine@ortho.med.kyushu-u.ac.jp

Materials and methods

NIH Image is a public domain image processing and analysis program, which was developed at the Research Services Branch (RSB) of the National Institute of Mental Health (NIMH), part of the National Institutes of Health. With this software, the degree of brightness or darkness can be quantified in any area of a picture on the computer. The value is normally set at zero for areas of maximum brightness and at 255 for areas of complete darkness. In the current study, however, the reverse mode was used, which means that the value was set at zero for an area of complete darkness, and at 255 for an area of maximum brightness. A picture of a radiograph is opened by NIH Image, and a square of 20 × 20 pixels is created in the center of the area where the bone volume is to be measured. NIH Image measures the degree of brightness/darkness in the square, and displays the mean value for the 400 pixels within the square. In this study, this mean value was defined as the brightness/darkness index (BDI) in the area measured, and was used to express bone volume.

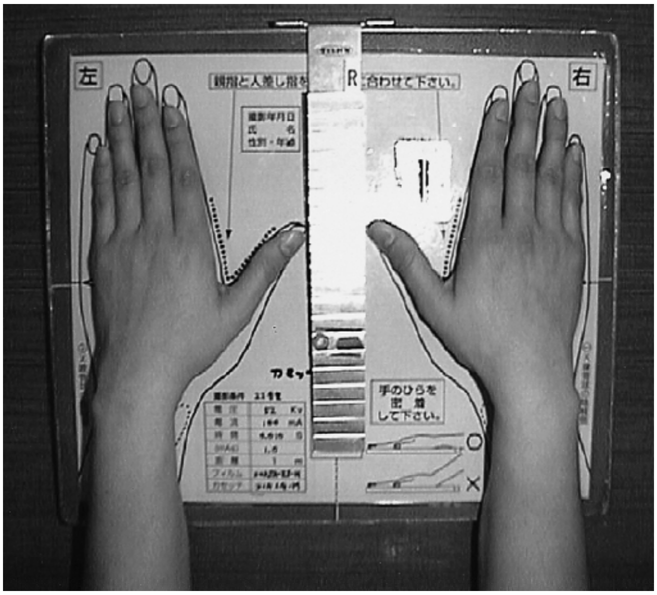

Fig. 1. An anteroposterior radiograph of hands with an aluminum step wedge was taken so that the distal part of the forearm was included. The cubic image distance was 1 m, and the radiograph was taken with 52 kV, 100 mA, and for 0.01 s. A marker was attached on the seventh step of the aluminum step wedge

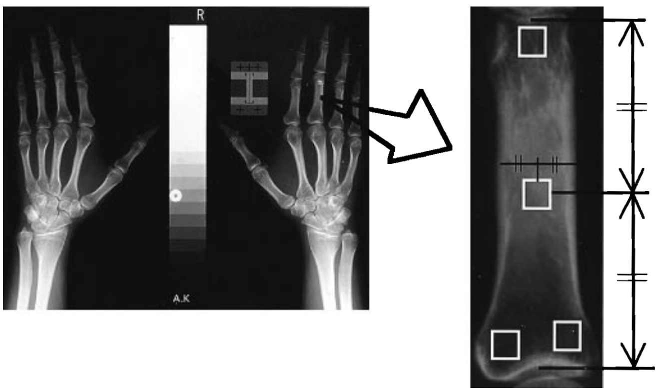

Fig. 2. Preparation of picture data from a radiograph. The radiograph was scanned, and the right third proximal phalanx was magnified nine times. Four squares, 20 × 20 pixels each, were set, one at the midpoint of the diaphysis and three at the distal and proximal epiphyses. Care was taken not to attach a square to a cortical bone itself

This paper reports on three studies. In all the studies, anteroposterior (AP) radiographs of both hands taken with an aluminum step wedge (Figs. 1 and 2) were used because these are taken regularly during the treatment of RA patients. The radiograph was taken so that the distal part of the forearm was included. The radiographs were scanned at a resolution of 150 dots per inch. The right hand was magnified nine times using the software "Adobe Photoshop" (Adobe Systems, San Jose, CA, USA), and saved as picture data. Next, the picture was opened by NIH Image. A square of 20 × 20 pixels was set where the bone volume was to be ascertained. The BDI was then measured.

