Osteoporos Int (1998) 8:75–81

Osteoporosis International

Original Article

Femoral Neck Axis Length, Height Loss and Risk of Hip Fracture in Males and Females

J. R. Center[1], T. V. Nguyen[1], N. A. Pocock[2], K. A. Noakes[2], P. J. Kelly[1], J. A. Eisman[1] and P. N. Sambrook[1]

[1]Bone and Mineral Research Division, Garvan Institute of Medical Research, and [2]Department of Nuclear Medicine, St. Vincent's Hospital, Sydney, Australia

Abstract. Hip axis length (HAL) has been proposed as an independent predictor of hip fracture risk in Caucasian females. Femoral neck axis length (FNAL) is a similar measure of femoral geometry but does not include acetabular structures. The aim of this study was to examine the association between hip geometry, using FNAL, and hip fractures in elderly males and females in relation to other anthropometric data. The study group comprised 123 females (23 hip fracture patients and 100 age-matched controls) and 137 males (13 hip fracture patients, 65 age-matched controls and 59 current-height-matched controls). All subjects had femoral neck bone mineral density measured by dual-energy X-ray absorptiometry. From these scans, FNAL was measured as the linear distance from the base of the greater trochanter to the apex of the femoral head. FNAL was correlated significantly with current height (r = 0.47 and r = 0.56 for females and males respectively; $p < 0.0001$) and peak height (r = 0.45 and r = 0.57 for females and males respectively; $p < 0.0001$) in both sexes. In females, FNAL in the fracture patients (91.5 $\pm$ 5.4 mm, mean $\pm$ SD) was not significantly different from FNAL in controls (89.7 $\pm$ 5.4 mm; p = 0.2). Fracture patients had the same current height as controls and a trend towards a greater peak height (163 $\pm$ 6 cm vs 160 $\pm$ cm; p = 0.09). After adjusting FNAL for current or peak height there was no difference in FNAL between fracture patients and controls. In males, FNAL in the fracture patients (103.9 $\pm$ 3.9 mm) was not significantly different from that of age-matched controls (103.4 $\pm$ 6.3 mm; p = 0.79). Fracture patients had a significantly lower current height (168 $\pm$ 6 cm) than the age-matched controls (174 $\pm$ 6 cm; p = 0 .0008) but had the same peak height. When adjusted for peak height there were no significant differences between height of hip fracture patients (102.0 $\pm$ 4.9 cm), age-matched controls (102.1 $\pm$ 5.1 cm) and current-height-matched controls (102.6 $\pm$ 5.3 cm). Fracture patients had a significantly greater height loss (peak height minus current height) than either control group. In logistic regression analyses peak height in females and height loss in males but not FNAL were independent predictors of hip fracture. The greater height, FNAL and presumably HAL in males versus females is not associated with increased hip fracture risk. However, in this study of elderly males and females, peak height (females) and height loss (males) were independent risk factors for hip fracture. Moreover, FNAL appears to have limited utility in the prediction of hip fracture risk and any role of HAL in the prediction of hip fracture does not relate to its major component of femoral neck length.

Keywords: Epidemiology; Femoral neck axis length; Hip fracture; Hip axis length; Height loss

Correspondence and offprint requests to: Dr Jacqueline Center, Bone and Mineral Research Division, Garvan Institute of Medical Research, St. Vincent's Hospital, 384 Victoria Street, Sydney NSW 2010, Australia. Tel: +61 2 9295 8271. Fax: +61 2 9295 8241. e-mail: j.center@garvan.unsw.edu.au.

Introduction

Hip fracture has increasingly become a major public health concern. The lifetime risk of hip fracture is comparable to that of breast cancer [1], and there is evidence suggesting hip fracture incidence will increase

exponentially [1,2] as the world population ages. A number of prospective studies have demonstrated that bone mineral density (BMD), particularly at the femoral neck, is one of the best predictors of hip fracture [3–7]. However, even when femoral neck BMD is used in conjunction with all the known lifestyle risk factors, including the risk of falling, the risk of hip fracture still cannot be reliably predicted.

