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Evaluation of Compressive Strength Index of the Femoral Neck in Caucasians and Chinese

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Abstract

Compressive strength index (CSI) of the femoral neck is a parameter that integrates the information of bone mineral density (BMD), femoral neck width (FNW), and body weight. CSI is considered to have the potential to improve the performance of assessment for hip fracture risk. However, studies on CSI have been rare. In particular, few studies have evaluated the performance of CSI, in comparison with BMD, FNW, and bending geometry, for assessment of hip fracture risk. We studied two large populations, including 1683 unrelated U.S. Caucasians and 2758 unrelated Chinese adults. For all the study subjects, CSI, femoral neck BMD (FN_BMD), FNW, and bending geometry (section modulus [Z]) of the samples were obtained from dual-energy X-ray absorptiometry scans. We investigated the age-related trends of these bone phenotypes and potential sex and ethnic differences. We further evaluated the performance of these four phenotypes for assessment of hip fracture risk by logistic regression models. Chinese had significantly lower FN_BMD, FNW, and Z, but higher CSI than sex-matched Caucasians. Logistic regression analysis showed that higher CSI was significantly associated with lower risk of hip fracture, and the significance remained after adjusting for covariates of age, sex, and height. Each standard deviation (SD) increment in CSI was associated with odds ratios of 0.765 (95% confidence interval, 0.634, 0.992) and 0.724 (95% confidence interval, 0.569, 0.921) for hip fracture risk in Caucasians and Chinese, respectively. The higher CSI in Chinese may partially help explain the lower incidence of hip fractures in this population compared to Caucasians. Further studies in larger cohorts and/or longitudinal observations are necessary to confirm our findings.

Keywords

Osteoporosis; Bone mineral density; Compressive strength index; Femoral neck width; Section modulus; Hip fracture

Hip fractures are the most severe clinical outcome of osteoporosis and are associated with a high degree of morbidity and mortality, especially in the elderly [1]. Reduced bone strength at the proximal femur is the leading cause of hip fracture [2].

Bone mineral density (BMD) is the most widely used phenotype to assess bone strength and predict fracture risk [3, 4]. However, only 50–70% of total bone strength can be attributed to BMD [5, 6]. The patterns of BMD variation are not always consistent with the hip fracture rates among different populations. For example, Asians have on an average a lower hip BMD than Caucasians of the same age range [7, 8]; however, hip fracture rates of Asians are lower than that of Caucasians [7, 9]. Other factors, such as geometric parameters of the femoral neck (e.g., femoral neck width [FNW] and bending geometry [section modulus, Z, an index of bone bending strength]), also describe hip strength [10], but the data have been

inconsistent [11-15]. Lower body weight was found to be associated with unfavorable changes in some of the geometric parameters of the femoral neck, which subsequently compromises hip strength [16].

Because various bone phenotypes assess hip bone strength and hip fracture risk in nonadditive ways, the concept of compressive strength index (CSI) of the femoral neck was developed [17]. CSI is calculated as (BMD 9 FNW)/weight. Because CSI measures the capacity to withstand compressive forces proportional to body weight along the main femoral neck axis, it is considered to have the potential to improve the performance of assessment of hip bone strength and fracture risk. However, studies of CSI have been rare; in particular, few studies have evaluated the performance of CSI, in comparison with BMD, FNW, and bending geometry Z, for assessment of hip fracture risk.

In this study, we investigated and compared the basic characteristics of CSI, femoral neck BMD (FN_BMD), FNW, and Z in U.S. Caucasians and Chinese. In addition, we evaluated the performance of CSI, FN_BMD, FNW, and Z for assessment of hip fracture risk in these two populations.

Materials and Methods

Subjects

A sample of 1683 healthy unrelated U.S. Caucasian subjects (including 629 men and 1054 women) and a sample of 2758 healthy unrelated Chinese subjects (including 1497 men and 1261 women) were used in the study. All the subjects signed informed consent documents before entering the studies.