The first study assessed the reproducibility of the BDI. Six AP radiographs of both hands of four normal volunteers from our hospital were taken with an aluminum step wedge. The cubic Image distance was 1 m, and the radiograph was taken with 52 kV, 100 mA, for 0.01 s. The same piece of radiographic equipment was used throughout this study. The BDI was measured in the center of the cancellous bone at the midpoint of the diaphysis of the right third proximal phalanx. The BDI was also measured at the seventh step of the aluminum step wedge. In a preliminary study, the BDI was measured at the seventh step on 50 radiographs. The mean BDI at the seventh step was 203. This value was used to correct the measured BDI data. On each radiograph, the value of the BDI of the right third proximal phalanx was corrected using the discrepancy between the BDI at the seventh step of the aluminum step wedge and 203. Then the coefficient of variation (CV) was calculated. Next, AP radiographs were taken six times using the same method in another hospital with the same volunteers. The CV was calculated as before, and the reproducibility of the BDI between different hospitals was then assessed.

The second study assessed the correlation between the BDI and BMD. The subjects were 50 patients with RA. The mean age of the patients was 59.4 years (range 39–81 years). All the patients were Japanese women. The RA stage, as defined by Steinbrocker et al.,[5] was I in 2 patients, II in 12, III in 11, and IV in 25. In each patient, BMD was measured in the distal one-tenth of the right radius using DEXA. The area measured was 1 cm wide. An AP radiograph of both hands was then taken. A square of 20 × 20 pixels within the area of cancellous bone in the right radius, which was 2 cm proximal from the distal articular surface, was set on the computer and the BDI was measured. Although the areas measured on the radiographs and by DEXA were not exactly the same, the regression coefficient between the BDI and BMD in the diaphysis of the radius could still be assessed.

The subjects in the third study were 54 RA patients and 146 normal volunteers. The mean age of the RA patients was 56 years (range 20–85 years), and the mean age of the volunteers was 50 years (range 21–89 years). The RA stage was I in 10 patients, II in 4, III in 14 and IV in 26. Four separate squares were set on the AP radiographs of each patient, within the area of cancellous bone of the right third proximal phalanx. These were placed at the distal end, at the midpoint of the diaphysis, and at the medial and lateral sides of the proximal end (Fig. 2). The third proximal phalanx was selected because the proximal phalanx lies between the proximal interphalangeal (PIP) joint and the metacarpophalangeal (MCP) joint. The squares in the distal and proximal epiphyses were located as close as possible to the cortical bone. Great care was taken not to attach the square to the cortical bone itself. The BDI was measured in these four squares (Fig. 2). The BDI of each square was compared between RA patients and normal volunteers. Next, the differences between the BDI at the midpoint of the diaphysis and the BDI in the other three regions in the epiphyses were calculated in order to assess periarticular bone atrophy in RA patients.

Results

In the first study, the mean CV in our hospital was 2.28%. However, the mean interhospital CV was 4.96%.

In the second study, the mean BMD in the distal one-tenth of the right radius was 0.469 g/cm^2, with a standard deviation (SD) of 0.133 g/cm^2. The BDI of the square which was 2 cm proximal from the distal articular surface of the right radius was 156.7 ± 29.9 (mean ± SD). The correlation between the BDI and BMD was statistically significant ($r = 0.823$, $P < 0.001$) (Fig. 3). This result clearly showed that the value of the BDI could be used to assess bone volume from radiographs.

The results of the third study are shown in Figs. 4 and 5. The mean BDI at the midpoint of the diaphysis was 100 in RA patients and 176 in normal volunteers, while those at the medial side of the proximal end were 75 and 145, respectively, those at the lateral side of the proximal end were 86 and 156, respectively, and those at the distal end were 88 and 156, respectively. These results show that the BDI was significantly lower in all areas in RA patients when compared with that of normal volunteers ($P < 0.0001$). The difference between RA patients and normal volunteers was greatest within the younger study subjects. The results of the mean differences between the BDI at the midpoint of the diaphysis and the BDI in the other three regions in the epiphyses are shown in Fig. 6. The difference was generally largest between the diaphysis and the medial side of the proximal end. In some RA patients, the difference between the BDI in the diaphysis and that at the medial side of the

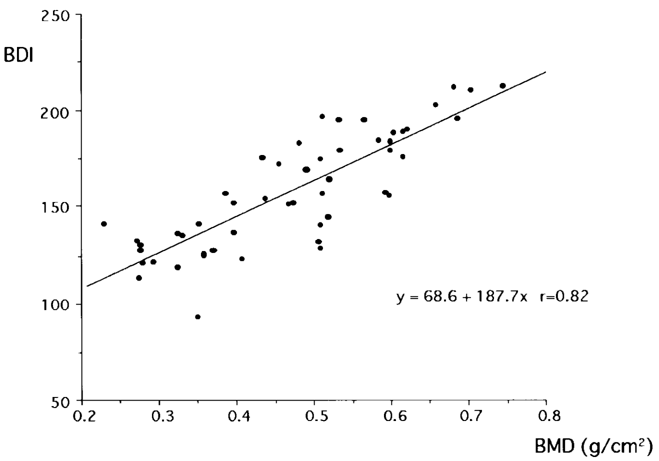

Fig. 3. Correlation between the BDI and BMD. BDI, brightness/darkness index, which was measured using NIH Image. BMD, bone mineral density, which was measured using dual energy X-ray Absorptiometry. BMD was measured in the distal one-tenth of the right radius. The BDI was measured in a square 2 cm proximal from the distal articular surface of the right radius. The correlation between the BDI and BMD was statistically significant ($r = 0.823$, $P < 0.001$)

