Journal of Hainan Medical University

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Evaluation value of three−dimensional finite element model analysis for bone mineral density and bone metabolism activity in patients with osteoporosis

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ARTICLE INFO

Article history:
Received 28 Jul 2017
Received in revised form 9 Aug 2017
Accepted 19 Aug 2017
Available online 28 Aug 2017

Keywords:
Osteoporosis
Three-dimensional finite element model analysis
Bone mineral density
Bone metabolism

ABSTRACT

Objective: To study the evaluation value of three-dimensional finite element model analysis for bone mineral density (BMD) and bone metabolism activity in patients with osteoporosis. **Methods:** A total of 218 patients who were diagnosed with osteoporosis in the hospital between February 2014 and January 2017 were collected as observation group, and 100 healthy volunteers who received physical examination in the hospital during the same period were selected as normal control group. The femoral head of the two groups was analyzed by three-dimensional finite element model, and the femoral head BMD levels and serum bone metabolism index contents were measured. Pearson test was used to evaluate the evaluation value of femoral head three-dimensional finite element model for osteoporosis. **Results:** The cancellous bone and cortical bone Von Mises stress value of observation group were lower than those of normal control group, and femoral neck BMD value of observation group was lower than that of normal control group; serum bone metabolism index BGP content was lower than that of normal control group while NBAP, TRACP-5b and CTX-1 contents were higher than those of normal control group. Pearson test showed that the cancellous bone and cortical bone Von Mises stress value of patients with osteoporosis were directly correlated with BMD value and bone metabolism index contents. **Conclusion:** The three-dimensional finite element model analysis resultsof patients with osteoporosis can objectively reflect the femoral headBMD value and bone metabolism activity, and is a reliable way to evaluate the risk of long-term fractures.

1. Introduction

Osteoporosis is the bone metabolic disorder seen mostly in the elderly (especially elderly women after menopause), it is mainly characterized by decrease of bone mineral density (BMD) value, destruction of bone microstructure, increase of bone brittleness, etc., and the incidence of long-term fracture incidence in these patients is several times higher than that in patients at same age and without osteoporosis[1−3]. Femoral head is the place where osteoporosis most easily occurs or is the most obvious, and the determination of its bone mass change can effectively reflect the systemic bone metabolism state, so femoral head was mostly commonly used as the example of clinical research of patients with osteoporosis[4,5]. Three-dimensional finite element model is an important part of computer-assisted orthopedic surgery, the method is superior in the mechanics characteristics of irregular objects, and it has been gradually used in the biomechanics research of bone, especially the hip. In the research, three-dimensional finite element model was used to analyze the femoral head state in patients with osteoporosis, and the inner link of its parameters with femoral head BMD value, bone metabolism activity and so on was further discussed, now reported as follows.

2. Information and methods

2.1 General information

A total of 218 patients who were diagnosed with osteoporosis in the hospital between February 2014 and January 2017 were selected as observation group, and 100 healthy volunteers who received

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Fund Project: National Science Foundation of China No: 81301292.

physical examination in the hospital during the same period were selected as normal control group. Observation group included 100 men and 118 women that were 58-79 years old; normal control group included 47 men and 53 women that were 56-78 years old. There was no significant difference in the gender and age distribution between the two groups, the follow-up data were comparable, and the hospital ethics committee approved the study.

Inclusion criteria: (1) diagnosed with osteoporosis for the first time and receiving no targeted treatment outside the hospital; (2) without history of osteoporotic fracture; (3) cooperating with the whole inspection and with complete data. Exclusion criteria (1) with long-term use of glucocorticoids; (2) combined with systemic infectious diseases; (3) combined with severe heart, liver and kidney insufficiency; (4) combined with bone tumors.

2.2 Three-dimensional finite element model analysis

Immediately after admission, 64-slice spiral CT (Toshiba, model TH02s) was used to scan the two lower limbs of the study subjects, and scanning conditions were: voltage 120 kV, current 300 mA, and scanning thickness 0.8 mm. Mimics was used to import the above scanning results, and three-dimensional finite element model of femur was established. Elasticity modulus of cortical bone was 15.1 GPa and poisson ratio was 0.3; the elasticity modulus of cancellous bone was 445 MPa and poisson ratio was 0.22, and the Von Mises stress values of femoral cancellous bone and cortical bone were calculated.