The Caucasian subjects were selected from our previously recruited samples (including nuclear families and pedigrees) for genetic studies of osteoporosis and related health problems [18, 19]. These 1683 subjects were parents of the nuclear families and/or pedigrees, and thus they were unrelated. The subjects were recruited by a comprehensive suite of inclusion/exclusion criteria, which have been described elsewhere [20]. In brief, subjects with diseases, treatments, or conditions that would be apparent, nongenetic, causes for abnormal bone mass were excluded from the study. All of them were of Northern European origin living in Omaha, Nebraska, and its surrounding areas.

The Chinese subjects were recruited from Han adults living in Changsha, Hunan province, China. Among the 2758 unrelated subjects, 810 were parents of the 405 recruited Chinese nuclear families, and the rest were random unrelated subjects recruited using a population-based strategy without regard to any specific disease status or traits. The same exclusion criteria were used for recruitment of both samples.

Measurements

For both of the Caucasian and Chinese samples, BMD (g/cm^2) and bone area (cm^2) at the femoral neck were measured by Hologic QDR 4500 dual-energy x-ray absorptiometry (DXA) scanners (Hologic, Bedford, MA). The scanners were calibrated daily. The coefficients of variation of BMD measurements were 1.87% for Caucasians and 1.98% for

Chinese. Weight was measured while the subjects wore light indoor clothing with a calibrated balance beam scale, and height was measured with a calibrated stadiometer. Body mass index (BMI, kg/m²) was calculated as weight (kg) divided by height squared (m²). The CSI at the femoral neck was calculated as $CSI = (BMD \times FNW)/weight$, where BMD refers to areal BMD of the femoral neck [17]. FNW is the periosteal diameter of the femoral neck and can be approximated by dividing the areal bone size of the femoral neck by the width of the region of interest (in Hologic DXA systems, the width of the femoral neck region is standardized at 1.5 cm) [21]. The calculation of section modulus (Z), an index of bone bending strength, has been detailed elsewhere [22].

For recruitment of U.S. Caucasians, a standardized questionnaire was used to obtain general health information and fracture history at a one-time visit. Subjects were asked whether the fracture was the result of a fall, an accident, a sports injury, or a spontaneous event. For verification of fractures, fracture sites and the date of self-reported fractures were confirmed by review of medical records. Self-reported fractures that could not be verified by radiology reports or medical records, or fractures resulting from a traffic accident or major trauma were excluded. For recruitment of Chinese subjects, a similar standardized questionnaire with slight modifications was administered to obtain the general health information and fracture history at the time of visit.

In this study, only the subjects with hip fractures were included in the logistic regression analysis for assessment of hip fracture risk. The subjects with a history of hip fractures were classified as the case group, and those without were classified as the control group. In our study samples, 38 Caucasian subjects (25 women and 13 men) had a low trauma hip fracture history, and 42 Chinese (32 women and 10 men) had a low trauma hip fracture history. In Caucasians, the incidence of hip fracture in women and men was 2.37% and 2.07%, respectively (female/male ratio = 1.1). In Chinese, the incidence of hip fracture in women and men was 2.54% and 0.77%, respectively (female/male ratio = 3.3).

Statistical Analysis

Distributions of the baseline characteristics according to sex and ethnicity were examined by **Student's *t*-test**. Many factors, such as age, sex, and height, may have significant effects on BMD, FNW, Z, and CSI. These factors were modeled as covariates in subsequent statistical analyses.

To examine the patterns of change along with age, the subjects were stratified into six groups, each group having a 10-year span. The phenotypic differences among the different age groups were tested by one-way analysis of variances (ANOVA). To further examine the pattern of association between CSI and age in our study populations, we used the maximum likelihood estimator as implemented in the statistical package Man-6 [23]. Estimation of the parameters of the model was based on the least mean squares method, assuming normal distribution of the study trait [24]. Histograms of CSI distribution for both Caucasians and Chinese were constructed and separated into class intervals increasing by 0.5 g/kg m.

In addition, we tested the differences of FN_BMD, FNW, Z, and CSI between men and women after adjustment for age and height. The above analyses were performed in Caucasians and Chinese separately.

