Comparison of Hip Structure Analysis and Grip Strength Between Femoral Neck and Basicervical Fractures

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Abstract

Objective: The purpose of this study was to analyze differences in the geometrical properties of the proximal femur and predict the occurrence of basicervical fractures through a comparative study of femoral neck and basicervical fractures in patients undergoing hip structural analysis (HSA).

Methods: All patients with hip fractures who were at least 65 years old and admitted to our hospital between March 2017 and December 2019 were eligible for this study. During the study period, 149 femur neck fractures (FNF) and basicervical fractures (intertrochanteric fractures of A31.2) were included in the study. Fifty-nine people were included in the final analysis. The factors considered to be the most important confounders affecting the occurrence of basicervical hip fractures were chosen for propensity-score analysis. A logistic model with basicervical hip fractures as the outcome and age, sex, weight, spinal T-score, hip T-score, and vitamin D levels as confounders was used to estimate the propensity score.

Results: The cross-sectional moment of inertia (CSMI) of the intertrochanter was significantly lower in the basicervical hip fracture (HF) patients than in the FNF patients (p = 0.045). However, there were no significant differences in any other HSA variable between the two groups. The results of ROC analysis showed that the cutoff points for HSA were 100 in hip axis length (HAL) (AUC = 0.659, p < 0.001) and 5.712 in the CSMI of the intertrochanter (AUC = 0.676, p < 0.001). After considering three variables, including HAL, the CSMI of intertrochanter, and handgrip strength, the results of the receiver operating characteristic (ROC) analysis were 104.8, 8.75, and 16.9 (AUC = 0.726, p < 0.001), respectively.

Conclusion: Proximal femoral geometric analysis using HSA is a useful method for predicting the type of hip fracture. Additionally, a lower CSMI, shorter HAL, and lower grip strength are major predictors of basicervical fractures.

Introduction

Hip fractures, which are reported to occur in more than 250,000 people in the United States each year, are currently estimated to double in 2050 [1, 2]. In particular, osteoporotic hip fractures are considered to be a socioeconomic problem in Asia [3, 4]. Hip fractures are classified anatomically as intracapsular fractures and extracapsular fractures, with femoral neck fractures and intertrochanteric fractures in each category [5]. Several factors, such as demographic factors, the comorbidity of the patient, and fracture location, are considered to determine the treatment method [6].

A basicervical femoral fracture is a fracture located at the boundary of two fractures. The fracture line passes through the base of the femoral neck at its junction with the intertrochanteric region [7]. For this reason, they are classified as femoral neck fractures. However, from a therapeutic point of view, the approach is similar to intertrochanteric fractures because it is close to the intertrochanteric line [8]. Studies have reported the treatment for basicervical fractures by fixing the fracture using dynamic hip screws (DHS) or cephallomedullary nailing (CMN) and suggested different results. Watson et al. reported that six of 11 patients had a fixation failure and that CMN was inadequate for the treatment of fractures [7]. In a multicenter retrospective study by Lee et al., 8.6% of the patients underwent conversion arthroplasty for fixation failure and reported higher failure rates when DHS was used [9]. But, the common view is that fracture fixation failure rates are high. The causes of the high failure rate have been explained by the anatomical location of the fracture, implant problems, and lack of rotational stability [10, 11]. However, the previous research lacked bone quality and geometrical analyses.

Bone mineral density measurements using dual-energy x-ray absorptiometry (DXA) can assess bone quantities, but geometrical properties can be evaluated using hip structural analysis (HSA), an output function of the DXA machine. Studies have predicted the risk of hip fracture by evaluating the geometrical properties of the femurs in hip fracture patients [12, 13].

Therefore, the purpose of this study was to analyze the differences in geometrical properties of the proximal femur and predict the occurrence of basicervical fractures through a comparative study of femoral neck and basicervical fracture patients undergoing HSA.

Materials And Methods

Ethics statement

The design and protocol of this retrospective study were approved by the Institutional Review Board of our hospital (GNUH-2019-05-018-007). The requirement to obtain informed consent was waived by the board.

