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Sexual orientation-based disparities in bone health: Evidence of reduced bone mineral density and mineral content among sexual minority men but not women in multiple NHANES waves

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Abstract

Introduction: Sexual minority (SM) people experience significant stress associated with stigma, contributing to a higher rate of adverse health outcomes. Several known factors (eg, smoking) elevate risk of poor bone health, but to date little research has examined disparities in bone health among SM people. To address this, we analyzed sexual orientation differences in an available bone mineral density (BMD) cross-sectional dataset assessed via dual X-ray absorptiometry.

Methods: We combined the 2007 to 2008, 2009 to 2010, and 2013 to 2014 cycles of US National Health and Nutrition Examination Survey to examine sexual orientation-based differences in *z*-scored BMD in the proximal femur (greater trochanter and intertrochanter locations), bone mineral content (BMC) in the femur and spine, and osteoporosis risk among Lesbian/Gay (n = 53), Bisexual (n = 97), Same-Sex Experienced (n = 103), and Heterosexual (n = 2990) adults.

Results: Sexual orientation-based disparities in bone mass were observed across all anatomical sites. This effect was due to differences between heterosexual and gay men and persisted in linear regressions after adjusting for risk factors. We found differences in femoral and femoral neck BMC in heterosexual and gay men ($P = .02$) and in femoral, femoral neck and spinal BMC between heterosexual and bisexual women ($P = .05$). Sexual orientation remained significant in BMC regressions.

Conclusion: Our findings suggest that SM men but not women are at greater risk for poor bone health relative to heterosexuals and this disparity is independent of the lifestyle and psychosocial risks included in our models.

1 | INTRODUCTION

The maintenance of a healthy skeletal system enables mobility, protects from injury, and stores adequate amounts of minerals necessary for the normal functioning of other physiological systems and is essential for people to lead high-quality lives (OSG, 2004). Over 53 million Americans have been diagnosed with osteoporosis or are at elevated risk due to low bone mass (NIH, 2018). Osteoporosis is a noncommunicable disease

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characterized by low bone mass, structural deterioration of bony tissues, and compromised bone strength, which can result in greater bone fragility, fracture risk, and reduced mobility (Cosman et al., 2014). World Health Organization (WHO) assessment criteria define osteoporosis as a bone mineral density (BMD) that is 2.5 standard deviations or more below the average value for a young healthy person (a *T*-score of <−2.5 SD) (Kanis, 2002; Kanis et al., 2008; WHO, 1994).

Pathogenic bone loss during adulthood arises from the dysregulation and impairment of the bone remodeling cycle, where there is an imbalance between excess bone resorption and insufficient ossification of new bony tissue (Drake, Clarke, & Lewiecki, 2015). Lifestyle factors such as nutrition, physical activity levels, excess adiposity, and tobacco in adulthood can negatively affect the rate of bone turnover and bone loss (Cosman et al., 2014; Drake et al., 2015). Increasingly, research is recognizing the early life origins of osteoporosis and poor bone health during adulthood, highlighting the importance of optimizing peak bone mass (PBM) attainment (eg, achieving the full genetic potential for bone strength) throughout growth and development, which is critical for the maintenance of healthy bones in adulthood (Cooper, Harvey, Cole, Hanson, & Dennison, 2009; Heaney et al., 2000). PBM reflects the total acquisition of bone tissue attained in an individual by age 18 to 25 following the cessation of skeletal growth (Cosman et al., 2014). An adult's bone mass reflects the amount of bone loss since attainment of PBM (Cosman et al., 2014; Drake et al., 2015), which reflects the rate of bone metabolism or remodeling (Cosman et al., 2014; Drake et al., 2015; Kanis, 2002).

Although postmenopausal women have historically been identified as a major group at risk for osteoporosis and low BMD (Lorentzon & Cummings, 2015; Seeman, 2002), osteoporosis can affect any individual regardless of gender or ethnicity (OSG, 2004). Further, a number of socioeconomic, behavioral, and ecological factors can influence population variation in BMD and osteoporosis risk, including nutritional status, physical activity, psychosocial stress, and consumption of controlled substances (Bhattacharya, Shen, & Sambamoorthi, 2014; Cizza, Ravn, Chrousos, & Gold, 2001; Cosman et al., 2014; Eskandari et al., 2007). These social risk factors are not uniformly distributed, rather they arise out of particular cultural, socioeconomic and political contexts to influence health behaviors (Hernandez & Gibb, 2020), and therefore represent important sources of variation in bone health. For instance, sexual and gender minority people (individuals who identify as 2-Spirit, an indigenous spiritual identity including both feminine and masculine qualities; Lesbian; Gay; Bisexual; Trans; Queer; Intersex; and/or Asexual, commonly abbreviated as 2SLGBTQIA+) experience significant stress associated with discrimination, stigma, social exclusion, and hate-motivated violence (Juster, Vencill, & Johnson, 2017), as well as disproportionately high rates of mental and physical illness (Frost, Lehavot, & Meyer, 2015; Lick, Durso, & Johnson, 2013). These high rates of discriminatory stress and violence contribute to increased drug, alcohol, and tobacco use among sexual minority (SM) people and may also negatively impact bone health. To date very little research has examined bone health among persons of minority sexual orientations, independent of HIV infection (Diamant & Wold, 2003; Grijsen et al., 2013). As the global incidence of osteoporosis increases, it is critical to investigate the socioeconomic, psychosocial, and ecological risk factors for osteoporosis among individuals from marginalized and minority subpopulations in order to develop comprehensive policies that meet the needs of diverse communities.

In order to gain a better understanding of the factors influencing bone health among SM people we analyzed cross-sectional NHANES data that included BMD, BMC, SM status, and multiple social, economic, and behavioral risk factors. The primary goal of our analysis is to understand how these factors contribute to variability in skeletal health indicators based on participants' sexual orientation. We predict that (a) SM people will exhibit poorer indicators of skeletal health compared to their heterosexual peers and (b) that patterns of reduced BMD will be mediated by the higher prevalence of substance abuse and adverse mental health outcomes experienced by SM people.

2 | METHODS

2.1 | Study participants

The US National Health and Nutrition Examination Survey (NHANES) is a large cross-sectional study conducted annually by the National Center for Health Statistics (NCHS) at the US Centers for Disease Control and Prevention (CDC). The NCHS uses a complex multi-process sampling design to gain health information on a nationally representative population of non-institutionalized US residents. Written informed consent is obtained from all participants and is approved by the NCHS Research Ethics Review Board. Data, surveys, and methods are publicly accessible and available for download from the CDC's website.

Data from the 2007-2008, 2009-2010, and 2013-2014 NHANES cycles were combined to examine differences in *z*-scored BMD in the lumbar spine (L1-4 vertebrae), proximal femur (femoral head, greater trochanter, and

TABLE 1 Descriptive statistics for risk factors for study sample NHANES male participants

