Current Osteoporosis Reports (2023) 21:670–684
https://doi.org/10.1007/s11914-023-00838-y

Racial/Ethnic Differences in Bone Mineral Density for Osteoporosis

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Accepted: 13 November 2023 / Published online: 29 November 2023

Abstract

Purpose of Review We primarily aim to review differences in bone mineral density (BMD) for osteoporosis among different racial/ethnic groups and to highlight the magnitude of racial/ethnic differences in obesity and diabetes. We also explore the factors contributing to the BMD differences among various subgroups. In addition, we investigate the existing disparities in research, educational initiatives, screening practices, and treatment options for osteoporosis and discuss these findings' clinical and public health implications.

Recent Findings Racial/ethnic differences in BMD for osteoporosis exist in the USA and other countries. There are disparities regarding osteoporosis screening and treatment. Understanding the factors contributing to these differences can help develop targeted interventions and policies to reduce their impact. Clinicians should consider the racial/ethnic differences in BMD when making treatment decisions and providing preventive care. Future research could contribute to developing effective strategies for preventing osteoporosis among different racial/ethnic groups.

Summary This review offered a comprehensive examination of differences in BMD across various racial and ethnic groups, elucidating the influence of genetic, lifestyle, and cultural factors on these differences. This review also highlighted the disparities in osteoporosis screening, treatment options, research on medical effectiveness, and educational outreach tailored to each subgroup. Recognizing the importance of addressing these inequalities, we present this review to advocate for targeted interventions to reduce disparities in osteoporosis and improve bone health for all populations.

Keywords Bone mineral density · Health disparities · Osteoporosis · Race · Ethnicity · Risk

Introduction

Osteoporosis is a global public health concern, with millions affected, particularly women and older adults, due to age-related declines in bone density [1, 2]. Osteoporosis affects approximately 200 million people worldwide, which is expected to increase by 23% over the next decade [2, 3]. In the USA alone, around 10 million individuals have osteoporosis, while an additional 44 million have low bone mass, predisposing them to higher fracture risks [4]. These fractures, prevalent in older adults, lead to disability, dependency, and increased healthcare utilization, contributing to a significant societal burden [5, 6]. The economic impact of osteoporotic fractures is substantial, with direct medical costs ranging from $17 to $20.3 billion, and it is anticipated that these costs will exceed $25 billion annually by 2025, with hip fractures alone incurring a median incremental cost of $11,241 [7].

Bone mineral density (BMD) measurement is crucial to osteoporosis diagnosis, and its clinical importance has been well established [8, 9]. The World Health Organization (WHO) utilizes BMD measurements to define osteoporosis, specifically a T-score of −2.5 or below [10]. BMD measurement is essential for identifying individuals at risk of osteoporotic fracture, monitoring disease progression, and assessing treatment efficacy.

Racial and ethnic differences in BMD and disparities in research, education, screening, and treatment of osteoporosis are concerning. Research reveals variations in BMD across different racial and ethnic groups [11–15]. Black women tend to have higher hip BMD but lower spine BMD than White women, while Asian women exhibit lower BMD at

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both hip and spine regions than White women [16•]. Genetics, lifestyle, diet, and environmental factors contribute to these differences. Additionally, disparities exist in osteoporosis and fracture risk assessment [17•, 18], with Black individuals facing lower screening, referral, and treatment rates than their White counterparts. Medication effectiveness also differs among Asian adults compared to White adults. Recognizing these disparities' epidemiology and clinical significance is crucial for tailored educational efforts and mitigation strategies.

This review provides a comprehensive overview of recent research on BMD differences among populations, uncovering genetic, lifestyle, and cultural influences. It addresses disparities in osteoporosis screening, treatment, and medication effectiveness research, offering insights into diverse demographic challenges. The review also explores interventions to mitigate these disparities, providing a holistic understanding of osteoporosis in diverse populations.

Racial/Ethnic Differences of BMD

An increasing body of research suggests significant differences in BMD levels across different racial and ethnic groups. The extent and direction of these differences vary among different demographic categories, age ranges, and genders. They may be more pronounced in specific skeletal sites (Table 1), as demonstrated by the most recent trend and difference in femur neck BMD (FN-BMD) in multiethnic populations in the USA (Fig. 1, [16•]). To provide a more detailed analysis and facilitate a better understanding of the unique challenges and opportunities for intervention within specific racial or ethnic groups, we will focus on one race/ethnicity at a time in this section.

Black Population

Studies have indicated that, in general, Black adults tend to have the highest BMD and the lowest prevalence of bone loss compared to Hispanic, Mexican, White, and Asian adults [19•]. However, these differences may vary by BMD sites and age groups and may be mitigated by factors such as hormones and body fat. For instance, among US adults over 50, Black adults had the lowest prevalence of low bone mass, with Asian men showing the highest prevalence after age adjustment [20•]. However, a study in postmenopausal women found similar rates of bone loss between Black and White women at the tibia, with some attenuation after clinical factors adjustment [21••]. This difference is not limited to the US; a large UK-based tri-ethnic cohort study found higher BMD in the African Caribbean than Europeans [22••].

Genetics, specifically polymorphisms in the vitamin D receptor (VDR), have been implicated in explaining the higher BMD [23] observed in Black individuals compared to their White counterparts. Distinct expressions of VDR BsmI genotypes, such as homozygous "bb" carriers, are associated with significantly higher BMD but are not found in Black individuals, common among Whites [24]. Similarly, disparities in VDR FokI genotypes suggest that Black-White differences in allele frequencies may contribute to BMD variations [25]. Additionally, Black individuals may benefit from more efficient calcium absorption due to genetic factors like TRPV6 and TRPV5 single nucleotide polymorphisms [26, 27]. Cultural practices promoting physical activities and healthier lifestyles, including lower rates of smoking [28] and diets rich in calcium and vitamin D [29], also contribute to the BMD difference between Black and White populations.

While genetics provide a BMD advantage, educational efforts are crucial for optimal bone health among Black individuals [30]. Despite efficient calcium absorption, many fall short of the recommended daily intake, necessitating dietary education [31]. Obesity is a growing concern, affecting over 75% of Black individuals aged 20 to 74, potentially impacting calcium intake despite the potential benefits of increased body mass [32]. Thus, promoting balanced diets and physical activity is crucial. Furthermore, awareness of the elevated risk of secondary osteoporosis within the Black population is essential due to prolonged use of medications like corticosteroids, a common cause of secondary osteoporosis [33]. Comprehensive education can empower this ethnic group to prioritize bone health.

Asian Population

The literature on differences in mean BMD between Asian and other racial groups (White and Black) is inconsistent [14, 20•, 34–36]. Some studies reported that Asian individuals have lower mean BMD values than White and Black individuals, while others reported similar or higher BMD values in Asian individuals. These differences may be due to variations in measured skeletal sites and age and gender groupings [37]. A large-scale study of Asian women found that Chinese, Filipina, and Japanese women had consistently lower FN-BMD values than White women, particularly among the older adults of 65–79 years old, with a difference of 6 to 8% [38••]. Conversely, the SWAN study revealed that pre- and early perimenopausal Chinese and Japanese women had higher LS-BMD values than White women after adjusting for weight and lifestyle factors [39••]. Furthermore, Asian women exhibited higher volumetric BMD, whereas areal BMD was similar in both groups [39••]. Studies that recruited men also reported inconsistent findings.

Table 1 Summary of publications on BMD racial differences in the last 5 years (2018–2023)

Reference	Study design	Country	Data source	Sample size	Sample characteristics	Bone measurement (site and tool)	Major Findings
Xu and Wu [16•]	Cross-sectional	US	NHANES, 2005–2010, 2013–2014	$N = 14{,}188$ NHW: $n = 7005$ NHB: $n = 2683$ NHO: $n = 925$ Hispanic: $n = 3575$	Race: NHW, NHB, NHO, Hispanic Gender: Male and female Age: > 30	FN-BMD DXA	• The age-adjusted mean FN-BMD remained steady from 2005–2005 to 2009–2010 but drastically dropped in 2013–2014 for both genders in all races • Age-adjusted mean FN-BMD value: NHB > Hispanics > NHW > NHO
Tayie and Wu [58]	Cross-sectional	US	NHANES, 2009–2014	$N = 7425$ NHB: $n = 1365$ NHW: $N = 3929$ Mexican: $N = 2131$	Race: NHW, NHB, Hispanic Gender: Male and female Age: 18–75	Femur BMD DXA	• The peak femur BMD value ($p < 0.001$): NHBs (men: 1.12 g/cm^2, women: 1.01 g/cm^2) > Hispanics (men: 1.05 g/cm^2, women: 0.96 g/cm^2) > NHWs (men: 1.04 g/cm^2, women: 0.93 g/cm^2) • Hispanics had the lowest critical femur BA but not the lowest femur BMD. NHWs had the biggest femur BA but the smallest femur BMD. NHBs had the highest femur BMD, but their critical femur BA was not the highest • South Korean men with diabetes mellitus and prediabetes had greater LS-BMD, total hip BMD, and FN-BMD
Jang et al. [79]	Cross-sectional	South Korean	KNHANES, 2008–2011	$N = 3383$	Race: Asian (South Korean) Gender: male Age: ≥ 50	Hip, FN- and LS-BMDs DXA	• Longer diabetes mellitus durations were associated with lower total hip and FN-BMDs (> 5 years: total hip BMD 0.940 ± 0.008 g/cm^2, FN-BMD 0.746 ± 0.008 g/cm^2; ≤ 5 years: total hip BMD 0.968 ± 0.009 g/cm^2, FN-BMD 0.786 ± 0.009 g/cm^2)