Participants

All patients with a hip fracture who were at least 65 years old and admitted to our hospital between March 2017 and December 2019 were eligible for this study. During the study period, 149 femur neck and basicervical fractures (intertrochanteric fractures of A31.2) were included in the study. Of these, 59 (39.6%) were excluded because there was no time to perform DXA preoperatively due to the need for urgent surgical repair, 16 (10.7%) were excluded because they refused examinations, and 15 (10.1%) were excluded due to mental health issues, such as dementia, delirium, depression, and mental retardation. Finally, 59 people were included in the final analysis.

Demographic characteristics patients with basicervical hip fractures

Forty patients with femur neck fractures (FNF) and 19 patients with basicervical hip fractures (HF) were ultimately included in the study. Comparison of the demographic data by the type of hip fractures showed that age ($p = 0.433$), sex ($p = 0.222$), weight ($p = 0.254$), spinal T-score ($p = 0.147$), hip T-score ($p = 0.603$), skeletal muscle index ($p = 0.303$), and vitamin D level ($p = 0.238$) showed no statistically significant differences between the groups. However, height and grip strength were significantly different between the groups (Table 1).

Table 1
Demographic characteristics by presence of basicervical hip fracture

	FNF (N = 40)	Basicervical HF (N = 19)	P-value
Age (years)	77.38 ± 9.31	79.50 ± 9.48	0.433
Sex			0.222
Male	13 (32.5%)	3 (15.8%)	
Female	27 (67.5%)	16 (84.2%)	
Height (m)	160.45 ± 7.72	155.73 ± 6.16	0.015
Weight (kg)	55.48 ± 8.25	52.87 ± 8.02	0.254
Spine T-score	− 1.54 ± 1.40	-1.79 ± 1.65	0.147
Hip T-score	− 1.88 ± 0.82	-1.99 ± 0.71	0.603
SMI (kg/m^2)	5.71 ± 1.12	5.46 ± 0.68	0.303
Grip strength (kg)	15.37 ± 6.77	11.65 ± 4.92	0.021
VitD (ng/ml)	13.99 ± 11.05	17.96 ± 12.24	0.238

FNF; femur neck fracture, HF; hip fracture, BMI; body mass index, SMI; skeletal muscle index

Demographic characteristics by type of hip fracture after propensity score matching

Following propensity score matching, 19 patients in the FNF group and 19 patients in the basicervical HF group were ultimately included in the study. Comparison of the demographic data by the type of hip fracture, showed that age (p = 0.579), sex (p = 1.00), weight (p = 0.311), spinal T-score (p = 0.957), hip T-score (p = 0.968), SMI (p = 0.231), and vitamin D level (p = 0.682) were not significantly different between the groups (Table 2).

Table 2
Demographic characteristics by presence of basicervical hip fracture after Propensity score matching

	FNF **(N = 19)**	**Basicervical HF** **(N = 19)**	**P-value**
Age (years)	80.58 ± 6.59	79.11 ± 9.37	0.579
Sex			1.000
Male	4 (21.1%)	3 (15.8%)	
Female	15 (78.9%)	16 (84.2%)	
Height (cm)	159.87 ± 7.96	155.73 ± 6.16	0.082
Weight (kg)	55.79 ± 9.46	52.87 ± 8.02	0.311
Spine T-score	− 1.98 ± 1.39	-1.95 ± 1.62	0.957
Hip T-score	− 2.00 ± 0.89	-1.99 ± 0.71	0.968
SMI (kg/m^2)	5.86 ± 1.25	5.46 ± 0.68	0.231
Grip strength (kg)	16.85 ± 6.78	11.65 ± 4.92	0.011
VitD (ng/ml)	16.17 ± 14.41	17.96 ± 12.24	0.682

FNF; femur neck fracture, HF; hip fracture, BMI; body mass index, SMI; skeletal muscle index

Biochemical analyses

Serum 25-hydroxyvitamin D (25[OH] vitamin D) levels were measured using the 1470 Wizard gamma counter (Perkin Elmer, Finland), an Automatic Analyzer 7600 (Hitachi, Japan), and LIAISON (DiaSorin, U.S.A.) by radioimmunoassay (25-hydroxyvitamin D ^{125}I RIA Kit; DiaSorin).

