

Research Article

The Slovak Predictive Regression Model of Fall-Related Femoral Neck Fracture Risk

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Abstract *Objectives.* Femur strength index (FSI) has been previously described as a reliable measure of femur fracture risk in a fall. FSI computation requires software associated with bone densitometry equipment and incorporates measures of bony structural integrity. Because such software is not universally available, in the present study, we describe the evaluation of the biomechanical predictors of femur fracture in a fall combined with commonly available measures of bony strength as an alternative means of predicting FSI values. *Design.* Binary logistic regression was used to evaluate the effect on the value of FSI when *T-score total hip (bone densitometry results)*, *body mass index (BMI)*, *alpha angle*, *theta angle*, and *hip axis length (HAL)* were increased by one whole unit of relevant measurement (i.e., 1 degree, 1 millimeter). *Setting.* Outpatient radiology facility. *Participants.* A sample of 3,216 East Slovak women aged 20–89 years with primary or secondary osteoporosis, osteopenia, or risk factors for osteoporosis who were referred to a facility for bone densitometry. *Main outcome measures.* FSI value of <1 was used as a proxy for pathological degree of fall-fracture risk. *Results.* A one-unit increase of the predictive variables were found to affect the odds of FSI <1 as follows: an increase by 1° of α angle = odds of FSI <1 by 1.11 times, an increase by 1° of θ angle = odds of FSI <1 by 1.23 times, an increase by 1 mm of the HAL = odds of FSI <1 by 1.04 times, an increase by 10 kg/m² of BMI = odds of FSI <1 by 1.30 times, and an increase by +1 SD of the T-score total hip *decreased* the odds of FSI <1 by 1.98 times. *Conclusions.* The Slovak Regression Model for Fall-Related Femoral Neck Fracture Risk is an effective model for estimating fall related hip fracture based on relevant biomechanical and geometric variables. Prospective epidemiological study of fall related fracture is needed to validate the model.

Keywords osteoporosis; femoral neck fractures; logistic regression; biomechanics

1. Introduction

Bone mineral density (BMD), as measured by bone densitometer DXA (dual energy X-ray absorptiometry), has been found to be a reliable index of absolute risk of osteoporotic fractures [6,8,9,12]. Prior authors have described the assessment of future fracture risk by combining BMD (quantitative variable) values with other relevant patient

information (qualitative variables) that has been found to be predictive of fracture [1,5,11]. More recent models have included the use of logistic regression as a means of identifying the group of risk factors that most strongly predict the risk for the fracture in the future. A logistic regression model is a type of generalized linear regression model, whereby a group of independent variables can be assembled that best predict a dependent categorical variable. The independent (predictive) variables in the model can be quantitative or qualitative. In the case of binary logistic regression, the dependent or outcome variable is dichotomous, with only two possible categorized values, 0 or 1, indicating the absence or presence of the outcome of interest [10].

In evaluation of osteoporotic fracture risk, the femur strength index (FSI) has been shown to be a reliable index of the odds of fracture [2]. Thus, FSI values can serve as a validated proxy for fracture risk when assessing the utility of a predictive model. FSI computation requires proprietary software used in conjunction with DXA equipment (called hip strength analysis [HSA] software) and incorporates a measure of the geometric shape of proximal femur, cross-sectional moment of inertia (CSMI) in the femoral neck area, derived from X-ray absorption curves, along with other measures of bony geometrics and structural integrity [19]. The software required to compute FSI is not universally available at clinical bone densitometry facilities; thus, an alternative means of estimating fall-related femur fracture risk is needed.

In the present paper, we describe a methodology for assessing fall-related femur fracture risk called the Slovak Regression Model (SRM). The model differs from previously described fracture models in that it employs quantitative variables of biomechanical and geometric

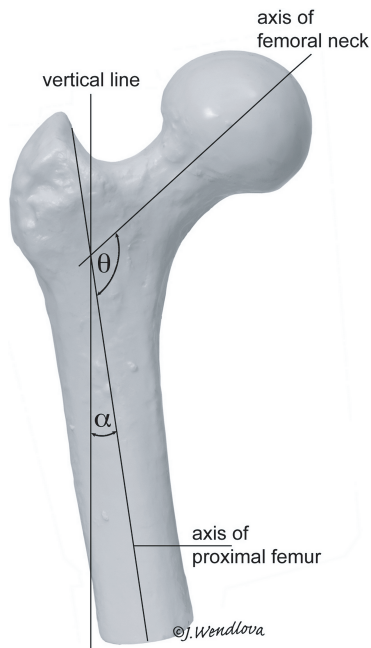


Figure 1: Proximal femur: angle α and angle θ .