Table 1 (continued)

Reference	Study design	Country	Data source	Sample size	Sample characteristics	Bone measurement (site and tool)	Major Findings
Huang et al. [52]	Cross-sectional	China	Guangzhou Nutrition and Health Study, 2010–2013	$N = 1495$	Race: Asian (Chinese) Gender: female Age: > 40	Hip BMD DXA	• Chinese women tea drinkers had 1.9% greater hip BMD ($p < 0.05$) than non-tea drinkers (tea drinker: 0.852 ± 0.005 g/cm^2, non-tea drinker: 0.836 ± 0.005 g/cm^2) • Tea intake was a significant and independent predictor of BMD ($\beta = 0.068$, $p < 0.05$)
Li et al. 2019 [53]	Cross-sectional	China	CKB, 2004-2008; 2013-2014	$N = 25{,}045$	Race: Asian (Chinese) Gender: Male and female Age: 38 - 86	Heel BMD Quantitative ultrasound	• Long-term Chinese women tea drinkers had increased heel BMD ($\beta = 0.98$, 0.22-1.74 95% CI) • Tea consumption was not associated with increased heel BMD in Chinese men.
Bredella et al. 2020 [70•]	Cross-sectional	US	Ongoing trial at the Massachusetts General Hospital, USA	$N = 77$ White: $n = 52$ Black: $n = 25$	Race: White, Black Gender: Male and female Age: 13 – 24 Physical condition: Moderate to severe obesity	Lumbar vBMD QCT	• Black obese adolescents (vBMD: 0.223 ± 0.296 g/cm2) exhibited greater vBMD than their White counterparts (0.192 ± 0.302 g/cm^2) ($p < 0.0001$).
Campoverde Reyes et al. [67•]	Cross-sectional	US	Ongoing observational study at Massachusetts General Hospital, USA	$N = 72$ White: $n = 48$ African American: $n = 24$	Race: White and African-American Gender: male and female Age: 13–24 Physical condition: Obesity	Hip, spine, and femoral neck BMD DXA	• African American obese adolescents (vBMD: 804.3–886.9 mg HA/cm^3) had greater distal tibia cortical vBMD than their White counterparts (vBMD: 790.4–890.1 mg HA/cm^3) ($p = 0.012$), while no significant different was found at the distal radius
Lo et al. [38••]	Cross-sectional	US	Northern California healthcare system, 1998–2017	$N = 139{,}632$ NHW: $n = 115, 318$ Chinese: $n = 10{,}648$ Japanese: $n = 2519$ Filipino: $n = 11{,}147$	Race: NHW and Asian Gender: female Age: 50–79	FN-BMD DXA	• NHW women (0.664 ± 0.121–0.744 ± 0.122 g/cm^2) had higher FN-BMD than Filipino (0.608 ± 0.115–0.724 ± 0.112 g/cm^2), Chinese (0.612 ± 0.106–0.719 ± 0.108 g/cm^2), and Japanese (0.598 ± 0.104–0.714 ± 0.109 g/cm^2) women • Asian, Japanese, and Filipino women had a decreased trend of BMD

Table 1 (continued)

Reference	Study design	Country	Data source	Sample size	Sample characteristics	Bone measurement (site and tool)	Major Findings
Durdin et al. [22••]	Cross-sectional	UK	SABRE, 2014–2018	*N* = 883 European: *n* = 387 African Caribbean: n = 208 South Asian: n = 288	Race: African Caribbean, South Asian, European Gender: male and female	FN-BMD, LS-BMD, total hip BMD	• Black Caribbean adults had greater BMD than their European counterparts at all sites after adjustment for age and height (men: femoral neck: $\beta = 1.00$, 95% CI, 0.75–1.25; total hip, $\beta = 0.90$, 95% CI, 0.64–1.15; lumbar spine, $\beta = 0.35$, 95% CI, 0.08–0.62. women: femoral neck, $\beta = 0.77$, 95% CI, 0.56–0.99; total hip, $\beta = 0.88$, 95% CI, 0.66–1.09; lumbar spine, $\beta = 0.54$, 95% CI, 0.31–0.77) • There was not a significant BMD difference between South Asian and European women • There was a significant BMD difference at the hip between South Asian and European men (femoral neck: $\beta = 0.34$, 95% CI, 0.15–0.54; total hip, $\beta = 0.23$, 95% CI, 0.03–0.43), however not at the lumbar spine
Johannesdottir et al. [21••]	Longitu-dina	US	SWAN, 2008–2013, 2016–2017	*N* = 217 White: *n* = 137 Black: *n* = 80	Race: White and Black Gender: female	total vBMD, cortical vBMD, trabecular vBMD HR-pQCT	• White women had more unadjusted bone loss than Black women at the radius. White and Black women had similar rates of cortical vBMD loss. The differences were attenuated after adjusting for clinical covariates

NHW, non-Hispanic White individuals; *NHB*, non-Hispanic Black individuals; *NHO*, non-Hispanic other including Asian
The majority of Hispanic individuals are of the Mexican–American population

BMD, bone mineral density; *FN-BMD*, femur neck BMD; *LS-BMD*, lumbar spine BMD; *vBMD*, volumetric BMD; β, difference in standardized BMD; *DXA*, dual-energy X-ray absorptiometry; *HR-pQCT*, high-resolution peripheral quantitative computed tomography; *NHANES*, National Health and Nutrition Examination Survey; *KHANES*, Korean Health and Nutrition Examination Survey; *CKB*, the China Kadoorie Biobank; *Health ABC*, the health, aging, and body composition; *SABRE*, the Southall and Brent Revisited study; *SWAN*, the Study of Women's Health Across the Nation; *LOS*, the Louisiana Osteoporosis Study

One study in the USA reported lower areal BMD in young Asian men compared to their White counterparts [40]. Conversely, Canadian studies found no significant baseline BMD differences between Chinese and White individuals, except for younger Chinese men displaying lower total hip BMD [41••]. Initial findings from the Canadian Longitudinal Study on Aging showed lower total hip BMD in East Asian participants than Whites. However, after adjusting for BMI, East Asian participants exhibited higher FN-BMD than their White counterparts [42••]. In a UK-based tri-ethnic cohort study, South Asian men had higher FN-BMD than European men [22••].

Lower BMD in Asians compared to other ethnic groups is influenced by genetic and lifestyle factors. Unfavorable VDR FokI and BsmI polymorphisms in Asians are linked to reduced BMD, particularly in women [23, 43]. Smaller bone size in Asians contributes to lower BMD [44–46], although adjusting body size reduces most ethnic differences [38••, 47, 48]. Established BMD reference data are available for US White, Black, and Hispanic populations but not for the US Asian group [47, 62], potentially leading to underestimated BMD and over-diagnosis of osteoporosis in Asian individuals [63•, 64]. Cultural factors like dietary habits and physical activity choices, shaped by body image and weight beliefs, can affect bone health. Dietary habits, often low in dairy and calcium-rich foods due to traditional Asian diets, may contribute to decreased BMD, exacerbated by lactose intolerance prevalent in some Asian subgroups [49]. High calcium intake in lactose-intolerant Asians can pose risks like kidney stones [50]. Limited sunlight exposure, influenced by cultural preferences, especially among individuals with darker skin, can result in vitamin D deficiency. Sedentary lifestyles and insufficient osteoporosis education further negatively impact bone health [51]. On the positive side, some Asian practices, like tea consumption, have been associated with increased bone strength, indicating potential benefits for bone health [52, 53].

Promoting bone health in Asian populations should prioritize lifestyle and cultural considerations. Educational initiatives must emphasize the crucial link between diet, physical activity, and sun exposure in building strong bones [54]. These educational initiatives should ideally be offered bilingually, catering to both English speakers and those who speak native Asian languages, addressing language barriers and limited education. Regarding dietary choices, lactose-intolerant Asians can opt for low-lactose hard cheeses like cheddar as sources of calcium. Additionally, dairy-free, calcium-rich foods such as beans and tofu can improve bone health in this ethnic group. Given the cultural preference for lighter skin in traditional Asian cultures, targeted education encouraging more sun exposure, especially among Asian women, can also be beneficial.