Recent studies have suggested that factors other than BMD may also be important in hip fracture prediction. These factors include the structural geometry of the proximal femur and the direction of the mechanical stresses applied to it [8–13]. One measure of structural geometry is hip axis length (HAL), measured as the linear distance from the base of the greater trochanter to the inner pelvic brim. HAL was found to be an independent risk factor for hip fracture in one prospective study of elderly white females in the USA [13]. This study reported a 1.8-fold increase in hip fracture risk for each standard deviation increase in HAL. A recent retrospective study examining the difference between type I and type II osteoporosis found that while there was no difference in BMD between the two groups, those women with hip fractures had a longer HAL than those with vertebral fractures [14]. It has also been suggested that the lower incidence of hip fracture in Asian women than Caucasian women relates to a shorter HAL [15–17]. However, the mechanism by which a longer HAL could be associated with an increase in hip fracture risk is yet to be verified.

Another measure of femoral neck geometry, femoral neck axis length (FNAL), defined as the linear distance from the base of the greater trochanter to the apex of the femoral head (and thus not including the acetabular portion of HAL), has been found to correlate well with HAL in a cross-sectional study using both X-rays and densitometric techniques [18]. Peacock et al. [19] in a retrospective study of elderly females found that unlike HAL, there was no significant association between either FNAL or acetabular width and fracture risk in univariate analysis, although after adjusting for BMD, both HAL and FNAL were associated with an increase in fracture risk. However, another recent retrospective study of females and males showed no significant association between FNAL and hip fracture risk in either sex [20].

The aim of the present study was to examine the relationship between FNAL and hip fracture in a population-based study of males and females in relation to other anthropometric data.

Materials and Methods

A nested case–control study was performed within the Dubbo Osteoporosis Epidemiology Study [3]. From 1989 to 1993, a total of 1902 males and females from an initial target population of 1960 males and 2161 females were recruited into the study. Baseline data including age, current height and weight were recorded. Peak height (lifetime maximum height) of the subjects was also recorded on entry. To obtain this latter piece of information, subjects were asked to recall their height at about age 21 years. In some males, this was at army recruitment. BMD of the femoral neck (g/cm^2) was measured using a Lunar DPX-L densitometer (Lunar, Madison, WI). The right hip was scanned in all cases unless there had been a hip fracture or a hip replacement, in which case the left hip was scanned. The coefficient of variation for the measurement at our institution in normal subjects is 1.5% for the lumbar spine and 1.3% for the femoral neck.

The standard bone windows on the Lunar DPX-L densitometer do not generally allow for the inner pelvic rim portion of HAL to be measured. Thus FNAL, a similar measured but excluding structures proximal to the apex of the femoral head, was measured in this study. In a separate group of 21 subjects these windows allowed HAL and FNAL measurements to be made on the same scans. FNAL was measured as the linear distance from the base of the greater trochanter to the apex of the femoral head by aligning the software ruler in the analysis procedure visually with the software-derived femoral neck axis (Fig. 1). All measurements were made by one operator masked to the fracture status of the subjects.

The reproducibility of FNAL was assessed on a separate group of 20 subjects who had had their right hip scanned twice on separate occasions. Within-operator reproducibility, including repositioning error, was determined by one operator who analyzed each scan, masked to the result of the paired scan. The intraclass correlation coefficient (R) was 0.98 and the root mean square error (RMSE) was 1.1 mm (coefficient of variation (CV) of 1.0). Inter-operator reproducibility,

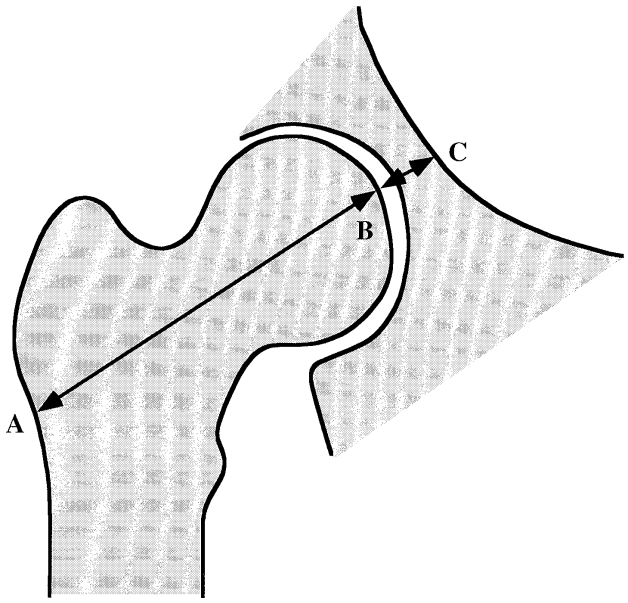

Fig. 1. Diagram of the hip showing the geometric measurements used and discussed in the text. AB, femoral neck axis length (FNAL), the measurement used in the study; AC, hip axis length (HAL); BC, acetabular width.

