

# Predictive value of different radiographic parameters evaluating the proximal femoral geometry for hip fracture in the elderly: what is the role of the true moment arm?

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## Abstract

**Introduction:** The purpose of the present study was to evaluate the value of radiographic measurements of the proximal femur as predictive factors for hip fracture in the elderly population independent of bone mineral density.

**Material and methods:** The study included 142 consecutive patients operated on for a hip fracture (group 1) and 86 healthy individuals without a hip fracture (group 2). The geometry of the contralateral nonfractured proximal femur in patients from group 1 was evaluated in comparison with healthy individuals from group 2. Anteroposterior pelvic roentgenograms were assessed to measure the geometric parameters of the proximal femur including femoral neck width, Q angle, medial cortical thickness (MCT), lateral cortical thickness (LCT), and true moment arm (TMA) for all hips. Lunar dual-energy X-ray absorptiometry (DXA) was used for bone mineral density measurements in both the fracture and control groups. Multivariate regression analysis was performed to determine the main predictive factors. A receiver operating characteristic curve was constructed for TMA to test the various cut-off points in predicting hip fracture.

**Results:** Regarding geometric measurement parameters, group 1 had significantly lower MCT and LCT values. The mean femoral neck width (FNW) and Q angle were significantly higher in group 1. Furthermore, TMA was also found to be significantly greater in patients with hip fracture compared to controls, 85 ±14 mm and 66 ±12 mm, respectively ( $p < 0.001$ ). The mean TMA was also significantly greater in group 1 for both age groups ( $\leq 65$  or  $> 65$  years) ( $p < 0.001$ ).

**Conclusions:** True moment arm may provide the most valuable radiographic information as a predictor for hip fracture in the elderly.

**Key words:** bone density, aged, predictive value of tests, hip fractures/pathology.

## Introduction

As the elderly population has been growing worldwide in recent decades, hip fracture has become a major public health problem due to increases in the number of adults with osteoporosis. Hip fractures in this

age group are among the most common acute pathologies in the daily clinical practice of orthopedic traumatology [1]. It has been estimated that the incidence of hip fracture will rise to more than 6 million by the year 2050 [2, 3]. Approximately 25% of the patients have been reported to die from complications within the first year after the fracture, whereas another 25% are at risk of losing independence [4]. Therefore, identifying individuals who are at high risk of hip fracture could prevent or delay fracture and its devastating consequences [5].

Although low bone mineral density (BMD) has been proposed as the major predictive factor in establishment of a risk level in the older population, a large overlap in the BMD values of fracture and non-fracture patients has led physicians to focus on investigating additional methods and parameters such as the proximal femoral geometry [6–8]. Hip axis length (HAL), femoral neck axis length (FNAL), femoral neck shaft angle (Q angle), femoral neck width (FNW), medial and lateral cortical thicknesses (MCT and LCT), and true moment arm (TMA) are the major radiographic parameters which have been tested as potential predictors of hip fracture [7, 9–12]. Some authors have suggested a combined assessment of proximal femur geometry and BMD values [10]. However, no consensus has been established yet on the validity of structural variations of the proximal femur which may potentially improve the clinical predictability of hip fractures in the elderly.

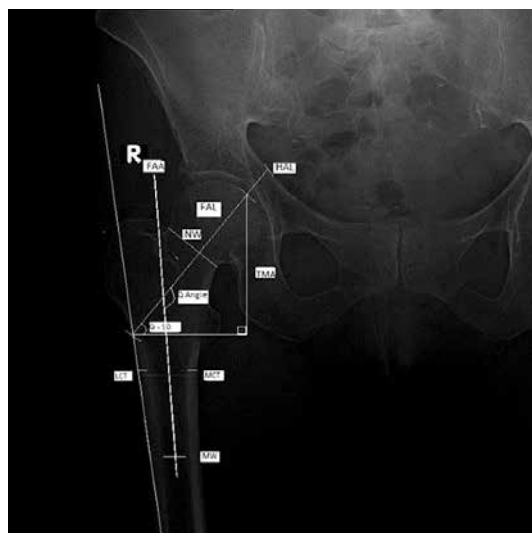
The purpose of the present study was to evaluate the value of radiographic measurements of the proximal femur including FNW, Q angle, MCT, LCT, and TMA as predictive factors for hip fracture in the elderly population and the ability to identify fracture-prone individuals, independently of BMD.