Hispanic Population

Most studies on Hispanic participants have focused on Mexican–American postmenopausal women and have reported varying findings across different skeletal sites and sample cycles. Some studies indicate intermediate BMD values between Black and White women, while others report lower BMD values in Mexican–American women compared to other groups [14, 20•]. However, a separate study found that Mexican–American women exhibited higher femoral neck BMD (FN-BMD) values than White women, with similar total hip BMD values after age adjustment [55]. In contrast, age-adjusted BMD values at both skeletal sites were comparable between White and Mexican–American men [55]. A recent cohort study among Puerto Rican older adults in the USA demonstrated a decreasing trend in FN-BMD and lumbar spine BMD (LS-BMD) with advancing age [56•]. The higher estimates of osteoporosis among younger Puerto Rican men present an intriguing phenomenon that warrants further investigation. One potential explanation is the contrast in physical activity levels across generations, with older Puerto Rican adults having led more active lifestyles throughout their lives, potentially providing a protective effect on bone health. Additionally, dietary changes associated with acculturation may contribute to the observed differences in bone health between younger and older Puerto Rican men in our current study. Specifically, the nutritional patterns of younger, more acculturated Puerto Rican adults often incorporate foods and beverages that could be detrimental to bone health. Understanding the interplay of these factors is critical to unraveling the complexities of osteoporosis prevalence within this population and guiding targeted interventions.

The relationship between Hispanic ethnicity and BMD is complex and influenced by several factors. Genetic variations, such as the VDR FokI polymorphism, have been linked to lower lumbar spine BMD and increased hip bone loss in postmenopausal Mexican–American women [57], with "ff" genotype carriers exhibiting nearly 13% lower lumbar spine BMD compared to "FF" carriers [57]. These genetic variations in Mexican American populations may affect the metabolism of vitamin D, reducing efficiency in converting vitamin D into its active form. Anthropometric reasons, such as bone geometry, have been proposed [45, 58], with longer hip axis length increasing hip fracture risk. Dietary practices in Hispanic populations may lead to a lower BMD. Traditional Mexican diets with higher intake of refined grains, red meats, and fats, while low in dairy products, leafy greens, and fortified foods, may lack sufficient calcium and vitamin D essential for bone health [59]. Some traditional Mexican dishes can be high in salt and spices, where excessive sodium intake can lead to calcium

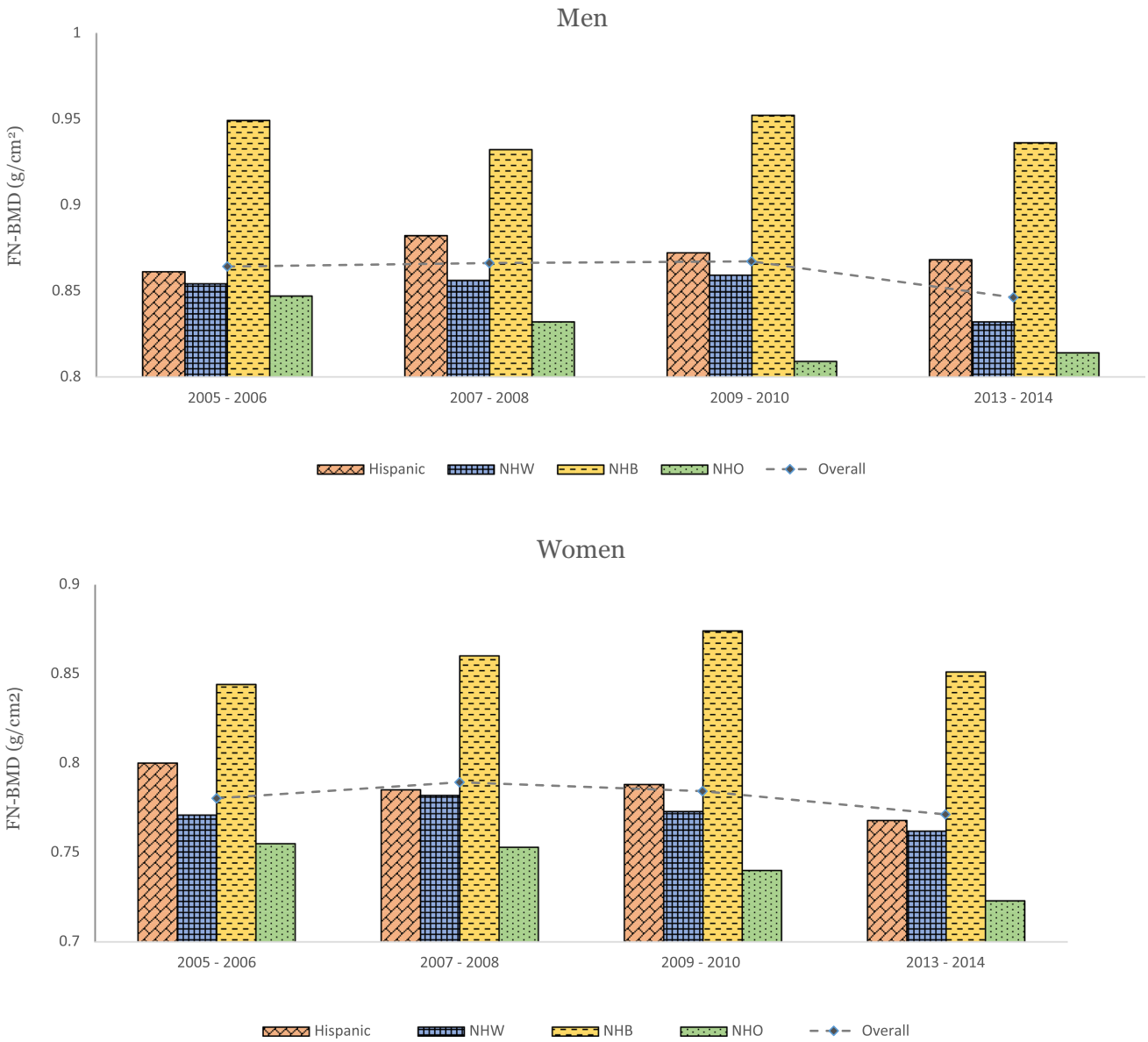

Fig. 1 Femur neck bone mineral density (FN-BMD) categorized by gender and by ethnicity from 4 NHANES cycles. *The figure was generated using the data from [16•]. Data source: the USA continuous National Health and Nutrition Examination Survey (NHANES) data from cycles of 2005–2006, 2007–2008, 2009–2010, and 2013–2014. Subjects younger than 40 years old were excluded. Method: A nationally representative sample of non-institutionalized civilians in the US population was selected using a complex, multistage probability design by NHANES. FN-BMD, femur neck BMD; NHW, non-Hispanic White; NHB, non-Hispanic Black; NHO, non-Hispanic other including Asian; Hispanic, majority Mexican Americans

loss through urine, negatively impacting bone health in lowering BMD and increasing the risk for osteoporosis [60–62]. Lifestyle factors such as physical activity levels and smoking rates also play a role, with higher physical activity and lower smoking rates associated with higher BMD [58, 63•]. Therefore, educational efforts promoting increased calcium and vitamin D intake, reduced salt consumption, and more physical activity are crucial for improving bone health in this population.

Racial Differences of BMD in Obesity

Childhood obesity, a prominent public health concern, is associated with an increased risk of fractures despite higher BMD compared to normal-weight peers [64]. Research indicates that childhood obesity can lead to structural changes in bone, such as heightened cortical thickness and trabecular bone volume, potentially raising BMD levels while compromising skeletal strength, thereby increasing fracture

susceptibility [65]. Furthermore, childhood obesity is linked to reduced physical activity and altered mechanical loading patterns, negatively affecting bone health by diminishing areal BMD and weakening bone strength [66].

An ongoing observational study of adolescents and young adults with moderate to severe obesity found that cortical vBMD was significantly higher in Black individuals than White individuals, while no significant differences were noted in aBMD and distal radius vBMD [67•]. This finding contrasts with previous research involving normal-weight adolescents and young adults, where Black individuals demonstrated higher aBMD at multiple skeletal sites [68, 69]. Another study focusing on Black and White adolescents/young adults with moderate to severe obesity identified racial differences in lumbar vBMD, with Black individuals having notably higher vBMD values than White individuals [70•]. The study also revealed an inverse relationship between marrow adipose tissue and vBMD in White individuals; however, this association was not observed in Black individuals, indicating the potential for racial differences in stem cell differentiation toward the bone and fat lineages [70•].

Among adolescents, BMD differences related to obesity were not significant. Black children tend to have higher BMD than other ethnic groups. Still, this difference is less pronounced than non-Black peers with normal weight, potentially indicating a blunting of protective bone health benefits in Black individuals with moderate to severe obesity during childhood. Additional research is needed to fully grasp the impact of moderate to severe obesity on adolescent and young adult bone parameters, necessitating longitudinal assessments of bone density, microstructure, and strength. To comprehensively understand this phenomenon, extensive population studies must consider factors such as inflammation status, lifestyle behaviors, and genetic influences.

