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The Relationship Between Asymmetrical Weight Bearing and Bone Mineral Density in Chronic Hemiplegic Limbs

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Abstract

Hemiplegia-induced immobilizatoin and reduction of mechanical loading in chronic stroke limbs are common cause of disuse osteoporosis. The purpose of this study was to investigate the effects of asymmetrical weight bearing on the loss of bone mineral in the individual with chronic stroke. Sixteen hemiplegic patients with strokes were evaluated. The measurements of bone mineral density (BMD) were evaluated with the quantitative ultrasound system on the calcaneus region of the paretic and non-paretic side. Plantar pressure was measured using the Mat-Scan system. The paretic side showed significantly smaller values in the T-score of BMD, and peak value of plantar pressure, which included forefoot, midfoot, and hindfoot, than the non-paretic side ($p<.05$). Results from the pearson correlation analysis showed statistically significant correlation between the BMD difference and the peak-pressure difference of midfoot pressure ($p<.05$). This finding indicated that BMD loss depended on decrease of body weight born on the paretic leg.

Key Words: Bone mineral density; Stroke; Weight bearing.

Introduction

Individuals who suffered strokes have a higher risk of bone fractures than the reference population. In addition, Stroke patients also have a higher risk of falls than the age-matched population (Demirbag et al, 2005). Reduction of mechanical stress on bone inhibits osteoblast-mediated bone formation and accelerates osteoclast-mediated bone resorption, leading to what has been called disuse osteoporosis. Prolonged therapeutic bed rest, immobilization due to motor paralysis from injury of the central nervous system or peripheral nerves, and application of casts to treat fractures are common causes of disuse osteoporosis. Mechanical stress on bone is one of the determinants of bone morphology, bone mineral density (BMD) and bone strength (Castillo and de la Rosa, 2009). Therefore, hemiplegia-induced immobilization after strokes accelerates bone resorption and depresses bone formation, consequently bone becomes atrophic and fragile (Jorgensen and Jacobsen, 2001).

Osteoporosis is common in hemiplegic patients due to the stroke and it can occur as a result of hemiplegic-induced immobilization of more than 1 month duration (Jorgensen et al, 2000b). The level of impairment following strokes differs greatly between patients. Many ambulatory patients walk asymmetrically with less weight bearing through their paretic leg (Worthen et al, 2005). Stroke impairments, such as poor balance, reduced mobility, and reduced motor control are some of the factors associated with high risk of falls (Smith et al, 2009). Decrease in bone and muscle health, as well as increase in risk of falls, may contribute to higher risk of fracture than that of the age-matched population (Poole et al, 2009).

Using the X-ray is the most popular method to measure the bone mineral density. However, it is difficult to estimate periodically and repeatedly the

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growth with X-ray because of the radiation problem (Brooke-Wavell et al. 2008). Recently, the estimation of bone mineral density by using ultrasound has been applied as a means of periodical and repetitive measurement for the diagnosis of osteoporosis (Maatta et al, 2009). Ultrasound is also considered a safe modality, suitable for repeated use. Foot pressure measurement with mat scan is a reliable and widely used assessment tool for foot deformity It may be also reflective of foot position during habitual walking as well as static foot pressure (Bennett et al, 2007).

The purpose of this study was to measure dynamic weight bearing and BMD between the paretic and non-paretic leg in chronic stroke patients, and to find the relationship of asymmetrical weight bearing and BMD.

Methods

Subjects

Sixteen patients with hemiparesis following strokes were recruited from the outpatient rehabilitation clinic. All fulfilled the following inclusion criteria: hemiparesis due to a single stroke which had occurred at least 6 months prior to this study, an age of ≥60 years, and that they were independent ambulators according to the Functional Ambulatory Category (FAC) scale. Patients who scored 3∼5 on the FAC scale were included in the study (Freivogel et al, 2008). Patients with a history of femur or wrist fracture and unilateral bone diseases were excluded. Informed written consents from all patients were provided.

Table 1. General characteristics of subjects (N=16)

Characteristics	Mean±SD	Range
Age (yrs)	58.4±7.9	56∼68
Hemiplegic side (R/L)	10/6	
Onset duration[a] (month)	41.2±20.8	31∼84
BMI[b] (kg/㎡)	23.8±1.7	20∼27
FAC[c]	4.3±1.0	3∼5

[a]Time since onset of stroke.
[b]Body mass index.
[c]Functional Ambulatory Category Score.