Measurements of the appendicular skeletal muscle mass, BMD, handgrip strength

Body composition and bone mineral density (BMD) in both groups (HF and non-HF group) were measured through DXA using the QDR 4500A apparatus (Hologic, U.S.A.). The bone mineral content, fat mass, and lean soft-tissue mass were measured separately for each part of the body, including the arms and legs. Notably, the lean soft-tissue masses of the arms and legs were nearly equal to the skeletal muscle mass. Because the absolute muscle mass correlates with height, the SMI was calculated as follows: lean mass [kg]/height [m]^2. The arm SMI was defined as the arm lean mass [kg]/height [m]^2 and the leg SMI was defined as the leg lean mass [kg]/height [m]^2. The appendicular SMI was defined as the sum of the arm and leg SMIs. The participants held a digital hand dynamometer (Digital Grip Strength

Dynamometer, T.K.K 5401, Takei Scientific Instruments Co., Ltd., Tokyo, Japan) in the sitting position. The elbow was flexed at 90 degrees with the shoulder attached to the torso and the wrist at a neutral posture (0 degrees) and the maximal grip strength was measured.

Definition of osteoporosis

Osteoporosis was defined as a BMD 2.5 standard deviations (SDs) below the peak bone mass of a young, healthy, gender- and race-matched reference population, according to the World Health Organization (WHO) diagnostic classification. The BMD (T-score) was used to classify osteoporotic (T-score ≤ -2.5), osteopenic ($-2.5 <$ T-score < -1.0), and normal patients (T-score ≥ -1) [14].

Hip-structure analysis (HSA)

To evaluate the hip-bone geometry, DXA scans were performed to analyze the femoral neck (FN), intertrochanteric region (IT), and femoral shaft (FS) using the HSA program. The cross-sectional area (CSA), width (W), and cortical thickness (CT) were measured based on the bone-mass profiles. The hip axis length (HAL) was measured along the femoral neck axis from the base of the greater trochanter to the inner pelvic brim. The femur axis length (FAL) was measured along the femoral neck axis from the base of the greater trochanter to the inner pelvic brim. We calculated the neck-shaft angle (NSA) as the angle between the neckline and a line through the shaft of the femur, which was set by the Hologic software on the outer cortex of the femoral shaft below the region of interest [15–17].

Statistical analyses

To select the control group, a propensity-score matching method was used. The factors considered to be the most important confounders affecting the occurrence of basicervical hip fractures were chosen for the propensity-score algorithm. A logistic model with basicervical hip fractures as the outcome and age, sex, weight, spinal T-score, hip T-score, and vitamin D levels, as confounders was used to estimate the propensity scores. To account for the matched design, we performed paired t-tests [18].

To compare the means and proportions of each group, Student's t-tests and the chi-squared (χ^2) tests were conducted. Variables with p-values of < 0.05 were included in the multivariate model.

A receiver operator curve analysis (ROC) was also performed to identify the cutoff value for diagnosing basicervical hip fractures using HSA. All of the statistical tests were two-tailed and statistical significance was defined as $p < 0.05$. All of the statistical calculations were performed using SPSS Statistics V.22 (SPSS, U.S.A.).

Results

Hip structural analysis by the presence of basicervical hip fracture

The cross-sectional moment of inertia (CSMI) of intertrochanter was significantly lower in basicervical hip fracture (HF) patients than in the FNF patients (p = 0.045). However, no other HAS variables were significantly different between the two groups (Table 3).