Racial Differences of BMD in Diabetes

Diabetes significantly impacts bone metabolism and BMD through a complex interplay of factors. Elevated insulin levels can promote increased BMD due to insulin's anabolic effects and its impact on sex hormone levels [71–73]. Elevated insulin resistance is associated with lower fasting insulin levels, and this connection becomes more pronounced with increasing insulin resistance [74]. However, insulin levels can rise and subsequently decline due to pancreatic ß-cell dysfunction, potentially weakening bone density [75]. Diabetes disrupts the balance of hormones crucial for bone metabolism, like parathyroid hormone, calcitonin, estrogen, and testosterone, potentially leading to reduced BMD. The decreased BMD may then lead to a higher risk of fracture. Recognizing and addressing these mechanisms is essential for managing and preventing bone-related complications in diabetes.

The recent National Health and Nutrition Examination Survey (NHANES) shed light on the evolving landscape of bone health in diabetes. Between 2005–2006 and 2013–2014, age- and BMI-adjusted mean BMD exhibited a concerning decline in both type 2 diabetes mellitus (T2DM) patients and non-diabetic individuals, signaling a need for heightened bone health vigilance among those with T2DM [76•]. On average, individuals with T2DM showed a 25 to 50% increase in BMD compared to non-diabetic counterparts [77], while type 1 diabetes mellitus (T1DM) decreased LS-BMD and whole-body BMD in children [78]. Within the diabetic population, variations in BMD emerged, particularly across racial groups. A meta-analysis revealed that children with T1DM had lower BMD in Asia and South America but no significant decrease in North America and Europe [78]. Furthermore, disparities in bone loss dynamics were evident, with older White women with T2DM experiencing faster femoral neck and total hip bone loss, unlike White men or Black women [79]. Indian T2DM patients also exhibited lower BMD than their non-diabetic counterparts [79]. However, studies on Asian T2DM patients yielded conflicting results regarding BMD levels [80–82].

The body mass index (BMI) of individuals with T2DM may help explain BMD variations among subgroups. Asian women tend to have lower BMI and waist circumference than their Black, Hispanic, and White counterparts [83]. Furthermore, they exhibit a lower prevalence of abdominal obesity than White women [84]. Lifestyle factors, such as lower physical activity levels and calcium intake in Asian children compared to White children, could also contribute to BMD differences in Asian T2DM patients [85, 86]. Notably, the conventional BMD T-score method for osteoporosis screening has been criticized for its one-size-fits-all approach [87–89]. Recent research suggests that a lower femoral neck BMD T-score better predicts fracture risk in diabetic patients [90]. Additionally, spine T-scores were notably lower in individuals with diabetes, albeit not at the hip [89]. Hence, in the clinic, it is advocated that the BMD T-score threshold should be ideally configured between diabetes and non-diabetes patients in different ethnic groups.

Disparities in Promoting Bone Health Across Non-White Ethnic Groups

Disparities in promoting bone health among non-White ethnic groups span screening, treatment, research, and education. These complexities arise from factors influencing bone health within diverse populations. Screening disparities using dual-energy X-ray absorptiometry (DXA) are evident among ethnic groups. Inequities exist in accessing osteoporosis treatments and interventions. Research gaps persist in addressing non-White populations' unique bone health

needs. Moreover, educational outreach disparities hinder bone health promotion efforts. This review illuminates the multifaceted challenges faced by non-White ethnic groups in attaining optimal bone health.

Screening

Inadequate osteoporosis screening implementation is a widespread concern, with specific groups, particularly postmenopausal Black women, facing significantly lower screening rates than their White counterparts. Multiple studies [91–95] have highlighted this disparity, with only 14% of Black women undergoing screening, in stark contrast to the 45% rate among White women. Moreover, older Black women face a 40% reduced likelihood of receiving DXA screening compared to their White peers. Even after adjusting for socioeconomic status, health status, and healthcare utilization patterns, Black women still have the lowest DXA screening rates at 18%, while Asian, Hispanic, and White women range from 22.0 to 22.7% ($p < 0.001$) [96]. Similar findings indicate that only 30% of Black women aged 60 years and older were referred for DXA scans, whereas 38% of White women were referred ($p < 0.05$) [94].

Disparities in DXA screening rates among Black women compared to their Asian, Hispanic, and White counterparts can be attributed to various factors, broadly categorized as clinically appropriate differences, environmental factors, and discrimination [97]. Firstly, the higher observed BMD in African American women, as per NHANES data, may influence healthcare provider behavior, potentially resulting in fewer DXA referrals and antiresorptive medication prescriptions. However, this viewpoint may overlook the prevalence of hypovitaminosis D, a significant risk factor for low BMD, which is more common in Black women than White women [98]. Physicians might also assume inherent differences in bone biology between racial groups, potentially leading to the belief that Black women are less prone to fractures.

Alternatively, competing comorbidities during clinic visits may limit the time for osteoporosis screening. In the realm of discrimination, qualitative studies reveal that Black women may underestimate their osteoporosis risk [99], possibly due to a lack of awareness about its significance relative to other health concerns. Some studies also showed that female physicians were more likely to discuss osteoporosis with their postmenopausal patients than were male physicians, but did not look at Black women patients in particular [100]. Efforts to address this disparity should focus on education, research, public awareness, and identifying root causes to improve screening rates among at-risk Black women, as access to care does not seem to be a primary issue.

Studies on DXA screening rates among Hispanic and Asian populations have produced inconsistent results. Some research has suggested lower screening rates among Hispanics, with one study reporting a 23 to 33% reduction in DXA screening rates compared to White individuals [101, 102]. Similarly, studies have indicated lower screening rates among Asians before experiencing hip fractures [103]. However, a recent study presented a contrasting view, showing that Asian and Hispanic postmenopausal women in certain age groups had higher odds of receiving screening than their White counterparts, with increases ranging from 13 to 20% [96].

Understanding screening practices in Hispanic and Asian populations remains challenging due to limited evidence and insufficient data on individual origin groups. Disparities in screening rates are influenced by factors like reduced access to preventive healthcare [104–106], language barriers, socioeconomic status, and variations in diagnostic tools. For instance, the USA widely-used fracture risk assessment tool (FRAX) computes lower osteoporotic fracture risk for Asian and Hispanic women, even when risk factors are equal [107]. To comprehensively address these disparities, we need additional quantitative and qualitative research focusing on diverse populations, considering their unique community-based resources and challenges.

Treatment

Numerous studies consistently report disparities in osteoporosis treatment rates, focusing on Black women [18, 103, 108]. Analysis of NHANES data from 2005 to 2010 reveals that among individuals over 50 with osteoporosis, Black women are less likely to receive treatment, including options like bisphosphonates, estrogen receptor modulators, teriparatide, calcitonin, or hormone replacement therapy, compared to White women or those from other racial backgrounds [109]. This discrepancy translates to a one-third to one-half reduction in the odds of Black patients receiving osteoporosis treatment [109–111]. In a Kaiser Permanente Southern California (KPSC) study, only 54.9% of Black women received therapy, compared to 63.9% for Asians, 72.0% for Hispanics, and 75.6% for Whites [103]. A survey of low-income Mexican–American women in Texas found that only 15% of premenopausal and 13% of postmenopausal participants recalled receiving osteoporosis counseling from healthcare providers, a significant factor influencing osteoporosis prevention in this group [112]. In general, osteoporosis medication utilization among males was notably lower compared to females, ranging from 11.1 to 35.0%. Black and Asian men had meager treatment rates at 11.1% and 13.3%, while Hispanic and White men had rates of 22.5% and 35.0%, respectively [103].

The disparity in osteoporosis treatment arises from several factors. Firstly, a lower prevalence of low bone mass or osteoporosis among Black patients than among White patients may

lead to under-recognition by healthcare providers. Socioeconomic status and treatment accessibility also play a role, with Black, Asian, and Hispanic populations facing reduced treatment likelihood. Language barriers, particularly in less-educated Asian and Hispanic people, hinder healthcare access. Medication cost and complexity can hinder treatment adherence, especially for patients with multiple comorbidities.

Research on Medication Effectiveness

Research on osteoporosis medication effectiveness has revealed racial and ethnic disparities. While bisphosphonates have proven effective in increasing BMD and reducing fractures in White women [113], data for minority women are limited. Black women are less likely to use antiresorptive medications like bisphosphonates than White women [114]. Studies suggest bisphosphonates are equally effective in the Asian population as in White [115, 116], but there is a lack of data for Hispanic people. Lower doses may suffice for pharmaceutical vitamin D treatments to prevent postmenopausal osteoporosis in the Asian population compared to White [117, 118], indicating potential sensitivity differences between the two ethnic groups. However, ethnicity-specific treatment recommendations require further research. Selective estrogen receptor modulators (SERMs) and recombinant human parathyroid hormone are FDA-approved for osteoporosis, but no race-specific effectiveness data are available.

Education

Reducing fracture risk necessitates addressing modifiable risk factors through lifestyle changes or medications, although biology also plays a significant role in bone health, especially in older Black and White women [119–123]. However, most intervention studies have primarily focused on White women, highlighting the need for more inclusive research spanning various ethnic groups, considering both biological and behavioral factors. Hispanic populations are diverse, with varying lifestyles, socioeconomic statuses, and genetic influences influencing BMD [124–126]. Factors like low calcium intake, physical inactivity, and higher smoking rates have been linked to lower BMD in some Hispanic subgroups, while others with higher activity levels and calcium intake exhibit higher BMD [58, 63•]. Healthcare disparities also impact BMD variability; Hispanics have reduced access to preventive healthcare and lower osteoporosis screening rates [104–106], potentially leading to underdiagnosis and undertreatment, ultimately affecting BMD levels. Language barriers further hinder bone health awareness and preventive measures.