	Heterosexual (N = 1491)	Bisexual (N = 21)	Same-sex experienced (N = 33)	Lesbian/gay (N = 28)	Overall (N = 1573)
Age					
Mean (SD)	35.8 (8.79)	33.7 (9.81)	37.7 (7.65)	35.0 (7.54)	35.8 (8.76)
Median [Min, Max]	37.0 [20.0, 49.0]	32.0 [20.0, 49.0]	39.0 [22.0, 48.0]	35.0 [22.0, 48.0]	37.0 [20.0, 49.0]
Ethnicity					
Non-Hispanic White	701 (47.0%)	9 (42.9%)	18 (54.5%)	10 (35.7%)	738 (46.9%)
Hispanic	428 (28.7%)	5 (23.8%)	13 (39.4%)	9 (32.1%)	455 (28.9%)
Non-Hispanic Black	258 (17.3%)	7 (33.3%)	1 (3.0%)	7 (25.0%)	273 (17.4%)
Other	104 (7.0%)	0 (0%)	1 (3.0%)	2 (7.1%)	107 (6.8%)
BMI category					
Below 18.5	404 (27.1%)	8 (38.1%)	10 (30.3%)	13 (46.4%)	435 (27.7%)
18.5-24.9	12 (0.8%)	0 (0%)	1 (3.0%)	1 (3.6%)	14 (0.9%)
25.0-29.9	591 (39.6%)	9 (42.9%)	14 (42.4%)	10 (35.7%)	624 (39.7%)
30.0 and Above	484 (32.5%)	4 (19.0%)	8 (24.2%)	4 (14.3%)	500 (31.8%)
Trochanter BMD *z*-score					
Mean (SD)	0.276 (1.13)	0.188 (0.913)	0.0202 (1.19)	−0.581 (1.03)	0.254 (1.13)
Median [Min, Max]	0.201 [−8.29, 4.94]	0.270 [−1.87, 1.90]	−0.145 [−1.68, 4.58]	−0.753 [−2.14, 1.58]	0.189 [−8.29, 4.94]
Intertrochanter BMD *z*-score					
Mean (SD)	0.284 (1.01)	0.253 (0.943)	−0.0595 (1.02)	−0.358 (0.978)	0.265 (1.01)
Median [Min, Max]	0.260 [−4.03, 4.53]	0.119 [−1.38, 2.60]	−0.340 [−1.90, 2.71]	−0.311 [−2.29, 1.37]	0.236 [−4.03, 4.53]
Femoral neck BMD *z*-score					
Mean (SD)	0.0519 (1.05)	−0.000938 (0.764)	−0.341 (1.09)	−0.638 (1.05)	0.0307 (1.05)
Median [Min, Max]	0.000940 [−6.63, 5.13]	−0.0793 [−1.60, 1.30]	−0.533 [−2.40, 2.93]	−0.625 [−2.36, 2.62]	−0.0236 [−6.63, 5.13]
Femoral BMC *z*-score					
Mean (SD)	43.6 (7.61)	43.3 (5.75)	40.6 (8.02)	37.9 (7.91)	43.4 (7.64)
Median [Min, Max]	43.1 [20.3, 69.3]	43.7 [35.4, 54.5]	40.1 [27.6, 63.7]	38.4 [26.9, 55.0]	43.0 [20.3, 69.3]
Femoral neck BMC *z*-score					
Mean (SD)	5.08 (0.825)	5.13 (0.729)	4.69 (0.822)	4.56 (0.869)	5.06 (0.829)
Median [Min, Max]	5.01 [2.78, 8.34]	5.05 [3.62, 6.56]	4.62 [3.37, 6.88]	4.48 [2.76, 6.28]	5.00 [2.76, 8.34]
Spinal BMC *z*-score					
Mean (SD)	70.8 (12.6)	68.9 (11.7)	66.1 (11.2)	66.8 (12.6)	70.6 (12.6)
Median [Min, Max]	69.8 [38.0, 124]	66.6 [50.5, 100]	66.0 [43.4, 82.8]	66.0 [38.0, 90.3]	69.6 [38.0, 124]

(Continues)

TABLE 1 (Continued)

	Heterosexual (N = 1491)	Bisexual (N = 21)	Same-sex experienced (N = 33)	Lesbian/gay (N = 28)	Overall (N = 1573)
Family history of osteoporosis					
Negative	1400 (93.9%)	20 (95.2%)	33 (100%)	26 (92.9%)	1479 (94.0%)
Positive	91 (6.1%)	1 (4.8%)	0 (0%)	2 (7.1%)	94 (6.0%)
Income					
Mean (SD)	8.84 (4.31)	7.95 (5.30)	8.76 (4.15)	9.50 (4.58)	8.83 (4.32)
Median [Min, Max]	8.00 [1.00, 15.0]	7.00 [1.00, 15.0]	8.00 [3.00, 15.0]	9.00 [2.00, 15.0]	8.00 [1.00, 15.0]
Avg. calcium (mg)					
Mean (SD)	1110 (550)	1170 (535)	1230 (531)	1080 (535)	1110 (549)
Median [Min, Max]	1020 [39.5, 3210]	1130 [379, 2400]	1080 [479, 2530]	993 [235, 2210]	1020 [39.5, 3210]
Vitamin D					
Mean (SD)	59.0 (21.5)	58.6 (27.6)	60.4 (22.4)	49.2 (27.3)	58.8 (21.7)
Median [Min, Max]	57.8 [9.38, 147]	53.7 [16.3, 115]	58.8 [22.6, 131]	42.6 [4.86, 119]	57.8 [4.86, 147]
Minutes sedentary per day					
Mean (SD)	333 (206)	281 (222)	298 (188)	365 (230)	332 (206)
Median [Min, Max]	300 [0, 1080]	240 [20.0, 840]	240 [60.0, 660]	360 [30.0, 720]	300 [0, 1080]
HIV status					
Negative	1486 (99.7%)	16 (76.2%)	33 (100%)	24 (85.7%)	1559 (99.1%)
Positive	5 (0.3%)	5 (23.8%)	0 (0%)	4 (14.3%)	14 (0.9%)
Lifetime history of Marijuana/Hashish use					
Negative	604 (40.5%)	7 (33.3%)	6 (18.2%)	10 (35.7%)	627 (39.9%)
Positive	887 (59.5%)	14 (66.7%)	27 (81.8%)	18 (64.3%)	946 (60.1%)
Lifetime history of cocaine/heroin/methamphetamine use					
Negative	1143 (76.7%)	12 (57.1%)	17 (51.5%)	18 (64.3%)	1190 (75.7%)
Positive	348 (23.3%)	9 (42.9%)	16 (48.5%)	10 (35.7%)	383 (24.3%)
Current cigarette use					
Never	676 (45.3%)	7 (33.3%)	18 (54.5%)	10 (35.7%)	711 (45.2%)
Daily	634 (42.5%)	12 (57.1%)	10 (30.3%)	13 (46.4%)	669 (42.5%)
Some days	181 (12.1%)	2 (9.5%)	5 (15.2%)	5 (17.9%)	193 (12.3%)
Avg. # of drinks per day/past year					
Mean (SD)	3.98 (3.32)	5.29 (4.23)	2.91 (1.61)	2.64 (1.68)	3.95 (3.29)
Median [Min, Max]	3.00 [1.00, 25.0]	4.00 [2.00, 20.0]	3.00 [1.00, 7.00]	2.00 [1.00, 8.00]	3.00 [1.00, 25.0]

TABLE 1 (Continued)

	Heterosexual (N = 1491)	Bisexual (N = 21)	Same-sex experienced (N = 33)	Lesbian/gay (N = 28)	Overall (N = 1573)
Depression categories					
Minimal	1206 (80.9%)	15 (71.4%)	20 (60.6%)	21 (75.0%)	1262 (80.2%)
Mild	191 (12.8%)	3 (14.3%)	11 (33.3%)	6 (21.4%)	211 (13.4%)
Moderate	63 (4.2%)	1 (4.8%)	2 (6.1%)	1 (3.6%)	67 (4.3%)
Moderate/severe	25 (1.7%)	2 (9.5%)	0 (0%)	0 (0%)	27 (1.7%)
Severe	6 (0.4%)	0 (0%)	0 (0%)	0 (0%)	6 (0.4%)

intertrochanteric line) and osteoporosis risk factors among adults. We excluded those (a) above the age of 50 to avoid any confounding effect of menopause; and (b) missing data for sexuality, BMD and BMC, calcium intake, vitamin D3, sedentary activity, family history of osteoporosis, drug use, and BMI. Because of a high degree of missingness in the data due largely to NHANES methodology, DVs were checked for missingness not at random (MNAR) using linear regressions and flag variables. Smoking status, alcohol use, and depression were found to be MNAR and were multiply imputed using the mice() function in the *mice* package. This function uses multivariate imputation by chained equations to generate imputed values. After exclusion and imputation, a sample of 3243 adult (mean age = 36.2, range 20-49) SM people (n = 253) and heterosexuals (n = 2990) was used for analysis. Descriptive statistics for study sample male and female participants are shown in Tables 1 and 2.

2.2 | Bone health

Dual-energy X-ray absorptiometry (DXA) is available for the 2007-2008, 2009-2010, and 2013-2014 NHANES cycles. BMC (gm) and BMDs (g/cm^2) were measured by DXA (Hologic QDR 4500A fan-beam densitometer). Age, ethnicity, and sex matched BMD means, and standard deviations calculated from NHANES III data were used to calculate *z*-scores. Carey and Delaney (2010) state that *z*-scores are preferred over *t*-scores for premenopausal women and adult men. NHANES III values are typically used to calculate *z*-scores within DXA machines (Carey & Delaney, 2010).