Measurement of Bone Mineral Density

BMD was measured in the calcaneus region from the paretic and non-paretic sides by a quantitative measurement system using the ultrasound[1]. To minimize inter-rater variation, all patients were scanned by one operator. There was input in the measurement system about the information subjects, which include age, height, weight, and foot size. The operator fit the space between second and third toe into mid-line of footplate, maintaining the uprighting position of trunk. The operator instructed the subject not to move his body during measurement. T-score was calculated as dependent variable for assessing bone mineral density. T-score is a widely used parameter to assist in the interpretation of BMD results. It measures the departure of the patient's BMD value from the mean BMD for a young healthy adult population in units of the population standard deviation (SD).

$$\text{T-score} = \frac{\text{Measure BMD} - \text{Young Adult Mean BMD}}{\text{Young Adult SD}}$$

Measurement of Plantar Pressure

Plantar pressures were recorded during level barefoot walking using the Mat-Scan system[2]. This system consists of a 5 ㎜-thick floor mat (432×368 ㎜) incorporating 2288 resistive sensors (1.4 sensors/㎠) sampling at a rate of 30 ㎐. The dynamic gait was used to obtain both plantar pressures. Three trials were recorded, which has been found to be sufficient to ensure adequate reliability of pressure data. Following data collection, F-Scan research TAM/STEM Version 6.00 software (Tekscan Inc., South Boston, MA, U.S.A.) was used to construct individual "masks" to determine the peak pressure

1) OsteoPro, BM Tech Co., Gumi, Korea.
2) Mat-Scan, Tekscan Inc., South Boston, MA, U.S.A.

(㎪) under three regions of the foot: forefoot, midfoot, and hindfoot (Figure 1).

Force asymmetry was analyzed by calculating the force ratio of paretic versus non-paretic legs from Mat-Scan values during gait. With dynamic weight-bearing measurements, the first and final steps of stance phases were excluded from the analysis due to force distribution variability, thus only forces recorded during the stance phase were subjected to analysis. The changes of peak pressure area on the paretic side versus the non-paretic sides were also calculated.

Statistical Analysis

The paired t-test was used to determine significant differences between paretic and non-paretic sides on BMD and plantar pressure. Pearson correlation analysis was used to analyze relationships between BMD difference and peak pressure difference during stance phase of gait. All the statistical analyses were assessed using SPSS, version 15.0, and $p<.05$ was used as the criterion for statistical significance.

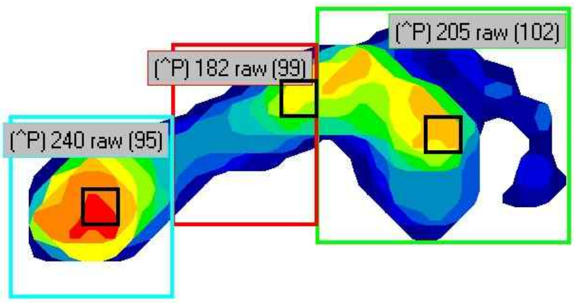

Figure 1. Peak plantar pressure under the forefoot, midfoot, and hindfoot.

Results

Bone Mineral Density

The BMD values of the paretic side showed a lower BMD value than the non-paretic side. The paired t-test showed statistically significant difference between the paretic and non-paretic sides ($p<.05$) (Table 2).

Plantar Pressure

There were statistically significant differences between sides in the peak pressure of 3 regions which included forefoot, midfoot, and hindfoot during dynamic weight-bearing gait activities ($p<.05$) (Table 2).

Correlation Between BMD Difference and Peak-Pressure Difference

Results from the pearson correlation analysis showed statistically significant correlation between the BMD difference and the peak-pressure difference of midfoot pressure ($p<.05$) (Table 3). However, statistical results failed to show any significant correlation in forefoot to BMD and hindfoot to BMD ($p>.05$) (Table 3).

Discussion

The purpose of this study is to exam whether asymmetrical weight bearing between the paretic and

Table 2. Comparison of the plantar pressure and BMD on the paretic and non-paretic side (N=16, Unit: ㎪)

Dependent variable	Paretic	Non-paretic	Difference	p
Plantar pressure				
Forefoot	165.50±27.97[a]	195.71±33.56	30.21±22.94	.00
Midfoot	81.79±46.57	199.86±53.05	18.07±19.67	.01
Hindfoot	162.43±47.44	188.79±33.86	26.36±25.36	.00
Bone mineral density				
T-score	-3.01±1.00	-2.17±1.03	.84±.72	.00

[a]Mean±SD.