$R = 0.99$ and RMSE = 0.92 mm (CV = 0.9), was determined by comparing the findings of two investigators who independently analyzed the first scan of the 20 patients. The intraclass correlation coefficient between left and right FNAL was 0.95 and RMSE was 1.3 mm (CV = 1.4) in a separate group of 23 patients who had had both right and left hips scanned. Where more than one scan was performed on either side, the mean length was used for analysis. FNAL was noted to be stable over time in 103 subjects who had had two scans performed over a mean of 2.3 $\pm$ 0.9 years. The difference between the two lengths was within the limits of measurement error, 0.16 $\pm$ 0.16 mm (mean $\pm$ SE). The correlation between the two measures was accordingly very high ($r = 0.98$). This stability and the high correlation between right and left sides allowed the inclusion of those subjects (9 females and 5 males) whose densitometry was performed after a hip fracture (contralateral hip measured).

The correlation between FNAL and HAL in 21 scans where both FNAL and HAL were able to be measured was 0.94 ($p < 0.0001$). The contribution of acetabular width was 12 mm of the 102 mm of HAL (i.e. 12%).

Hip fracture patients included in this study were identified by review of radiologists' reports from the two radiology services supplying the Dubbo area. Fractures due to major trauma were not included in the study. Forty-three proximal femur fractures with BMD data were identified. These were age- and sex-matched with 1:4 controls who had not suffered a hip fracture using the Caliper algorithm of matching [21]. This method matches the controls as a group. Thus the mean age of the control group is the same as that of the fracture subjects. After it was noted that there was a significant difference in current height between the male hip fracture and age-matched control groups a second 1:4 current-height- and sex-matched control group for the male hip fracture subjects was also studied. These height-matched male controls were also obtained using the Caliper algorithm of matching. Of the hip fractures, one was in fact a traumatic fracture and 6 were not analyzable due to insufficient femoral head being included in the scan window. This left 23 female and 13 male hip fractures.

Statistical Analyzis

Comparability between groups with respect to baseline demographic and clinical characteristics was assessed using an unpaired *t*-test. Analysis of covariance was used to assess differences in FNAL between hip fracture patients and controls, adjusted for current height or peak height. Logistic regression models were used to examine the association between FNAL and hip fracture risk. In addition, results were analyzed for one-to-one matching with a paired *t*-test and conditional logistic models. As several potential variables could have served as determinants of fracture in the logistic regression model, forwards and backwards elimination algorithms were used to search for a set of variables with maximum discriminatory power. The final model was based on the goodness-of-fit of the model and observed data, which was evaluated based on the likelihood chi-square statistic. Males and females were analyzed separately. All statistical tests were performed using the SAS statistical analysis system [22].

Results

There was no correlation between FNAL and age or BMD. By contrast, FNAL was correlated with current height in both females ($r = 0.47$, $p < 0.0001$) and males ($r = 0.56$, $p < 0.0001$). FNAL was also correlated with peak height ($r = 0.45$ and $r = 0.57$ for females and males, respectively; $p < 0.0001$). As expected, current height and peak height were highly correlated for both females ($r = 0.87$, $p < 0.0001$) and males ($r = 0.88$, $p < 0.0001$). The deviation from a perfect correlation is also expected, primarily due to differences in individual height loss (peak height minus current height) as well as recall variation. Height loss was associated both with age ($r = 0.33$, $p = 0.0004$ for females and $r = 0.40$, $p < 0.0001$ for males) and with BMD ($r = -0.23$, $p = 0.01$ for females and $r = -0.32$, $p = 0.0002$ for males). However, there was no significant association between height loss and FNAL ($r = -0.09$, $p = 0.35$ for females and $r = -0.03$, $p = 0.68$ for males).