Binary logistic regression analysis was performed to evaluate the hip fracture risk that can be assessed by FN_BMD, FNW, Z, and CSI separately. All the statistical analyses were performed by SPSS software (SPSS, Chicago, IL).

Results

Basic Characteristics of the Subjects

Table 1 shows the basic characteristics of the study subjects, stratified by ethnicity and sex. For both Caucasians and Chinese, men had significantly larger height, weight, BMI, FN_BMD, FNW, Z, and CSI than women. The Chinese subjects had significantly lower height, weight, BMI, FN_BMD, FNW, and Z, but higher CSI than sex-matched Caucasians. Table 2 shows the basic characteristics of Caucasians and Chinese in the fracture and non-fracture groups. The fracture subjects were older and had larger BMIs than did nonfracture subjects. In contrast, FN_BMD, FNW, Z, and CSI of the fracture subjects were significantly lower ($P < 0.001$) than that of the healthy controls.

Table 3 shows the covariates included in the models, the standardized regression coefficients, R^2 of the total covariates effect, and the corresponding levels of significance. For both Caucasians and Chinese, there was a significant positive correlation between age and FNW, and a significant negative correlation between age and FN_BMD and CSI ($P < 0.001$). For Caucasians, there was a significant negative correlation between age and Z, but no such relationship was detected in Chinese sample. For both populations, men had higher FN_BMD, FNW, Z, and CSI than those of women ($P < 0.001$). Height was positively correlated with FN_BMD, FNW, Z, and CSI.

Ethnic Differences of FN_BMD, FNW, and CSI

Table 4 compares FN_BMD, FNW, Z, and CSI between Caucasians and Chinese samples. The comparison was conducted before and after adjustment for the covariates of age, height, and sex (sex was not included as a covariate in sex-stratified analysis). It can be seen that in the total and sex-stratified subsamples, Caucasians had larger FN_BMD, FNW, and Z than those of the Chinese subjects. However, it is notable that Caucasians had lower CSI values than Chinese before and after adjustment for covariates ($P < 0.001$).

Change of FN_BMD, FNW, and CSI with Aging

Figures 1 and 2 display the changes of FN_BMD, FNW, Z, and CSI with age in Caucasians and Chinese, respectively. It is clear that FN_BMD and CSI decreased along with age ($P < 0.001$), and that a dramatic decrease of FN_BMD and CSI occurred at the age of 50 in Caucasian and Chinese women. FNW increased slightly with age in both populations. Z increased slightly with age in Caucasians and decreased moderately with age in Chinese. From Figs. 1 and 2, it can be seen that the patterns of age-associated trends for FN_BMD,

FNW, Z, and CSI are similar in the two populations. All the results shown in Figs. 1 and 2 were adjusted for body weight and height.

We further examined the distribution of CSI and its age-related trends for both Caucasians and Chinese using the maximum likelihood estimator as implemented in the statistical package Man-6 [23]. Supplementary Figures 1 and 2 show CSI distribution before and after adjustment for age in Caucasians and Chinese, respectively. CSI in both Caucasians and Chinese had a unimodal normal distribution. For both Caucasians and Chinese, the age-related trends of CSI were best fitted by the two-interval model (Fig. 3). In Caucasians, CSI in men had a relatively rapid decrease before age 32 (-0.085 ± 0.009 SD per 10 years), after which it decreased moderately (-0.007 ± 0.002 SD); and CSI in women had a relatively rapid decrease before age 30 (-0.071 ± 0.012 SD per 10 years), after which it decreased moderately (-0.013 ± 0.002 SD). In Chinese, CSI in men had a relatively rapid decrease before age 39 (-0.051 ± 0.005 SD per 10 years), after which it decreased moderately (-0.012 ± 0.003 SD); and CSI in women remained unchanged before age 27, after which it decreased rapidly (-0.035 ± 0.001 SD).

Sex Differences in FN_BMD, FNW, and CSI

As shown in Tables 1, 2, 4, 5, in both populations, men generally had larger FN_BMD, FNW, Z, and CSI than women, although in Caucasian, CSI did not reach the level of statistical significance. In Chinese, men had >7% higher values than women for all four phenotypes.