Table 3. Correlation among the plantar-pressure difference and BMD difference between the paretic and non-paretic side (N=16)

Plantar-pressure difference	BMD difference	
	Pearson r	p
Forefoot	-.13	.65
Midfoot	-.54	.05
Hindfoot	-.32	.26

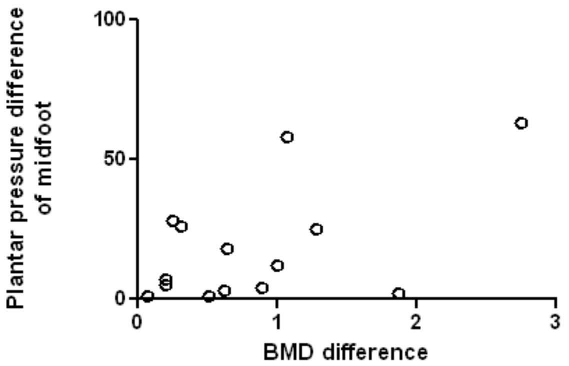

Figure 2. Correlation between plantar-pressure difference of midfoot and BMD difference.

non-paretic sides was associated with an accelerated bone loss following strokes. Results have shown that BMD of patients will decrease if the amount of asymmetrical weight bearing increases. Loss of BMD, the result of an imbalance between bone resorption and bone formation, is a potential problem for patients with hemiplegia because of the immobility commonly associated with this impairment (Poole et al, 2009).

Bone architecture might be more affected by the reduction of mechanical forces or piezoelectric forces (Smith et al, 2009). Negative charges accumulate on the stressed side by piezoelectric forces and positive charges are accumulate on the opposite side (Shan et al, 2009). Immobilization due to motor paralysis such as stroke and spinal cord injury causes disuse osteoporosis and may increase fracture risk. Jorgensen et al (2000b) suggested that lean muscle mass is rapidly lost, but may be regained shortly after a stroke, whereas loss of BMD appears difficult to prevent, especially on the paretic side (Pang and Mak, 2009). Therefore, bone health assessment of stroke patients should be measured as a variety of view (Kim and Gong, 2008). The calcaneus, which is used as the measurement region of this study, is known for being a reliable location for measuring BMD because more than 90% is composed of cartilage(Im et al, 2009). Furthermore, the calcaneous correlates with BMD of the lumbar and femur, which have high fracture risk (Kuwahata et al, 2008).

The distinction between the dominant and non-dominant lower limbs in normal population is not remarkable compared with upper limb because of reciprocal weight bearing of lower limb during gait (Shin et al, 2008). As a result, dominance may have little effect on BMD difference (Jorgensen et al, 2000a). Unlike normal population, demineralization in the hemiplegic limb begins following the first month. The amount of bone loss correlates positively with duration of hemiplegia (Maatta et al, 2009). Hamdy et al (1993) reported that bone loss of the lower limb (3.7%) was less than that of the upper limb (9.3%) by the fourth month after a stroke and demineralization occurred only in the paretic limbs. On the contrary, our study found bone loss in both non-paretic limbs (T-score=-2.17±1.03) and paretic limbs (T-score=-3.01±1.00), and paretic limb decreased statistically significant when compared to the non-paretic limb. Results from the correlation analysis between BMD difference and peak pressure difference of four compartments showed statistically significant correlation only between the BMD and the midfoot peak pressure (r=.54, p<.05). This finding is supposed to the effect of toe walking which is typical hemiplegic gait pattern. If more patients had been included, moderate correlation coefficient would have been higher.

Results of this study have shown that decreased weight bearing of chronic hemiplegic lower limb may induce a decrease of BMD by a remodeling response to skeletal loading and bone adaptation. Important factors, which cause the decrease of bone mineral density after strokes, may include ambulatory status, spasticity, muscle strength, and disuse after the stroke period, since the patients relearned to walk (Pang et al, 2007). This findings showed the correlation between BMD and peak pressure of foot. But, our possible limitation of our study is that was no predictive role to find the regression relationship between two variables because a small patients included. Therefore, further study with a larger number of subjects and longer duration follow-up would be useful.

We suggest that the BMD loss depended on decrease of body weight born on the paretic leg after strokes. As for preventing bone loss after strokes, the importance of relearning to walk symmetrically as soon as possible after strokes is underlined by these finding.

Conclusion

This study has shown the relationship between plantar pressure from the Mat-Scan system, and BMD in patients with chronic stroke. The findings indicate that plantar-pressure difference during dynamic gait correlates significantly to BMD difference between the paretic and non-paretic side.

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