2.3 | Sexual orientation

Beginning in 2001, the NHANES began assessing participant's sexual behavior and orientation identity for individuals 14 years and older. This included a detailed sexual history assessment as well as questions regarding whether respondents think of themselves as heterosexual or straight (ie, sexually attracted only to members of the opposite sex); homosexual or gay (ie, sexually attracted only to the same sex); bisexual (ie, sexually attracted to males and females); something else; or you are not sure. Combining these enabled inclusions of individuals who may not identify with prevailing sexual orientation identity categories but engage in non-heterosexual sexual behavior. Following the approach outlined by Mays, Juster, Williamson, Seeman, and Cochran (2018), participants were grouped as follows: (a) participants who reported identifying as gay or lesbian, regardless of sexual

TABLE 2 Descriptive statistics for risk factors for study sample NHANES female participants

	Heterosexual (N = 1499)	Bisexual (N = 76)	Same-sex experienced (N = 70)	Lesbian/gay (N = 25)	Overall (N = 1670)
Age					
Mean (SD)	36.9 (8.67)	32.6 (9.22)	35.4 (8.72)	35.8 (8.38)	36.6 (8.74)
Median [Min, Max]	39.0 [20.0, 49.0]	32.0 [20.0, 49.0]	36.0 [20.0, 49.0]	39.0 [20.0, 49.0]	39.0 [20.0, 49.0]
Ethnicity					
Non-Hispanic White	698 (46.6%)	40 (52.6%)	38 (54.3%)	12 (48.0%)	788 (47.2%)
Hispanic	460 (30.7%)	11 (14.5%)	15 (21.4%)	5 (20.0%)	491 (29.4%)
Non-Hispanic Black	238 (15.9%)	19 (25.0%)	15 (21.4%)	7 (28.0%)	279 (16.7%)
Other races	103 (6.9%)	6 (7.9%)	2 (2.9%)	1 (4.0%)	112 (6.7%)
BMI category					
Below 18.5	548 (36.6%)	24 (31.6%)	18 (25.7%)	10 (40.0%)	600 (35.9%)
18.5–24.9	32 (2.1%)	3 (3.9%)	1 (1.4%)	0 (0%)	36 (2.2%)
25.0–29.9	433 (28.9%)	13 (17.1%)	30 (42.9%)	5 (20.0%)	481 (28.8%)
30.0 and Above	486 (32.4%)	36 (47.4%)	21 (30.0%)	10 (40.0%)	553 (33.1%)
Trochanter BMD *z*-score					
Mean (SD)	0.165 (1.08)	0.382 (1.32)	0.362 (1.18)	0.576 (1.20)	0.189 (1.10)
Median [Min, Max]	0.149 [−3.21, 5.45]	0.242 [−2.54, 3.75]	0.221 [−1.76, 3.31]	0.571 [−1.46, 3.55]	0.160 [−3.21, 5.45]
Intertrochanter BMD *z*-score					
Mean (SD)	0.105 (1.03)	0.284 (1.15)	0.242 (0.909)	0.318 (0.954)	0.123 (1.03)
Median [Min, Max]	0.0891 [−3.85, 9.40]	0.181 [−1.98, 3.09]	0.154 [−1.94, 2.41]	0.250 [−1.43, 1.89]	0.108 [−3.85, 9.40]
Femoral neck BMD *z*-score					
Mean (SD)	0.0393 (1.04)	0.290 (1.23)	0.112 (0.941)	0.272 (1.06)	0.0572 (1.04)
Median [Min, Max]	−0.0134 [−3.57, 3.98]	0.289 [−2.12, 3.43]	−0.000734 [−1.85, 2.78]	0.581 [−1.87, 2.00]	0.00612 [−3.57, 3.98]
Femoral BMC *z*-score					
Mean (SD)	30.1 (5.37)	32.8 (6.47)	30.6 (5.10)	31.8 (5.64)	30.2 (5.45)
Median [Min, Max]	29.8 [14.6, 67.6]	32.8 [20.2, 47.0]	29.9 [19.7, 44.0]	32.8 [19.8, 39.1]	29.9 [14.6, 67.6]
Femoral neck BMC *z*-score					
Mean (SD)	4.07 (0.668)	4.42 (0.806)	4.09 (0.579)	4.25 (0.720)	4.09 (0.676)
Median [Min, Max]	4.03 [2.06, 6.57]	4.36 [2.64, 6.12]	4.09 [2.84, 5.37]	4.19 [3.00, 5.61]	4.04 [2.06, 6.57]
Spinal BMC *z*-score					
Mean (SD)	59.4 (10.3)	64.7 (13.1)	61.8 (9.67)	63.6 (10.5)	59.8 (10.5)
Median [Min, Max]	58.9 [20.3, 97.8]	64.5 [37.8, 115]	62.3 [44.3, 85.4]	61.5 [48.1, 80.1]	59.2 [20.3, 115]

TABLE 2 (Continued)

	Heterosexual (N = 1499)	Bisexual (N = 76)	Same-sex experienced (N = 70)	Lesbian/gay (N = 25)	Overall (N = 1670)
Family history of osteoporosis					
Negative	1315 (87.7%)	65 (85.5%)	62 (88.6%)	24 (96.0%)	1466 (87.8%)
Positive	184 (12.3%)	11 (14.5%)	8 (11.4%)	1 (4.0%)	204 (12.2%)
Income					
Mean (SD)	8.81 (4.45)	8.14 (4.60)	8.23 (4.13)	7.56 (3.92)	8.73 (4.44)
Median [Min, Max]	8.00 [1.00, 15.0]	7.00 [1.00, 15.0]	7.00 [2.00, 15.0]	8.00 [2.00, 15.0]	8.00 [1.00, 15.0]
Avg. calcium (mg)					
Mean (SD)	862 (410)	885 (425)	933 (432)	901 (373)	867 (411)
Median [Min, Max]	812 [91.0, 3090]	776 [215, 2610]	879 [312, 2440]	850 [364, 1710]	814 [91.0, 3090]
Vitamin D					
Mean (SD)	60.5 (26.6)	56.4 (26.9)	62.4 (25.1)	56.8 (19.9)	60.4 (26.5)
Median [Min, Max]	57.7 [6.12, 150]	54.6 [15.5, 133]	60.5 [15.4, 144]	57.4 [24.4, 107]	57.7 [6.12, 150]
Minutes sedentary per day					
Mean (SD)	324 (201)	390 (240)	388 (224)	355 (197)	330 (205)
Median [Min, Max]	300 [1.00, 1080]	330 [2.00, 1080]	360 [60.0, 900]	300 [60.0, 720]	300 [1.00, 1080]
HIV status					
Negative	1497 (99.9%)	76 (100%)	70 (100%)	25 (100%)	1668 (99.9%)
Positive	2 (0.1%)	0 (0%)	0 (0%)	0 (0%)	2 (0.1%)
Lifetime history of Marijuana/Hashish use					
Negative	808 (53.9%)	14 (18.4%)	10 (14.3%)	4 (16.0%)	836 (50.1%)
Positive	691 (46.1%)	62 (81.6%)	60 (85.7%)	21 (84.0%)	834 (49.9%)
Lifetime history of cocaine/heroin/methamphetamine use					
Negative	1331 (88.8%)	50 (65.8%)	38 (54.3%)	16 (64.0%)	1435 (85.9%)
Positive	168 (11.2%)	26 (34.2%)	32 (45.7%)	9 (36.0%)	235 (14.1%)
Current cigarette use					
Never	724 (48.3%)	24 (31.6%)	22 (31.4%)	7 (28.0%)	777 (46.5%)
Daily	589 (39.3%)	37 (48.7%)	42 (60.0%)	16 (64.0%)	684 (41.0%)
Some Days	186 (12.4%)	15 (19.7%)	6 (8.6%)	2 (8.0%)	209 (12.5%)
Avg. # of drinks per day/past year					
Mean (SD)	2.47 (2.05)	3.07 (2.61)	2.59 (1.83)	2.84 (1.93)	2.51 (2.07)
Median [Min, Max]	2.00 [1.00, 20.0]	2.00 [1.00, 16.0]	2.00 [1.00, 10.0]	2.00 [1.00, 8.00]	2.00 [1.00, 20.0]

(Continues)

TABLE 2 (Continued)

	Heterosexual (N = 1499)	Bisexual (N = 76)	Same-sex experienced (N = 70)	Lesbian/gay (N = 25)	Overall (N = 1670)
Depression categories					
Minimal	1088 (72.6%)	36 (47.4%)	40 (57.1%)	16 (64.0%)	1180 (70.7%)
Mild	251 (16.7%)	23 (30.3%)	19 (27.1%)	4 (16.0%)	297 (17.8%)
Moderate	102 (6.8%)	11 (14.5%)	7 (10.0%)	3 (12.0%)	123 (7.4%)
Moderate/severe	41 (2.7%)	4 (5.3%)	3 (4.3%)	0 (0%)	48 (2.9%)
Severe	17 (1.1%)	2 (2.6%)	1 (1.4%)	2 (8.0%)	22 (1.3%)

history (n = 53); (b) participants who identified as bisexual, regardless of sexual history (n = 97); (c) participants reporting a heterosexual identity but who engaged in sexual behavior with a member of the same sex (n = 103); (d) participants reporting a heterosexual identity, and who engage in exclusively heterosexual behavior, with no reports of same-sex sexual partners (n = 2990). These categories do not overlap. Individuals were excluded if they reported something else, not sure, do not know or refused to respond,

