REVIEW

# Effects of constitution, atraumatic vertebral fracture and aging on bone mineral density and soft tissue composition in women

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**Abstract: Constitution, atraumatic vertebral fracture and aging affect bone mineral density (BMD) and soft tissue composition. The high body weight of obese women involves a high mechanical load being exerted on weight bearing bones compared with thin women, which probably contributes to their higher BMD and the lower incidence of fractures in obese women compared with thin women. Atraumatic vertebral fracture (AVF) is a typical osteoporotic fracture and its favorite site of AVF is the vertebral bodies of the thoracolumbar region. The BMD of weight bearing bones is lower in patients with AVF than in patients without AVF, whereas there is no significant difference in soft tissue composition between the two. The regional and total BMD decrease with advancing age. The magnitude of the decrease in lumbar and thoracic BMD is high compared with other regional BMD, and total fat mass and total lean mass decline with age to their respective minimal level. The high rate of decrease in lumbar and thoracic BMD appears to be due to the high content of trabecular bone compared with other regional bones. J. Med. Invest. 49 : 18-24, 2002**

***Keywords*** : *bone mineral density, osteoporosis, constitution, fracture, aging*

## INTRODUCTION

Osteoporosis is a disease characterized by low bone mass and the microarchitecture deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture risk (1). In 2000, the Japanese Society for Bone and Mineral Research revised diagnostic criteria for primary osteoporosis. (2)

At present, large numbers of postmenopausal women in Japan are at high risk for osteoporosis and its associated fractures, which is an issue of clinical importance. Osteoporotic fractures are one of significant complications and an increasing health care burden in osteoporotic patients. Therefore, in the treatment of osteoporosis, prevention of fractures is undoubtedly a major goal. Smith showed that bone mineral density (BMD) accounted for approximately 75-80% of the variance in the bone strength (3). Based on this finding, measurement of BMD by dual energy X-ray absorptiometry is essential to assess bone strength and predict osteoporotic fractures. Advanced age and slender body habitus are risk factors for osteoporosis and osteoporotic fractures (4). This review focused on the effects on constitution, AVF and aging on total and regional BMD and soft tissue composition in women.

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## Dual energy X-ray absorptiometry

DXA has been shown to be of diagnostic value in metabolic bone disease and made it possible to analyze bone mineral content, BMD, fat mass and lean mass (5-9). The coefficient of variation (CV) for

DXA for total BMD and soft tissue mass was 0.5%-1.0% (5), whereas the CV for dual photon absorptiometry (DPA) with $^{153}Gd$ for total BMD was 1.0%-2.0% (10). The mean BMD of the 2nd to 4th lumbar vertebrae (L2-4BMD), total body BMD, regional BMD, total and regional soft tissue mass were measured by DXA. As shown in Figure 1, the regional BMD (g/cm$^2$) was measured in the head, arms, legs, ribs, thoracic spine, lumbar spine and pelvis. The lean mass (g) and the fat mass (g) of the head, arms, legs, and trunk were measured with a tissue bar.

## Constitution

Constitution is one of the important determinants of bone mineral density. Obese women have greater BMD of the lumbar spine (11), distal end of the radius (12), hip, and cortical area of the metacarpal bones (13) than women of a normal weight. Our previous study showed that obesity was associated with high BMD of weight bearing-bones (lumbar spine, thoracic spine, pelvis, leg bones) (Table 1A) (7). The high body weight of obese women involves a high mechanical load being exerted on weight bearing bones, which leads to osteoblast-mediated bone formation and inhibits osteoclasts-mediated bone resorption.

Lean mass of the legs and total body of obese women was significantly higher than that of thin women (Table 1B) (7). Saville *et al.* (14) showed that isotonic running exercise caused hypertrophy of both muscles and bones, and that the relation of muscle weight to bone weight remained constant. These findings suggest that an adequate mechanical load facilitates the synthesis of contractile proteins of leg muscles and bone formation to maintain or increase muscle volume and BMD.

Osteocytes play an important role in responding to mechanical load by changing bone metabolism (15-17). The gap junction of the long processes of osteocytes plays a key role in the transmission of a mechanical load to induce osteoblast-mediated bone formation, inhibition of osteoclast-mediated bone resorption, or a combination of the two (18). The higher mechanical load is one of the significant contributing factors for the higher BMD of weight bearing-bones observed in obese women. In addition, obesity appears to be instrumental in reducing postmenopausal bone loss (19).

