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REVIEW

Epidemiology and structural basis of racial differences in fragility fractures in Chinese and Caucasians

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Abstract Chinese have similar vertebral fracture prevalence but lower incidence of hip and distal forearm fractures than in Caucasians. The underlying structural and biomechanical basis of racial differences in bone fragility is still largely undefined but Chinese assemble their smaller appendicular skeleton with thicker cortices and trabeculae compared with Caucasians. Vertebral fracture prevalence is similar by race, but the incidence of hip and distal forearm fractures is lower in Chinese than in Caucasians. This racial dimorphism cannot be explained by differences in areal bone mineral density (aBMD) as aBMD is lower in Chinese mainly due to their smaller size. The underlying structural and biomechanical basis of racial differences in bone fragility is still largely undefined but Chinese assemble their smaller appendicular skeleton with more mineralised bone matrix within it; the cortices are thicker and perhaps less porous while trabeculae are fewer but thicker and more connected. This configuration produces a bone with a lower surface/volume ratio, which in turn reduces the surface available for remodelling to occur upon so that the lower surface/volume ratio may make the bone less exposed to remodelling and the thicker cortices and trabeculae less vulnerable to remodelling when it does occur during advancing age. However, prospective studies are needed to define racial differences at the age of onset, rate of bone loss from the intracortical, endocortical and trabecular components of the endosteal envelope and bone formation upon the periosteal envelope; notions of bone 'loss' are derived mainly from cross-sectional studies. Studies of the site- and surface-specific changes in bone modelling and remodelling are needed to better define racial differences in bone fragility in old age.

Keywords Bone microarchitecture · Caucasian · Chinese · pQCT

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Introduction

Fragility fractures are a major public health problem in women and in men of most, but not, all races. The high morbidity, mortality and financial burden of fractures is the result of the age-related decrease in bone strength that accompanies bone loss. The underlying material and structural abnormalities contributing to racial differences in fracture rates are largely unknown because non-invasive methods of determining bone microstructure have not been available until recently. Most comparative studies have focused on the racial differences in areal bone mineral density (aBMD), but most deficits in aBMD in Chinese relative to Caucasians is explained by differences in bone size. The review concerns the growth- and age-related origins of racial differences in bone macro- and microstructure and the resulting biomechanical basis of bone fragility in Chinese and Caucasians.

Epidemiology of fractures in Chinese and Caucasians

Vertebral fractures

The age-specific prevalence of vertebral fractures is similar in Chinese than in Caucasians [1–4] (Fig. 1). Using a similar method to classify vertebral fractures, Ling et al. [5] reported the prevalence of vertebral fracture in Chinese

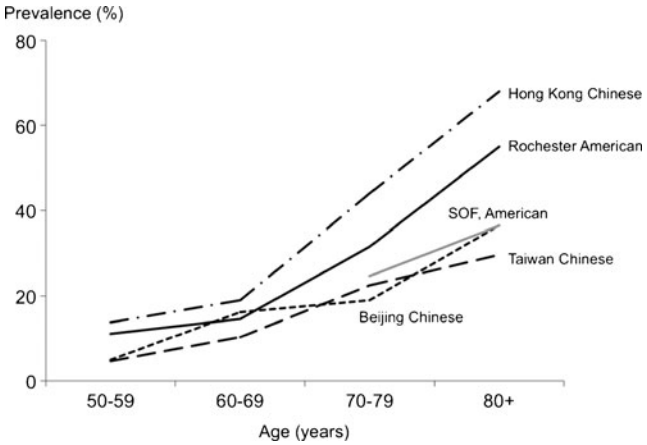

Fig. 1 Age-specific prevalence of vertebral fractures in Chinese compared to Caucasian women. Vertebral fracture is defined as more than 3SD below the mean of the vertebral height ratios. Data from Beijing Chinese [5], Hong Kong Chinese [4], Taiwan Chinese [8], Rochester American [6], and the Study of Osteoporotic Fractures (SOF) in USA [7]

women aged 50 years and older was 15.0% in Beijing; about 5.5% lower than Caucasians in Rochester, USA [6]. The prevalence of vertebral fractures was about 22% in Chinese postmenopausal women aged over 45 years from Hong Kong and 20% for Chinese women older than 65 years from Taiwan, similar to values found in Caucasian women [3, 4, 6–8]. The prevalence of vertebral fracture was ~14% for Chinese men older than 50 years, comparable to that reported in Caucasian men [8–10].

Like Caucasians, the prevalence of vertebral fractures is similar, or slightly higher, in Chinese women than Chinese men [1, 8–10] (Fig. 1). Nevertheless, these estimates remain uncertain given rigorous attention to standardized morphometric criteria are lacking. Moreover, as the data are cross-sectional, the timing of vertebral fractures, and whether they are the result of minimal trauma remains uncertain. Incidence figures have not been documented in China.

Hip fractures

In general, the incidence of hip fractures is lower in Chinese than Caucasians. Very low hip fracture rates in Chinese have been reported from two studies conducted in Northern China in Beijing and Shenyang [11, 12]. Despite the rapid increase in hip fracture incidence rates in Chinese, it was still only 50% that reported in Caucasians [13] (Fig. 2). A recent study from Beijing by Xia et al. [13] reported the standardized hip fracture incidence rates between 2002 and 2006 were 254 and 138 per 100,000 in Chinese women and men aged over 50 years, respectively.