FNAL and Hip Fracture in Females

In the females, there were 23 hip fracture patients and 100 age-matched controls, aged 76 $\pm$ 5 years (mean $\pm$ SD). Fracture patients had significantly lower femoral neck BMD ($p = 0.0006$) and body weight ($p = 0.0004$) and a trend towards a greater peak height ($p = 0.09$) (Table 1). However, there was no significant difference in current height ($p = 0.53$) between the fracture patients and controls. FNAL was slightly longer (1.8 mm; $p = 0.16$) in hip fracture patients compared with controls (Table 1) but this was not significant. Analysis for one-to-one matching using paired *t*-test yielded similar results. Adjustment for current height or peak height in the analysis of covariance model did not alter the results (Table 2).

There was no significant difference in FNAL between cervical or trochanteric fractures either unadjusted or adjusted for peak or current height.

FNAL and Hip Fracture in Males

In male controls, FNAL was 15% (14 mm) longer on average than that of female controls. There was no significant difference in peak height ($p = 0.59$) between hip fracture patients and age-matched controls but fracture patients had significantly lower current height ($p = 0.0008$), femoral neck BMD ($p < 0.0001$) and body

Table 1. Characteristics of the study sample

	Hip fracture patients	Age-matched controls	Height-matched controls
Females			
Number	23	100	
Age (years)	77 ± 6	76 ± 5	
Weight (kg)	54 ± 10	65 ± 13[c]	
Current height (cm)	159 ± 8	158 ± 6	
Peak height (cm)*	163 ± 6 (19)	160 ± 6 (97)	
FNAL (mm)	91.5 ± 5.4	89.7 ± 5.4	
BMD (g/cm^2)	0.65 ± 0.09	0.74 ± 0.11[c]	
Males			
Number	13	65	59
Age (years)	77 ± 9	75 ± 4	70 ± 7[a]
Weight (kg)	67 ± 14	77 ± 12[b]	72 ± 12
Current height (cm)	168 ± 6	174 ± 6[c]	167 ± 7
Peak height (cm)*	176 ± 5 (12)	176 ± 6 (62)	170 ± 7[b] (56)
FNAL (mm)	103.9 ± 3.9	103.4 ± 6.3	100.5 ± 5.3[a]
BMD (g/cm^2)	0.67 ± 0.15	0.89 ± 0.13[d]	0.88 ± 0.13[d]

Values are mean ± SD.
FNAL, femoral neck axis length.
p values for comparison with hip fracture group are: [a]$p<0.05$, [b]$p<0.01$, [c]$p<0.001$, [d]$p<0.0001$.
*Numbers of subjects for whom peak height was available are shown in parentheses.

Table 2. Femoral neck axis length (FNAL) in fracture patients and controls

FNAL	Hip fracture patients	Age-matched controls	Height-matched controls
Females			
Unadjusted	91.5 ± 5.4	89.7 ± 5.4	
Current-height-adjusted	91.2 ± 4.8	89.8 ± 4.8	
Peak-height-adjusted	90.9 ± 4.9	89.8 ± 4.8	
Males			
Unadjusted	103.9 ± 3.9	103.4 ± 6.3	100.5 ± 5.3[a]
Current-height-adjusted	105.3 ± 4.8	101.6 ± 5.1[c]	102.0 ± 5.0[b]
Peak-height-adjusted	102.0 ± 4.9	102.1 ± 5.1	102.6 ± 5.3

weight ($p = 0.01$). FNAL in fracture patients was virtually identical to that of age-matched controls (Table 1). Interestingly, FNAL adjusted for *current height*, was significantly longer in fracture patients (105.3 ± 4.8 mm vs 101.6 ± 5.1 mm; $p = 0.02$). However, when FNAL was adjusted for peak height, there were no significant differences between hip fracture patients (102.0 ± 4.9 mm) and age-matched controls (102.1 ± 5.1 mm; $p = 0.82$) (Table 2).