Total and regional fat mass is significantly higher in obese women than in nonobese women (Table 1C) (7). In postmenopausal women, 25-30% of the total extragonadal aromatization of androstenedione to estrone takes place in the skeletal muscles, and 10-15% in adipose tissue (20). This peripheral aromatization appears to be facilitated in obese women compared with nonobese women (21). Therefore, obese women obtain a greater supply of circulating estrogen which

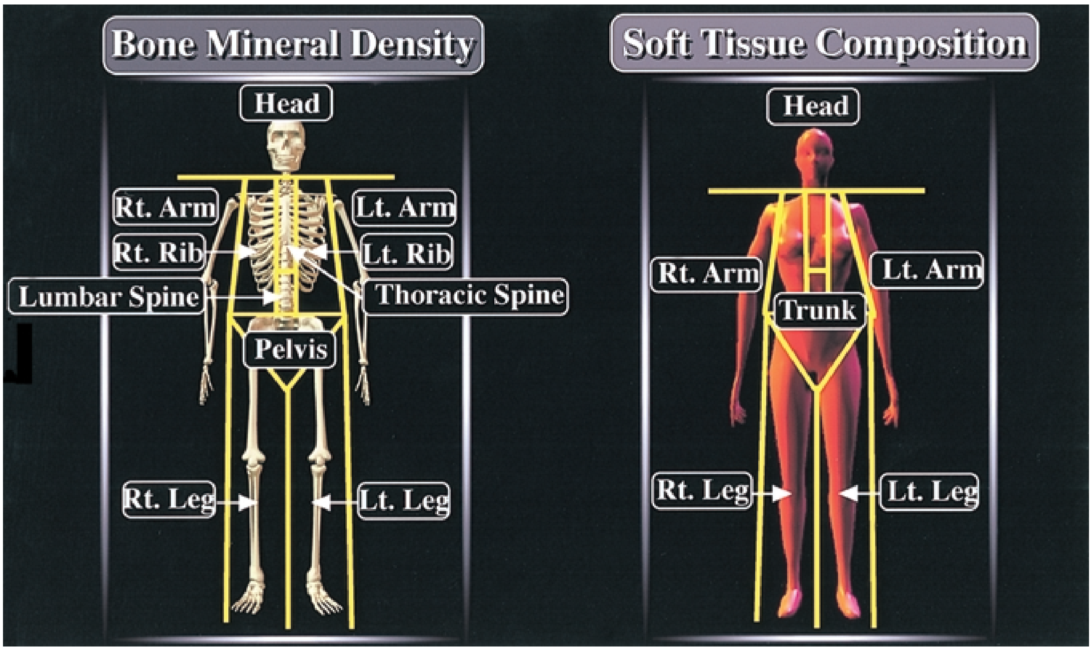


**Figure. 1** Screen display of total bone mineral and soft tissue in vivo. Lines superimposed upon the skeleton demarcate major anatomical areas. The horizontal line above the shoulders was located below the chin. The vertical lines at the shoulders was between the humeral head and glenoid fossa of the scapula. Two vertical lines adjacent to the thoracolumbar spine to measure spinal BMD. The small horizontal line between these two lines was at the level of L1-T12.The horizontal line above the pelvis was immediately above the iliac crest. The angled lines below the pelvis were used to bisect the bilateral femoral necks.

**Table 1. Comparison of BMD and soft tissue composition [7].**

**(A) BMD (g/cm²)**

| | Thin group (n=38) | Standard weight group (n=31) | Obese group (n=20) |
|---|---|---|---|
| L2-4BMD | 0.788±0.188[a, b] | 0.897±0.178 | 0.928±0.155 |
| Total body BMD | 0.907±0.131 | 0.938±0.115 | 0.961±0.116 |
| Lumbar spine | 0.770±0.214[a, b] | 0.877±0.206 | 0.929±0.217 |
| Thoracic spine | 0.699±0.129[a, b] | 0.802±0.182 | 0.804±0.183 |
| Pelvis | 0.857±0.175[a, b] | 0.961±0.148 | 1.006±0.156 |
| Left leg | 0.919±0.112[a, b] | 0.974±0.112 | 1.016±0.110 |
| Right leg | 0.922±0.121[a, b] | 0.979±0.107 | 1.018±0.120 |
| Head | 1.653±0.377 | 1.675±0.300 | 1.737±0.331 |
| Left arm | 0.583±0.073 | 0.608±0.660 | 0.620±0.051 |
| Right arm | 0.613±0.083 | 0.635±0.064 | 0.644±0.059 |
| Left rib | 0.491±0.069[a, b] | 0.524±0.067 | 0.537±0.067 |
| Right rib | 0.505±0.075[a, b] | 0.542±0.067 | 0.565±0.066 |