Table 3
Hip structural analysis (HSA) by presence of basicervical hip fracture after Propensity score matching

	FNF (N = 19)	**Basicervical HF** (N = 19)	**P-value**
FAL (cm)	104.58 ± 7.31	101.74 ± 5.78	0.192
HAL (cm)	105.00 ± 6.18	101.95 ± 7.43	0.177
FN_CSA (cm^2)	1.96 ± 0.41	1.95 ± 0.48	0.954
FN_CT (cm)	0.11 ± 0.03	0.11 ± 0.02	0.583
FN_Width (cm)	3.57 ± 0.37	3.43 ± 0.42	0.274
FN_CSMI (cm^4)	1.96 ± 0.75	1.81 ± 0.97	0.595
ITN_CSA (cm^2)	3.25 ± 0.83	2.86 ± 0.54	0.090
ITN_CT (cm)	0.25 ± 0.23	0.23 ± 0.04	0.171
ITN_Width (cm)	5.72 ± 0.65	5.45 ± 0.55	0.167
ITN_CSMI (cm^4)	9.90 ± 4.20	7.57 ± 2.46	0.045
FS_CSA (cm^2)	3.24 ± 0.72	3.02 ± 0.38	0.261
FS_CT (cm)	0.40 ± 0.08	0.38 ± 0.57	0.612
FS_Width (cm)	3.01 ± 0.32	2.91 ± 0.22	0.261
FS_CSMI (cm^4)	2.99 ± 1.21	2.53 ± 0.57	0.137

FNF; femur neck fracture, HF; hip fracture, FAL; femur axis length, HAL; hip axis length, CSA; cross sectional area, CT; cortical thickness, CSMI; cross sectional moment of inertia, FN; femur neck, ITN; intertrochanter, FS; femur shaft

ROC analysis for the diagnosis of Basicervical HF using HSA

The results of ROC analysis showed that the cutoff points for HSA were 100 for the HAL (AUC = 0.659, p < 0.001) and 5.712 for the CSMI of the intertrochanter (AUC = 0.676, p < 0.001). ROC analysis showed that the cutoff point for handgrip strength was 16.8 kg (AUC = 0.727, p < 0.001) (Fig. 1–3). The sensitivity and specificity are shown in Table 4.

Table 4
ROC analysis for diagnosis of Basicervical hip fracture

Variables	Cut-off point	Sensitivity	Specificity	AUC	P-value
HAL	100	47.4 %	84.2%	0.659	< 0.001
ITN_CSMI	8.433	73.7 %	63.2 %	0.676	< 0.001
HGS (kg)	16.8	84.2 %	57.9%	0.727	< 0.001
ROC; receiver operating curve, AUC; area under the ROC Curve, HAL; Hip axis length, CSMI; cross sectional moment of inertia, ITN; intertrochanter, HGS; hand grip strength					

After considering three variables, including the HAL, the CSMI of the intertrochanter, and handgrip strength, the results of ROC analysis were 104.8, 8.75, and 16.9 (AUC = 0.726, p < 0.001), respectively (Fig. 4).

Discussion

BMD predicts osteoporotic hip fractures relatively well, except for fractures caused by high energy trauma [19]. However, it does not explain the differences that exist between these fractures occurring in the vicinity of the proximal femur region. Fractures occur when the external force exceeds the bone's ability to absorb energy through the combined effects of elastic and plastic deformation [12]. Decreases in bone density due to aging and osteoporosis are accompanied by geometrical changes, which alter the bone's ability to absorb energy that resists fractures. These changes cannot be explained simply by BMD, however, they can be analyzed through HSA [13].