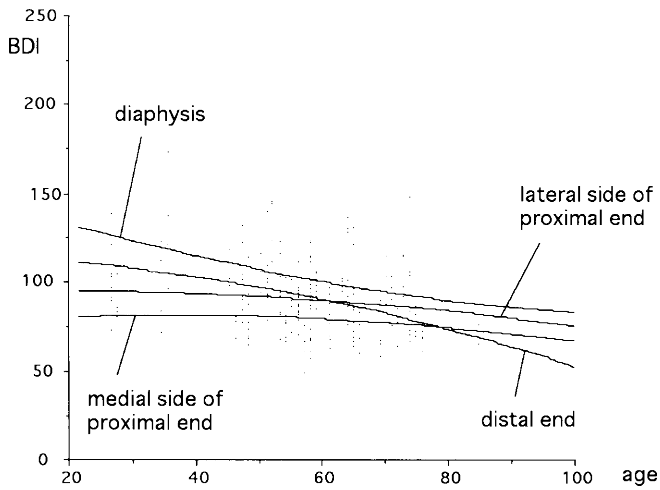

Fig. 5. BDI of the right third proximal phalanx in patients with RA. The BDI was lower in all areas than it was in normal volunteers. The differences among the four regions were greatest in the younger subjects. The BDI was highest at the midpoint of the diaphysis and lowest at the medial side of the proximal end

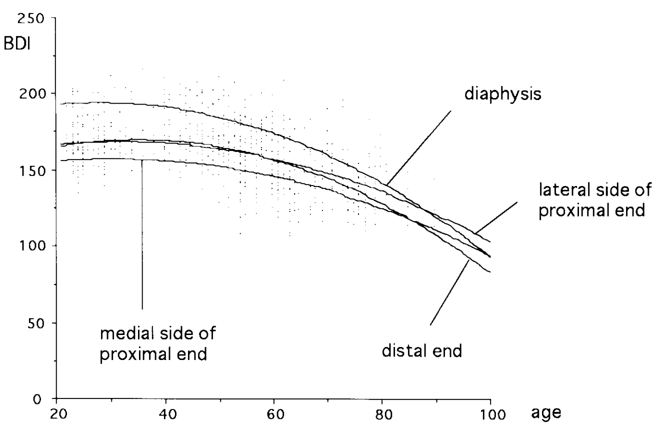

Fig. 4. BDI of the right third proximal phalanx in normal volunteers. The BDI in all areas gradually decreased with aging. Differences among the four regions were greatest in the younger subjects. The BDI was highest at the midpoint of the diaphysis and lowest at the medial side of the proximal end

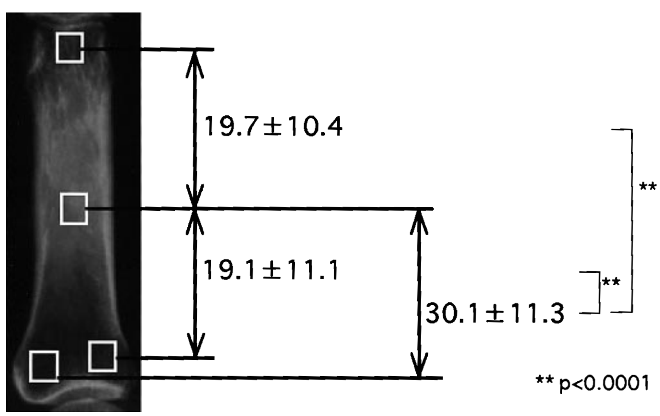

Fig. 6. Assessment of periarticular bone atrophy the differences were largest between the BDI at the diaphysis and that at the medial side of the proximal end. The medial side of the proximal end is the best region for assessing periarticular bone atrophy in the third proximal phalanx