**(B) Lean mass (g)**

| | Thin group (n=38) | Standard weight group (n=31) | Obese group (n=20) |
|---|---|---|---|
| Head | 3,300.9±201.9[a, b] | 3,461.4±326.0 | 3,676.0±448.0 |
| Left arm | 1,291.4±324.1 | 1,231.7±195.0 | 1,379.9±294.0 |
| Right arm | 1,455.6±460.0 | 1,447.5±216.5 | 1,573.8±336.1 |
| Left leg | 4,500.6±863.1[b] | 4,754.9±649.2 | 5,034.3±969.6 |
| Right leg | 4,749.6±874.4[b] | 4,971.0±696.4 | 5,292.1±1,101.0 |
| Total | 31,758.4±4,637.3[b] | 32,755.9±3,142.1 | 34,432.9±5,019.3 |

**(C) Fat mass (g)**

| | Thin group (n=38) | Standard weight group (n=31) | Obese group (n=20) |
|---|---|---|---|
| Head | 846.9±60.4[a, b] | 917.2±105.9 | 971.6±263.4 |
| Left arm | 750.7±302.7[a, b] | 1,322.8±281.1[b] | 1,727.3±432.9 |
| Right arm | 757.9±294.7[a, b] | 1,355.1±382.6[b] | 1,958.5±795.6 |
| Left leg | 2,274.3±792.5[a, b] | 3,306.4±912.8[b] | 4,135.0±792.2 |
| Right leg | 2,327.5±851.6[a, b] | 3,295.2±912.1[b] | 4,164.3±820.8 |
| Total | 11,555.0±3,504.7[a, b] | 19,147.5±4,974.7[b] | 24,951.5±5,150.0 |

Values given as mean±S.D.
[a]$p<0.05$ vs standard weight group.
[b]$p<0.05$ vs obese group.

contributes to their higher BMD in obese women compared with thin women.

## Atraumatic vertebral fracture

Atraumatic vertebral fracture (AVF) is the most typical fracture in osteoporotic patients, whereas hip fractures appear to occur in the most severe osteoporotic patients. Interestingly, AVF in osteoporotic patients is not always symptomatic, whereas appendicular fractures are always accompanied with local pain. AVF is easily identified by history of illness, physical examination and on radiographs. As shown in Figure 2, a vertebral fracture resulting in vertebral deformity (wedge, biconcave, or compression) was defined as a reduction of the anterior, central or posterior height of a vertebral body. BMD accounts for approximately 75-80% of the variance in the bone strength (3). Therefore, measurement of BMD is essential to assess bone strength and predict osteoporotic fractures. Previous studies have shown that BMD of osteoporotic patients with atraumatic fractures was lower than that without atraumatic fractures (22-25). In addition, lean mass and fat mass are confirmed as important factors in determining BMD (26, 27). Fast bone losers have a lower fat mass than slow bone losers in early postmenopause (27). Therefore, the measurement of lean mass and fat mass should be performed to predict bone loss and osteoporotic fractures.