Addressing racial disparities in osteoporosis management requires comprehensive awareness and screening programs. These programs should encompass educational initiatives targeting primary prevention and understanding of key bone health determinants: physical activity, nutrition, and hormonal status. Both healthcare providers, especially primary care physicians, and patients should receive this education. Public health efforts should also strategically target lifestyle factors and bridge educational gaps, particularly among minority populations, to work toward eliminating disparities in osteoporosis care.

Targeted Interventions to Reduce Disparities

Geriatric fracture programs aim to reduce disparities in managing fragility hip fractures by expediting surgery, facilitating collaboration between orthopedic surgeons and geriatric medicine physicians, standardizing care protocols, and involving social workers in discharge planning. Limited research suggests that these programs may help reduce surgery delay disparities based on gender or race [127], indicating the potential for standardized care pathways to address inequities in treating fragile hip fractures. Federal reimbursement policies, such as Comprehensive Care for Joint Replacement (CJR) [128] and Bundled Payments for Care Improvement Initiative (BPCI) [129], incentivize hospitals to provide high-quality, cost-effective care. Recent policy adjustments consider clinical and social risk factors to address disparities, but their impact on inequities in treating fragile hip fractures remains uncertain. Furthermore, the effects of such policies on fragility hip fractures not requiring arthroplasty, like BPCI Advanced, are unknown. Future research is essential to assess the influence of these policies on fragility hip fracture care disparities. In summary, both geriatric fracture programs and healthcare policies hold promise for reducing disparities in fragility hip fracture management, potentially enhancing care outcomes and equity.

Limitations of Existing Studies and Future Research Directions

Research on BMD and osteoporosis in diverse racial and cultural groups has limitations, including cross-sectional studies that do not track BMD changes over time or consider lifestyle factors and medical conditions. Lack of diversity in study populations hinders understanding of BMD variations. Multiethnic longitudinal studies are needed to explore BMD changes and risk factors among racial and ethnic minorities. Determining appropriate reference databases for defining osteoporosis in people of color is uncertain, as the standard WHO T-score [10] may lead to misdiagnosis due to skeletal differences [14, 19•, 130–135]. Methodological considerations, such as measurement sites and techniques [95, 96], may also influence results, particularly when comparing by race and ethnicity [97–100].

Future research should examine socioeconomic determinants, lifestyle variables, and comorbidities' impact on bone health in different racial and ethnic groups to inform public health policies. Addressing lifestyle factors in diagnoses and treatment recommendations can reduce disparities in osteoporosis care and promote bone health for all.

Conclusion

Racial and ethnic differences exist in BMD and osteoporosis prevalence, with non-Hispanic White individuals having higher rates than Black and Hispanic individuals. Lifestyle choices and genetic factors contribute to these variations. Obesity and diabetes increase osteoporosis risk, particularly affecting certain racial/ethnic groups disproportionately. Disparities extend to osteoporosis research, education, screening, and treatment. Enhancing BMD awareness and access to preventive measures is vital. Recognizing these differences informs clinical decisions and policymaking for targeted interventions and public health programs to reduce disparities. Improved screening and diagnostic methods can enable earlier intervention and better outcomes.

Funding The research and analysis described in the current publication were supported by a grant (R21MD013681) from the National Institute on Minority Health and Health Disparities and a grant (R01AG080017) from the National Institute on Aging. The funding sponsors were not involved in the analysis design, genotype imputation, data analysis, interpretation of the analysis results, or the preparation, review, or approval of this manuscript.

Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights All reported data from human studies performed and published by the authors previously complied with all applicable ethical standards and have been approved by the institutional review boards.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Wright NC, Looker AC, Saag KG, Curtis JR, Delzell ES, Randall S, et al. The recent prevalence of osteoporosis and low bone mass in the United States based on bone mineral density at the femoral neck or lumbar spine. J Bone Miner Res. 2014;29:2520–6.
2. Sözen T, Özışık L, Başaran NÇ. An overview and management of osteoporosis. Eur J Rheumatol. 2017;4:46–56.
3. Salari N, Ghasemi H, Mohammadi L, Behzadi M hasan, Rabieenia E, Shohaimi S, et al. The global prevalence of osteoporosis in the world: a comprehensive systematic review and meta-analysis. J Orthop Surg. 2021;16:609.
4. LeBoff MS, Greenspan SL, Insogna KL, Lewiecki EM, Saag KG, Singer AJ, et al. The clinician's guide to prevention and treatment of osteoporosis. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2022;33:2049–102.
5. Williams SA, Daigle SG, Weiss R, Wang Y, Arora T, Curtis JR. Economic burden of osteoporosis-related fractures in the US Medicare population. Ann Pharmacother. 2021;55:821–9.
6. Burge R, Dawson-Hughes B, Solomon DH, Wong JB, King A, Tosteson A. Incidence and economic burden of osteoporosis-related fractures in the United States, 2005–2025. J Bone Miner Res Off J Am Soc Bone Miner Res. 2007;22:465–75.
7. Rashki Kemmak A, Rezapour A, Jahangiri R, Nikjoo S, Farabi H, Soleimanpour S. Economic burden of osteoporosis in the world: a systematic review. Med J Islam Repub Iran. 2020;34:154.
8. Haseltine KN, Chukir T, Smith PJ, Jacob JT, Bilezikian JP, Farooki A. Bone mineral density: clinical relevance and quantitative assessment. J Nucl Med. 2021;62:446–54.
9. Watts NB, Adler RA, Bilezikian JP, Drake MT, Eastell R, Orwoll ES, et al. Osteoporosis in men: an endocrine society clinical practice guideline. J Clin Endocrinol Metab. 2012;97:1802–22.
10. Kanis JA. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis: synopsis of a WHO report. WHO Study Group. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 1994;4:368–81.
11. Looker AC, Orwoll ES, Johnston CC, Lindsay RL, Wahner HW, Dunn WL, et al. Prevalence of low femoral bone density in older US adults from NHANES III. J Bone Miner Res Off J Am Soc Bone Miner Res. 1997;12:1761–8.
12. Siris ES, Miller PD, Barrett-Connor E, Faulkner KG, Wehren LE, Abbott TA, et al. Identification and fracture outcomes of undiagnosed low bone mineral density in postmenopausal women: results from the National Osteoporosis Risk Assessment. JAMA. 2001;286:2815–22.
13. Cauley JA, Lui L-Y, Ensrud KE, Zmuda JM, Stone KL, Hochberg MC, et al. Bone mineral density and the risk of incident nonspinal fractures in black and white women. JAMA. 2005;293:2102–8.
14. Barrett-Connor E, Siris ES, Wehren LE, Miller PD, Abbott TA, Berger ML, et al. Osteoporosis and fracture risk in women of different ethnic groups. J Bone Miner Res. 2005;20:185–94.
15. Nam H-S, Kweon S-S, Choi J-S, Zmuda JM, Leung PC, Lui L-Y, et al. Racial/ethnic differences in bone mineral density among older women. J Bone Miner Metab. 2013;31:190–8.
16.• Xu Y, Wu Q. Decreasing trend of bone mineral density in US multiethnic population: analysis of continuous NHANES 2005–2014. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2018;29:2437–46. **An important study examined the trend and disparity in femur neck BMD in four NHANES cycles from 2005-2014.**
17.• Lewiecki EM, Wright NC, Singer AJ. Racial disparities, FRAX, and the care of patients with osteoporosis. Osteoporos Int. 2020;31:2069–71. **An important study examined the racial disparities in the FRAX tool and the care of patients among various races.**
18. Curtis JR, McClure LA, Delzell E, Howard VJ, Orwoll E, Saag KG, et al. Population-based fracture risk assessment and

osteoporosis treatment disparities by race and gender. J Gen Intern Med. 2009;24:956–62.