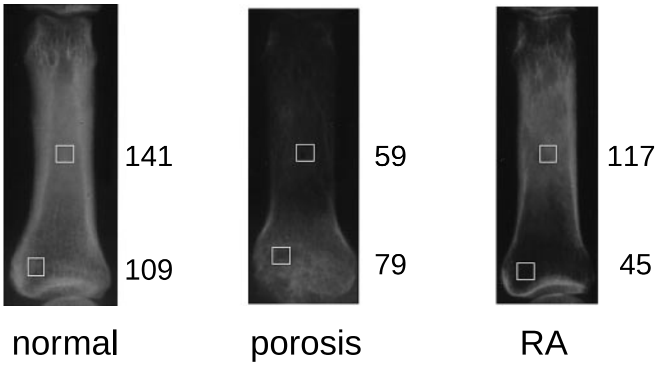

Fig. 7. Differences in BDI between osteoporosis and RA, showing typical examples of the right third proximal phalanx. In some RA patients with periarticular bone atrophy, the difference between the BDI at the midpoint of the diaphysis and that at the medial side of the proximal end was very large. In patients with osteoporosis, the difference was small, but the BDI was significantly low at both sites

proximal end was very large, demonstrating periarticular bone atrophy. Figure 7 shows typical examples of normal bone, and bone in cases with RA and osteoporosis.

Discussion

Bone mineral density is the most popular index used for assessing bone volume in the extremities and the spine.[1–3,6–13] A densitometer is also used to quantify bone density on radiographs,[14,15] but evaluation of the cortical thickness on radiographs is no longer popular.[4,16] It is convenient for rheumatologists to use radiographs of the hands, which are taken regularly during the treatment of RA. Therefore, we developed a method based on the NIH Image program which can assess the bone volume of cancellous bone in the phalanx from radiographs. NIH Image has mainly been used to measure areas on the computer, but the degree of brightness or darkness can also be measured, and such measurements can be performed in any area of a picture. In cases where the area is very small, the picture can be magnified on the screen. Nowadays, almost all hospitals have their own computers, and medical software applications are widely used. Therefore, it is now possible for each individual hospital to assess bone volume from radiographs. Data from radiographs can also be preserved permanently as digital data. With this method, both periarticular bone atrophy in the epiphysis and osteoporotic changes in cancellous bone in the diaphysis can be assessed regularly.

It has been reported that the CV of the BMD of the radius is 1.1%–1.9%.[2,13] However, the CV of the BDI was higher than that of the BMD. This is the most serious problem arising from this method, and means that even if the condition of the radiographs is the same, and even if an aluminum step wedge is used for the corrections, the value of the BDI would differ in different hospitals. For this reason, use of the BDI cannot be recommended when comparing radiographs from different hospitals. The second and third studies in this report were performed using identical pieces of radiographic equipment in our own hospital. We were thus able to conclude that the BDI can be used for a comparison between different areas on the same radiograph. The results showed that the difference in the BDI was largest when comparing that at the midpoint of the diaphysis with that at the medial side of the proximal end (Fig. 6). At the lateral side of the proximal end of the third proximal phalanx, several trabeculae can be observed. On the other hand, few trabeculae can be seen at the medial side of the proximal end. This phenomenon means that the load is transferred through the lateral side of the proximal phalanx in the third finger. The medial side of the proximal end is the best region for assessing bone loss in the third proximal phalanx. Otherwise, trabeculae can be observed at the medial side of the proximal end in the fifth proximal phalanx in some cases. The BDI is almost the same at the distal end and at the lateral side of the proximal end. The most sensitive method of assessing periarticular bone atrophy is to quantify the difference in bone volume between the midpoint of the diaphysis and either side of the proximal end where the trabeculae are not observed in the proximal phalanx.

The BDI can also be used to evaluate bone volume in cases of osteoporosis. Figure 7 clearly demonstrates differences in bone volume between normal subjects, RA patients, and osteoporosis patients. In normal subjects, the mean difference between the BDI at the midpoint of the diaphysis and that at the medial side of the proximal end was 30. However, in the RA patient in Fig. 7 who has periarticular bone atrophy, the difference was greater than 70. In patients with osteoporosis the difference was small, but the BDI was significantly low both at the midpoint of the diaphysis and at the medial side of the proximal end.

With this method, bone volume can also be quantified from radiographs in other diseases such as reflex sympathetic dystrophy (RSD), fractures, and bone tumors. Since the analogue data of the radiographs is converted to digital data by the computer, the lower reliability of this method compared with BMD measurements is the greatest problem. Currently, computed radiographs (CRs) are becoming popular. We are now developing a system in which the digital data of CRs can be transported to a computer, and bone volume can then be quantified directly.

Conclusion

Using radiographs of patients with rheumatoid arthritis, bone volume in cancellous bone was assessed quantitatively using the NIH Image computer program. The value of the bone volume, which was defined by a value on the brightness/darkness index, was significantly correlated with bone mineral density as ascertained by dual energy X-ray absorptiometry. We conclude that periarticular bone atrophy in RA patients can be assessed quantitatively using NIH Image.

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