We clarified the characteristics of total body and

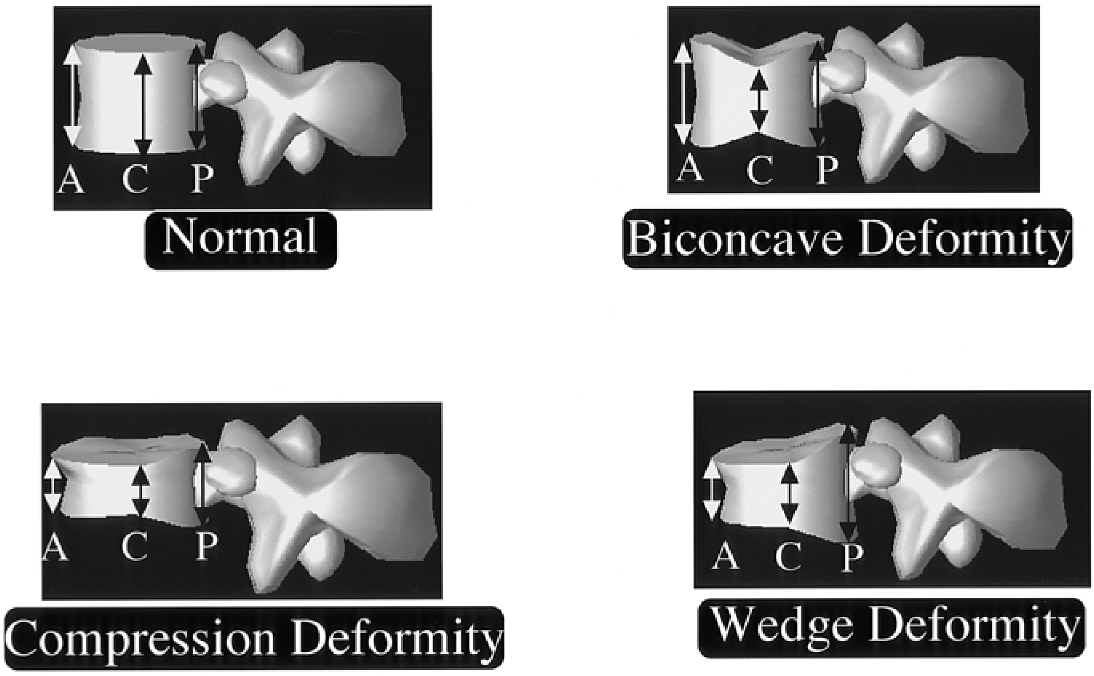


**Figure. 2 Definition of vertebral fracture.**
**Biconcave deformity : greater than 20% reduction in central height compared with anterior or posterior height.**
**Compression deformity:greater than 20% reduction in anterior, central, and posterior height compared with respective height of neighboring vertebrae.**
**Wedge deformity : greater than 25% reduction in anterior height compared with posterior height.**
**A, anterior height ; C, central height ; P, posterior height**

regional BMD and soft tissue composition in patients with AVF (8). The number of atraumatic fractures of L1 was the greatest of all thoracic and lumbar vertebrae, and that of Th12 was the second greatest (Figure 3). The most common site of atraumatic vertebral fracture was the vertebral bodies of the thoracolumbar region. In this study, in the patients with AVF, the BMD of weight bearing bones, except for that of the legs, was significantly lower than that of the patients without AVF. In contrast, there is no significant difference in soft tissue composition between the patients with AVF and the patients without AVF (Table 2A-C). The pattern of bone loss in different regions varies, and the difference may be attributable to a site-specific cortical to trabecular bone ratio. The relative content of trabecular bone was reported to vary different parts of the skeleton : the content of trabecular bone of vertebrae was 66-90%, that of the intertrochanteric region of femur was 50%, that of the femoral neck was 25%, that of the distal radius was 25%, that of the mid-radius was 1%, and that of the femoral shaft was 5% (28). Bone metabolism of the trabecular bone is approximately eight-fold as metabolically active as that of cortical bone, because the surface of trabecular bone is larger than that of cortical bone (29). The low BMD of the pelvis and thoracolumbar vertebrae observed in patients with AVF may be due to inhibition of bone formation and/or acceleration of bone resorption.

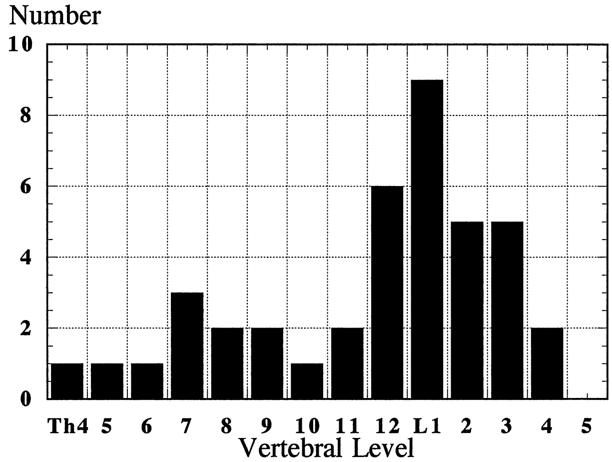


**Figure. 3 Distribution of atraumatic vertebral fractures. The number of atraumatic fractures of L1 was the greatest of all thoracic and lumbar vertebrae, and that of Th12 was the second greatest. [8]**

## Aging

Aging is associated with low mechanical stress

**Table 2.** Comparison of BMD and soft tissue composition between the patients with AVF and the patients without AVF [8].