2.3 Bone mineral density

Immediately after admission, dual-energy X-ray absorptiometry (Shanghai Aishen Science and Technology Development Co., Ltd., specifications DEXAUNIT2000) was used for partial femoral head bone mineral density measurement, and partial femoral head bone mineral density (BMD) was obtained.

2.4 Bone metabolism indexes

Immediately after admission, 3.0 mL of morning (7: 00 am-8:00 am) fasting cubital venous blood was extracted from both groups, anti-coagulated, let stand at room temperature (25 ℃ or so) for stratification and centrifuged at low speed to get the upper serum. Radioimmunoassay method was used to determine the contents of serum bone metabolism indexes, including bone alkaline phosphatase (NBAP), osteocalcin (BGP), tartrate-resistant acid phosphatase 5 b (TRACP-5b) and cross-linked C-terminal telopeptides of type I collagen (CTX). The RIA kit was purchased from Shanghai Westang Biotechnology Company, and the cargo Numbers were MD0981, LD2667, ND5182 and DS2715 respectively.

2.5 Statistical processing

SPSS 23.0 software was SPSS 23.0. Von Mises stress value, BMD value and bone metabolism indexes belonged to measurement data and were in terms of mean ± standard deviation, and comparison was by t test. Correlation analysis was by Pearson test. Statistics $P<0.05$ indicated statistical significance in differences.

3. Results

3.1 Von Mises Stress value

Comparison of the cancellous bone and cortical bone Von Mises stress value between two groups of subjects was as follows: the cancellous bone and cortical bone Von Mises stress value of observation group were (7.06±0.85) MPa and (15.27±1.93) MPa respectively and both significantly lower than those of normal control group. Differences in Von Mises Stress value levels were statistically significant between the two groups of subjects ($P<0.05$), shown in Table 1.

3.2 Bone mineral density

Comparison of BMD value between the two groups of subjects was as follows: femoral neck BMD value of control group was (1.67±0.35) g/cm^2 and femoral neck BMD value of observation group was (1.24±0.33) g/cm^2. Femoral neck BMD value of observation group was significantly lower than that of normal control group, and differences in femoral neck BMD value were statistically significant between the two groups of subjects ($P<0.05$).

3.3 Bone metabolism indexes

Comparison of serum bone metabolism indexes NBAP (μg/L), BGP (μg/L), TRACP-5b (mg/L) and CTX-1 (μg/L) contents between the two groups of subjects was as follows: serum BGP content of

Table 1.
Comparison of Von Mises Stress value between the two groups of subjects (MPa).

Groups	*n*	Cancellous bone	Cortical bone
Control group	100	12.83±1.94	27.64±3.52
Observation group	218	7.06±0.85	15.27±1.93
t		11.297	15.309
P		<0.05	<0.05

Table 2.
Comparison of serum bone metabolism index contents between the two groups of subjects.

Groups	*n*	NBAP	BGP	TRACP-5b	CTX-1
Control group	100	13.56±2.79	28.49±3.52	3.27±0.38	0.73±0.09
Observation group	218	27.49±3.18	20.76±2.81	4.95±0.64	0.98±0.14
t		10.982	12.753	7.221	6.983
P		<0.05	<0.05	<0.05	<0.05

Table 3.
Correlation between femoral head Von Mises stress value and illness in patients with osteoporosis.

Indexes	Cancellous bone Von Mises stress value		Cortical bone Von Mises stress value	
	Determination coefficient r	*P*	Determination coefficient r	*P*
BMD	0.725	<0.05	0.609	<0.05
NBAP	-0.647	<0.05	-0.723	<0.05
BGP	0.593	<0.05	0.587	<0.05
TRACP-5b	-0.672	<0.05	-0.615	<0.05
CTX-1	-0.599	<0.05	-0.673	<0.05

observation group was lower than that of normal control group while NBAP, TRACP-5b and CTX-1 contents were higher than those of normal control group. Differences in serum bone metabolism indexes NBAP, BGP, TRACP-5b and CTX-1 contents were statistically significant between the two groups of subjects ($P<0.05$), shown in Table 1.