Higher rates have been reported in Chinese living in Hong Kong, Taiwan and Singapore compared to those living in Northern China. A multi-national study conducted in four Asian countries showed the age-adjusted rates in Hong Kong (180 in men and 459 in women) and Singapore (164 in men and 442 in women), were almost identical to Caucasian men and 80% of rates in Caucasian women (187 in men and 535 in women), while the rate in Thailand and Malaysia were 60% and 50% of the Hong Kong rates, respectively [14]. From 1996 to 2000, the age-adjusted incidence rates of hip fracture were 225 per 100,000 in Chinese men and 505 in women in Taiwan; similar to the rates in Caucasians [15]. Koh et al. [16] also reported age-adjusted incidence of hip fractures was 168 per 100,000 in Chinese men and 410 in women in Singapore between 1991 and 1998.

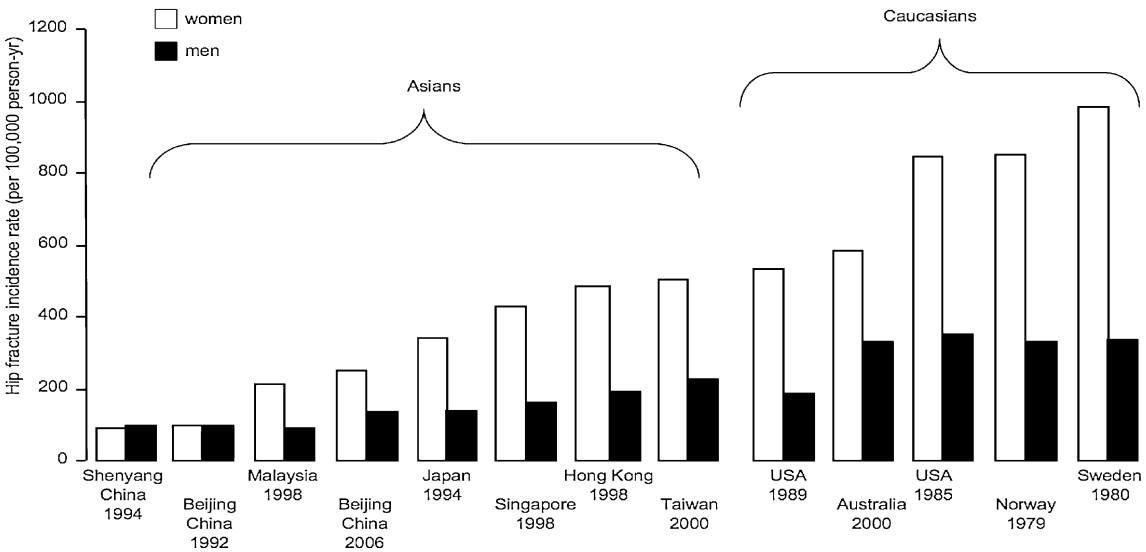

Fig. 2 Age- and sex-adjusted hip fracture incidence (per 100,000 person-years) in Asian and Caucasian women and men, which standardised for the 1990 United States non-Hispanic White population [117]

The incidence of hip fracture appears to be stable or decreasing in some countries such as North America, Europe, and Australia [17–19]. In Hong Kong, the incidence of hip fracture increased 2.5-fold and 1.7-fold in women and men, respectively, from 1966 to 1985, and has slightly declined between 1991 and 2004 [20, 21]. By contrast, the incidence is still increasing in mainland China and Singapore. In Northern China, Xia et al. [13] reported that hip fracture incidence rates have also increased 2.5-fold in women and 1.4-fold in men from 1988 to 2006. In Singapore, hip fracture rates have increased 5-fold in women and 1.5-fold in men from 1955 to 1998 [16].

Distal forearm fractures

Distal forearm fractures occur less commonly in Asians than Caucasians [22–25] (Fig. 3). A recent study from Norway suggested that Asian immigrants in Oslo have a slightly lower distal forearm fracture risk than Norwegians (relative risk: 0.72; 95% confidence interval [CI], 0.53–1.00) [23].

Morbidity, mortality and cost

Morbidity following vertebral fractures, such as limited physical function and back pain, has been reported in Chinese women and men [5, 26]. The mortality rate in hip, vertebral and other major fracture patients is higher than in the general population at the same age. Despite the lower incidence of hip and vertebral fracture in men, mortality is higher in men than women [27, 28]. In Caucasians, the mortality rate is 36% in men and 21% in women in the year following a hip fracture [29]. The mortality at 1 year after hip fracture is 11.5–18% in Japan, 17% in Thailand, 15% in Singapore, and 9% in China [30–34]. Asian men also have higher mortality than Asian women [31–33].

Although the total national annual cost of osteoporosis has not been reported in China, Luo and Xu [35] estimated the annual direct medical costs for one hip fracture patient was RMB 32,776 (or US$4,680). In Hong Kong, the annual cost related to hip fractures is $HK130 million (or US$17 million), accounting for 1–2% of the total hospital budget [36]. This figure is comparable to that of the 0.9% of the annual health service expenditure was attributed to hip fractures in Australia [37].

Pathogenesis of bone fragility in Chinese and Caucasians

Growth-related factors

Bone fragility results from abnormalities in the material composition and structural design of bone. Most comparative studies have focused on racial differences in aBMD acquired from dual energy X-ray absorptiometry (DXA). The lower aBMD in Chinese than Caucasians is largely due to smaller bone size in Chinese [38]. The structural and biomechanical basis that likely to contribute to racial differences in fracture rates has only recently become better understood.