2.4 | Mental health indicators

Depression severity was measured using the Patient Health Questionnaire 9 item depression scale (PHQ-9), which is a widely used tool to assess depression in both clinical and research settings (Kroenke & Spitzer, 2002). The diagnostic validity of the scale has been previously established (Kroenke et al., 2001) with scores >10 having both a sensitivity and specificity of 88% for major depressive disorder (MDD). Internal consistency in two different patient populations was >0.85 (Kroenke et al., 2001) and measured 0.87 in our sample. Increased PHQ-9 scores have been associated with worse functional health status, self-reported disability days, clinic visits, and other measures supporting its construct validity (Kroenke et al., 2001). Summed scores range from 0-27 and can be subdivided into depression severity categories (0-4 = none, 5-9 = mild depression, 10-14 = moderate depression, 15-19 = moderately severe depression, 20-27 = severe depression) (Kroenke & Spitzer, 2002).

2.5 | Covariates

Family history of osteoporosis was determined based on responses to the question "Including living and deceased, were either of your biological parents ever told by a health professional that they had osteoporosis or brittle bones?" Average calcium intake (mg.) was calculated based on 2 days of dietary intake data. Quantitative detection of serum vitamin D3 (25-hydroxyvitamin D3) was determined using ultra-high performance liquid chromatography tandem mass spectrometry. These data reflect the types and amounts of foods and beverages consumed within a 24-hour period. Data for the first day was collected in-person in the NHANES Mobile Examination Center while data for the second 24-hour period was collected by phone 3-10 days after examination. Total nutrient intake values were calculated by NHANES for all foods/beverages consumed using the USDA's Food and

Nutrient Database for Dietary Studies. Typical sedentary minutes per day was assessed by asking the participant about time spent sitting or reclining at work, home, and school, and includes activities such as traveling by car, watching television, and using a computer. HIV status was determined by enzyme immunoassay (EIA) and confirmed by Western blot (WB). An HIV+ status was defined as a positive EIA and a positive WB. Lifetime history of marijuana/hashish and cocaine/heroin/methamphetamine use was determined by self-report. Current cigarette smoking status was classified as every day, some days, or not at all by self-report. Body mass index (BMI) was calculated in the NHANES data as kg/m2.

2.6 | Data analysis

All statistical analyses were conducted using R v 3.5.1 (R Core Team, 2018). Separate analysis was performed on participants based on sex. Descriptive statistics were used to characterize participants by sexual orientation. Shapiro-Wilk tests were used to assess normality of continuous variables. ANOVAs or Kruskal-Wallis tests were used to assess differences between sexualities for BMD *z*-scores, sedentary minutes, and average drinks per day in the past year. Fisher's exact tests using Monte Carlo simulations (n = 2000) to compute p values were used to compare differences in categorical and ordinal variables. Multiple OLS regression analysis was used to assess the relationship between sexual orientation and covariates in predicting BMD *z*-scores and BMC scores. The check_model() function of the *performance* package was used to assess model performance. Linear relationships between DVs and continuous IVs were visually verified using scatterplots. Clustered standard errors are reported to account for homogeneity within survey strata; standardized betas are reported for continuous variables. Significance was set at $P < .05$. All p values are reported.

2.7 | Ethics review

This analysis was exempt from review by Institutional Research Ethics Board. NHANES data is publicly available and are de-identified for secondary data analysis. Informed consent is collected from each NHANES participant during data collection. The NHANES was approved by the National Center for Health Statistics Research Ethics Review Board and is held under the requirements of the Public Health Service Act (42 USC 242 k) and the Privacy Act of 1974 (5 USC 552A) to conserve the privacy of participant identities.

3 | RESULTS

3.1 | Sexual orientation differences in risk factors

Descriptive statistics for risk factors by sexuality in men only are presented in Table 1. Comparing risk factors across sexualities, we found a significant difference with regard to HIV status by Fisher's Exact Test ($P < .001$), likely driven by the relatively elevated number of positive cases in bisexual and gay men (Table 1). Differences in lifetime use of hard drugs (cocaine, heroin, and/or methamphetamine) were also found ($P < .001$) as were differences in alcohol consumption ($\chi^2 = 10.76$, $P = .01$). Pairwise post-hoc tests showed differences between heterosexual and bisexual (adj. $P = .05$), bisexual and same-sex experienced (adj. $P = .02$), heterosexual and gay (adj. $P = .05$), and bisexual and gay (adj. $P = .01$) (Table 1).

Table 2 presents descriptive statistics for risk factors in women. Age was significantly different between heterosexuals and bisexuals (Table 3; $\chi^2 = 18.75$, $P < .001$, post-hoc adj. $P < .001$). Significant differences were found for sedentary minutes ($\chi^2 = 11.12$, $P = .01$) but no between group differences survived post-hoc *P* value adjustment. Fisher's exact tests revealed a difference in the distribution of lifetime marijuana/hashish use ($P < .001$), cocaine/heroin/methamphetamine use ($P < .001$), and smoking status ($P < .001$) between sexualities. Finally, depression category distributions varied between sexualities ($P < .001$).

3.2 | Sexual orientation and sex differences in BMD *z*-scores

Bone mineral density *z*-scores for all three anatomical locations were non-normal by Shapiro-Wilk tests ($P < .001$ for all). There were significant differences by sexual orientation in the trochanter ($\chi^2 = 18.06$, $P = .0004$), inter-trochanter ($\chi^2 = 14.75$, $P = .002$), and femoral neck ($\chi^2. = 16.77$, $P = .008$) *z*-scores in men only. Post-hoc Dunn tests with Benjamini-Hochberg correction for multiple tests found significant differences in trochanter *z*-scores between heterosexual men (mean = 0.28, SD = 1.13) and gay men (mean = −0.58, SD = 1.03) (adj. $P = .0006$) and bisexual (mean = 0.19, SD = 0.91) and gay men (adj. $P = .05$). Similarly, significant differences were found between heterosexual men (mean = 0.284, SD = 1.01) and gay men (mean = −0.36, SD = 0.98) in inter-trochanter *z*-scores (adj. $P = 0.01$) and femoral neck *z* scores (mean = 0.05 and SD = 1.05, mean = −0.64 and

TABLE 3 Bone mineral density *z*-score models for study sample NHANES male participants

	Dependent variable		
	Intertrochanter	**Trochanter**	**Femoral neck**
Bisexual[d]	0.126	0.044	0.021
	(0.211)	(0.206)	(0.159)
Same-sex experienced	−0.291*	−0.215	−0.376**
	(0.114)	(0.188)	(0.132)
Lesbian/gay	−0.357	−0.578**	−0.423**
	(0.186)	(0.181)	(0.164)
Age (standardized)	0.002	0.043	0.004
	(0.026)	(0.025)	(0.025)
BMI < 18.5[a]	−1.170***	−0.958***	−1.105***
	(0.247)	(0.191)	(0.181)
BMI 25-30	0.488***	0.426***	0.415***
	(0.066)	(0.067)	(0.078)
BMI > 30	0.836***	0.726***	0.833***
	(0.069)	(0.068)	(0.078)
Hispanic[b]	0.042	0.063	−0.104
	(0.053)	(0.071)	(0.062)
Non-Hispanic Black	−0.034	0.086	0.037
	(0.073)	(0.079)	(0.080)
Non-Hispanic Other	0.164	−0.014	−0.093
	(0.107)	(0.132)	(0.125)
Household income (standardized)	0.057	0.068*	0.059*
	(0.032)	(0.033)	(0.028)
Family history of osteoporosis[c]	−0.402***	−0.431***	−0.442***
	(0.091)	(0.121)	(0.096)
Avg. calcium (standardized)	0.068*	0.090**	0.103***
	(0.027)	(0.030)	(0.025)
Vit. D (standardized)	0.072	0.122*	0.111*
	(0.042)	(0.052)	(0.048)
Sedentary minutes (standardized)	−0.053	−0.033	−0.052
	(0.038)	(0.043)	(0.038)
HIV positive[e]	−0.199	−0.200	−0.070
	(0.269)	(0.320)	(0.344)
Ever used marijuana[f]	0.034	0.058	0.050
	(0.053)	(0.062)	(0.053)
Ever used hard drugs[g]	−0.059	−0.064	0.022
	(0.071)	(0.083)	(0.076)
Daily smoker[f]	−0.003	−0.050	0.003
	(0.048)	(0.054)	(0.048)
Some days smoker	−0.046	−0.153	−0.146
	(0.073)	(0.087)	(0.076)
Avg. # drinks/session/year (standardized)	0.018	0.022	0.020
	(0.020)	(0.017)	(0.019)