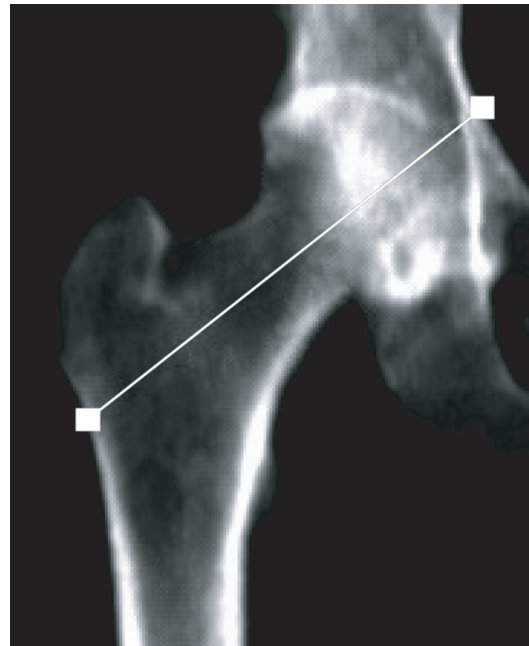


Figure 2: Hip axis length (HAL).

measurements, and results in the prediction of femoral neck fracture by fall based on patient characteristics, thus providing a tool for the individualized assessment of contemporaneous threat of femur fracture secondary to the most common cause of such fractures.

Objective of the study:

(1) To demonstrate that bony geometric variables as well as weight and height are important in the assessment of femoral neck fracture risk resulting from a fall.

(2) To construct a binary logistic regression model of the ranked order of statistically significant predictive variables according to the intensity of their influence on the value of the FSI outcome variable.

(3) To determine from the model the effect on the odds of a pathological FSI value, defined as $FSI < 1$, when the value of the variables T-score total hip, BMI, alpha angle, theta angle, and HAL change by a single relevant whole unit (i.e., 1 degree, 1 SD, 1 millimeter).

(4) To provide clinicians with an alternative means of assessing fall-related femur fracture risk based on easily measured clinical, biomechanical, and geometric variables without the need for the software required to evaluate FSI.

2. Methods and materials

A sample of 3,216 women from East Slovakia with primary or secondary osteoporosis, osteopenia, and risk factors for osteoporosis aged 20–89 years, (mean 58.9 years, 95% CI 58.4, 59.4) were examined via bone densitometry DXA (Prodigy-Primo, GE, USA).

BMD was evaluated in the standard region of interest (ROI), which is the left total hip area. BMD values were given in absolute numbers in g of Ca-hydroxyapatite crystals per square cm, as well as in relative numbers as a T-score (the number of standard deviations from the reference group of young healthy women). Osteoporosis or osteopenia were diagnosed in accordance with the WHO criteria, in which the normal population is defined as those with a BMD T-score of less than 1.0 SD below the mean, osteopenia is between 1.0 and 2.5 SD below the mean, and osteoporosis is >2.5 SD below the mean.

All subjects were scanned on the same device, operated by one of two experienced technicians. The following variables were measured or calculated by the proprietary software [13]:

- Theta angle (θ): defined as the angle formed by the femoral neck axis and the femoral shaft axis.
- Alpha angle (α): defined as the angle formed by the femoral shaft axis and the vertical. The alpha angle can be either positive or negative, depending whether the femur is in a valgus or varus position (Figure 1).
- HAL (hip axis length): defined as the distance in mm from the inferolateral aspect of the greater trochanter to the pelvic inner rim, measured along the long axis of the femoral neck (Figure 2).
- FSI (femur strength index): defined as the ability or strength of femoral neck to resist compressive forces acting on the proximal femur during a fall. The FSI is the ratio of estimated elastic limit stress in compression of the femoral neck to the expected compressive stress

on the femoral neck caused by a fall onto the greater trochanter, adjusted for the patients height and weight. A normal value of FSI is defined as ≥ 1 , and a pathological value is <1 .