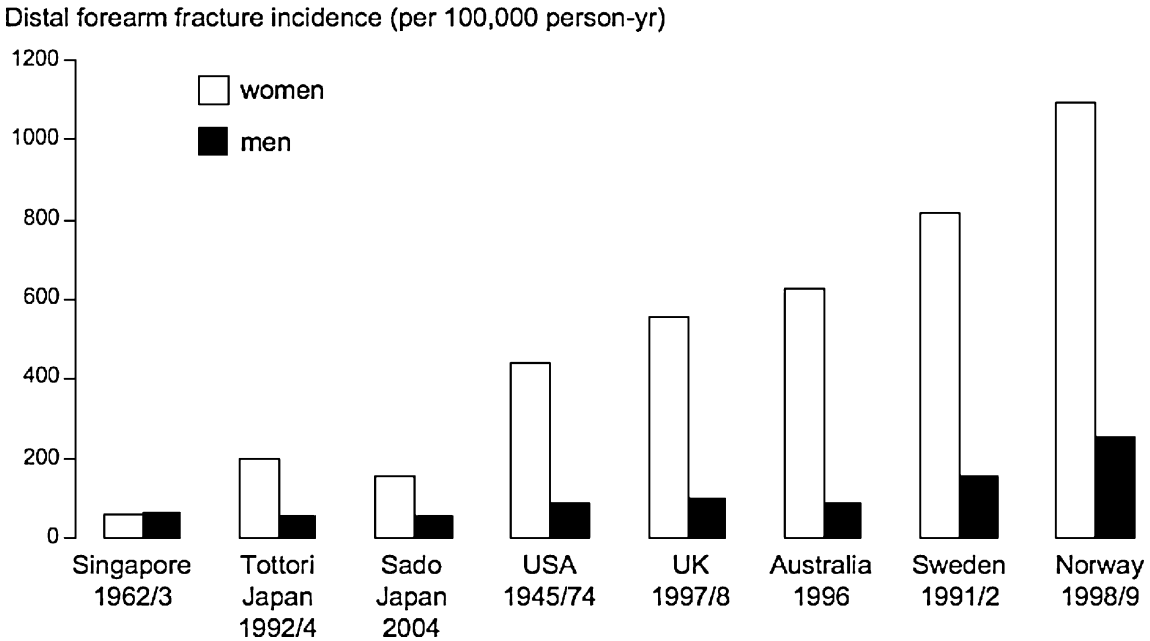

Fig. 3 Age-adjusted incidence (per 100,000 person-years) of distal forearm fractures in Asians and Caucasians (standardized to the population of Oslo in 1999) [23]

Attainment of peak bone strength during growth

About 40% of the peak bone mass is accrued during adolescence in both sexes and in both Asian and Caucasians [39–44]. Before puberty, no racial differences are present for total body (TB) and lumbar spine (LS) bone mineral content (BMC) in either sex after height, weight, and bone area adjustment [38, 45, 46]. By contrast, femoral neck (FN) BMC and aBMD are lower in Asian pre-pubertal boys before and after accounting for body size. There are no racial differences in these FN traits in girls before or after accounting for body size [45].

After early puberty, the lower BMD at the TB, LS and FN in Asians are largely, but not entirely, explained by racial differences in bone size and body weight [47–49]. Seven-year longitudinal study indicated that BMC accrual at the TB did not differ by race between 10 years and 17 years of age but this ignores the regional heterogeneity. At the FN, Asian boys and girls accrued 0.1 g and 0.2 g less BMC per year than Caucasians. At the LS, Asian girls accrued 1.6 g more BMC per year, while no racial differences were observed for boys [48].

Chinese females achieve smaller vertebrae during growth. However, peak vertebral body trabecular volumetric BMD (vBMD) is 12% higher in Chinese than Caucasian females [50, 51]. Chinese girls aged 10–18 years also have smaller metacarpal width and thinner cortices than Caucasians [52]. At the midshaft of the tibia, pre- and early pubertal Asian (54% were Chinese) boys and girls had smaller cortical area, but cortical vBMD was greater in Asian girls but similar in Asian boys compared with Caucasians [53].

No differences in the microarchitecture of the distal radius and tibia in 58 Chinese and 60 Caucasian girls aged 7–17 years were reported in any bone trait assessed using high-resolution peripheral quantitative computed tomography (pQCT) prior puberty [54]. Peri- and post-pubertal Chinese girls had smaller total CSA and trabecular area than their respective Caucasian counterparts. After menarche, Chinese girls had thicker cortices within a smaller radial total cross-section. Therefore total and cortical BMD was higher in Chinese girls with thicker but fewer trabeculae so net trabecular BMD and BV/TV did not differ by race. Similar observations were reported in premenopausal women [55, 56].

Linear and radial growth

The shorter stature of Asians is predominantly due to shorter leg length; trunk length is similar in Asians and Caucasians [57, 58]. These differences in the upper and lower segment are likely attributable to the racial differences in the tempo, duration and extent of the pubertal growth spurt and therefore the duration of longitudinal growth before puberty. The median age for onset of breast development in urban Chinese girls is 9.2 years of age [59], compared with 10.4 years of age in Caucasians [60]. The age at menarche is about 6 months earlier in Chinese than Caucasian [59, 61–63]. Thus, earlier exposure to estrogen and thus earlier epiphyseal fusion may produce a shorter leg and FN lengths.