To further examine the relationships between height, FNAL and hip fracture in males, a group of 59 males was selected with *the same current height* as the hip fracture patients. These height-matched controls were significantly younger, heavier, and had a higher BMD than the fracture patients. The controls also had a significantly lower peak height than the fracture patients (170 ± 7 cm vs 176 ± 5 cm; $p = 0.002$). FNAL in these controls was, on average, 3.4 mm ($p = 0.32$) shorter than in fracture patients (Table 1). However, when FNAL was adjusted for peak height, there were no significant differences in FNAL between fracture patients and the current-height-matched controls (102.0 ± 4.9 mm vs 102.6 ± 5.3 mm; $p = 0.74$) (Table 2).

These differences in FNAL according to whether it was adjusted for either current height or peak height were due to differences in estimated height loss (peak height minus current height) between the fracture and control groups. Men with hip fracture had experienced greater height loss (8.0 ± 4.3 cm, mean ± SD) than either age-matched controls (2.0 ± 2.8 cm) or height-matched controls (2.1 ± 2.6 cm).

There was no significant difference in FNAL between cervical or trochanteric fractures either unadjusted or adjusted for peak or current height.

Model-Fitting Analyzes

In univariate logistic regression analysis, femoral neck BMD was consistently the strongest or equivalently

Table 3. Hip fracture risk and anthropometric parameters: univariate logistic regression

		Males		Females
		Matched for age	Matched for current height	Matched for age
BMD	− 0.13 g/cm^2	**3.2** (1.6–6.4)	**2.5** (1.4–4.5)	**1.7** (1.2–2.3)
Current height	− 6 cm	**1.9** (1.2–3.0)	1.1 (0.8–1.7)	1.1 (0.8–1.4)
Peak height	+ 6 cm	1.0 (0.7–1.4)	**2.6** (1.3–5.2)	1.3 (1.0–1.7)
Height loss	+ 3.2 cm	**2.5** (1.5–4.1)	**2.4** (1.4–4.2)	1.1 (0.9–1.5)
Weight	− 12.5 kg	**1.6** (1.1–2.4)	1.1 (0.8–1.7)	**1.8** (1.3–2.6)
FNAL	+ 4.9 mm	1.1 (0.8–1.6)	**2.1** (1.2–3.6)	1.2 (0.9–1.6)

Values are odds ratios per standard deviation (SD) changes with 95% confidence intervals in parentheses. All analyzes are adjusted for age. Values in bold type are significantly different from 1.0.

strong discriminant of fracture risk across all groups (Table 3). FNAL was not a significant predictor of hip fracture when compared with either the female (odds ratio (OR) = 1.2; 95% confidence interval (CI) = 0.9–1.6) or male age-matched control groups (OR = 1.1; 95% CI = 0.8–1.6). These results were essentially the same when analyzed according to prediction of either cervical or trochanteric fracture risk. OR and 95% CI for female cervical and trochanteric fracture risk were 1.4 (0.9–1.9) and 1.3 (0.95–1.9), respectively. For the males the corresponding risks were 1.1 (0.6–1.8) and 1.1 (0.7–1.7). Analysis for one-to-one matching using conditional logistic models confirmed no relationship between FNAL and hip fracture risk. FNAL was only a significant predictor of hip fracture (OR = 2.1; 95% CI = 1.2–3.6) in the current-height-matched male controls, although the association between fracture risk and height loss or peak height was stronger than that between fracture risk and FNAL.

To account for the correlation between these factors in assessing hip fracture risk, several model-fitting analyses using BMD, FNAL, current height, peak height and height loss were performed. The age-matched male and female control groups were chosen as appropriate controls. The best model was that which incorporated BMD and peak height for the females and BMD and height loss for the males. When FNAL was forced into these models there was no significant improvement ($p = 0.40$ for the females and $p = 0.99$ for the males). Although FNAL did contribute marginally to the model incorporating BMD and height loss in the females ($p = 0.06$), this model did not fit the data as well as the model including BMD and peak height alone (log likelihood ratio 90.6 vs 89.1).

In stepwise logistic regression analysis (using age-matched female and male control groups), once femoral neck BMD was included in the model for fracture risk, the only significant additional variables were peak height for the females ($p = 0.03$) and height loss for the males ($p = 0.01$). FNAL was not an independent predictor in either females or males. These results were unchanged whether FNAL was adjusted for peak height or for current height.