- Minimum cross-sectional area (mCSA): defined as the smallest cross sectional area (mm^2) in the femoral neck, also known as the “dangerous cross-sectional area” for its propensity to fracture.

In addition to these variables, body mass index (BMI), defined as $(\text{weight in kg})/(\text{height in meters})^2$, was calculated for all of the subjects.

Statistical analysis

The statistical analysis used was binary logistic regression (PROC LOGISTIC command), utilizing commercially available statistical analysis software (SAS® Enterprise Guide 4.0) [4, 10, 16, 17].

The logistic regression model was populated with the results of a clinical study that included 3,216 East Slovak female patients.

The dichotomous dependent (outcome) variable in the model was the FSI variable, categorized as $\text{FSI} \geq 1 = \text{no increased fracture risk (FSI categor} = 0 \text{ in the model)}$, and $\text{FSI} < 1 = \text{increased fracture risk (FSI categor} = 1 \text{ in the model)}$ [4, 10, 16, 17]. The sample included 470 (14.51%) patients with FSI values indicating increased fracture risk and 2,746 (85.37%) patients, whose FSI values could be considered as normal (FSI categor = 0).

Independent (predictor) variables, shortlisted for the regression model, included: BMI, age, alpha angle, theta angle, HAL, T-score total hip.

The method of stepwise regression was applied in the selection of the most optimal subset of independent variables for regression model.

3. Results

The model with the variables BMI, alpha angle, theta angle, HAL, T-score total hip was statistically significant as a whole; thus, we were able to reject the null hypothesis H_0 : that the model as a whole was not statistically significant. Age was not found to be a significant predictor of FSI in the model.

The ability of the model to discriminate between the subjects with normal versus pathological values of FSI, based on the values of dependent variables, was evaluated with the Hosmer-Lemeshow Goodness of Fit test. At the significance level of $\alpha = 0.01$, the null hypothesis (i.e., that the model was a good fit to the data and thus could discriminate between the subject groups) was accepted. The H-L test result was $p = 0.125$ ($\chi^2 = 12.6364$, $df = 8$); thus, the null was rejected [10].

Table 1 shows the results of the Wald’s test for statistical significance of the predictor variables, ranked by the

Table 1: The order of dependent variables according to the intensity of their influence (statistical significance) upon the occurrence of the categorical *FSI* outcome variable.

Analysis of maximum likelihood estimates					
Variable	DF	Estimate β	Standard error	Wald chi-square	<i>P</i>
Intercept	1	-40.7612	2.4387	279.3576	<.0001*
BMI	1	0.2639	0.0148	316.6411	<.0001*
Angle theta left	1	0.2082	0.0173	145.0853	<.0001*
T-score total hip left	1	-0.6824	0.0603	127.9164	<.0001*
Angle alpha left	1	0.1051	0.0177	35.0879	<.0001*
HAL left	1	0.0423	0.00959	19.4942	<.0001*

Table 2: Regression model with the OR (odds ratio) values of the dependent variables.

Odds ratio estimates			
Variable	Point estimate	95% Wald confidence limits	
T-score total hip left	0.505	0.449	0.569
Angle alpha left	1.111	1.073	1.150
Angle theta left	1.231	1.190	1.274
HAL left	1.043	1.024	1.063
BMI	1.302	1.265	1.340

intensity of their influence on the categorical *FSI* variable. Table 2 presents the estimated values of the odds ratios (OR) of the predictor variables. None of the estimated 95% confidence intervals (CI) contains the value of 1. There is a direct relationship between the predictor variable values *BMI*, *alpha angle*, *theta angle*, and *HAL* and an *FSI* value of <1 , in that an increase of one relevant unit of measurement in these variables increases the odds of fall-related fracture. As an example, if the value of the *BMI* variable increases by 1.0 kg/m^2 and the values of remaining predictor variables remain constant, then the odds of $\text{FSI} < 1$ increases 1.302 times (approximately 30%). The same interpretation applies to the variables *alpha angle*, *theta angle*, and *HAL*.

In contrast, an increase in the *T-score total hip* is indirectly related to fracture risk, in that an increase by 1 SD *decreases* the odds of $\text{FSI} < 1$ by 0.505 and conversely increases the odds of $\text{FSI} \geq 1$ by 1.98 times (95%CI = 1.76–2.23).