Based on indirect comparison from the published literature, the pattern of linear growth velocity of body height is similar in Asian and Caucasian girls and boys [57, 64–67]. Nevertheless the peak height velocity (PHV) is lower, the duration is longer, and occurs approximately 1 year earlier in Asians than Caucasians (Fig. 4). However, a recent longitudinal study involved 138 Asian and 161 Caucasian children mean aged 10.3 years at the baseline living in Canada with completed measurements on 36 Asians and 79 Caucasians at ten time points across 7 years reported that the timing of PHV was 6 months earlier in Asian than Caucasian boys, but 2 months later in Asian than Caucasian girls [48]. The timing of peak bone mass accrual (expressed as aBMD) tended to occur earlier in Asians than Caucasians in both sexes [47].

Using high-resolution pQCT, two studies from Melbourne, Australia and New York, USA, both reported thicker cortices and trabeculae within a smaller bone at the distal radius and distal tibia in Chinese lived in these areas than Caucasian women in young adulthood [55, 56]. In 61 healthy premenopausal Chinese and 111 Caucasian women aged 18–45 years living in Melbourne [56], cortical thickness was 8.8% greater within a 14.3% smaller total cross-sectional area (CSA) at the distal radius in Chinese (Fig. 5). Total vBMD was 10.3% higher in Chinese because of 2.8% greater cortical density. Trabecular vBMD and bone volume/tissue volume (BV/TV) did not differ by race because trabeculae were 7.0% fewer but 10.8% thicker in Chinese than Caucasians. Similar results were found at the distal tibia. Walker et al. reported similar results [55]. Using individual trabeculae segmentation and micro finite element analysis on high-resolution pQCT images, Chinese-American women had 80–95% higher plate bone volume fraction, 18–20% greater plate number density, two times higher plate to rod ratio and more axially aligned trabecular network than Caucasians [68]. The risk of buckling is determined by the ratio of bone radius to the cortical thickness [69]. Therefore, the thicker cortices and stronger trabeculae within a smaller bone is likely to confer a lower buckling risk in Chinese than Caucasians and so may contribute to the lower risk of hip fractures in Chinese.

Age-related factors

Bone loss may commence shortly after attainment of peak bone mass. There is evidence that trabecular bone loss

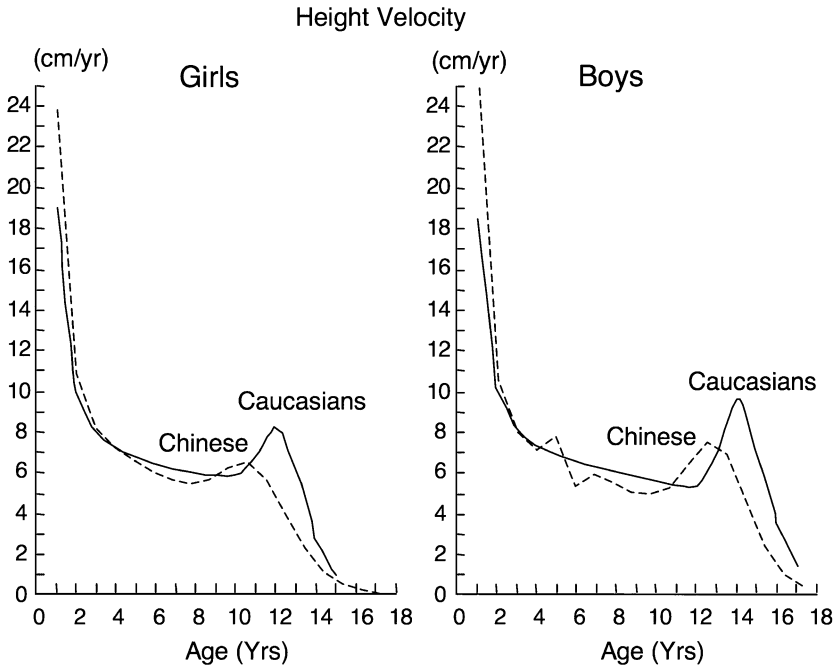

Fig. 4 The peak height growth velocity during puberty is lower and occurs approximately 1 year earlier in Chinese than Caucasian girls and boys. Adapted from [118] with permission from ©2005 World Scientific

begins in the 20s in both sexes, particularly at axial skeleton, and then loss accelerates in midlife in women [70, 71]. Estrogen deficiency is most likely to contribute to the trabecular bone loss in both women and men [72–74]. The onset of cortical bone loss is said to begin at midlife in both sexes [71, 75]. However, this has not been rigorously assessed with methods that are sufficiently sensitive to detect and include trabecularization of cortical bone in adulthood. Thus, the 'trabecular' density will be falsely elevated as cortical remnants are included. Cortical density is also falsely elevated because it is calculated from compact appearing cortex only, the porosity creating the cortical remnants is not included in the calculation of total cortical density (compact appear-