Discussion

While the usefulness of femoral neck BMD in the assessment of risk of hip fractures has been well documented, geometrical structure of the femur has only recently been explored. A 1 SD increase in HAL, a measure derived from the Hologic QDR densitometer, was associated with a 1.8-fold increase in risk of hip fracture in elderly females [13]. There has been no prospective study of the association between femoral geometric structure and hip fracture risk in males.

The standard bone windows on the Lunar DPX-L densitometer do not in general allow for the inner pelvic rim portion of HAL to be measured. Thus FNAL, a similar measure but excluding structures proximal to the apex of the femoral head, has been used in several retrospective and cross-sectional studies. For the same reason, FNAL was measured in this study as HAL could not be calculated. Although HAL has been shown to be associated with hip fracture risk in females, the literature concerning FNAL has been contradictory despite the fact that FNAL has been shown to correlate well with HAL [18], including in the present study.

In the present study, it was found that FNAL was not a significant predictor of hip fracture risk in either males or females. In contrast, peak height in females and height loss in males were independent risk factors for hip fracture.

Greater height loss had occurred in the male hip fracture patients compared with that of the controls (8.0 $\pm$ 4.3 vs 2.0 $\pm$ 2.8; $p = 0.0006$). This explained the difference in FNAL according to whether it was adjusted for current or peak height and is consistent with the finding that estimated height loss in males was an independent predictor of fracture risk. Greater height loss was also reported in the first study of the association between HAL and hip fractures in females but peak height corrections for HAL were not reported [13]. These results suggest that the greater height loss in hip fracture patients may reflect a more generalized state of bone loss. Vertebral deformity has also been associated with subsequent non-vertebral fractures (including hip fracture) independent of bone mineral density [23]. In

addition, preliminary analyzis of an elderly cohort of women from the Framingham study found recent height loss to be predictive of subsequent hip fracture [24].

Although peak height is a recalled measure, remote recall of childhood anthropometric data is in close agreement with measured values [25]. Although men may overestimate peak height, it was not different between the hip fracture and age-matched control group. Thus recall bias seems unlikely to have contributed to the apparent differences in height loss between male fracture patients and controls.

There was a significant correlation between FNAL and height in this study, consistent with previous findings [13,15,20]. Height, in turn, has recently been shown in several large prospective studies in women and men to be related to hip fracture [26–28]. A fall from a greater height may be expected to impact the surface at a greater velocity [29]. The baseline heights reported in these studies would have been likely to approximate the peak height measure used in the current study. The association between peak height and hip fracture in females in the current study is consistent with these larger studies and it seems logical to adjust FNAL for peak rather than current height. In the women studied here, there was a trend to greater height in the hip fracture group as has been observed in other association studies [26–29]. The lack of significance of this trend may relate to the sample size, as may the apparent lack of difference in peak heights in male hip fracture and non-fracture subjects.

The lack of a significant association between FNAL and hip fracture observed in the present study is consistent with a recent case–control study of FNAL and hip fractures [20]. In another case–control study [19] where both FNAL and HAL were measured, HAL but not FNAL was associated with fracture risk in univariate analysis. After adjusting for BMD, both variables became significant. The difference between FNAL and HAL is the joint space and acetabular rim (often referred to as the acetabular width), which is included in the measurement of HAL but not of FNAL. In our study, this accounted for 12% of HAL. Thus the association between HAL and fracture risk may, in part, be mediated through this acetabular width [30]. However, unlike HAL, which has been associated with both trochanteric and femoral neck fractures, acetabular width was only shown to be associated with femoral neck fractures in one study [12] and was not found to be associated with either fracture type in another study [19]. Osteoarthritis, which is associated with a decrease in the hip joint space and hip fracture [31] may confound the association between HAL and hip fracture. Thus if there is a relationship between HAL but not FNAL and hip fracture, this might relate in part to the inclusion of this joint space and any changes in it.

