Standardisation of the neck-shaft angle and measurement of age-, gender- and BMI-related changes in the femoral neck using DXA

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INTRODUCTION The morphology of the proximal femur has often been investigated in the literature, but the normal population ranges and standard deviations have still not been determined for this area. This study aimed to determine the age-, gender- and body mass index (BMI)-related changes in the femoral neck, especially on the neck-shaft angle, by using dual-energy X-ray absorptiometry (DXA) measurements.

METHODS Retrospective analyses of DXA images of the proximal femur from 18,943 individuals aged 20–108 years were performed. The age, gender, weight and height of each individual were obtained at the time of bone measurement. Data on theta angle were obtained from DXA measurements. Simple linear regression analysis and Pearson's correlation coefficients were used to investigate the relationships between theta and age, gender and BMI.

RESULTS There was a significant correlation between theta and age ($p < 0.001$). We also found a significant difference between the various age groups using analysis of variance ($p < 0.001$), but there was no meaningful correlation between theta and BMI ($p = 0.377$) and the BMI groups ($p = 0.180$). There were small but statistically significant differences in the neck-shaft angle between males and females ($p < 0.05$).

CONCLUSION In this study, DXA-based measurements were used and many parameters of proximal femur geometry were calculated with limited radiation exposure. We have demonstrated that the mean neck-shaft angle is greater in males than in females, and that theta increases with age. We also found a significant difference between different age groups, but no meaningful correlation between theta and BMI.

Keywords: DXA femur, hip, neck-shaft angle
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INTRODUCTION

The morphology of the proximal femur, especially the relationship between the head, neck and the proximal shaft, has been investigated numerous times in the literature. There are many pathologies whose treatment may benefit from greater understanding of the anatomy of this area; this has caused researchers to start studying the measurements of the proximal femur.[1] Osteoporosis, a major predisposing factor for hip fracture, has serious effects on quality of life. Bone mineral density (BMD) itself is not the only factor determining the strength of bone; age-related factors and geometric properties also play an important role on this entity. Both body mass and height can affect the risk of hip fracture, which means that genetic factors affect the bone size, shape and mineral density. Also, bone geometry such as the diameter of the femoral neck, longer hip axis length and the angles of this area may change bone strength and determine fracture risk.[2-5]

Femoroacetabular impingement (FAI) is a hip disorder that results in damage to the hip joint cartilage and labrum. The alpha angle is the most important index to determine sphericity of the femoral head, and it has been suggested as a predictor for the risk of FAI. Studies have also shown a significant correlation between alpha angle and the degree of cartilage defects.[3,6] Obesity seems to lighten the effects of osteoporosis by increasing BMD and by reducing the likelihood of fractures. The risk of fracture depends not only on the strength of the bone, but also the severity of trauma. Heavier patients are generally less active and may have fewer trauma risks; when trauma does occur, their soft tissue moderates the trauma. Although BMD does increase with weight, it is still unclear whether BMD and bone strength are in proportion to weight in obese individuals. In children, femoral geometric strength is known to be reduced relative to body weight.[7]

Although the relationship between the head, neck and the proximal shaft of the femur and their measurements have been studied many times in the current literature, the normal population ranges and standard deviations of the proximal femur have still not been determined. The main purpose of this study was to determine the age-, gender- and body mass index (BMI)-related changes in the femoral neck, especially on the neck-shaft angle, using dual-energy X-ray absorptiometry (DXA) measurements. The second purpose was to determine a standard range of neck-shaft angle or theta in different age groups and between male and female patients.

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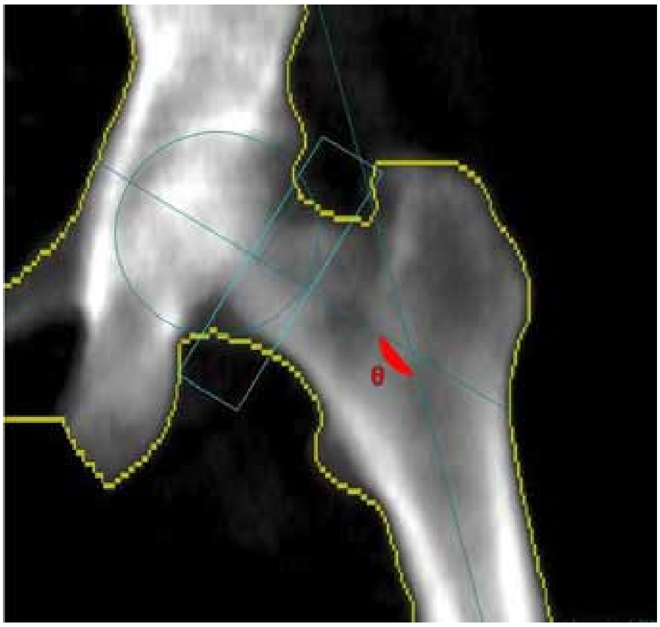

Fig. 1 Illustration shows the measurement of the theta angle.