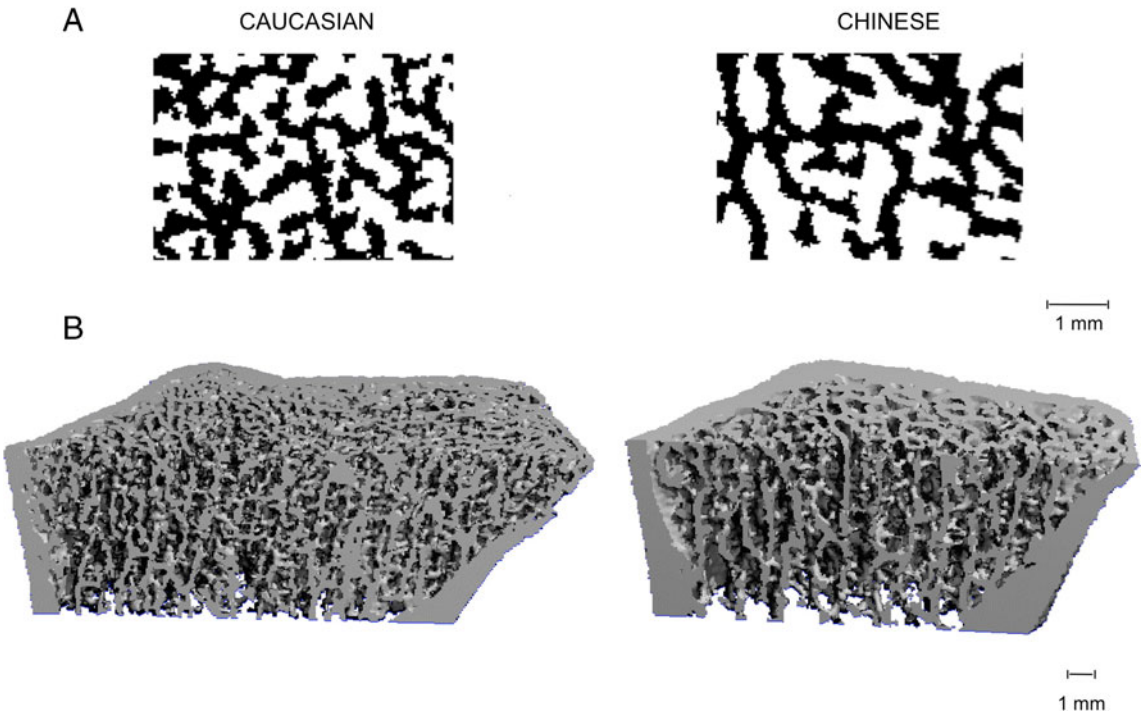

Fig. 5 2-D images of trabeculae (**a**) and 3-D images (**b**) of distal radius from a Caucasian woman (*left panel*) and a Chinese woman (*right panel*). Adapted from Wang et al. [56], with permission from the American Society for Bone and Mineral Research

ing plus transitional zone of trabecularized cortex and porosity) [76].

Axial skeleton

Vertebral aBMD is 4–18% lower in Chinese women and men than Caucasians [77–81]. This racial difference attenuates after height and weight adjustment [77, 78, 81, 82]. Using QCT, trabecular vBMD of the vertebral body was higher in Chinese premenopausal women, but racial differences were no longer apparent after 40 years of age when compared to an American Caucasian database after cross-calibration [50, 51]. Duan et al. [80] reported 10% higher vBMD of the vertebral body (derived from posteroanterior and lateral vertebral DXA scans) presented in Chinese young women but similar by race in women over 60 years of age. In men, vBMD of the vertebral body was higher in Chinese than Caucasians in both young adulthood and old age [80].

Cross-sectional studies suggest that the pattern of age-related decline in vertebral aBMD is similar in Chinese and Caucasians in both sexes [50, 83]. Longitudinal data also suggest that vertebral bone loss around menopause is likely to be similar in Asians and Caucasians [84]. Data from the Women's Health Across the Nation (SWAN) study compared the rates of bone loss longitudinally in multiple-ethnic groups in the U.S. and reported that the vertebral aBMD loss accelerated in late perimenopause in all ethnic groups [84]. Vertebral aBMD loss was most rapid in Chinese and Japanese women, intermediate in Caucasian women, and slowest in African-American women during late perimenopause and postmenopause. When a subgroup of women who weighed 50–78 kg was analyzed, the racial differences in rates of spine aBMD loss were no longer evident.

Diminution in trabecular bone at the vertebral body is similar or slightly greater in Chinese than Caucasians in cross-sectional studies [50, 80]. Yu et al. [50] reported vertebral trabecular vBMD, measured by QCT, declined with age, and the rate of bone loss was similar in Chinese and Caucasian women (1.05% vs. 1.00%) after cross-calibration. Duan et al. [80] reported a slightly greater diminution in vBMD in Chinese than Caucasian women (33% vs. 29%, $p<0.01$) across age using DXA. The age-related decrease in vBMD of the vertebral body was reported to be similar by race in Chinese and Caucasian men [80]. The age-related changes of thinning of the vertebral cortex and increased cortical porosity have not been evaluated.

Duan et al. [80] studied 687 healthy Chinese (449 women) and 1,181 Caucasians (788 women) living in Melbourne, Australia. Biomechanical parameters, such as load per unit CSA (stress), strength and FRI, were calculated using engineer principles. They reported that young adult Chinese women and men had a smaller vertebral body with higher vBMD than Caucasians. From young adulthood (~30 years) to old age (~70 years), vertebral body CSA increased more in Chinese than Caucasian women (9% vs. 6%) and increased less in Chinese than Caucasian men (9% vs. 12%). The age-related increase in CSA reduces stress of the vertebral body but vBMD decreased so the FRI increased; ~25% of elderly Chinese and Caucasian women and ~5% of elderly Chinese and Caucasian men had a FRI above unity [80] (Fig. 6). This was consistent with the similar prevalence of vertebral fractures between Chinese and Caucasians.