Assessment of Hip Fracture Risk

Logistic regression analysis was conducted to evaluate the performance of FN_BMD, FNW, Z, and CSI in assessment of hip fracture risk. Age and sex were included in the models as covariates. Table 6 shows the results of logistic regression analysis in the Caucasian and Chinese samples. It can be seen that higher CSIs were associated with lower risk of hip fracture risk. Each standard deviation increment in CSI was associated with odds ratios of 0.765 in Caucasian sample. Similar results were obtained in the Chinese sample. It is noted that the odds ratio is significant for CSI only (odds ratio = 0.765, $P = 0.005$ in Caucasians; odds ratio = 0.724, $P = 0.009$ in Chinese).

Discussion

CSI is constructed from structural engineering principles, which measures the maximum compressing load that the femoral neck could withstand per unit thickness cross-sectional slice and the unit of normal compression load exerted on the femoral neck. Because hip fractures are often a direct consequence of this compressive force, among other forces, such as bending force, CSI may represent a more direct measure of hip bone strength.

In this cross-sectional study with 1683 U.S. Caucasians and 2758 Chinese, we observed that although Chinese had on average smaller FN_BMD, FNW, and Z than Caucasians, their CSI values were larger. The value of CSI biomechanically gives the capacity to withstand compressive forces proportional to body weight along the main femoral neck axis. The greater CSI in Chinese may partially explain the lower hip fracture rates in Chinese

compared to Caucasians. Because FN_BMD, FNW, and Z were lower in Chinese, the greater CSI in Chinese could only be explained by a difference in body weight between Chinese and Caucasians. Earlier prospective studies in European and U.S. populations suggested that lower baseline BMI and weight loss may contribute to the increased hip fracture risk because BMI and weight loss were negatively related to total hip BMD [25-27]. A straightforward explanation is that a larger body weight imposes a greater mechanical loading on bone and that bone mass increases to accommodate the greater load. However, from the biomechanical point of view, body weight alone may not be an ideal factor predicting hip fracture risk, as absolute femoral neck strength is not as important as strength relative to the size of the load. Structures that are exposed to larger loads need to be stronger than structures exposed to less heavy loads. Thus, the eventual risk of hip fracture is more likely to be influenced by the femoral neck strength relative to the body size (weight and bone size) rather than the absolute strength. This may partially explain the observation that Chinese have lower fracture rates despite their relatively lower baseline body weight, because the hip bone strength relative to the body size is larger in Chinese than in Caucasians.

We found that higher CSI were associated with lower risk of hip fractures in both Caucasians and Chinese, and notably, the odds ratio remained significant for CSI in Chinese after adjusting for covariates. Our results are consistent with an earlier study in a prospective cohort of community-dwelling women, which reported that each standard deviation increment in CSI was associated with the relative risk of 0.39 [17]. In our Caucasian and Chinese samples, men had higher CSIs than women, suggesting that men generally have a greater capacity to withstand compressive forces proportional to body weight along the main femoral neck axis. The variation in CSI between men and women may partially explain the lower risk of hip fracture in men.

Areal BMD measured by DXA is one of the most important factors for prediction of hip fractures. However, the unparallel patterns of areal BMD and hip fracture rates among different ethnic groups have been observed. For example, although Asian women have on average lower areal BMD than Caucasian women [28], they have lower hip fracture rate [7, 9]. A possible explanation is that FN_BMD measured by DXA among Caucasians was overestimated as a result of the relatively larger skeletons of Caucasians [29]. This is because wider hip bones are usually also deeper [29, 30], and FN_BMD (calculated as bone mass content/bone area) measured by DXA cannot completely take into account the 3-dimensional information of hip bone structure. This potential shortcoming may partially be addressed by other measurement technologies such as quantitative computed tomography (QCT). QCT measures volumetric BMD (vBMD) which may confer potential advantages for assessment of femoral neck bone strength. A recent study using the Osteoporotic Fractures in Men (MrOS) cohorts compared femoral neck dimensions and vBMD from QCT among black, Asian, Hispanic, and white men ≥ 65 years [10]; the study found that black and Asian men had thicker cortices and higher trabecular vBMD, which could help explain the lower hip fracture rates in these populations [10]. However, there were data that did not favor the use of QCT-derived vBMD for prediction of fracture risk [31]. Moreover, QCT is related to a higher amount of radiation exposure and greater cost, and it is thus of limited use in large-scale epidemiology studies.