Bending and axial compression forces are applied to the proximal femoral area when an elderly person falls [12]. In a previous comparative study of HSA between hip fracture patients and non-fracture patients, the hip fracture patients were characterized by lower bending (section modulus) and axial strength (coronal sectional area), thinner cortex, and wider diameter [12]. This study also reported that the HSA parameters were more consistent with the identification of intertrochanteric fractures than femoral neck fractures. We hypothesized that there would be differences in HSA parameters between these fractures occurring at close anatomical locations and the main finding in this study was that the CSMI was significantly lower in basicervical fractures. The CSMI is used to measure the distribution of material around the neck axis necessary to calculate the resistance to bending. The mechanical stress within a cross-section subjected to bending is inversely related to the CSMI and varies with the distance from the neutral axis [20, 21]. In other words, basicervical fractures have a lower bending strength compared to femoral neck fractures, which occurs near the intertrochanteric line.

Lower CSMIs in basicervical fractures can have clinical significance from two perspectives. The first is the importance in terms of diagnostic prediction. Several HSA studies on the prediction of various hip fracture incidences reported that various HSA parameters were important, including bone cross-sectional area, outer diameter, selection modulus, buckling ratio, the HAL and the strength index [22, 23]. Among them, the section modulus is a strength parameter derived from the CSMI and is equal to the CSMI divided by the centroidal distance, the distance from the centroidal axis to the edge of the section [13]. Also, in a study by Kaptoge et al., BMD, CSA, the CSMI, section modulus, and the cortices in the hip fracture group were lower than those in the fracture-free group [12]. Resistance to bending strength is important for the prediction of hip fracture occurrence. Moreover, the CSMI, an indicator of bending strength, can be used as an index to predict the location of hip fractures. Second in importance is the therapeutic aspects of the fractures. Various studies have reported a high rate of treatment failure for basicervical fractures [4, 7, 9, 10]. These studies noted the morphological characteristics that tended to collapse into the intertrochanteric area due to their anatomical location and identified them as the major causes of treatment failure. Although the use of extramedullary or intramedullary devices in implants is controversial, clinically, the current study found that the use of a fixed angle device for the internal fixation of basicervical fractures is a reasonable treatment option to reinforce the weakness of this bending strength.

Leslie et al. hypothesized that different types of bone geometry can predict fractures. In the Fracture Risk Prediction Model using DXA-based finite element analysis, a study reported that the HAL and strength index were significantly associated with the incidence of hip fracture. In a study by Faulkner et al., the HAL of the hip fracture group was also significantly shorter than that of the control group, [24] indicating a reduced capacity to withstand a fall and identifying the HAL as an independent predictor of hip fractures. They reported that an increase in HAL equivalents to 1 SD was associated with a 1.8-fold increase in the risk of hip fractures in women. The results of this study showed that the average HAL of the basicervical fracture patient was shorter than that of the femoral neck fracture patients and the diagnostic significance of basicervical fractures was found in the ROC analysis. Thus, HAL is not only a predictor of fracture risk but also a significant predictor of fracture type.

The European Working Group on Sarcopenia in Older People developed a clinical definition of sarcopenia based on low muscle mass and reduced muscle function [25]. Grip strength is recommended as a good simple measure of muscle strength. In older people, falls are associated with lower physical activity, which is one of the signs of reduced physical function [26, 27]. Sarcopenia is also closely related to osteoporosis and osteoporotic hip fractures. A study by Travison et al. on the correlation between body mass index and proximal femur strength reported a fracture prevention effect in people with high BMI, not because of fat, but because of muscle mass. Our study confirmed that the handgrip strength was decreased statistically in the basicervical fracture group and proven statistically as a predictive factor for basicervical fracture diagnosis. We do not know the exact mechanism to explain this result, but it is thought that it affects the loading occurring during falls or the absorption of impact force. Therefore, further studies are needed.

There were several limitations to this study. First, the study sample size was small. However, we used propensity score matching to address this problem. Second, the study design was retrospective and we cannot exclude the possibility of selection bias. Third, we did not consider comorbidity and the use of anti-osteoporotic medications by the patients. However, we tried to complement this by analyzing factors, such as skeletal muscle index, grip strength, and vitamin D levels.

In conclusion, proximal femoral geometric analysis using HSA is a useful method for predicting the type of hip fracture. Additionally, lower CSMI, shorter HAL, and lower grip strength are major predictors of basicervical fractures.