## Material and methods

After having approval from the local ethical research committee (ref. 15144-468), the present study comparatively evaluated the data of patients who underwent surgical treatment for a hip fracture with the data of healthy individuals. Informed consent was obtained from all individual participants included in the study. Polytrauma patients, bilateral hip fractures, fractures associated with a primary or secondary tumor of the bone, patients who had a past medical history of hip surgery, those with primary or secondary musculoskeletal deformities of the lower extremity, metabolic diseases of bone except osteoporosis, and patients with inappropriate or incomplete radiographic records were excluded. The study population consisted of 142 consecutive patients operated on for a hip fracture (group I) and 86 healthy individuals without a hip fracture (group II). The

mean age of the patients in group I was  $78.3 \pm 9.2$  years at the time of hip fracture and  $76.3 \pm 9.4$  years in group II. The mean body mass index (BMI) was  $25.5 \pm 2.1$  kg/m<sup>2</sup> in hip fracture patients and  $25.4 \pm 3.5$  kg/m<sup>2</sup> in the control group. Group I included 92 (64.7%) females and 50 (35.2%) males, whereas group II included 62 (72%) females and 24 (28%) males. In group I, the preoperative diagnosis was intracapsular femoral neck fracture in 64 (45%) patients, and intertrochanteric or subtrochanteric fracture in 78 (55%).

The geometry of the contralateral nonfractured proximal femur in patients from group I was comparatively evaluated with the geometry of the proximal femur in healthy individuals from group 2. The right and left hips (172 hips of the 86 subjects) were examined in the control group, while the nonfractured hips including 59 right and 83 left sides were examined in the fracture group. The standardized anteroposterior (AP) pelvic roentgenograms were assessed. The standard AP pelvic image was taken while the patient was lying in a supine position with the tube perpendicular to the table and the central beam was between the upper border of the symphysis pubis and anterior superior iliac spines. The optimal AP image was accepted as the coccyx points toward the symphysis pubis with a distance of 1 to 2 cm to it. The measured geometric parameters of the proximal femur included femoral neck width, Q angle, medial and lateral cortical thickness, and the true moment arm for all hips (Figure 1). The formula described by Ulusoy *et al.* [9] was applied to calculate TMA. The formula used to calculate TMA was as follows;  $TMA = \sin(Q - 90) \times \text{femur}$



**Figure 1.** Measurement of geometric parameters of the proximal femur on X-ray

HAL – hip axis length, FNAL – femoral neck axis length, TMA – true moment arm, FNW – neck width, FAA – femur anatomic axis, LCT – lateral cortical thickness, MCT – medial cortical thickness, MG – medullary width.

axis length (FAL). All of the radiographic measurements were performed by two of the authors. Correlation coefficients for the measurements were 0.96, 0.91, 0.99, 0.99 and 0.90 for FNW, Q angle, MCT, LCT, and TMA, respectively.

Lunar DXA was used for BMD measurements for all hips in both the fracture and control groups. The measurements were performed on the non-fractured side of the patients in group I and on both hips of the subjects in group II. BMD measurements were obtained as femoral neck, trochanteric region, and total BMD values.

### Statistical analysis

Categorical data were presented as frequencies with percentages and continuous data as means with standard deviations. Relations between categorical variables were assessed using the  $\chi^2$  test. The two-sample *t*-test and Mann-Whitney *U* test were used to compare independent variables. Multivariate regression analysis was performed to determine the main predictive factors. A receiver operating characteristic (ROC) curve was constructed for TMA length to test the various cut-off points in predicting hip fracture. The level of significance was set at  $p \leq 0.05$ .

### Results

Table I demonstrates the mean and standard deviation (SD) values for age, BMI, and BMD values in both the fracture and control groups. There were no significant differences in age, BMI, or BMD values between the groups ( $p > 0.05$ ).

**Table I.** Demographic data of study population

Parameter	Group 1 (mean $\pm$ SD)	Group 2 (mean $\pm$ SD)	P-value
Age [years]	78.3 $\pm$ 9.2	76.3 $\pm$ 9.4	0.118
BMI [kg/m <sup>2</sup> ]	25.5 $\pm$ 2.1	25.4 $\pm$ 3.5	0.810
Femoral neck T score [g/cm <sup>2</sup> ]	0.68 $\pm$ 0.11	0.70 $\pm$ 0.14	0.185
Trochanteric T score [g/cm <sup>2</sup> ]	0.59 $\pm$ 0.17	0.61 $\pm$ 0.10	0.264
Total hip T-score [g/cm <sup>2</sup> ]	-1.7 $\pm$ 1.1	-1.64 $\pm$ 0.99	0.671