19.• Noel SE, Santos MP, Wright NC. Racial and ethnic disparities in bone health and outcomes in the United States. J Bone Miner Res. 2021;36:1881–905. **An important survey paper summarized the previous findings on BMD, fracture, and osteoporosis prevalence disparities among different races.**

20.• Looker AC, Sarafrazi Isfahani N, Fan B, Shepherd JA. Trends in osteoporosis and low bone mass in older US adults, 2005–2006 through 2013–2014. Osteoporos Int. 2017;28:1979–88. **An important study examined the trend and disparity on the proximal femur and lumbar spine BMD and osteoporosis prevalence in adults 50 years of age and older in four NHANES cycles from 2005-2014.**

21.•• Johannesdottir F, Putman MS, Burnett-Bowie S-AM, Finkelstein JS, Yu EW, Bouxsein ML. Age-related changes in bone density, microarchitecture, and strength in postmenopausal Black and White women: the SWAN longitudinal HR-pQCT study. J Bone Miner Res. 2022;37:41–51. **An important longitudinal study examined the trends and BMD disparities in White and Black Postmenopausal women in the US.**

22.•• Durdin R, Parsons C, Dennison EM, Williams S, Tillin T, Chaturvedi N, et al. Inflammatory status, body composition and ethnic differences in bone mineral density: the Southall and Brent Revisited study. Bone. 2022;155:116286. **An important tri-ethnic research examined BMD disparities in men and women from various ethnic backgrounds in the UK.**

23. Ahmad I, Jafar T, Mahdi F, Arshad Md, Das SK, Waliullah S, et al. Association of vitamin D receptor (FokI and BsmI) gene polymorphism with bone mineral density and their effect on 25-hydroxyvitamin D level in North Indian postmenopausal women with osteoporosis. Indian J Clin Biochem. 2018;33:429–37.

24. Nelson DA, Vord PJV, Wooley PH. Polymorphism in the vitamin D receptor gene and bone mass in African-American and white mothers and children: a preliminary report. Ann Rheum Dis. 2000;59:626–30.

25. Harris SS, Eccleshall TR, Gross C, Dawson-Hughes B, Feldman D. The vitamin D receptor start codon polymorphism (FokI) and bone mineral density in premenopausal American black and white women. J Bone Miner Res Off J Am Soc Bone Miner Res. 1997;12:1043–8.

26. Na T, Zhang W, Jiang Y, Liang Y, Ma H-P, Warnock DG, et al. The A563T variation of the renal epithelial calcium channel TRPV5 among African Americans enhances calcium influx. Am J Physiol-Ren Physiol. 2009;296:F1042–51.

27. Peng J-B. TRPV5 and TRPV6 in transcellular Ca2+ transport: regulation, gene duplication, and polymorphisms in African populations. In: Islam MdS, editor. Transient Recept Potential Channels [Internet]. Dordrecht: Springer Netherlands. 2011;239–75. Available from: https://doi.org/10.1007/978-94-007-0265-3_14.

28. Nguyen-Grozavu FT, Pierce JP, Sakuma K-LK, Leas EC, McMenamin S, Kealey S, et al. Widening disparities in cigarette smoking by race/ethnicity across education level in the United States. Prev Med. 2020;139:106220.

29. Laird E, O'Halloran AM, Carey D, Healy M, O'Connor D, Moore P, et al. The prevalence of vitamin D deficiency and the determinants of 25(OH)D concentration in older Irish adults: data from the Irish longitudinal study on ageing (TILDA). J Gerontol A Biol Sci Med Sci. 2018;73:519–25.

30. Sadler C, Huff M. African-American women: health beliefs, lifestyle, and osteoporosis. Orthop Nurs. 2007;26:96.

31. Kessenich CR. Osteoporosis and African-American women. Womens Health Issues Off Publ Jacobs Inst Womens Health. 2000;10:300–4.

32. National Center for Health Statistics (US). Health, United State, with chartbook on trends in the health of Americans. Hyattsville (MD): National Center for Health Statistics (US). 2005. Available from: https://www.cdc.gov/nchs/data/hus/hus05.pdf. Accessed26 Nov 2023

33. Briot K, Roux C. Glucocorticoid-induced osteoporosis. RMD Open. 2015;1:e000014.

34. Walker MD, Babbar R, Opotowsky AR, Rohira A, Nabizadeh F, Badia MD, et al. A referent bone mineral density database for Chinese American women. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2006;17:878–87.

35. Danielson ME, Beck TJ, Lian Y, Karlamangla AS, Greendale GA, Ruppert K, et al. Ethnic variability in bone geometry as assessed by hip structure analysis: findings from the hip strength across the menopausal transition study. J Bone Miner Res Off J Am Soc Bone Miner Res. 2013;28:771–9.

36. Walker MD, McMahon DJ, Udesky J, Liu G, Bilezikian JP. Application of high-resolution skeletal imaging to measurements of volumetric BMD and skeletal microarchitecture in Chinese-American and White women: explanation of a paradox. J Bone Miner Res. 2009;24:1953–9.

37. Morton DJ, Barrett-Connor E, Kritz-Silverstein D, Wingard DL, Schneider DL. Bone mineral density in postmenopausal Caucasian, Filipina, and Hispanic women. Int J Epidemiol. 2003;32(1):150–156. https://doi.org/10.1093/ije/dyg024.

38.•• Lo JC, Chandra M, Lee C, Darbinian JA, Ramaswamy M, Ettinger B. Bone mineral density in older U.S. Filipino, Chinese, Japanese, and White women. J Am Geriatr Soc. 2020;68:2656–61. **An important large-scale study examined the femur neck BMD disparities among Asian women.**

39.•• Cauley JA, Karlamangla AS, Ruppert K, Lian Y, Huang M, Harlow S, et al. Race/ethnic difference in trabecular bone score in midlife women: the Study of Women's Health Across the Nation (SWAN). Arch Osteoporos. 2021;16:91. **An important longitudinal study examined racial and ethnic disparities in trabecular bone scores in midlife women from various ethnic backgrounds in the US.**

40. Kepley AL, Nishiyama KK, Zhou B, Wang J, Zhang C, McMahon DJ, et al. Differences in bone quality and strength between Asian and Caucasian young men. Osteoporos Int. 2017;28:549–58.

41.•• Morin SN, Berger C, Liu W, Prior JC, Cheung AM, Hanley DA, et al. Differences in fracture prevalence and in bone mineral density between Chinese and White Canadians: the Canadian Multicentre Osteoporosis Study (CaMos). Arch Osteoporos. 2020;15:147. **An important study examined disparities in BMD and fracture prevalence between East Asian (Chinese) and White Canadians.**

42.•• Morin SN, Berger C, Papaioannou A, Cheung AM, Rahme E, Leslie WD, et al. Race/ethnic differences in the prevalence of osteoporosis, falls and fractures: a cross-sectional analysis of the Canadian Longitudinal Study on Aging. Osteoporos Int. 2022;33:2637–48. **An important longitudinal large-scale study consisting of both men and women examined disparities in BMD patterns and fracture prevalence in Canadians of various racial and ethnic backgrounds.**

43. Arai H, Miyamoto K, Taketani Y, Yamamoto H, Iemori Y, Morita K, et al. A vitamin D receptor gene polymorphism in the translation initiation codon: effect on protein activity and relation to bone mineral density in Japanese women. J Bone Miner Res Off J Am Soc Bone Miner Res. 1997;12:915–21.

44. Zengin A, Pye SR, Cook MJ, Adams JE, Wu FCW, O'Neill TW, et al. Ethnic differences in bone geometry between White, Black and South Asian men in the UK. Bone. 2016;91:180–5.