TABLE 3 (Continued)

	Dependent variable		
	Intertrochanter	**Trochanter**	**Femoral neck**
Mild depression[g]	−0.074	−0.128	0.006
	(0.072)	(0.083)	(0.078)
Moderate depression	−0.152	−0.250*	−0.082
	(0.148)	(0.113)	(0.115)
Moderate/severe depression	−0.224	−0.207	−0.312
	(0.204)	(0.253)	(0.190)
Severe depression	−0.262	−0.569*	−0.439
	(0.345)	(0.282)	(0.269)
R^2	0.158	0.126	0.156
Adjusted R^2	0.145	0.112	0.142
Residual std. error	0.934 (df = 1547)	1.063 (df = 1547)	0.976 (df = 1547)
F statistic	11.648*** (df = 25; 1547)	8.960*** (df = 25; 1547)	11.421*** (df = 25; 1547)

*$P < .05$.
**$P < .01$.
***$P < .001$.
[a]Reference group: 18.5-25.2.
[b]Reference group: white.
[c]Reference group: no family history of osteoporosis.
[d]Reference group: heterosexual.
[e]Reference group: HIV negative.
[f]Reference group: never used.
[g]Reference group: no depression.

SD = 1.05, respectively, adj. $P = .002$). There were no significant differences in *z*-scores for any anatomical location in women. Because of this, we limited further analyses of *z*-scores to men only.

Linear regressions showed that gay sexual identity was significantly associated with lower inter-trochanter and trochanter BMD *z*-scores in men (Tables 3). Low, moderate, and high BMI categories were significantly associated with *z*-scores across all models in both anatomical locations, relative to BMIs between 18.5 and 25. A positive family history of osteoporosis was also significantly and negatively associated with BMD *z*-scores in both sites. Occasional smoking was associated with reduced trochanter BMD, and moderate depression was negatively associated with *z*-scores ($b = -0.1$, $P < .01$). There were no changes to estimates or p values of non-sexuality predictors when using bisexuals as a reference category; the statistical differences between bisexual and homosexual men in trochanter BMD values persisted (results not shown). More minutes spent sedentary was negatively associated with inter-trochanter BMD (Table 3).

3.3 | Sexual orientation and sex differences in BMC values

We found a significant difference between heterosexual (mean = 43.6, SD = 7.61) and gay men (mean = 37.9, SD = 7.91; $\chi^2 = 17.97$, $P = .0004$; post-hoc adj. $P = .002$) and bisexual (mean = 43.3, SD = 5.75) and gay men in femur BMC values (post-hoc adj. $P = .04$). We also found significant pairwise differences ($\chi^2 = 14.99$, $P = .002$) between heterosexual (mean = 5.08, SD = 0.85) and same-sex experienced men (mean = 4.69, SD = 0.82; adj. $P = .03$), heterosexual and gay men (mean = 4.56, SD = 0.87; adj. $P = .02$), and bisexual (mean = 5.13, SD = 0.729) and gay men (adj. $P = .04$) in femoral neck BMC.

In women, significant differences in femur, femoral neck, and spine BMC values were found ($\chi^2 = 15.90$, $P = .001$; $\chi^2 = 15.72$, $P = .001$; and $\chi^2 = 19.23$, $P = .0002$, respectively). Femoral BMC values differed between heterosexual (mean = 30.1, SD = 5.37) and bisexual women (mean = 32.8, SD = 6.47; adj. $P = .002$). Femoral neck BMC values also differed between heterosexuals (mean = 4.07, SD = 0.67) and bisexuals (mean = 4.42,

TABLE 4 Bone mineral content models for study sample NHANES male participants

	Dependent variable	
	Femoral	**Femoral neck**
Bisexual[d]	0.214	0.007
	(1.200)	(0.140)
Same-Sex experienced	−2.229*	−0.255*
	(1.065)	(0.103)
Lesbian/Gay	−3.600*	−0.345*
	(1.436)	(0.156)
Age (standardized)	−0.398	−0.237***
	(0.234)	(0.018)
BMI < 18.5[a]	−10.839***	−1.022***
	(1.072)	(0.124)
BMI 25–30	2.743***	0.301***
	(0.445)	(0.054)
BMI > 30	5.658***	0.612***
	(0.523)	(0.055)
Hispanic[b]	−0.700	−0.036
	(0.496)	(0.051)
Non-Hispanic Black	2.938***	0.497***
	(0.519)	(0.064)
Non-Hispanic Other	−1.358*	−0.036
	(0.631)	(0.079)
Household Income (standardized)	0.305	0.037
	(0.193)	(0.022)
Family history of osteoporosis[c]	−2.426**	−0.281***
	(0.836)	(0.075)
Avg. calcium (standardized)	1.097***	0.104***
	(0.186)	(0.020)
Vit. D (standardized)	0.939**	0.089**
	(0.300)	(0.034)
Sedentary minutes (standardized)	−0.191	−0.032
	(0.262)	(0.027)
HIV positive[e]	−2.450	−0.198
	(2.169)	(0.284)
Ever used marijuana[f]	1.195**	0.088*
	(0.413)	(0.042)
Ever used hard drugs[f]	−0.668	−0.009
	(0.516)	(0.056)
Daily smoker[f]	0.174	0.025
	(0.388)	(0.035)
Some days smoker	−0.804	−0.105
	(0.547)	(0.056)

TABLE 4 (Continued)

	Dependent variable	
	Femoral	**Femoral neck**
Avg. # drinks/session/year (standardized)	0.004	0.009
	(0.164)	(0.016)
Mild depression[g]	−0.838	−0.041
	(0.551)	(0.061)
Moderate depression	−1.984*	−0.148
	(0.892)	(0.086)
Moderate/severe depression	−2.501	−0.248
	(1.576)	(0.139)
Severe depression	−2.896	−0.440
	(1.921)	(0.230)
R^2	0.190	0.243
Adjusted R^2	0.177	0.231
Residual std. error	6.935 (df = 1547)	0.727 (df = 1547)
F statistic	14.490*** (df = 25; 1547)	19.917*** (df = 25; 1547)

*$P < .05$.
**$P < .01$.
***$P < .001$.
[a]Reference group: 18.5-25.2.
[b]Reference group: white.
[c]Reference group: no family history of osteoporosis.
[d]Reference group: heterosexual.
[e]Reference group: HIV negative.
[f]Reference group: never used.
[g]Reference group: no depression.

SD = 0.81; adj. $P = .001$), as did spinal BMC values (mean = 59.4, SD = 10.3 and mean = 64.7, SD = 13.1, respectively; adj. $P = .001$).

We used linear regression to analyze femoral and femoral neck BMC in men (Tables 4) as well as femoral, femoral neck and spinal BMC in women (Tables 5). BMI, family history of osteoporosis, non-Hispanic black ethnicity, and calcium intake were significantly associated with femoral BMC in men (Table 4). Lifetime marijuana use was associated with increased BMC, contrary to predictions, and severe depression was negatively associated with BMC. Calcium intake, vitamin D status, same-sex experienced, and lifetime marijuana use were significant femoral neck BMC in men. Age, BMI, and ethnicity were significant for female participants the femoral neck BMC. BMI, ethnicity, household income, average calcium, vitamin D status, and a bisexual sexual identity were all significant female participants the femoral BMC. BMI, ethnicity, household income, and a bisexual sexual identity were all significant for female participants the spinal BMC. Sexuality remained a significant predictor of femoral BMC when using bisexuals as the reference group. There were no other changes to the estimates and p values in Tables 4 and 5 in the releveled model (results not shown).