In our logistic regression analysis, the geometric structure parameters of the femoral neck, FNW and Z, were not significantly associated with hip fractures. In fact, the relationship of FNW and hip fractures has been the subject of debate. Some studies found that a narrower femoral neck is related to higher fracture risk as a result of lower resistance to bending [32], but others have argued that larger femoral necks may confer higher fracture risk as a result of a longer hip axis [33]. Studies of hip fractures found that the FNW of the subjects with hip fractures was wider [12, 14, 33, 34], similar [11, 13, 15, 21], or narrower [17, 32] than the controls. Some studies showed that Z, an index of bone bending strength, did not have better performance than conventional DXA BMD in predicting fractures [35, 36]. This situation may suggest that the geometric structure parameters of the femoral neck alone also have limitations in assessment of hip fracture risk.

This study has some potential limitations. First, our study is cross-sectional in nature, and the fractures reported are past fractures. Further longitudinal prospective studies in larger cohorts of different populations are necessary to help enhance our understanding of femoral neck strength and fracture risk. Second, the two populations used in the study are different in some aspects, which may confound the obtained results. However, the U.S. Caucasian and Chinese samples selected for this study were recruited using the same exclusion criteria, which may help alleviate the potential cohort effects, if any. Moreover, the potential confounding factors (such as age, sex, and height) and their influences on bone phenotypes were appropriately controlled in the statistical analyses as covariates. Finally, it should be noted that CSI *per se* is a simplistic rendition of the estimated strength of the femoral neck in compression and could be limited as a predictive measure alone.

Despite these limitations, our study suggests that CSI, constructed in a simple fashion from data available in routine DXA scan, may help explain the differences of hip fracture rate among different ethnic groups. Further studies in larger cohorts and/or longitudinal observations are necessary to confirm our findings.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Fig. 1. Results of ANOVA for FN_BMD, FNW, Z, and CSI in age-stratified groups in Caucasians. The sample was stratified into 6 groups by age at a 10-year span. *FN_BMD* bone mineral density, *FNW* femoral neck width, *Z* section modulus, *CSI* compressive strength index

Fig. 2.

Results of ANOVA for FN_BMD, FNW, Z, and CSI in age-stratified groups in Chinese. The sample was stratified into 6 groups by age at a 10-year span. *FN_BMD* bone mineral density, *FNW* femoral neck width, *Z* section modulus, *CSI* compressive strength index

Fig. 3. Scatterplots of age dependence for compressive strength index (CSI) for Caucasian (*top graphs*) and Chinese (*bottom graphs*). The line shows the best fitted model of relationship between CSI (y-axis) and age (x-axis)

Table 1

Characteristics of the study subjects

Characteristic	Caucasian		Chinese	
	Male (n = 629)	Women (n = 1054)	Male (n = 1497)	Women (n = 1261)
Age (years)	50.24 ± 18.32	50.03 ± 15.89	36.30 ± 16.21	36.96 ± 15.65
Height (m)	1.77 ± 0.07	1.64 ± 0.07 [*]	1.68 ± 0.07	1.57 ± 0.05 [*]
Weight (kg)	89.11 ± 15.62	71.80 ± 16.11 [*]	64.05 ± 9.46	53.31 ± 8.01 [*]
BMI (kg/cm ²)	28.29 ± 4.61	26.89 ± 6.05 [*]	22.57 ± 3.12	21.62 ± 3.29 [*]
FN_BMD (g/cm ²)	0.856 ± 0.145	0.781 ± 0.128 [*]	0.845 ± 0.133	0.746 ± 0.112 [*]
FNW (cm)	3.902 ± 0.332	3.313 ± 0.321 [*]	3.512 ± 0.243	3.089 ± 0.283 [*]
Z (cm ³)	2.243 ± 0.535	1.466 ± 0.343 [*]	1.766 ± 0.325	1.211 ± 0.262 [*]
CSI (g/kg m)	3.814 ± 0.773	3.717 ± 0.827 [◇]	4.683 ± 0.832	4.384 ± 0.850