The racial differences in the contributions of periosteal bone 'gain' and endosteal bone 'loss' to the net bone loss of the vertebral body were also estimated in this cross-sectional study [80]. Despite the similar net diminution at the vertebral body by race, it was the result of differing degrees of the endosteal bone 'loss' and periosteal bone 'gain' in Chinese and Caucasian women and men. In women, the similar net bone 'loss' in Chinese and Caucasians was the results of similar estimated periosteal bone 'deposited' and similar estimated endosteal bone 'lost' in both races. Whereas in men, the similar net 'loss' in Chinese and Caucasians was due to less periosteal bone 'deposited' and less endosteal bone 'loss' in Chinese [80]. The cross-sectional design limits the veracity of this study, particularly because secular trends in bone mass and dimensions make the data difficult to interpret [85]. Prospective studies are needed to confirm these cross-sectional observations.

Chinese have a smaller vertebral body but also have a lower body weight and less muscle mass. Therefore the loads per unit CSA (stress) on bone may be similar between Chinese and Caucasians [80]. The similar vertebral fracture prevalence may reflect similar stress to strength ratio (expressed as FRI) at the vertebral body in Chinese and Caucasians.

Similar to the sex differences in Caucasians, vertebral bone loss is slightly greater in Chinese women than men in cross-sectional studies [50, 80, 86]. Tsai et al. [86] also reported that bone area of L2–L4 (derived from DXA) increased in both Chinese women and men over 20–70 years of age, and was slightly greater in Chinese women than men after height and weight adjustment. However, Duan et al. [80] observed similar periosteal bone gain at the vertebral body in Chinese women and men. The greater net bone loss in Chinese women was due to greater endosteal bone loss than in men, which differed with Caucasians whose greater net bone loss in women was the results of less periosteal bone gain in women than in men with similar endosteal bone loss [80].

Appendicular skeleton

The lower aBMD of the FN in Chinese than Caucasians is largely due to their smaller bone size [38, 77, 81, 82, 87].