4 | DISCUSSION

4.1 | Male sexual orientation and bone health

In our analysis of NHANES data, we found that gay men, but not bisexual males or SM females, were characterized by lower *z*-scored BMD values in their trochanter, intertrochanter and femoral neck regions. No other significant differences were found in BMD values from other anatomical sites. Significant differences in femoral and femoral neck BMC values were also identified between heterosexuals and gay males. Our results are consistent with prior research documenting a pattern of reduced BMD among SM males (Grijsen et al., 2013). The BMD

TABLE 5 Bone mineral content models for study sample NHANES female participants

	Dependent variable		
	Femoral neck	**Femur**	**Spine**
Bisexual[d]	0.206*	2.058***	4.589**
	(0.084)	(0.623)	(1.436)
Same-sex experienced	−0.057	−0.069	1.694
	(0.055)	(0.515)	(1.097)
Lesbian/gay	0.095	1.281	3.599
	(0.160)	(1.219)	(2.108)
Age (standardized)	−0.129***	−0.052	0.325
	(0.020)	(0.126)	(0.277)
BMI < 18.5[a]	−0.386***	−3.774***	−3.510
	(0.097)	(0.896)	(1.946)
BMI 25–30	0.258***	2.231***	1.251*
	(0.038)	(0.322)	(0.529)
BMI > 30	0.591***	4.482***	2.187***
	(0.049)	(0.383)	(0.561)
Hispanic[b]	−0.194***	−1.996***	−5.189***
	(0.039)	(0.275)	(0.490)
Non-Hispanic Black	0.232***	0.893*	2.609***
	(0.059)	(0.434)	(0.702)
Non-Hispanic Other	−0.162**	−0.704	−2.217**
	(0.054)	(0.497)	(0.799)
Household income (standardized)	0.065***	0.462**	0.984***
	(0.017)	(0.141)	(0.238)
Family history of osteoporosis[c]	−0.026	−0.600	−0.272
	(0.038)	(0.327)	(0.635)
Avg. calcium (standardized)	0.051**	0.695***	0.550
	(0.019)	(0.144)	(0.356)
Vit. D (standardized)	0.016	0.237*	0.303
	(0.016)	(0.109)	(0.247)
Sedentary minutes (standardized)	−0.018	−0.067	0.026
	(0.017)	(0.144)	(0.306)
HIV positive[e]	−0.281**	−5.385	−7.249
	(0.088)	(3.227)	(6.653)
Ever used marijuana[f]	−0.021	−0.014	0.207
	(0.034)	(0.298)	(0.439)
Ever used hard drugs[f]	0.018	0.117	−0.401
	(0.050)	(0.468)	(0.817)
Daily smoker[f]	0.012	−0.074	−0.445
	(0.037)	(0.273)	(0.580)
Some days smoker	−0.027	−0.621	−1.017
	(0.063)	(0.415)	(0.886)
Avg. # drinks/session/year (standardized)	0.024	0.266	0.615
	(0.025)	(0.214)	(0.423)

TABLE 5 (Continued)

	Dependent variable		
	Femoral neck	**Femur**	**Spine**
Mild depression[g]	0.001	0.024	−0.649
	(0.044)	(0.334)	(0.629)
Moderate depression	−0.030	−0.295	−0.101
	(0.069)	(0.513)	(1.100)
Moderate/severe depression	−0.074	0.257	1.243
	(0.068)	(0.801)	(1.572)
Severe depression	−0.110	−1.016	−2.428
	(0.159)	(1.155)	(2.312)
R^2	0.228	0.195	0.118
Adjusted R^2	0.216	0.183	0.105
Residual std. error	0.598 (df = 1644)	4.926 (df = 1644)	9.891 (df = 1644)
F statistic	15.962*** (df = 25; 1644)	19.428*** (df = 25; 1644)	8.794*** (df = 25; 1644)

*$P < .05$.
**$P < .01$.
***$P < .001$.
[a]Reference group: 18.5-25.2.
[b]Reference group: white.
[c]Reference group: no family history of osteoporosis.
[d]Reference group: heterosexual.
[e]Reference group: HIV negative.
[f]Reference group: never used.
[g]Reference group: no depression.

differences reported in our study have important implications for understanding SM people's risk of osteoporotic fracture. Hip fractures can be categorized into femoral neck and trochanteric fractures (Johnell & Kanis, 2005). Trochanteric factors are associated with osteoporotic bone loss as well as more adverse short-term outcomes relative to femoral neck fractures (Johnell & Kanis, 2005). Low trochanter BMD is associated with an elevated risk for trochanteric hip fractures (Greenspan et al., 1994). We also found significant differences in the distribution of depression categories between sexual orientation groups, and moderate depression was identified as having a significant association with reduced trochanter BMD, independent of sexual orientation. Although these variables were significant predictors independent of one another, given the elevated rates of depression and other mental health conditions consistently observed among SM people relative to heterosexual people (Plöderl & Tremblay, 2015), they are likely highly correlated with one another and reflect structural inequities rooted in anti-2SLGBTQIA+ discrimination and stigma. Future work should seek to clarify the additive effect of sexual orientation, discrimination and depression on bone health.

Our results offer modest support for our initial hypothesis. Consumption of marijuana/hashish, but not other lifestyle factors (eg, consumption of alcohol, tobacco or other controlled substances), was positively associated with femoral and femoral neck BMC (Table 4). This is surprising given that cigarette smoking (Wong, Christie, & Wark, 2007), and alcohol consumption (Maurel, Boisseau, Benhamou, & Jaffre, 2012) are well-established risk factors for poor bone heath, while the effects of marijuana on bone health remain poorly understood (Ehrenkranz & Levine, 2019). For example, tobacco consumption can impair calcium absorption (Krall & Dawson-Hughes, 1999) and alter secretion of adrenal cortical hormones (Yoon, Maalouf, & Sakhaee, 2012). While heavy alcohol consumption can adversely impact a number of physiological systems, including the skeleton, and is known to increase risk for secondary osteoporosis (Beresheim, Pfeiffer, Grynpas, & Alblas, 2018; Maurel et al., 2012). Conversely, clinical research using mouse models suggests that cannabinoids may affect bone remolding and in turn enhance bone healing (Raphael-Mizrahi & Gabet, 2020), yet recent epidemiological work has found evidence that heavy cannabis use is associated with increased bone turnover but worse indicators of

bone health (Sophocleous et al., 2017). Although we did not observe elevated rates of a number of lifestyle associated behavioral risk factors in our study sample, SM individuals often exhibit an increased prevalence of such risk factors which has been linked to their experiences with discrimination (Slater, Godette, Huang, Ruan, & Kerridge, 2017). Thus, public health policy and interventions aimed at promoting bone health among SM individuals should consider the lifelong health benefits of targeting multiple risk factors.

Our finding that moderate depression was negatively associated with BMD *z*-scores, independent of sexuality, is consistent with a number of studies which find a correlation between psychosocial factors (eg, depression, anxiety, and stress) and poorer bone health among postmenopausal women (Cizza et al., 2001; Cizza, Primma, & Csako 2009; Cizza et al., 2012; Eskandari et al., 2007; Follis et al., 2019; Williams et al., 2011). Depression can indirectly impact skeletal health by interfering with appetite and in turn influence the intake of nutrients such as calcium and dietary intake of vitamin D (Holick, 1996), which are essential for bone metabolism. Additionally, depression is associated with low vitamin D levels, which is essential for calcium absorption (Anglin, Samaan, Walter, & McDonald, 2013; Wong et al., 2007). Moreover, depression is consistently associated with reduced levels of physical activity (Kandola, Ashdown-Franks, Hendrikse, Sabiston, & Stubbs, 2019; Teychenne, Ball, & Salmon, 2008), which further implicates the role of psychosocial factors in bone health. Furthermore, low levels of physical activity are increasingly being associated with lower vitamin D status possibly as a by-product of reduced sun exposure (Al-Othman et al., 2012; Brock et al., 2010; Manios et al., 2018). Future work should seek to examine the relationship between depression, physical activity and vitamin D status among SM individuals. There is some evidence finding that depression correlates with elevated levels of cortisol (Burke, Davis, Otte, & Mohr, 2005; Doolin et al., 2017; Vreeburg et al., 2009), which suggests the hypothalamus-pituitary-adrenal (HPA) axis dysregulation (Rein et al., 2019) could impact skeletal health among depressed participants through elevated cortisol levels (Altindag et al., 2007; Furlan et al., 2005) Due to the increased prevalence for depression and other adverse mental health outcomes (Plöderl & Tremblay, 2015), SM people may be at a higher risk for osteoporosis; depression risk may indirectly mediate bone mass. Therefore, SM people with depression should be targeted for increased screening for osteoporosis and bone health.