45. Zengin A, Prentice A, Ward KA. Ethnic differences in bone health. Front Endocrinol. 2015;6:24.

46. Finkelstein JS, Lee M-LT, Sowers M, Ettinger B, Neer RM, Kelsey JL, et al. Ethnic variation in bone density in premenopausal and early perimenopausal women: effects of anthropometric and lifestyle factors. J Clin Endocrinol Metab. 2002;87:3057–67.
47. Roy D, Swarbrick C, King Y, Pye S, Adams J, Berry J, et al. Differences in peak bone mass in women of European and South Asian origin can be explained by differences in body size. Osteoporos Int. 2005;16:1254–62.
48. Davis JW, Novotny R, Ross PD, Wasnich RD. The peak bone mass of Hawaiian, Filipino, Japanese, and white women living in Hawaii. Calcif Tissue Int. 1994;55:249–52.
49. Anal AK. Pandemics and innovative food systems. CRC Press; 2023. https://doi.org/10.1201/9781003191223.
50. Hodges JK, Cao S, Cladis DP, Weaver CM. Lactose intolerance and bone health: the challenge of ensuring adequate calcium intake. Nutrients. 2019;11:718.
51. Tan S, Ji L, Tsai J, Eng J, Ko H-J, Yau A, et al. Greater osteoporosis educational outreach is desirable among Chinese immigrants in Chinatown, Chicago. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2009;20:1517–22.
52. Huang H, Han G-Y, Jing L-P, Chen Z-Y, Chen Y-M, Xiao S-M. Tea consumption is associated with increased bone strength in middle-aged and elderly Chinese women. J Nutr Health Aging. 2018;22:216–21.
53. Li X, Qiao Y, Yu C, Guo Y, Bian Z, Yang L, et al. Tea consumption and bone health in Chinese adults: a population-based study. Osteoporos Int. 2019;30:333–41.
54. Osteoporosis Among Asian American Women - Wei-Chen Tung. 2012. Available from: https://doi.org/10.1177/1084822312441702.
55. Looker AC, Melton LJ, Harris TB, Borrud LG, Shepherd JA. Prevalence and trends in low femur bone density among older US adults: NHANES 2005–2006 compared with NHANES III. J Bone Miner Res. 2010;25:64–71.
56.• Noel SE, Mangano KM, Griffith JL, Wright NC, Dawson-Hughes B, Tucker KL. Prevalence of osteoporosis and low bone mass among Puerto Rican older adults. J Bone Miner Res Off J Am Soc Bone Miner Res. 2018;33:396–403. **An important study examined osteoporosis and low bone mass among Puerto Rican older adults.**
57. Gross C, Eccleshall TR, Malloy PJ, Villa ML, Marcus R, Feldman D. The presence of a polymorphism at the translation initiation site of the vitamin D receptor gene is associated with low bone mineral density in postmenopausal Mexican-American women. J Bone Miner Res. 1996;11:1850–5.
58. Tayie F, Wu C. Large bone not necessarily high bone mineral density: evidence from a national survey. Calcif Tissue Int. 2018;104:145–51.
59. Denova-Gutiérrez E, Clark P, Tucker KL, Muñoz-Aguirre P, Salmerón J. Dietary patterns are associated with bone mineral density in an urban Mexican adult population. Osteoporos Int. 2016;27:3033–40.
60. Nordin BE, Need AG, Morris HA, Horowitz M. The nature and significance of the relationship between urinary sodium and urinary calcium in women. J Nutr. 1993;123:1615–22.
61. Jones G, Beard T, Parameswaran V, Greenaway T, von Witt R. A population-based study of the relationship between salt intake, bone resorption and bone mass. Eur J Clin Nutr. 1997;51:561–5.
62. Heaney RP. Role of dietary sodium in osteoporosis. J Am Coll Nutr. 2006;25:271S-276S.
63.• Denova-Gutiérrez E, Méndez-Sánchez L, Muñoz-Aguirre P, Tucker KL, Clark P. Dietary patterns, bone mineral density, and risk of fractures: a systematic review and meta-analysis. Nutrients. 2018;10:1922. **An important systematic review study of dietary patterns on BMD and fracture risks.**
64. Valerio G, Gallè F, Mancusi C, Di Onofrio V, Guida P, Tramontano A, et al. Prevalence of overweight in children with bone fractures: a case control study. BMC Pediatr. 2012;12:166.
65. Dimitri P. The impact of childhood obesity on skeletal health and development. J Obes Metab Syndr. 2019;28:4.
66. Fritz J, Cöster ME, Nilsson J-Å, Rosengren BE, Dencker M, Karlsson MK. The associations of physical activity with fracture risk—a 7-year prospective controlled intervention study in 3534 children. Osteoporos Int. 2016;27:915–22.
67.• Campoverde Reyes KJ, Cody Stanford F, Singhal V, Animashaun AO, Bose A, Gleeson EL, et al. Bone density, microarchitecture and strength estimates in White versus African American youth with obesity. Bone. 2020;138:115514. **An interesting study examined the BMD and bone microarchitecture between White and African-American youth with obesity.**
68. Popp KL, Hughes JM, Martinez-Betancourt A, Scott M, Turkington V, Caksa S, et al. Bone mass, microarchitecture and strength are influenced by race/ethnicity in young adult men and women. Bone. 2017;103:200–8.
69. Misra M, Ackerman KE, Bredella MA, Stanford FC, Faje AT, Nordberg A, et al. Racial differences in bone microarchitecture and estimated strength at the distal radius and distal tibia in older adolescent girls: a cross-sectional study. J Racial Ethn Health Disparities. 2017;4:587–98.
70.• Bredella MA, Singhal V, Hazhir Karzar N, Animashaun A, Bose A, Stanford FC, et al. Racial differences in lumbar marrow adipose tissue and volumetric bone mineral density in adolescents and young adults with obesity. Bone Rep. 2020;13:100726. **An interesting study analyzed the disparities in volumetric BMD and lumbar marrow adipose tissue among Black and White young adults with obesity.**
71. de Liefde II, van der Klift M, de Laet CEDH, van Daele PLA, Hofman A, Pols H a. P. Bone mineral density and fracture risk in type-2 diabetes mellitus: the Rotterdam study. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2005;16:1713–20.
72. Thrailkill KM, Lumpkin CK, Bunn RC, Kemp SF, Fowlkes JL. Is insulin an anabolic agent in bone? Dissecting the diabetic bone for clues. Am J Physiol Endocrinol Metab. 2005;289:E735–45.
73. Dennison EM, Syddall HE, Aihie Sayer A, Craighead S, Phillips DIW, Cooper C. Type 2 diabetes mellitus is associated with increased axial bone density in men and women from the Hertfordshire cohort study: evidence for an indirect effect of insulin resistance? Diabetologia. 2004;47:1963–8.
74. Shin D, Kim S, Kim KH, Lee K, Park SM. Association between insulin resistance and bone mass in men. J Clin Endocrinol Metab. 2014;99:988–95.
75. Ohn JH, Kwak SH, Cho YM, Lim S, Jang HC, Park KS, et al. 10-year trajectory of β-cell function and insulin sensitivity in the development of type 2 diabetes: a community-based prospective cohort study. Lancet Diabetes Endocrinol. 2016;4:27–34.
76.• Xu Y, Wu Q. Trends in osteoporosis and mean bone density among type 2 diabetes patients in the US from 2005 to 2014. Sci Rep. 2021;11(1):3693. Available from: https://www.nature.com/articles/s41598-021-83263-4. **An important study analyzed the BMD and osteoporosis prevalence trends among type 2 diabetes patients.**
77. Ma L, Oei L, Jiang L, Estrada K, Chen H, Wang Z, et al. Association between bone mineral density and type 2 diabetes mellitus: a meta-analysis of observational studies. Eur J Epidemiol. 2012;27:319–32.
78. Zhu Q, Xu J, Zhou M, Lian X, Xu J, Shi J. Association between type 1 diabetes mellitus and reduced bone mineral density in children: a meta-analysis. Osteoporos Int. 2021;32:1143–52.