Note: Data are expressed as mean ± SD. The results were significant after correction for multiple testing

^{*} $P < 0.001$ for comparison between men and women in the same ethnic group

$P < 0.001$ for comparison between different ethnic groups of the same sex

[◇] $P < 0.01$ for comparison between men and women in the same ethnic group

Table 2

Characteristics of the fracture and nonfracture subjects

Characteristic	Caucasian			Chinese		
	Fracture (<i>n</i> = 38, female = 25)	Nonfracture (<i>n</i> = 1645, female = 1029)	<i>P</i>	Fracture (<i>n</i> = 42, female = 32)	Nonfracture (<i>n</i> = 2716, female = 1229)	<i>P</i>
Age (years)	51.52 ± 13.93	49.77 ± 17.46	0.053	56.95 ± 12.69	36.61 ± 16.01	<0.001 [*]
Height (m)	1.67 ± 0.09	1.69 ± 0.10	<0.001 [*]	1.59 ± 0.08	1.63 ± 0.08	<0.001 [*]
Weight (kg)	77.74 ± 19.21	78.40 ± 17.69	0.567	61.03 ± 10.08	59.15 ± 10.30	0.001 [*]
BMI (kg/cm ²)	27.94 ± 6.23	27.29 ± 5.42	0.081	23.95 ± 3.27	22.14 ± 3.24	<0.001 [*]
FN_BMD (g/cm ²)	0.795 ± 0.137	0.813 ± 0.140	0.039	0.713 ± 0.131	0.800 ± 0.133	<0.001 [*]
FNW (cm)	3.422 ± 0.426	3.560 ± 0.430	<0.001 [*]	3.245 ± 0.404	3.319 ± 0.336	0.001 [*]
Z (cm ³)	1.617 ± 0.527	1.790 ± 0.572	<0.001 [*]	1.303 ± 0.392	1.512 ± 0.407	<0.001 [*]
CSI (g/kg m)	3.600 ± 0.763	3.790 ± 0.815	<0.001 [*]	3.823 ± 0.751	4.547 ± 0.855	<0.001 [*]

Note: Data are expressed as mean ± SD. *P* values are the results of *t*-tests

^{*} The results were significant after correction for multiple testing

Table 3

Contribution of covariates to FN_BMD, FNW, Z, and CSI

Ethnicity	Phenotype	Standardized regression coefficient			
		Age (years)	Sex	Height (m)	R ²
Caucasian	FN_BMD (g/cm ²)	−0.450 ^{***}	−0.258 ^{***}	0.378 ^{***}	0.296
	FNW (cm)	0.103 ^{***}	−0.660 ^{***}	0.661 ^{***}	0.545
	Z (cm ³)	−0.002 ^{**}	−0.372 ^{***}	2.914 ^{***}	0.572
	CSI (g/kg m)	−0.385 ^{***}	−0.058 ^{**}	0.130 ^{***}	0.152
Chinese	FN_BMD (g/cm ²)	−0.372 ^{***}	−0.227 ^{***}	0.205 ^{***}	0.337
	FNW (cm)	0.267 ^{***}	−0.430 ^{***}	0.308 ^{***}	0.507
	Z (cm ³)	0.0004	−0.287 ^{***}	2.358 ^{***}	0.565
	CSI (g/kg m)	−0.551 ^{***}	−0.196 ^{***}	0.222 ^{***}	0.323

Note: The results shown are from multiple linear regression analyses. In the regression models, “0” denoted male and “1” denoted female

**
P < 0.01;

P < 0.001

Table 4Comparison of FN_BMD (g/cm²), FNW (cm), Z (cm³), and CSI (g/kg m) between Caucasians and Chinese