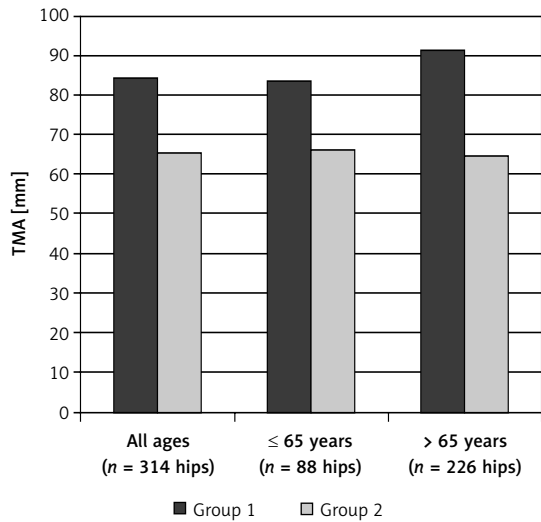
**Table II.** Univariate analysis of the radiographic parameters tested as predictors of hip fracture

Parameter	Group 1 (mean $\pm$ SD)	Group 2 (mean $\pm$ SD)	P-value
Femoral neck width [mm]	38.3 $\pm$ 3.9	35.5 $\pm$ 4.2	< 0.001
Q angle [°]	132.1 $\pm$ 6.5	129.2 $\pm$ 5.9	< 0.001
Medial cortical thickness [mm]	6.6 $\pm$ 1.5	9.1 $\pm$ 1.6	< 0.001
Lateral cortical thickness [mm]	6.1 $\pm$ 1.4	7.6 $\pm$ 1.4	< 0.001
True moment arm [mm]	85 $\pm$ 1.4	66 $\pm$ 12	< 0.001

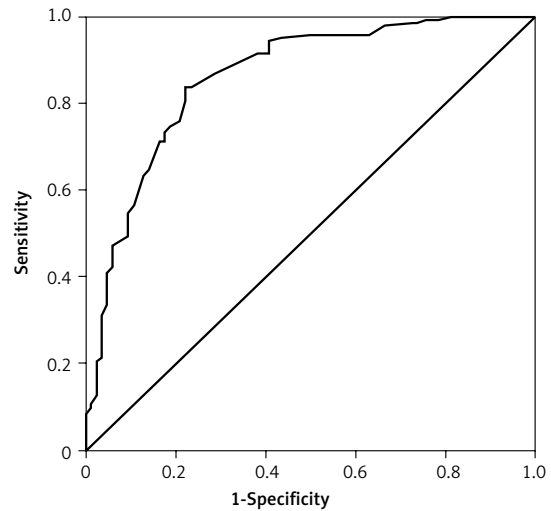
Regarding geometric measurement parameters, the patients in group I had significantly lower MCT and LCT values (Table II). The mean FNW and Q angle were significantly higher in group I. Furthermore, TMA length was also found to be significantly greater in patients with hip fracture compared to controls, 85  $\pm$  14 mm and 66  $\pm$  12 mm respectively ( $p < 0.001$ ). When the mean TMA lengths were compared between the groups with the age ( $\leq 65$  or  $> 65$  years) determined as the independent variable, the mean TMA length was also significantly greater in group I for both age groups ( $p < 0.001$ ) (Figure 2). However, we did not detect any significant difference between the male and female gender ( $p = 0.6$ ). Although the FNW, Q angle, MCT, LCT, and TMA length were significantly correlated with hip fracture risk according to univariate analysis, multiple regression analysis demonstrated that the TMA length was the most significant variable in predicting the fracture risk ( $p < 0.001$ ; 95% CI: 0.852–0.912). The sensitivity of TMA length was 85% and the specificity was 75% with the cut-off value determined as  $\geq 72$  mm according to the ROC curve (Figure 3).

### Discussion

The etiology and the mechanisms leading to hip fracture in the elderly have been reported as related to multiple factors [13]. Therefore, measuring femoral BMD alone may not accurately predict fracture risk, especially when measured BMD is not yet in the osteoporotic range [10]. Proximal femoral geometry has been investigated by several authors as an additional tool with



**Figure 2.** Comparison of mean TMA lengths among the age groups



**Figure 3.** Receiver operating characteristic (ROC) curve for TMA to test the cut-off points in predicting hip fracture