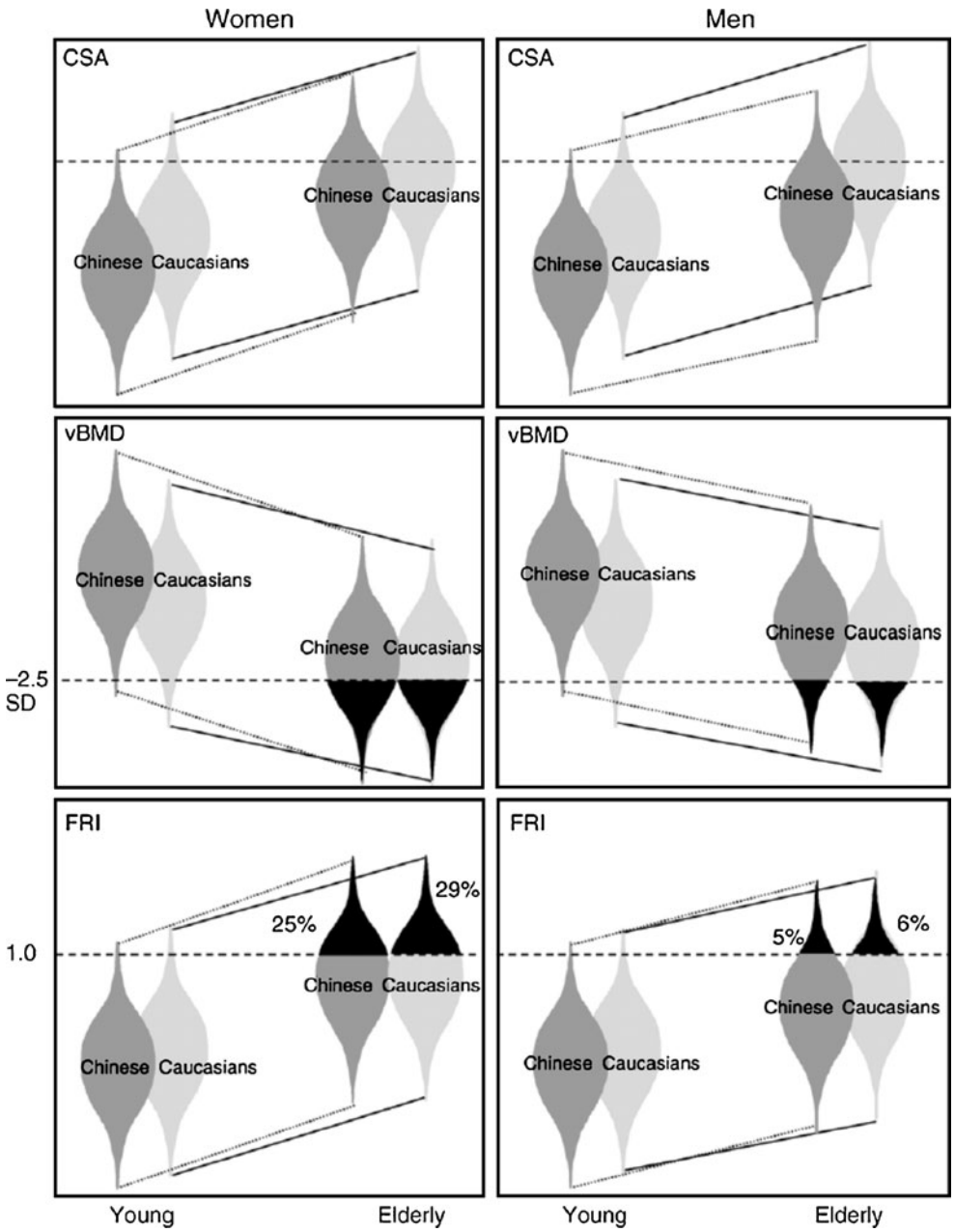

Fig. 6 In young adulthood, vertebral body cross-sectional area (*CSA*) was smaller with higher vBMD in Chinese than Caucasians in both sexes. During ageing, vertebral body CSA increased with age but slightly so more in Chinese than Caucasian women but less so in Chinese than Caucasian men; vBMD declined more in Chinese than Caucasian women but similarly in Chinese and Caucasian men. The fracture risk index (*FRI*) is a ratio of vertebral body compressive stress to strength, that is the ability to resist load which is a function of vertebral cross-sectional area and its vBMD. FRI = stress/(8,515 × $vBMD^{1.6}$). The FRI increased, and a similar proportion of elderly Chinese and Caucasian women and elderly Chinese and Caucasian men have FRI greater than unity. Adapted from Duan et al. [80], with permission from Elsevier

Using QCT, the MrOS study showed that FN total and trabecular vBMD were higher in Asian men aged over 65 years than Caucasians living in the United States [88]. The cortical vBMD was similar by race at the FN but greater in Asian men at the femoral midshaft.

Walker et al. [55] studied 29 postmenopausal Chinese-American and 68 Caucasian women using high-resolution pQCT. The smaller CSA, thicker cortices and trabeculae were extended from the premenopausal to postmenopausal Chinese women [55, 56, 89]. FN diameter was smaller in Asians, and this difference disappeared after adjusted for body size in men only [88, 90, 91]. The smaller bone in Asians conferred lower bending strength as bending resistance varies with the fourth power of the radius of bone [92]. Marshall et al. [88] reported that Asian men had thicker cortices at the FN and shaft compared with Caucasian men aged over 65 years. At the FN, total, medullary and cortical bone volume was similar by race after age, height, BMI and FN length adjustment. However, the ratio of cortical volume divided by total bone volume was 4% greater in Asian men. At the femoral shaft, Asian men had smaller CSA and medullary area but similar cortical area, thus greater cortical thickness compared with Caucasian men [88]. Therefore, the thicker cortex within a smaller bone confers a lower buckling risk in Asians than Caucasians so partly contributes to the lower risk of hip fractures in Asians.

Differences in age-related appendicular bone loss between Chinese and Caucasians are still not clear. Data from cross-sectional studies indicate that the age-related decline in FN aBMD in Chinese men and women is either less than Caucasians [79, 93], similar [83, 94], or greater than Caucasians [87, 95]. One longitudinal study showed a slower decline rate in Asian-American than Caucasian men aged over 65 years old at the FN aBMD [96]. In women, longitudinal data suggest that vBMD at the distal radius begins to decline in premenopausal Asian women, and the rates are higher than Caucasian women [75, 97–101]. The trabecular and cortical bone loss at the distal radius was