(A) BMD (g/cm²)

| Region | Patients with AVF (n=30) | Patients without AVF (n=34) | *P* value |
|---|---|---|---|
| L 2-4 BMD | 0.659±0.113 | 0.784±0.148 | 0.0003 |
| Left arm | 0.540±0.043 | 0.564±0.055 | 0.055 |
| Right arm | 0.565±0.041 | 0.590±0.053 | 0.058 |
| Left ribs | 0.447±0.044 | 0.468±0.047 | 0.0686 |
| Right ribs | 0.468±0.044 | 0.487±0.056 | 0.143 |
| Thoracic spine | 0.604±0.077 | 0.691±0.106 | 0.0005 |
| Lumbar spine | 0.609±0.119 | 0.745±0.153 | 0.0002 |
| Pelvis | 0.771±0.111 | 0.858±0.143 | 0.0093 |
| Left leg | 0.849±0.086 | 0.866±0.161 | 0.5938 |
| Right leg | 0.843±0.084 | 0.877±0.163 | 0.3026 |
| Head | 1.434±0.221 | 1.564±0.590 | 0.2607 |
| Total body | 0.814±0.064 | 0.858±0.093 | 0.0325 |

(B) Lean mass (g)

| Region | Patients with AVF (n=30) | Patients without AVF (n=34) | *P* value |
|---|---|---|---|
| Left arm | 1,273.8±193.9 | 1,292.9±229.1 | 0.722 |
| Right arm | 1,415.9±216.8 | 1,430.8±336.2 | 0.8364 |
| Trunk | 16,288.0±1,756.5 | 15,644.4±3,786.5 | 0.397 |
| Left leg | 4,750.5±568.2 | 4,723.8±745.9 | 0.8739 |
| Right leg | 4,916.2±643.3 | 4,946.2±728.9 | 0.8632 |
| Head | 3,387.6±251.1 | 3,445.5±346.4 | 0.4525 |
| Total body | 30,858.8±5,777.7 | 32,274.1±3,717.3 | 0.2429 |

(C) Fat mass (g)

| Region | Patients with AVF (n=30) | Patients without AVF (n=34) | *P* value |
|---|---|---|---|
| Left arm | 1,031.9±556.1 | 1,084.5±538.9 | 0.7024 |
| Right arm | 1,022.2±610.3 | 1,135.6±833.4 | 0.5414 |
| Trunk | 6,698.6±3,922.0 | 7,514.4±4,190.7 | 0.4113 |
| Left leg | 2,745.2±1,114.4 | 2,849.2±1,108.0 | 0.7098 |
| Right leg | 2,726.9±1,258.2 | 2,850.0±1,150.8 | 0.6838 |
| Head | 902.3±88.2 | 896.0±187.2 | 0.8661 |
| Total body | 15,517.0±6,812.9 | 16,416.0±7,552.0 | 0.6207 |

Values are mean±S.D.

on bone as a result of a decrease in physical activity, estrogen deficiency (4, 30), low production of vitamin $D_3$ (31), low calcium absorption in the small intestines (32) and activation of tumor necrosis factor, interleukin (IL)-1 and IL-6 (33-35), all of which are risk factors for the development of osteoporosis. The BMD of the lumbar spine in women reaches its maximum between 20 and 30 years of age (36), and remains almost constant until the 40's. Thereafter, the BMD decreases rapidly with the onset of menopause, and thereafter continues to decline slowly with age (37, 38). Osteoclast-mediated bone resorption is prominently accelerated in the first five or ten years after menopause. Women lose approximately 50% of their peak trabecular bone and approximately 35% of their peak cortical bone over their lifetime (39).

We showed that the magnitude of the decrease in lumbar and thoracic BMD was high compared with other regional BMDs, and that total fat mass and total lean mass declined with age to their respective minimal level (40). The lumbar and thoracic spines are rich in trabecular bone (28), and this may explain why the decrease in BMD is more marked in the spine compared with other regions. As for soft tissue, Reid *et al.* (41) showed that total fat mass was the most consistent predictor of BMD, while in contrast, lean mass showed no correlation with BMD at any site. Soft tissue composition may become a predictor of BMD in lumbar and thoracic BMD.

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