3.4 Correlation analysis

Correlation analysis of femoral head three-dimensional finite element model parameters with bone mineral density and bone metabolism in patients with osteoporosis was as follows: Pearson test showed that the femoral head cancellous bone and cortical bone Von Mises stress value of patients with osteoporosis were positively correlated with BMD value, and negatively correlated with bone metabolism indexes NBAP, TRACP-5b and CTX-1 contents while positively correlated with BGP content ($P<0.05$), shown in Table 3.

4. Discussion

There are obvious osteopenia and increased bone brittleness in patients with osteoporosis, and the femoral head is the easiest involved area where osteoporosis is the most obvious, so the incidence of clinical femoral fractures is high in the elderly[6,7]. The changes of bone formation/bone resorption in femoral head can quantitatively reflect the changes in human bone metabolism, which is a reliable way to determine the severity of osteoporosis. With the development of computer technology and the improvement of CT scanning accuracy, spiral CT was used to scan the hip and input the original data into finite element analysis software for modeling, the real-time contour map can be obtained and the stress can be analyzed[8,9]. Von Mises stress is the main parameter of three-dimensional finite element model analysis, it is that the material begins to yield when the change of the element deviator strain energy reaches a certain extent, so its level is directly proportion to the object hardness and inversely proportional to the object brittleness. In the research, the differences in femoral head 3 d finite element model parameter levels were analyzed at first, and it was found that compared with normal control group, observation group were with lower cancellous bone and cortical bone Von Mises stress values, indicating that there are the decreased bone stress and increased brittleness in patients with osteoporosis. There is less relevant research about the correlation between Von Mises stress value and the severity of osteoporosis, and the correlation of femoral head Von Mises stress value with BMD value and bone metabolism activity in patients with osteoporosis was further explored in this study in order to provide an accurate and convenient way to judge the severity of osteoporosis, fracture risk and so on.

BMD is also called bone mineral density, so it is the most common index for clinical judgment of bone strength, the decrease of its levels predicts an increased risk of osteoporosis and bone fractures, but the BMD sensitivity to changes in bone mass is not high, and the BMD values significantly change only when there is significant osteopenia[10,11]. In this study, the differences in femoral head BMD value were compared between the two groups of subjects, and it was found that compared with the normal control group, the observation group was with lower femoral head BMD value, which was consistent with the status of osteoporosis. Further Pearson test showed that the cancellous bone and cortical bone Von Mises stress value of patients with osteoporosis were positively correlated with BMD value, confirming that the parameter values after three-dimensional finite element model analysis of femoral head can quantitatively reflect bone strength, and are sensitive indicators to judge the bone mass change of the femoral head.

The change of bone metabolism activity is the root cause of osteoporosis, which includes the decrease of osteoblast activity and the increase of osteoclast activity[12,13]. NBAP is one of the phenotypic markers of osteoblasts, it can directly reflect the activity of osteoblasts, and the NBAP secretion increases when the

calcium deposit in the bone is insufficient. BGP also belongs to osteoblast markers, is massively secreted during the peak period of bone mineralization, and can promote bone mineral deposit and bone formation[14,15]. TRACP-5b and CTX-1 are both markers of osteoclasts, and their high expression is a sign of the increased activity of osteoclasts, and also indicates poor bone formation[16]. In this study, differences in serum levels of bone metabolism markers were compared between the two groups, and it was found that compared with normal control group, the observation group were with lower serum BGP content, and higher NBAP, TRACP-5b and CTX-1 contents, indicating that there is decreased osteoblast activity/increased osteoclast activity in patients with osteoporosis. Further Pearson test showed that the femoral head cancellous bone and cortical bone Von Mises stress value of patients with osteoporosis were positively correlated with BGP content, and negatively correlated with NBAP, TRACP-5b and CTX-1 contents, confirming that the parameter values after three-dimensional finite element model analysis of femoral head can quantitatively reflect bone metabolism activity.

The femoral head cancellous bone and cortical bone Von Mises stress value decrease in patients with osteoporosis, and their specific levels could objectively reflect the BMD value and bone metabolism activity. Three-dimensional finite element model analysis is an effective and reliable method to accurately determine the severity of osteoporosis, and it is worth popularization and application in future clinical practice.

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