A previous study has suggested that femoral geometry may be more critical in females than males [11] and a recent study reported no difference in HAL between black males and white males, despite a lower reported risk of hip fracture in black males [32]. In the present study, it was found that FNAL in males was significantly longer (by about 14 mm, or more than 2 SD) than in females. These differences in FNAL are in the opposite direction to the differences in the relative fracture rates between males and females, which would predict a *shorter* FNAL in males [33]. This discrepancy may reflect the multifactorial nature of hip fracture risk and possible different risk profiles between the sexes.

A type II sampling error could account for the non-significant difference in FNAL between hip fracture patients and controls in our sample, but this appears unlikely. Using a standardized difference (a ratio of the difference to SD) of 0.55–0.6 (as observed in the Study of Osteoporotic Fractures [13]) between hip fracture patients and controls, it can be estimated that our sample had a $>80\%$ chance of detecting a 3 mm difference in FNAL between fracture patients and controls in females. In the males, our sample had a $>80\%$ chance of detecting a standardized difference of 0.7, i.e. a 4 mm difference in FNAL between fracture patients and controls. The difference in FNAL between fracture patient and controls found in the females in this study was 0.33 SD, which was not significant although the power to detect a difference of this size was only 31%. In the males the difference in FNAL between fracture patients and controls was 0.1 SD.

In this study, FNAL and height were highly correlated; however, peak height in females and estimated height loss in males rather than FNAL appeared to be independent risk factors for hip fracture. Moreover the longer FNAL in males than in females is not associated with increased hip fracture risk. We conclude that there is limited utility of FNAL in the assessment of hip fracture risk in elderly males and females and the reported association of HAL with hip fracture seems not to be related to stresses or strains in femoral neck length. The relationship between parameters of femoral neck geometry, height, height loss and hip fracture needs further examination in prospective studies of hip fracture risk.

Acknowledgements. This work was supported by the Australian Institute of Health and National Health and Medical Research Council of Australia. We acknowledge the help of Dr R. Slack-Smith and Mr M. Russell in radiological procedures, and Janet Watters and Karen Green in the measurement of bone densitometry. The authors also gratefully acknowledge the support of the staff of Dubbo Hospital (particularly Mr B. Lutton and Mr B. Ayrton). J. R. C. is the recipient of a medical postgraduate scholarship from the National Health and Medical Research Council of Australia.

This work was presented in abstract form at the Seventeenth Annual Meeting of the American Society for Bone and Mineral Research, Baltimore, MD, September 1995.

References

1. Cummings SR, Black DM, Rubin SM. Lifetime risks of hip, Colles', or vertebral fracture and coronary heart disease among white postmenopausal women. Arch Intern Med 1989;149:2445–8.