4. Discussion

In our fracture risk model, we describe a means of assessing fracture risk associated with falling by predicting a pathological value of *FSI* using proxies and in doing so distinguish the model from previously published models. Recently, several papers have been published describing regression models intended to predict future osteoporotic fracture risk for five, ten, or more years [3, 7, 14, 15]. There are readily acknowledged shortcomings of such models, including the fact that some potent risk factors are imprecisely defined (smoking, alcohol consumption,

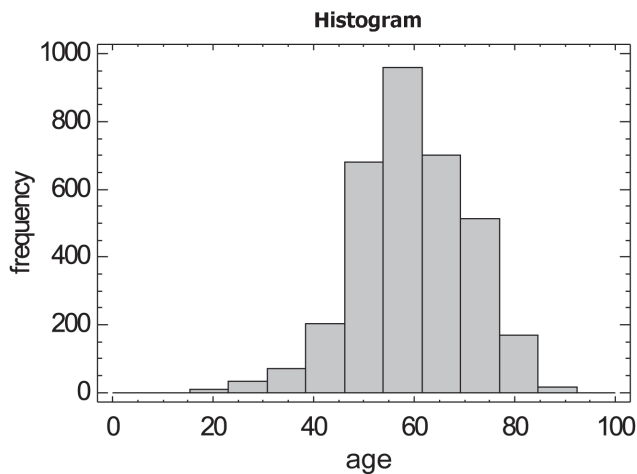


Figure 3: Age distribution histogram.

metabolic diseases, glucocorticoid usage, *inter alia*). It is not feasible to enter into a regression model precise quantification, including duration and intensity, of such risk factors. Another disadvantage of some prior models is the lack of study subjects of ≥ 80 years of age, despite the fact that this is the demographic most prone to osteoporotic fracture of the femoral neck. In our model were enrolled women of ≥ 80 years (Figure 3).

Since the most common mechanism of femur fracture is a fall, the risk of fracture *given a fall* is likely to have more value in predicting the occurrence of a fracture in comparison with an assessment of fracture due to any cause. Thus, models that assess the five- or ten-year risk of fracture from all causes suffer from a lack of information on the future adoption of strategies designed to reduce the probability of a fall leading to a femur fracture, such as exercises for improving balance or education in relatively safer falling techniques [18].

Previously published models have employed only one parameter of bone quality; *BMD*. In comparison, the SRM includes measures of bone elasticity in compression, geometrical variables and the magnitude of impact force in a fall. In the SRM, *BMI* was the most statistically significant predictor variable affecting the categorical outcome *FSI* variable. The explanation for this finding is simple mechanics; a heavier patient generates higher focal loads at impact than does a lighter patient who falls the same distance.

Once other risk factors were accounted for, age was not found to be predictive in our regression model and therefore was excluded. This is not to say that age is not predictive of fracture, but rather that *T-score total hip (BMD)* and *FSI* values are both a function of age (moreover, *FSI* is adjusted for age) and more predictive of fracture than is age alone. An advantage of the SRM is that in the cases where age would be a poor predictor of fracture risk, such as in the younger

patient who has been exposed to diseases that increase osteoresorption (thyrotoxicosis, chronic hepatic disease, etc.), the model is less likely to give a misleading result because the young age of the patient. Geometric variables of proximal femur (alpha angle, theta angle, HAL) + *BMD (T-score total hip)* + *BMI* variable appear to provide a reliable estimate of the probability of the occurrence of pathological values of *FSI* in the femoral neck area.

At present, *FSI* is the most reliable measure of fracture risk that accounts for biomechanical variables of femur load resulting from a fall, values of which are determined by DXA in a routine ambulatory setting and utilizing proprietary HSA software. The value of the SRM is that it makes it possible to evaluate the probability of a pathological value of *FSI* in settings where such software is not present or available.

In the present model, the study population was confined to East Slovak women. Although it can be reasonably supposed that the results in this population can be extrapolated to central European populations of women, this supposition is unvalidated, and further study is required to evaluate the generalizability of our findings.

5. Conclusion

With the present study, we have demonstrated a new methodology for estimating the odds of fall-related femoral neck fracture by fall, based upon bone quality determination and other easily evaluated predictive parameter with the SRM.

We believe that there are a number of benefits of the SRM over previously published models; but foremost is that fall-related fracture risk assessment can be performed using variables that predict, rather than rely on *FSI*.

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