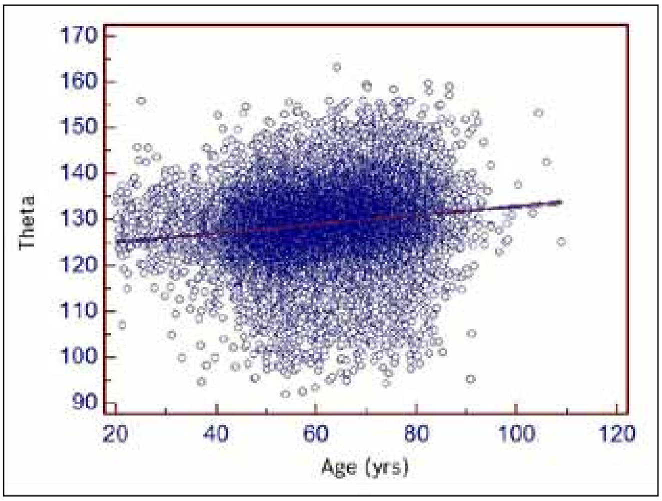

Fig. 2 Graph shows significant correlation between age and theta ($p < 0.0001$).

Table I. World Health Organization (WHO) classification of body mass index (BMI).[8]

Category	BMI (kg/m²)
Severely underweight	< 16
Underweight	16–20
Normal	20–25
Overweight	25–30
Obese Class I	30–35
Obese Class II	35–40
Obese Class III	> 40

METHODS

We retrospectively analysed the DXA images of the proximal femur of 18,943 individuals aged 20–108 years in 1997–2010. The participants underwent bone densitometry by DXA using a Lunar DPX-L densitometer (GE Lunar Corp, Madison, WI, USA). The age, gender, weight and height of each participant were obtained at the time of bone measurement, and the BMI was calculated (kg/m^2). Data on theta angle were obtained from the DXA measurements. Theta angle was measured at the intersection of two lines between the femoral shaft axis and the femoral head-neck axis (Fig. 1). The lines were drawn and theta angle calculated automatically by the Lunar DPX-L densitometer. The participants were categorised into age groups by decades (i.e. 20, 30, 40 years, and so on), and those < 20 years or > 90 years were classified into two separate groups. The World Health Organization (WHO) classification of BMI (seven categories)[8] was adopted for this study (Table I).

All statistical analyses were performed using MedCalc Statistical Software (MedCalc Software, Mariakerke, Belgium). Simple linear regression analysis and Pearson's correlation coefficients were used to investigate the relationships between theta and age, gender and BMI. Analysis of variance (ANOVA) was used to test differences among the means of subgroups for the genders, BMI groups and age groups. Descriptive analyses were used to calculate the mean, standard deviation (SD) and 95% confidence interval (CI).

RESULTS

We found a significant correlation between theta and age ($p < 0.001$) based on DXA calculations, and our findings indicated that theta increases with age (Fig. 2). We also found a significant difference between the different age groups using ANOVA ($p < 0.001$, Fig. 3), but there was no meaningful correlation between theta and BMI ($p = 0.377$, Fig. 4) and the BMI groups ($p = 0.180$, Fig. 5). There were small but statistically significant differences in neck-shaft angle between males and females ($p < 0.05$). Females tended to have lower neck-shaft angles than males. The mean theta value for all groups was 129.171° (95% CI 129.065–129.278), while those for females and males were 129.142° (95% CI 129.032–129.252) and 129.630° (95% CI 129.157–130.104), respectively. The mean BMI for females was 29.022 kg/m^2 (95% CI 28.951–29.093) and that for males was 24.380 kg/m^2 (95% CI 24.159–24.604) in all age groups. The mean BMI of all the participants was calculated as 28.719 kg/m^2 (95% CI 28.649–28.789) .