Our findings of low BMD among gay males have public health implications especially in the context of human immunodeficiency virus (HIV) prevention. HIV has had a significant impact on the health of sexual and gender minorities (SGMs) and has historically driven much of health research conducted among SGMs, yet it is rarely considered that HIV may obscure pre-existing medical conditions or noncommunicable disease risk. Daily pre-exposure prophylaxis (PrEP) with oral emtricitabine and tenofovir disoproxil fumarate (FTC/TDF) is a critical therapeutic intervention for decreasing risk of HIV acquisition and disrupting the transmission of HIV/AIDS among at risk populations. It should be noted that our study sample participants were unlikely to be taking PrEP, as PrEP was not widely used during the NHANES cycles included in our analysis. The CDC and WHO both recommend that SM men consider taking daily, continuing oral doses of TDF/FTC (CDC, 2018; WHO, 2017) as an additional method to prevent HIV infection. The use of FTC/TDF in both HIV infected and HIV-seronegative individuals is associated with decreases in BMD (Mulligan et al., 2015; Glidden et al., 2017; Spinelli et al., 2019; Havens et al., 2020). Additionally, it is well known that people living with HIV are at elevated risk for osteoporotic fracture (Premaor & Compston, 2020). Therefore, BMD should be carefully monitored among SM men who are engaged in prolonged used of PrEP, and bone mass of SM youth should be particularly monitored. Furthermore, public health campaigns aimed at decreasing HIV transmission among SM people should also consider targeting bone health by potentially integrating vitamin D supplementation into their design (Nanayakkara et al., 2019).

4.2 | Female sexual orientation and bone health

Our finding that bisexual women have higher BMC values than heterosexual and other sexual minority women is surprising and contradict existing evidence which increasingly documents a pattern of poorer health outcomes among bisexual people generally, and bisexual women in particular, relative to other sexual orientation groups (Ross et al., 2018). Biphobia often manifesting as various social, political-economic and structural inequities in has been identified as contributing to this heterogeneity in health outcomes among bisexual people relative to other sexual orientation groups (Feinstein & Dyar, 2017; Friedman et al., 2014; Ross, Dobinson, & Eady, 2010). Bisexual women in particular might experience a compounding of stressors related to their experiences of both biphobia and misogyny directed at them by both their heterosexual, lesbian and gay peers (Colledge, Hickson, Reid, & Weatherburn, 2015; Flanders, Dobinson, & Logie, 2015; Watson, Morgan, & Craney, 2018).

A possible explanation for the higher BMC indictors in our sample is the relatively younger age of the bisexual identifying females in our study sample. Furthermore, although statistically nonsignificant, lesbian and bisexual females in our sample consistently display better indicators of bone mass compared to heterosexual and same-sex experienced women, despite experiencing a number of elevated risk factors (lower income, elevated BMI, tobacco consumption, etc.), potentially pointing to some as of yet unexplained factors contributing to increased resilience among SM women. Nevertheless, our finding that bisexual women, and to a lesser extent lesbian women, have better bone health than other female participants, warrants further investigations, Identifying the factors that contribute to these outcomes might be beneficial to public health policy and intervention aimed at improving bone health among all women. Future studies should seek to disentangling the biocultural factors contributing to these sexual orientation-based differences in bone health using larger, more representative study samples, as well as assessing sexual orientation-based differences in bone health in a variety of age groups, including among adolescents, and post-menopausal women.

4.3 | Limitations and next steps

A number of limitations warrant further consideration. One limitation concerns the narrow scope of gender diversity represented in our sample. NHANES survey data categorizes sexual orientation into gay or lesbian, bisexual, and heterosexual, as well as reporting sexual experience with a member of the same sex or opposite sex. NHANES does not collect data on participant's gender identity, and their assessment of "sex" only allows for binary categorization of male or female, therefore excluding individuals who may be or report any disorders of sexual development. Although a number of studies has assessed the safety and efficacy of gender affirming hormonal therapies on the bone health of transgender and gender diverse (TGD) people (Haraldsen, Haug, Falch, Egeland, & Opjordsmoen, 2007; Rosen et al., 2019; Stevenson & Tangpricha, 2019; Van Caenegem & T'Sjoen, 2015), no study to date has examined the relationship between psychosocial stress, lived experience and bone health among TGD people. Future studies should consider intersex and transgender status, which are likely significant factors in bone health given our findings in the present study. Further, NHANES does not measure or collect data on participants' experiences of being discriminated against on the basis of their sexual orientation, which limits our ability to directly assess the impact of discrimination on participants' health. Our lower sample of lesbian identifying participants may be obscuring any significant differences in bone health between lesbians relative to other sexual orientation groups. Furthermore, with few exceptions, the SM participants in our sample do not show elevated risk factors. This might be the result of some kind of selection bias on the part of NHANES, which may ultimately obscure the actual severity of bone health experienced by SM people in the population at large. Finally, although derived from a validated survey, our analysis would have benefited from physical activity data collected using actigraphy. Finally, unaccounted biomechanical factors could mediate the findings in our study, as there is some evidence to suggest that differences in the load carrying abilities and volume of trabecular and cortical bone at trochanteric region relative to the femoral head influence femoral BMD (Lotz, Cheal, & Hayes, 1995).

In addition to adult behaviors, it is also important to consider how socioeconomic, psychosocial, and nutritional conditions during growth contribute to the development of bone mass and osteoporosis risk in adulthood. For example, depression and other psychosocial factors may also impact SM peoples' skeletal health by interfering with bone mass accrual and PBM attainment during adolescence. Indeed, among adolescents, higher depression scores have been found to be associated with lower BMD and BMC (Calarge et al., 2014; Dorn et al., 2008), and there is some evidence that the bone mass of males may be particularly impacted by depression and psychosocial stress (Fazeli et al., 2013). For example, Zhu et al. (2016) found that a significant relationship existed between reduced bone mass and higher cortisol levels in male participants, but not females, thus corroborating the idea that males are more vulnerable to environmental perturbations relative to females (Stinson, 1985). Further, adult sexual orientation has been found to modulate cortisol stress reactivity (Juster et al., 2015), and future work should examine the relationship between stigma, endocrine stress reactivity and bone health among both SM adults and youth. Psychosocial stress and chronic HPA activation experienced during growth can reduce appendicular skeletal growth, resulting in short adult stature (Lampl & Schoen, 2017; Nyberg et al., 2012) and low PBM, which is associated with elevated osteoporosis risk later in life. SM youths are reported to have a disproportionately higher prevalence of adverse mental health conditions such as depression, anxiety, stress, and suicidal ideation relative to heterosexual youths (Burton, Marshal, Chisolm, Sucato, & Friedman, 2013; Marshal et al., 2011; Mustanski, Andrews, & Puckett, 2016; Mustanski, Garofalo, & Emerson, 2010), which might discourage their involvement in physical activity during childhood and adolescence, which is important for the

development and maintenance of healthy bones. Future work should examine sexual orientation differences in childhood and adolescent skeletal growth, bone mass accrual and PBM attainment in relation to psychosocial stress, nutrition and physical activity to better inform public health interventions. Particular attention should be directed at how psychosocial factors mediate outcomes in skeletal growth, especially in regard to the high rates of depression reported among SM youth (Russell & Fish, 2016).

5 | CONCLUSION

This is the first investigation to examine the social determinants of skeletal health among SM people. We find that SM men have lower BMD and BMC values relative their heterosexual peers. Cannabis consumption was associated with lower femoral BMC suggesting that behavioral factors likely influence bone health outcomes among SM people. Moderate depression severity was significantly associated with BMD independent of sexuality. Minority stress has been implicated as a major contributing factor in health disparities experienced by SM people (Hatzenbuehler & Pachankis, 2016; Meyer, 2003) and warrants further investigation in how minority stressors mediate vulnerability to poor bone health. Understanding the role of lived experiences and stress physiology in shaping population variability in bone health will enable policymakers to design more effective public health policy and interventions. SM's chronic exposure to adversity during development and adulthood will have consequences to their long-term health -such as elevated risk of osteoporosis. Further, due to the significant independent association between sexual orientation and worse bone health observed in our study, programs aimed at addressing sexual orientation-based discrimination and against SM people during their childhood and adolescence when they are the most vulnerable to long term health consequences should be supported by public health policy and initiatives. Characterizing the unique socioeconomic, psychosocial, and ecological risk factors that result in an increased vulnerability to poor bone health among SM people is important for designing therapeutic and public health interventions for this community, especially as the population of SM older adults grows. In addition to improving our understanding of the causes of health disparities, this research may help identify ways in which public health professionals and government officials can construct health policies and interventions that may reduce the risk for negative health consequences experienced by sexual minorities by identifying critical periods of development early in their life.