Declarations

Ethics Committee Approval:

The design and protocol of this retrospective study were approved by the Institutional Review Board of our hospital (GNUH-2019-05-018-007).

Informed Consent:

The requirement to obtain informed consent was waived by the board.

Author Contributions:

Concept – YJI, CYH; Design - YJI, CYH; Supervision - YJI, CYH; Materials - YJI, CYH; Data Collection and/or Processing - YJI, CYH; Analysis and/or Interpretation - YJI, CYH; Literature Search - YJI, CYH; Writing Manuscript - YJI, CYH; Critical Review - YJI, CYH

Conflict of Interest:

The authors have no conflicts of interest to declare.

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Figures

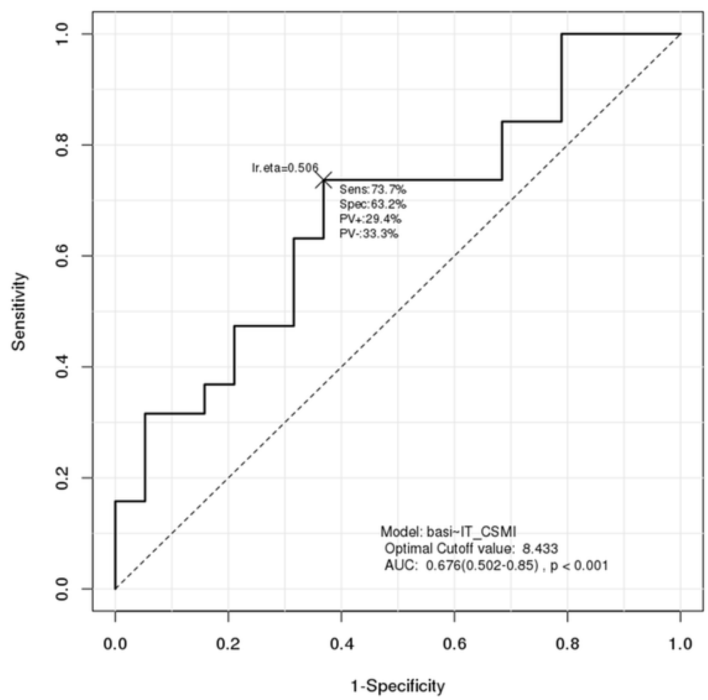

Figure 1

ROC analysis for the diagnosis of hip fractures using CSMI of the intertrochanter.

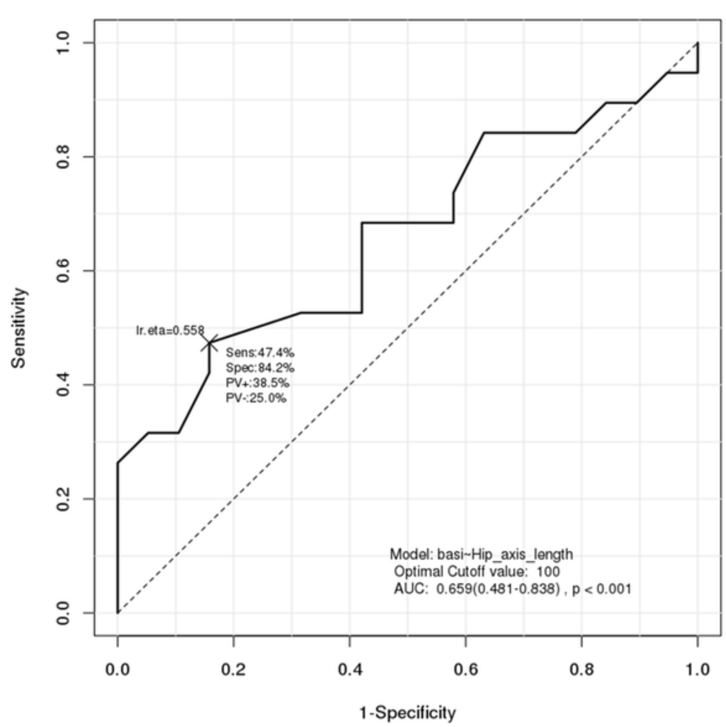

Figure 2

ROC analysis for the diagnosis of hip fractures using hip axis length.