DISCUSSION

Despite the numerous studies that have been dedicated to describing and defining the anatomy of the proximal femur, the quantitative relationship between age and theta angle, and the association between BMI and theta have yet to be determined. Many studies have depended on radiographs and computed tomography for evaluating proximal femoral geometry. In our study, DXA-based measurements were used to calculate the neck-shaft angle. This method appears to be more advantageous than other methods, as DXA enables the measurement of many parameters of proximal femur geometry with less radiation exposure. The measurement of the neck-shaft angle by radiography, however, is affected by femoral neck version, hip rotation and femoral bowing.[9-11]

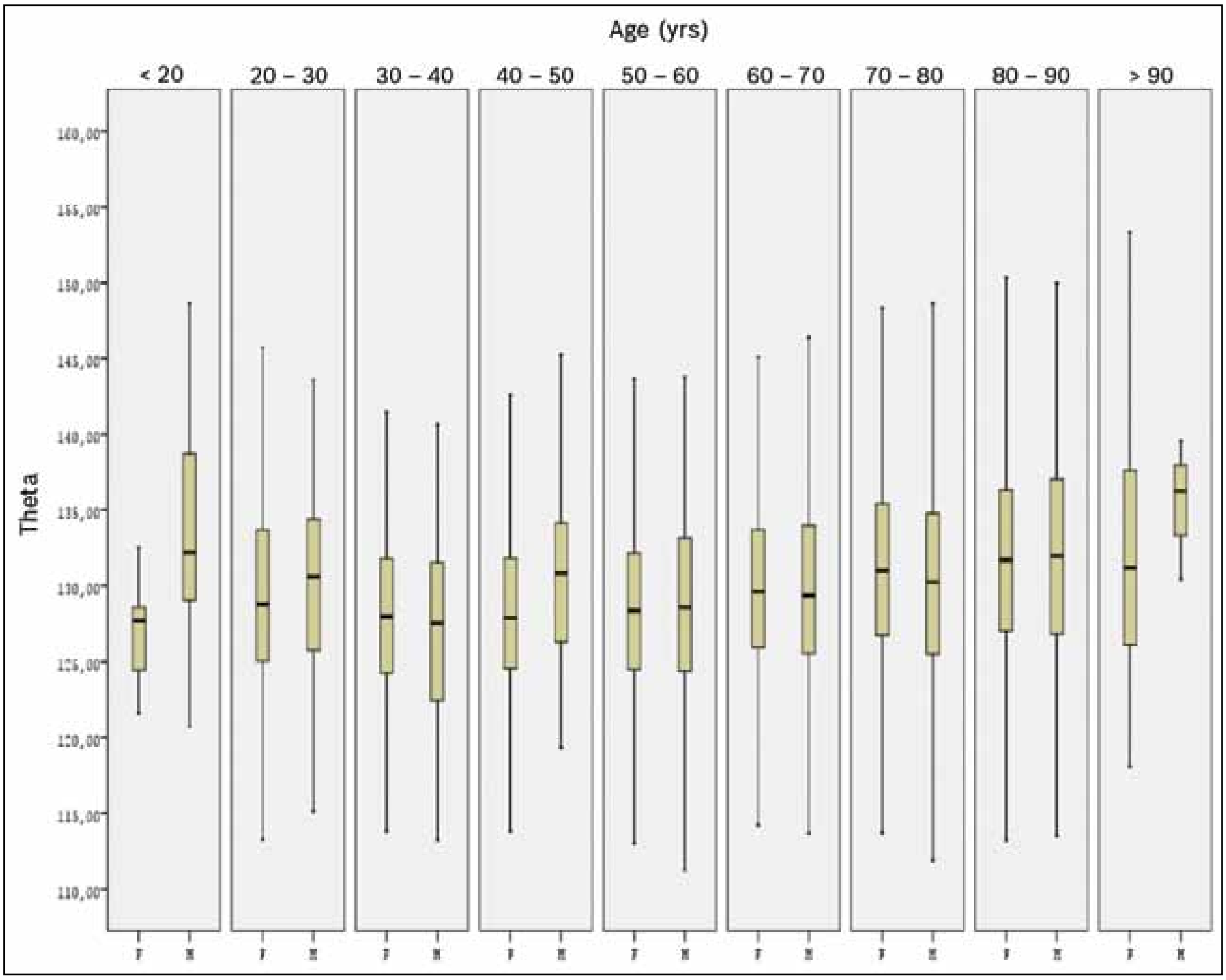

Fig. 3 Graph shows significant difference between the age groups and genders ($p < 0.001$).

