Relationship between bone mineral density and bone stiffness in bone fracture

Abstract

Objectives. Using cancellous bone blocks of racehorses, the relationship between bone mineral density (BMD), which indicates bone strength, and stiffness in bone fracture occurrences was studied.

Methods. Two groups of cancellous bone blocks were prepared: a fractured group, using the first phalangeal bones of seven racehorses with sagittal fractures; and a nonfractured group, using the first phalangeal bones of nine autopsied racehorses without any fractures. By a peripheral quantitative computed tomography scan, the BMD values were shown as color images and evaluated. In addition, the BMD values obtained from the fractured and nonfractured groups were compared with the stiffness values obtained from a compression test.

Results. The difference between the average BMD values of the fractured and nonfractured groups was easily observed on the BMD color-conversion display image. The average BMD of the fractured group (472.1 mg/cm³) was significantly higher than that of the nonfractured group (284.5 mg/cm³, P = 0.005). Moreover, the average stiffness of the fractured group (5564.5 N/cm) was significantly higher than that of the nonfractured group (3808.6 N/cm, P = 0.008).

Conclusion. These results suggest that the occurrence of a fracture does not depend on the BMD or the bone stiffness value.

Key words Peripheral quantitative computed tomography (pQCT) · Bone mineral density (BMD) · Stiffness · Trabeculae

Introduction

Approximately ten million people suffer from osteoporosis in Japan. A nationwide study conducted in 1987 reported that 50,000 patients a year experience a fracture of the femoral neck. By 1997, this number had increased to approximately 90,000. In other words, the number of patients with this particular fracture almost doubled in a decade. Bone fractures are a major contributor to elderly patients becoming bedridden; therefore, the prevention of fractures, as opposed to their treatment, is a priority for patients with osteoporosis. Consequently, an effective screening method to determine bone strength should be established to anticipate bone fractures. The bone mineral density (BMD) test, mechanical property test, and blood test applied to patients' bone samples are the current standards of practice for measuring bone strength. Among these tests, the BMD test is believed to be the most important. It has been suggested that bone strength increases together with an increase in the BMD and that the correlation of BMD with bone strength is 80%. On the other hand, studies have demonstrated the difficulty of distinguishing normal patients from patients with osteoporosis. In this study, we investigated the relationship between BMD and bone stiffness with regard to the occurrence of bone fractures in racehorses. The cancellous bone shaft from the first phalanges of racehorses that had experienced bone fractures was used because it is difficult to obtain bone samples from patients who have experienced bone fractures.

Materials and methods

Materials

Fractured first phalanges (n = 7) and nonfractured first phalanges (n = 9) were extracted from ten racehorses (nine males and one female; 2 to 5 years old; average age, 3.1 years). Using a microcutter, 1 cm³ samples of cancellous bone blocks were obtained from the centers of the mesial
epiphyses of both fractured and nonfractured first phalanges. The distance between the fracture line and each bone region of interest (ROI) was set at an average of 2 ± 0.5 cm.

Construction of the BMD color-converted images

The BMD values in the bone blocks were estimated using peripheral quantitative computed tomography (pQCT; XCT Research SA+, Stratec Medizintecnik, Pforzheim, Germany). The obtained values were resolved into 29 gray-scale values from -222.2 mg/cm³ to +741.0 mg/cm³, and a BMD color-converted image was constructed for each slice. A BMD of +741 mg/cm³ was displayed as white, and the areas from gray to black represented empty space. A color spectrum was made with a red-based color indicating a low BMD and a blue-based color indicating a high BMD. Kumasaka et al. previously described the color palette used. The voxel size was 8 μm, and the CT scan speed was 9.0 μm/s.

Examination of a mechanical property

A compression test with a maximum load of 500 kgf (50 N) (MZ-500S, Maruto, Tokyo, Japan), which was read in a proximal to distal direction, was used to measure the stiffness of each bone block. Using a 30-mm-diameter iron rod, the compression test was performed at a crosshead speed of 10 mm/min.

Statistical analysis

Significant differences were analyzed with Student’s t test.

Results

Examples of BMD color-converted images of the bone blocks of phalanges obtained from racehorses in the fractured and nonfractured groups are shown in Fig. 1. In the fractured example, the mostly mineralized area (BMD, approximately 400–600 mg/cm³) has a yellow-blue color; the mineralized area (BMD, approximately 601–741 mg/cm³) has a blue-white color. In the nonfractured example, the mostly mineralized area (BMD, approximately 200–400 mg/cm³) is red, and the mineralized area (BMD, approximately 601–741 mg/cm³), with a blue-white color, is minimal in size.

The average BMD values of the cancellous bone blocks for the fractured group (472.1 mg/cm³) was significantly higher than that of the nonfractured group (284.5 mg/cm³, P = 0.005).

The average stiffness values of the cancellous bone blocks for the fractured and nonfractured groups are shown in Fig. 3. The average stiffness of the fractured group (5564.5 N/cm) was significantly higher than that of the nonfractured group (3808.6 N/cm, P = 0.008).