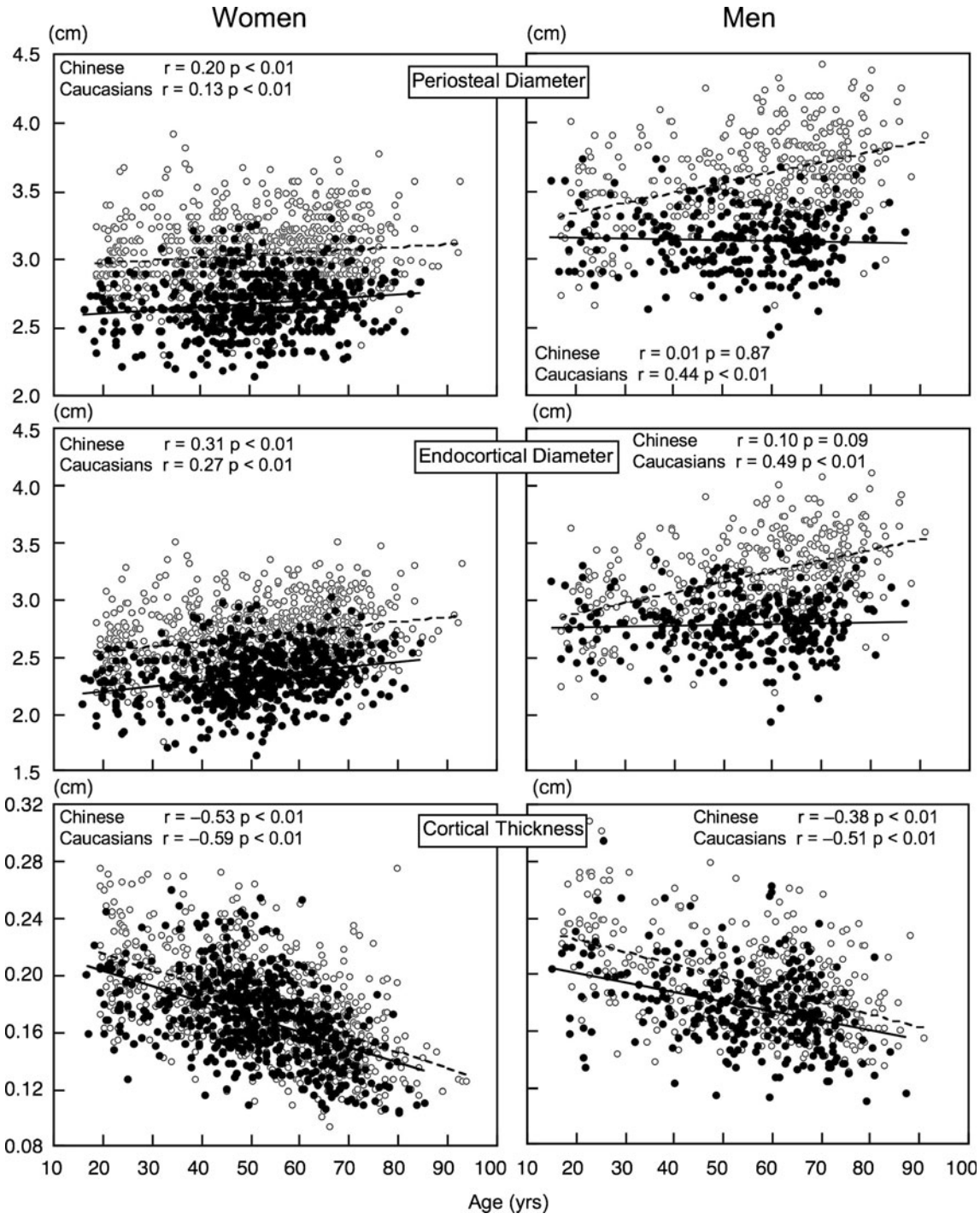

Fig. 7 Measured (unadjusted) femoral neck periosteal diameter, endocortical diameter and cortical thickness plotted against age in healthy Caucasian (*open dots, dashed lines*) and Chinese (*filled dots, solid lines*) women and men. Adapted from Wang et al. [105], with permission from Elsevier

approximately 3–4% and 2% in early postmenopausal Asian women compared with 1% and 0.4% in Caucasian women of same age, respectively [75, 97, 98].

FN periosteal expansion with ageing has been reported in Chinese men and women [102–105]. From direct or indirect comparisons of these cross-sectional studies, age-related periosteal apposition seems to be less in Chinese than Caucasian men but similar or greater in Chinese than Caucasian women. For instance, FN periosteal expansion was reported as 0.5–0.6% per decade in Chinese men, compared with about 0.8–1.0% per decade in Caucasian men [102, 104, 106]. In 829 healthy Chinese and 1,181 healthy Caucasian women and men aged 18–93 years, hip structure analysis suggests periosteal apposition and endosteal resorption were both less in Chinese than Caucasian men, while they were similar in Chinese and Caucasian women [105] (Fig. 7). Cortical thinning was less in Chinese men, but similar in Chinese and Caucasian women. The relatively thicker cortices in Chinese young women were retained at the old age [105]. Therefore, the racial differences in age-related periosteal apposition and endosteal resorption were sex-specific. However, these findings are based on cross-sectional studies and may be limited by the estimation of the FN structure. Increased FN cortical porosity was documented in elderly Chinese women with hip fractures by scanning electron microscopy [107].

Another structural factor that may contribute to hip fracture risk is hip axial length (HAL) or FN axis length (FNAL). HAL is measured as the linear distance from the base of the greater trochanter through the FN to the inner pelvic brim near the acetabulum of the femoral head [108]. FNAL is the length of long axis of the FN from the lateral aspect of the femur below the greater trochanter to the cortical rim of the femoral head (excluding the acetabular width in HAL) [109]. FNAL correlates with HAL [110]. As reported in the prospective Study of Osteoporotic Fractures (SOF), HAL is an independent predictor of hip fracture; so shorter HAL in blacks and Asians may contribute to their lower hip fracture rates than Caucasians [90, 108, 111–113]. However, similar HAL or FNAL between hip fracture patients and age-matched controls has been reported [110, 113]. As HAL and FNAL both correlated significantly with height, whether they are still shorter after adjusted for shorter stature in Asians has not been consistently reported [114]. Moreover, the longer HAL or FNAL in men than women is not associated with increased hip fracture risk [110]. Thus, the ability of HAL and FNAL to predict hip fracture risk is likely limited.

Asians have similar trunk length but shorter leg length than Caucasians [57, 115]. Whether the disproportionate shorter leg length is associated with better gait balance thus a reduced propensity for falls in Asians is uncertain [2, 116]. When falls occur, the shorter leg length may be protective because of the distance to the ground results in less force on the hip [2].

Summary and conclusion

Chinese have similarly vertebral fracture prevalence but lower hip and distal forearm fracture rates compared with Caucasians despite their lower aBMD. During puberty, Chinese females assemble their smaller appendicular skeleton with thicker cortices and trabeculae; there is more bone within the bone than in Caucasian females. Chinese women and men have disproportionately shorter leg length and FN length, and thicker cortices within the smaller FN in old age. These differences may partly account for the lower risk of appendicular fractures in Chinese. This review was limited by comparing locations without assessment of nutritional and lifestyle factors as these are difficult to quantify. Racial differences in bone loss and its structural consequences have not been assessed in well designed prospective studies. Future studies are likely to benefit from including studies of patients with fractures and more detailed assessment of material composition and bone microarchitecture as well as assessment of other factors such as bone remodelling markers.

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Conflict of interest None.

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