Group	Phenotypes	Mean		Difference (%)	P
		Caucasian	Chinese		
Male	FN_BMD	0.856	0.845	1.30	0.058
	FN_BMD-adjusted	0.869	0.839	3.58	<0.001*
	FNW	3.902	3.512	11.10	<0.001*
	FNW-adjusted	3.762	3.571	5.35	<0.001*
	Z	2.243	1.766	27.01	<0.001*
	Z-adjusted	2.052	1.846	11.16	<0.001*
	CSI	3.814	4.682	-18.54	<0.001*
	CSI-adjusted	4.078	4.571	-10.79	<0.001*
Female	FN_BMD	0.781	0.746	4.69	<0.001*
	FN_BMD-adjusted	0.791	0.739	7.04	<0.001*
	FNW	3.312	3.089	7.22	<0.001*
	FNW-adjusted	3.212	3.174	1.20	0.010*
	Z	1.466	1.211	21.06	<0.001*
	Z-adjusted	1.392	1.272	9.43	<0.001*
	CSI	3.717	4.384	-15.21	<0.001*
	CSI-adjusted	3.894	4.235	-8.05	<0.001*
Total	FN_BMD	0.809	0.800	1.13	0.029
	FN_BMD-adjusted	0.831	0.787	5.59	<0.001*
	FNW	3.533	3.319	6.45	<0.001*
	FNW-adjusted	3.464	3.361	3.06	<0.001*
	Z	1.756	1.512	16.14	<0.001*
	Z-adjusted	1.700	1.547	9.89	<0.001*
	CSI	3.753	4.546	-17.44	<0.001*
	CSI-adjusted	3.995	4.398	-9.16	<0.001*

Note: Caucasians: $n = 1683$ (629 men and 1054 women); Chinese: $n = 2758$ (1497 men and 1261 women). The mean values shown in the table include the raw data and the data after adjusting for age, sex and height. Difference (%) was calculated as: (Caucasian – Chinese)/Chinese. P values are the results of the t -tests

* The results were significant after correction for multiple testing

Table 5

FN_BMD, FNW, Z, and CSI in men and women after adjusting for age and height

Ethnicity	Phenotype	Mean		Difference (%)	P
		Male	Female		
Caucasian	FN_BMD (g/cm ²)	0.827	0.799	3.50	0.001 [*]
	FNW (cm)	3.719	3.422	8.68	<0.001 [*]
	Z (cm ³)	1.989	1.617	23.01	<0.001 [*]
	CSI (g/kg m)	3.793	3.730	1.69	0.245
Chinese	FN_BMD (g/cm ²)	0.828	0.767	7.95	0.006 [*]
	FNW (cm)	3.451	3.161	9.17	<0.001 [*]
	Z (cm ³)	1.643	1.357	21.08	<0.001 [*]
	CSI (g/kg m)	4.699	4.364	7.68	<0.001 [*]

Note: Difference was calculated as (male – female)/female. *P* values are the results of *t*-tests

^{*}The results were significant after correction for multiple testing

Table 6

Assessment of hip fracture risk in Caucasians and Chinese

Ethnicity	Phenotype	Regression coefficient	Standard error	χ^2	Odds ratio (95% confidence interval) ^a	<i>P</i> ^b
Caucasian	FN_BMD	-0.012	1.285	53.219	0.988 (0.080, 12.256)	0.993
	FNW	-0.531	0.634	53.219	0.588 (0.170, 2.037)	0.402
	Z	0.404	0.629	53.219	1.498 (0.437, 5.139)	0.520
	CSI	-0.268	0.096	53.219	0.765 (0.634, 0.922)	0.005
Chinese	FN_BMD	0.742	1.801	577.554	2.101 (0.062, 71.613)	0.680
	FNW	-0.840	0.859	577.554	0.432 (0.080, 2.328)	0.329
	Z	0.933	0.996	577.554	2.543 (0.361, 17.925)	0.349
	CSI	-0.323	0.123	577.554	0.724 (0.569, 0.921)	0.009

^aOdds ratios for hip fractures adjusting for the covariates of age and sex. *CI* confidence interval^b*P* values are for odds ratios