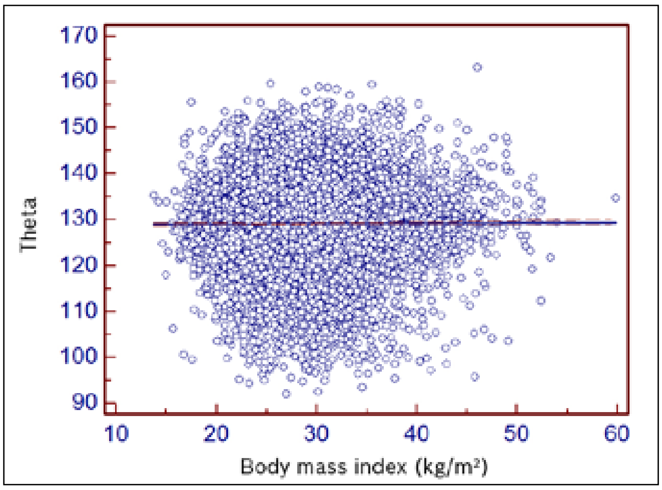

Fig. 4 Graph shows no significant correlation between theta and BMI ($p = 0.377$).

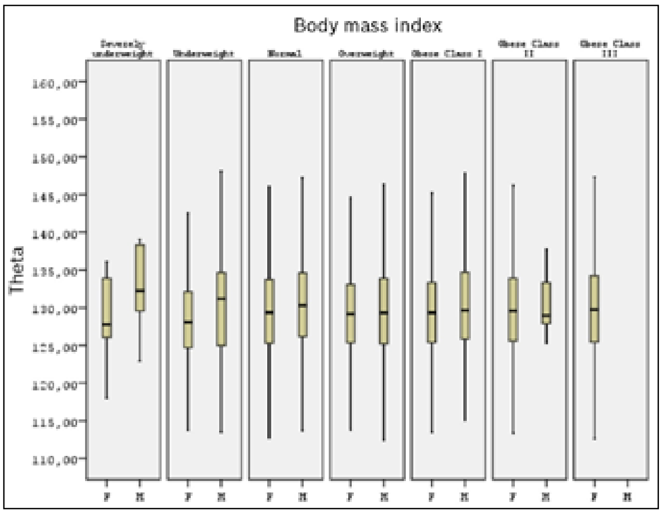

Fig. 5 Graph shows no significant correlation between theta and BMI groups ($p = 0.180$).

For total hip arthroplasty operations, understanding the proximal femur anatomy is very important. The aim of total hip arthroplasty is to create a stable anatomical articulation with an optimised range of motion. Significant limb-length discrepancy and failure to obtain adequate hip offset can result in functional deficiency of the hip. Therefore, it is important to be familiar with the anatomy of the proximal femur in order to make optimal decisions during operations.(9) There is a significant correlation between BMD of the femoral neck and its mechanic strength. In postmenopausal women, BMD and strength decrease with age. Although BMD is an important factor for hip fracture, no significant relation between the two has been found in our study.(5)

Ethnicity is one of the most important factors in osteoporotic fracture risk, and ethnic differences in body size and shape can affect the mechanics of the hip. Although the fracture rates in all non-Hispanic white and Native American women have been reported to be similar, half of these fractures had occurred in the minorities.[12] In this paper, the observation that obesity rates tended to be higher in ethnic minorities such as Mexican-American and African-American women appears to be confusing, as a previous meta-analysis had shown that a higher BMI affects hip fracture rates.[12] There were also important environmental interrelations between most of the femur geometry and BMI, which were generally higher than those between femur geometry and weight. In addition, nutrition and exercise play an important role in the prevention of bone fragility.[2] In our study, however, there was no meaningful correlation between theta and BMI. Beck et al, who examined how femur BMD and geometry varied with BMI, found that heavier women have stronger femurs but the strength is not proportional to their higher weight.[7] In our study, there was a significant correlation between theta and age, as calculated using DXA, which indicates that theta increases with age. We also found a significant difference between the various age groups using ANOVA.

Research on the role of gender in osseous anatomy is on-going, and researchers are still discovering differences between the genders. Previous studies have shown that females have a smaller femoral axis than males. A shorter femoral neck or smaller neck-shaft angle would reduce the bending moment on proximal cross-sections.[7] Our study has demonstrated that the neck-shaft angle was different between the genders, with the mean neck-shaft angle higher in males than females. The average femoral neck-shaft angle for both genders measured was 129.173°. This is higher than that in most of the previous studies,[12,13] except for Unnanuntana et al's study, which reported a neck-shaft angle of 133°.[9]

Knowledge of the anatomic and morphologic details of the proximal femoral geometry is important, as it could help surgeons understand the biomechanics of total hip arthroplasty.[14] This study has provided information about the standard range of neck-shaft angle or theta in different age groups as well as determined age-, gender- and BMI-related changes in the femoral neck using DXA measurements.

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