79. Jang M, Kim H, Lea S, Oh S, Kim JS, Oh B. Effect of duration of diabetes on bone mineral density: a population study on East Asian males. BMC Endocr Disord. 2018;18:61.
80. Shan P-F, Wu X-P, Zhang H, Cao X-Z, Gu W, Deng X-G, et al. Bone mineral density and its relationship with body mass index in postmenopausal women with type 2 diabetes mellitus in mainland China. J Bone Miner Metab. 2009;27:190–7.
81. Shaw C-K. An epidemiologic study of osteoporosis in Taiwan. Ann Epidemiol. 1993;3:264–71.
82. Shilbayeh S. Prevalence of osteoporosis and its reproductive risk factors among Jordanian women: a cross-sectional study. Osteoporos Int. 2003;14:929–40.
83. Torréns JI, Skurnick J, Davidow AL, Korenman SG, Santoro N, Soto-Greene M, et al. Ethnic differences in insulin sensitivity and beta-cell function in premenopausal or early perimenopausal women without diabetes: the Study of Women's Health Across the Nation (SWAN). Diabetes Care. 2004;27:354–61.
84. Ford ES, Giles WH, Dietz WH. Prevalence of the metabolic syndrome among US adults: findings from the third National Health and Nutrition Examination Survey. JAMA. 2002;287:356–9.
85. McKay HA, Petit MA, Khan KM, Schutz RW. Lifestyle determinants of bone mineral: a comparison between prepubertal Asian- and Caucasian-Canadian boys and girls. Calcif Tissue Int. 2000;66:320–4.
86. Boot AM, de Ridder MA, Pols HA, Krenning EP, de Muinck Keizer-Schrama SM. Bone mineral density in children and adolescents: relation to puberty, calcium intake, and physical activity. J Clin Endocrinol Metab. 1997;82:57–62.
87. Choksi P, Jepsen KJ, Clines GA. The challenges of diagnosing osteoporosis and the limitations of currently available tools. Clin Diabetes Endocrinol. 2018;4:12.
88. Yang Y, Hu X, Zhang Q, Zou R. Diabetes mellitus and risk of falls in older adults: a systematic review and meta-analysis. Age Ageing. 2016;45:761–7.
89. Kim JH, Choi HJ, Ku EJ, Kim KM, Kim SW, Cho NH, et al. Trabecular bone score as an indicator for skeletal deterioration in diabetes. J Clin Endocrinol Metab. 2015;100:475–82.
90. Schwartz AV, Hillier TA, Sellmeyer DE, Resnick HE, Gregg E, Ensrud KE, et al. Older women with diabetes have a higher risk of falls: a prospective study. Diabetes Care. 2002;25:1749–54.
91. Wilkins CH, Goldfeder JS. Osteoporosis screening is unjustifiably low in older African-American women. J Natl Med Assoc. 2004;96:461–7.
92. Miller RG, Ashar BH, Cohen J, Camp M, Coombs C, Johnson E, et al. Disparities in osteoporosis screening between at-risk African-American and white women. J Gen Intern Med. 2005;20:847–51.
93. Hamrick I, Steinweg KK, Cummings DM, Whetstone LM. Health care disparities in postmenopausal women referred for DXA screening. Fam Med. 2006;38:265–9.
94. Hamrick I, Cao Q, Agbafe-Mosley D, Cummings DM. Osteoporosis healthcare disparities in postmenopausal women. J Womens Health. 2012;21:1232–6.
95. Amarnath ALD, Franks P, Robbins JA, Xing G, Fenton JJ. Underuse and overuse of osteoporosis screening in a regional health system: a retrospective cohort study. J Gen Intern Med. 2015;30:1733–40.
96. Gillespie CW, Morin PE. Trends and disparities in osteoporosis screening among women in the United States, 2008–2014. Am J Med. 2017;130:306–16.
97. Nelson A. Unequal treatment: confronting racial and ethnic disparities in health care. J Natl Med Assoc. 2002;94:666–8.
98. Nesby-O'Dell S, Scanlon KS, Cogswell ME, Gillespie C, Hollis BW, Looker AC, et al. Hypovitaminosis D prevalence and determinants among African American and white women of reproductive age: third National Health and Nutrition Examination Survey, 1988–1994. Am J Clin Nutr. 2002;76:187–92.
99. Fiscella K, Franks P, Gold MR, Clancy CM. Inequality in quality: addressing socioeconomic, racial, and ethnic disparities in health care. JAMA. 2000;283:2579–84.
100. Schrager S, Kausch T, Bobula JA. Osteoporosis risk assessment by family practice faculty and residents: a chart review. WMJ Off Publ State Med Soc Wis. 1999;98:34–6.
101. Neuner JM, Zhang X, Sparapani R, Laud PW, Nattinger AB. Racial and socioeconomic disparities in bone density testing before and after hip fracture. J Gen Intern Med. 2007;22:1239–45.
102. Neuner JM, Binkley N, Sparapani RA, Laud PW, Nattinger AB. Bone density testing in older women and its association with patient age. J Am Geriatr Soc. 2006;54:485–9.
103. Navarro RA, Greene DF, Burchette R, Funahashi T, Dell R. Minimizing disparities in osteoporosis care of minorities with an electronic medical record care plan. Clin Orthop. 2011;469:1931–5.
104. Rangel Gómez MG, López Jaramillo AM, Svarch A, Tonda J, Lara J, Anderson EJ, et al. Together for health: an initiative to access health services for the Hispanic/Mexican population living in the United States. Front Public Health [Internet]. 2019 [cited 2023 Feb 5];7. Available from: https://doi.org/10.3389/fpubh.2019.00273.
105. Alcalá HE, Chen J, Langellier BA, Roby DH, Ortega AN. Impact of the affordable care act on health care access and utilization among Latinos. J Am Board Fam Med. 2017;30:52–62.
106. Oh H, Trinh MP, Vang C, Becerra D. Addressing barriers to primary care access for Latinos in the US: an agent-based model. J Soc Soc Work Res. 2020;11:165–84.
107. Vyas DA, Eisenstein LG, Jones DS. Hidden in plain sight—reconsidering the use of race correction in clinical algorithms. N Engl J Med. 2020;383:874–82.
108. Liu SK, Munson JC, Bell J-E, Zaha RL, Mecchella JN, Tosteson ANA, et al. Quality of osteoporosis care of older Medicare recipients with fragility fractures: 2006 to 2010. J Am Geriatr Soc. 2013;61:1855–62.
109. Cunningham TD, Di Pace BS, Ullal J. Osteoporosis treatment disparities: a 6-year aggregate analysis from national survey data. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2014;25:2199–208.
110. Jennings LA, Auerbach AD, Maselli J, Pekow PS, Lindenauer PK, Lee SJ. Missed opportunities for osteoporosis treatment in patients hospitalized for hip fracture. J Am Geriatr Soc. 2010;58:650–7.
111. Liu Z, Weaver J, de Papp A, Li Z, Martin J, Allen K, et al. Disparities in osteoporosis treatments. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2016;27:509–19.
112. Orces CH, Casas C, Lee S, Garci-Cavazos R, White W. Determinants of osteoporosis prevention in low-income Mexican-American women. South Med J. 2003;96:458–64.
113. Bell NH, Bilezikian JP, Bone HG, Kaur A, Maragoto A, Santora AC, et al. Alendronate increases bone mass and reduces bone markers in postmenopausal African-American women. J Clin Endocrinol Metab. 2002;87:2792–7.
114. Wei GS, Jackson JL, O'Malley PG. Postmenopausal osteoporosis risk management in primary care: how well does it adhere to national practice guidelines? J Am Med Womens Assoc. 1972;2003(58):99–104.
115. Kung AWC, Yeung SSC, Chu LW. The efficacy and tolerability of alendronate in postmenopausal osteoporotic Chinese women: a randomized placebo-controlled study. Calcif Tissue Int. 2000;67:286–90.

116. Wasnich RD, Ross PD, Thompson DE, Cizza G, Yates AJ. Skeletal benefits of two years of alendronate treatment are similar for early postmenopausal Asian and Caucasian women. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 1999;9:455–60.
117. Orimo H, Shiraki M, Hayashi Y, Hoshino T, Onaya T, Miyazaki S, et al. Effects of 1 alpha-hydroxyvitamin D3 on lumbar bone mineral density and vertebral fractures in patients with postmenopausal osteoporosis. Calcif Tissue Int. 1994;54:370–6.
118. Shikari M, Kushida K, Yamazaki K, Nagai T, Inoue T, Orimo H. Effects of 2 years' treatment of osteoporosis with 1 alpha-hydroxy vitamin D3 on bone mineral density and incidence of fracture: a placebo-controlled, double-blind prospective study. Endocr J. 1996;43:211–20.
119. Carter MI, Hinton PS. Physical activity and bone health. Mo Med. 2014;111:59–64.
120. Zhu J, March L. Treating osteoporosis: risks and management. Aust Prescr. 2022;45:150–7.
121. Kling JM, Clarke BL, Sandhu NP. Osteoporosis prevention, screening, and treatment: a review. J Womens Health. 2014;23:563–72.
122. Bliuc D, Tran T, van Geel T, Adachi JD, Berger C, van den Bergh J, et al. Reduced bone loss is associated with reduced mortality risk in subjects exposed to nitrogen bisphosphonates: a mediation analysis. J Bone Miner Res. 2019;34:2001–11.
123. Newcomb PA, Trentham-Dietz A, Hampton JM. Bisphosphonates for osteoporosis treatment are associated with reduced breast cancer risk. Br J Cancer. 2010;102:799–802.
124. Mattei J, Sotres-Alvarez D, Daviglus ML, Gallo LC, Gellman M, Hu FB, et al. Diet quality and its association with cardiometabolic risk factors vary by Hispanic and Latino ethnic background in the Hispanic community health study/study of Latinos. J Nutr. 2016;146:2035–44.
125. Siega-Riz AM, Sotres-Alvarez D, Ayala GX, Ginsberg M, Himes JH, Liu K, et al. Food-group and nutrient-density intakes by Hispanic and Latino backgrounds in the Hispanic community health study/study of Latinos. Am J Clin Nutr. 2014;99:1487–98.
126. Morales LS, Lara M, Kington RS, Valdez RO, Escarce JJ. Socioeconomic, cultural, and behavioral factors affecting Hispanic health outcomes. J Health Care Poor Underserved. 2002;13:477–503.
127. Parola R, Neal WH, Konda SR, Ganta A, Egol KA. No differences between White and non-White patients in terms of care quality metrics, complications, and death after hip fracture surgery when standardized care pathways are used. Clin Orthop Relat Res. 2023;481:324.
128. Comprehensive Care for Joint Replacement Model|CMS Innovation Center. 2021. Available from: https://innovation.cms.gov/innovation-models/cjr. Accessed 26 Nov 2023.
129. Bundled Payments for Care Improvement (BPCI) Initiative: General Information | CMS Innovation Center. 2021. Available from: https://innovation.cms.gov/innovation-models/bundled-payments. Accessed 26 Nov 2023.
130. Ho-Pham LT, T Nguyen UD, Pham HN, Nguyen ND, Nguyen TV. Reference ranges for bone mineral density and prevalence of osteoporosis in Vietnamese men and women. BMC Musculoskelet Disord. 2011;12:182.
131. Lo JC, Kim S, Chandra M, Ettinger B. Applying ethnic-specific bone mineral density T-scores to Chinese women in the USA. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2016;27:3477–84.
132. Chen KK, Wee S-L, Pang BWJ, Lau LK, Jabbar KA, Seah WT, et al. Bone mineral density reference values in Singaporean adults and comparisons for osteoporosis establishment–the Yishun Study. BMC Musculoskelet Disord. 2020;21:633.
133. Wu XP, Liao EY, Huang G, Dai RC, Zhang H. A comparison study of the reference curves of bone mineral density at different skeletal sites in native Chinese, Japanese, and American Caucasian women. Calcif Tissue Int. 2003;73:122–32.
134. Leslie WD. Ethnic differences in bone mass—clinical implications. J Clin Endocrinol Metab. 2012;97:4329–40.
135. Wilkin LD, Jackson MC, Sims TD, Haddock BL. Racial/ethnic differences in bone mineral density of young adults. Int J Exerc Sci. 2010;3:197–205.