2. Melton LJ III, Chrischilles EA, Cooper C, Lane AW, Riggs BL. Perspective: how many women have osteoporosis? J Bone Miner Res 1992;7:1005–10.
3. Nguyen T, Sambrook P, Kelly P, et al. Prediction of osteoporotic fractures by postural instability and bone density. BMJ 1993;307:1111–5.
4. Hui SL, Slemenda CW, Johnston CC. Baseline measurement of bone mass predicts fracture in white women. Ann Intern Med 1989;111:355–61.
5. Black DM, Cummings SR, Genant HK, et al. Axial and appendicular bone density predict fractures in older women. J Bone Miner Res 1992;7:633–8.
6. Cummings SR, Black DM, Nevitt MC, et al. Bone density at various sites for prediction of hip fractures. The study of Osteoporotic Fractures Research Group. Lancet 1993;341:72–5.
7. Chevalley T, Rizzoli R, Nydegger V, et al. Preferential low bone mineral density of the femoral neck in patients with a recent fracture of the proximal femur. Osteoporos Int 1991;1:147–54.
8. Beck TJ, Ruff CB, Warden KE, Scott WWJ, Rao GU. Predicting femoral neck strength from bone mineral data: a structural approach. Invest Radiol 1990;25:6–18.
9. Yoshikawa T, Turner CH, Peacock M, et al. Geometric structure of the femoral neck measured using dual-energy X-ray absorptiometry. J Bone Miner Res 1994;9:1053–64.
10. Beck TJ, Ruff CB, Bissessur K. Age-related changes in femoral neck geometry: implications for bone strength. Calcif Tissue Int 1993;53:S41–6.
11. Beck TJ, Ruff CB, Scott WW, et al. Sex differences in geometry of the femoral neck with aging: a structural analyzis of bone mineral data. Calcif Tissue Int 1992;50:24–9.
12. Glüer CC, Cummings SR, Pressman A, et al. Prediction of fractures from pelvic radiographs: the Study of Osteoporotic Fractures. J Bone Miner Res 1994;9:671–7.
13. Faulkner KG, Cummings SR, Black D, et al. Simple measurement of femoral geometry predicts hip fracture: the Study of Osteoporotic Fractures. J Bone Miner Res 1993;8:1211–7.
14. Boonen S, Koutri R, Dequecker J, et al. Measurement of femoral geometry in type 1 and type 11 osteoporosis: differences in hip axis length consistent with heterogeneity in the pathogenesis of osteoporotic fractures. J Bone Miner Res 1995;10:1908–12.
15. Cummings SR, Cauley JA, Palermo L, et al. Racial differences in hip axis lengths might explain racial differences in rates of hip fracture. Osteoporos Int 1994;4:226–9.
16. Nakamura T, Turner CH, Yoshikawa T, et al. Do variations in hip geometry explain differences in hip fracture risk between Japanese and White Americans? J Bone Miner Res 1994; 9:1071–6.
17. Wahner HW, Looker A, Walters L, Dunn WL. Racial and gender differences in the shape of the proximal femur. J Bone Miner Res 1994;9:S401.
18. Kuiper JW, Slis H, van Daele P, Pols HAP. A comparison of femoral geometry measurements using DXA and conventional radiography. Program and Abstracts, Perth International Bone Meeting: Bone fragility in the year 2000—clinical measurement. Perth, Australia, 1995.
19. Peacock M, Turner CH, Liu G, et al. Better discrimination of hip fracture using bone density, geometry and architecture. Osteoporos Int 1995;5:167–73.
20. Karlsson KM, Serbno I, Obrant KJ, Redlund-Johnell I, Johnell O. Femoral neck geometry and radiographic signs of osteoporosis as predictors of hip fracture. Bone 1996;18:327–30.
21. Anderson S, Auquier A, Hauck WW, et al. Statistical methods for comparative studies: techniques for bias reduction. New York: Wiley, 1980.
22. SAS Institute. SAS/STAT: user's guides. Cary, NC: SAS Institute, 1990.
23. Burger H, van Daele PLA, Algra D, et al. Vertebral deformities as predictors of non-vertebral fractures. BMJ 1994;309:991.
24. Hannan MT, Anderson JJ, Kiel DP, Felsen DT. Height loss in women as an indicator of subsequent incident hip fracture. J Bone Miner Res 1995;10:S465.
25. Must A, Willett WC, Dietz WH. Remote recall of childhood height, weight, and body build by elderly subjects. Am J Epidemiol 1993;138:56–64.
26. Meyer HE, Tverdal A, Falch JA. Risk factors for hip fracture in middle-aged Norwegian women and men. Am J Epidemiol 1993;137:1203–11.
27. Hemenway D, Azrael DR, Rimm EB, Feskanich D, Willett WC. Risk factors for hip fracture in US men aged 40 through 75 years. Am J Public Health 1994;84:1843–5.
28. Hemenway D, Feskanich D, Colditz GA. Body height and hip fracture: a cohort study of 90 000 women. Int J Epidemiol 1995;24:783–6.
29. Greenspan SL, Myers ER, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. JAMA 1994;271:128–33.
30. Faulkner KG. Hip axis length and osteoporotic fractures [letter]. J Bone Miner Res 1995;10:506–8.
31. Wand JS, Reeve J. Coxarthrosis and femoral neck fracture. Clin Orthop 1990;278:88–94.
32. Nelson DA, Jacobsen G, Barondess DA, Parfitt AM. Ethnic differences in regional bone density, hip axis length and life style variables among healthy black and white men. J Bone Miner Res 1995;10:782–7.
33. Jones G, Nguyen T, Sambrook PN, et al. Symptomatic fracture incidence in elderly men and women: the Dubbo Osteoporosis Epidemiology Study (DOES). Osteoporos Int 1994;4:277–82.

Received for publication 22 April 1997
Accepted in revised form 23 July 1997