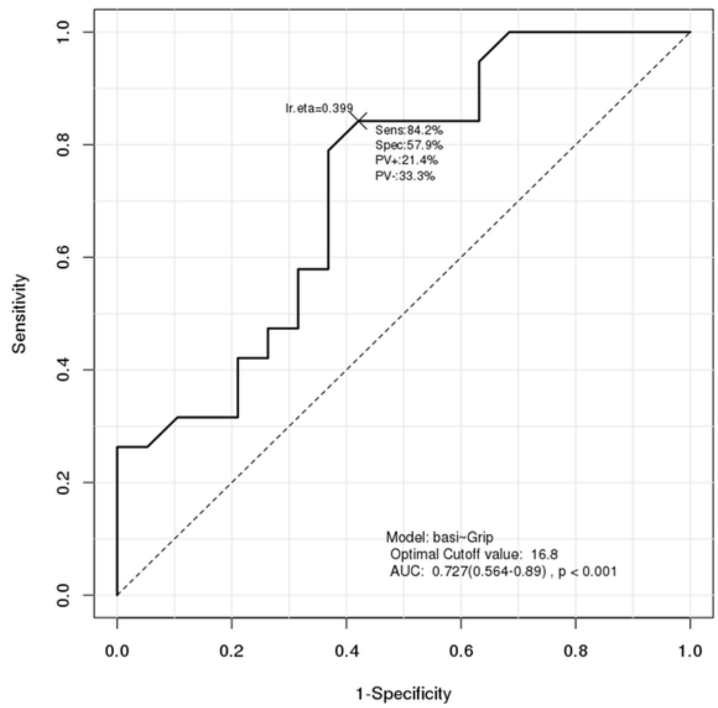

Figure 3

ROC analysis for the diagnosis of hip fractures using handgrip strength.

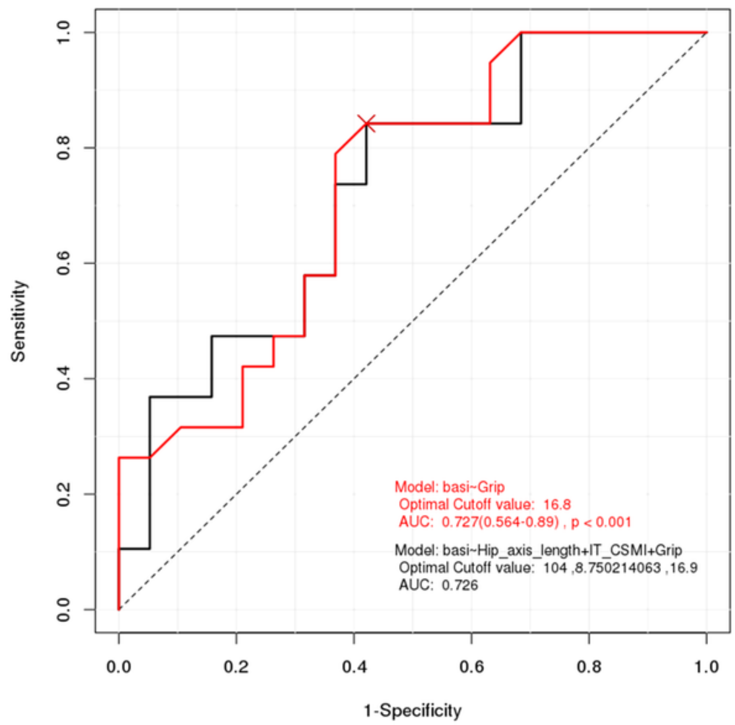

Figure 4

ROC analysis for the diagnosis of hip fractures using three variables.