BMD measurements for the establishment of the risk for a hip fracture in the elderly [6–9, 11]. Various segments of the proximal femur contribute to the strength and resistance to the impact stress caused by a fall; thus several geometric measurements have been tested to develop a better understanding of the biomechanical properties increasing the fracture risk [7, 9–12]. According to Gregory *et al.*, both the shape of the femur and the appearance of the trabecular architecture are associated with fracture risk [5]. Ulusoy *et al.* also reported that independently from BMD, geometric parameters significantly discriminated fractured patients [9]. The disproportional stress loading on the hip joint that originated due to a fall was demonstrated as positively correlated with a longer HAL as well as a longer FAL [14]. Femoral neck shaft angle (Q angle) is another geometric parameter which has widely been assessed by several investigators in the literature [7, 12, 15–17]. However, the results from different studies regarding the relationship between the increased risk of hip fracture with higher HAL, FAL, and Q angle values have been inconsistent and conflicting, mainly because these parameters may have great variations with respect to the height, weight, race, gender and age of the individual [5, 18]. In the present study, there were no differences between the groups according to age, gender distribution, BMI, and BMD values. Femoral neck shaft angle (Q angle) was found to be significantly greater in the fracture group. Our findings were consistent with the literature.

Femoral neck width, MCT, and LCT are parameters which have also been evaluated as radiographic predictors of hip fracture in the elderly [9, 15, 19, 20]. Greater FNW has been found to be associated with an increased risk of hip fracture [10]. It was suggested that an increase in FNW may reflect

adaptation to a gradual decrease in bone mass, with the possible mechanism for it being proposed as periosteal apposition [21]. On the other hand, Alonso *et al.* also hypothesized that greater FNW increased the moment of inertia to compensate for age-related bone loss, which may reduce the fracture risk [15]. Decreased MCT and LCT were also reported by different authors as significantly correlated with fracture risk [19, 20]. Although several studies demonstrated an association between the changes in FNW, MCT, and LCT, many others have concluded that there was no significant relationship [10]. Therefore, there has been no consensus on the exact value of those geometric analyses. Ulusoy *et al.* emphasized that an MCT  $\leq$  8 mm and LCT  $\leq$  7 mm had 88% and 82% sensitivity to predict hip fracture risk, whereas their specificity was questionable [9]. According to the data that we acquired during the current study, FNW, MCT, and LCT were significantly different in the fracture group. The sensitivity of MCT  $\leq$  8 mm was 92%, and it was 85% for LCT  $\leq$  7 mm in our study.

Although the overall evidence has suggested that assessing and measuring hip geometry can significantly improve the ability to identify people at risk for hip fracture, more research and product development has been emphasized as necessary to explore the application of radiographic markers in the clinical setting [10]. True moment arm, a relatively new geometric parameter described as a radiographic predictor, has been developed in order to achieve a stronger evaluation of the biomechanical load with respect to HAL, FAL, Q angle, and FNW [9]. The longer the TMA, the higher is the moment formed and the higher is the impact energy transmitted to the femoral neck. Ulusoy *et al.* concluded that TMA length of  $\geq$  75.11 mm had a sensitivity of 44.1% for predicting hip fracture [9]. In our study, TMA length was found to be sig-

nificantly greater in patients with a hip fracture compared to controls. Furthermore, it was the most significant radiographic measurement in predicting the fracture risk according to multiple regression analysis. The sensitivity of TMA length was 85% and the specificity was 75%, with the cut-off value determined as  $\geq 72$  mm. The sensitivity and specificity of TMA length were found to be higher than the value mentioned by Ulusoy *et al.* [9]. However, their study included 34 fracture cases and 36 controls, whereas our study was conducted with 142 fracture cases with 172 intact hips of 86 healthy controls. With age ( $\leq 65$  or  $> 65$  years) as an independent variable, the difference was also significant for both age groups, while the sensitivity of TMA length did not show variations according to age groups.

We can note some limitations of the present study. First, it was not a prospectively designed study. Second, we did not apply a prior calculation for the sample sizes. However, post hoc analysis was performed, and the statistical power of our study in the aspect of making a comparison between the two groups according to FNW, Q angle, MCT, LCT, and TMA was 0.99 for each of the radiographic variables with an  $\alpha$  value of 0.05. Also, our patient groups had similar demographic features, which allowed us to obtain more comparable data.

In conclusion, predicting the risk of hip fracture in the elderly is crucial to establish preventive measures for reducing the incidence of hip fractures and, in turn, the burden on healthcare services. According to the data acquired during the present study, radiographic measurements including FNW, Q angle, MCT, LCT, and TMA length are simple, non-invasive, and effective tools for the prediction of fracture risk independently of BMD. Especially the TMA length may provide the most valuable radiographic information as a predictor for hip fracture in the elderly. Further prospective studies with larger cohorts are required to test the reproducibility of our findings.

### Conflict of interest

The authors declare no conflict of interest.

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