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AUTHOR CONTRIBUTIONS

James Gibb: Conceptualization; formal analysis; writing-original draft; writing-review and editing. **Eric Shattuck:** Conceptualization; formal analysis; writing-original draft; writing-review and editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in NHANES website: https://wwwn.cdc.gov/nchs/nhanes/Default.aspx.

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REFERENCES

Al-Othman, A., Al-Musharaf, S., Al-Daghri, N. M., Krishnaswamy, S., Yusuf, D. S., Alkharfy, K. M., ... Sabico, S. (2012). Effect of physical activity and sun exposure on vitamin D status of Saudi children and adolescents. *BMC Pediatrics*, *12*(1), 92.

Altindag, O., Altindag, A., Asoglu, M., Gunes, M., Soran, N., & Deveci, Z. (2007). Relation of cortisol levels and bone mineral density among premenopausal women with major depression. *International Journal of Clinical Practice*, *61*(3), 416–420.

Anglin, R. E., Samaan, Z., Walter, S. D., & McDonald, S. D. (2013). Vitamin D deficiency and depression in adults: Systematic review and meta-analysis. *The British Journal of Psychiatry*, *202*(2), 100–107.

Beresheim, A. C., Pfeiffer, S. K., Grynpas, M. D., & Alblas, A. (2018). Sex-specific patterns in cortical and trabecular bone microstructure in the Kirsten Skeletal Collection, South Africa. *American Journal of Human Biology*, *30*(3), e23108.

Bhattacharya, R., Shen, C., & Sambamoorthi, U. (2014). Excess risk of chronic physical conditions associated with depression and anxiety. *BMC Psychiatry*, *14*(1), 10.

Brock, K., Huang, W. Y., Fraser, D. R., Ke, L., Tseng, M., Stolzenberg-Solomon, R., ... McCarty, C. (2010). Low vitamin D status is associated with physical inactivity, obesity and low vitamin D intake in a large US sample of healthy middle-aged men and women. *The Journal of Steroid Biochemistry and Molecular Biology*, *121*(1-2), 462–466.

Burke, H. M., Davis, M. C., Otte, C., & Mohr, D. C. (2005). Depression and cortisol responses to psychological stress: A meta-analysis. *Psychoneuroendocrinology*, *30*(9), 846–856.

Burton, C. M., Marshal, M. P., Chisolm, D. J., Sucato, G. S., & Friedman, M. S. (2013). Sexual minority-related victimization as a mediator of mental health disparities in sexual minority

youth: A longitudinal analysis. *Journal of Youth and Adolescence*, *42*(3), 394–402.

Calarge, C. A., Butcher, B. D., Burns, T. L., Coryell, W. H., Schlechte, J. A., & Zemel, B. S. (2014). Major depressive disorder and bone mass in adolescents and young adults. *Journal of Bone and Mineral Research*, *29*(10), 2230–2237.

Carey, J. J., & Delaney, M. F. (2010). T-scores and Z-scores. *Clinical Reviews in Bone and Mineral Metabolism*, *8*(3), 113–121.

Centers for Disease Control and Prevention (CDC). (2018). *Pre-exposure prophylaxis for the prevention of HIV infection in the United States—2017 Update: A clinical practice guideline.* Retrieved from https://www.cdc.gov/hiv/pdf/risk/prep/cdc-hiv-prep-guidelines-2017.pdf.

Cizza, G., Mistry, S., Nguyen, V. T., Eskandari, F., Martinez, P., Torvik, S., … POWER Study Group. (2012). Do premenopausal women with major depression have low bone mineral density? A 36-month prospective study. *PLoS One*, *7*(7), e40894. https://doi.org/10.1371/journal.pone.0040894.

Cizza, G., Primma, S., & Csako, G. (2009). Depression as a risk factor for osteoporosis. *Trends in Endocrinology & Metabolism*, *20*(8), 367–373.

Cizza, G., Ravn, P., Chrousos, G. P., & Gold, P. W. (2001). Depression: A major, unrecognized risk factor for osteoporosis? *Trends in Endocrinology & Metabolism*, *12*(5), 198–203.

Colledge, L., Hickson, F., Reid, D., & Weatherburn, P. (2015). Poorer mental health in UKbisexual women than lesbians: Evidence from the UK2007 Stonewall Women's Health Survey. *Journal of Public Health*, *37*(3), 427–437.

Cooper, C., Harvey, N., Cole, Z., Hanson, M., & Dennison, E. (2009). Developmental origins of osteoporosis: The role of maternal nutrition. In *Early nutrition programming and health outcomes in later life* (pp. 31–39). Dordrecht: Springer.

Core Team, (2018). R: A language and environment for statistical computing. Vienna, Germany: Foundation for Statistical Computing. Retrieved from https://www.R-project.org

Cosman, F., de Beur, S. J., LeBoff, M. S., Lewiecki, E. M., Tanner, B., Randall, S., & Lindsay, R. (2014). Clinician's guide to prevention and treatment of osteoporosis. *Osteoporosis International*, *25*(10), 2359–2381.

Diamant, A. L., & Wold, C. (2003). Sexual orientation and variation in physical and mental health status among women. *Journal of Women's Health*, *12*, 41–49.

Doolin, K., Farrell, C., Tozzi, L., Harkin, A., Frodl, T., & O'Keane, V. (2017). Diurnal hypothalamic-pituitary-adrenal axis measures and inflammatory marker correlates in major depressive disorder. *International Journal of Molecular Sciences*, *18*(10), 2226.

Dorn, L. D., Susman, E. J., Pabst, S., Huang, B., Kalkwarf, H., & Grimes, S. (2008). Association of depressive symptoms and anxiety with bone mass and density in ever-smoking and never-smoking adolescent girls. *Archives of Pediatrics & Adolescent Medicine*, *162*(12), 1181–1188.

Drake, M. T., Clarke, B. L., & Lewiecki, E. M. (2015). The pathophysiology and treatment of osteoporosis. *Clinical Therapeutics*, *37*(8), 1837–1850.

Ehrenkranz, J., & Levine, M. A. (2019). Bones and joints: The effects of cannabinoids on the skeleton. *The Journal of Clinical Endocrinology & Metabolism*, *104*(10), 4683–4694.

Eskandari, F., Martinez, P. E., Torvik, S., Phillips, T. M., Sternberg, E. M., Mistry, S., … Reynolds, J. C. (2007). Low bone mass in premenopausal women with depression. *Archives of Internal Medicine*, *167*(21), 2329–2336.

Fazeli, P. K., Mendes, N., Russell, M., Herzog, D. B., Klibanski, A., & Misra, M. (2013). Bone density characteristics and major depressive disorder in adolescents. *Psychosomatic Medicine*, *75*(2), 117–123.

Feinstein, B. A., & Dyar, C. (2017). Bisexuality, minority stress, and health. *Current Sexual Health Reports*, *9*(1), 42–49.

Flanders, C. E., Dobinson, C., & Logie, C. (2015). "I'm never really my full self": Young bisexual women's perceptions of their mental health. *Journal of Bisexuality*, *15*(4), 454–480.

Follis, S. L., Bea, J., Klimentidis, Y., Hu, C., Crandall, C. J., Garcia, D. O., … Chen, Z. (2019). Psychosocial stress and bone loss among postmenopausal women: Results from the Women's Health Initiative. *Journal of Epidemiology and Community Health*, *73*(9), 888–892.

Friedman, M. R., Dodge, B., Schick, V., Herbenick, D., Hubach, R. D., Bowling, J., … Reece, M. (2014). From bias to bisexual health disparities: Attitudes toward bisexual men and women in the United States. *LGBT Health*, *1*(4), 309–318.

Frost, D. M., Lehavot, K., & Meyer, I. H. (2015). Minority stress and physical health among sexual minority individuals. *Journal of Behavioral Medicine*, *38*(1), 1–8.

Furlan, P. M., Ten Have, T., Cary, M., Zemel, B., Wehrli, F., Katz, I. R., … Evans, D. L. (2005). The role of stress-induced cortisol in the relationship between depression and decreased bone mineral density. *Biological Psychiatry*, *57*(8), 911–917.

Glidden, D. V., Mulligan, K., McMahan, V., Anderson, P. L., Guanira, J., Chariyalertsak, S., … Grant, R. M. (2017). Recovery of bone mineral density following discontinuation of tenofovir-based HIV pre-exposure prophylaxis. *Journal of Acquired Immune Deficiency Syndromes*, *76*(2), 177.

Greenspan, S. L., Myers, E. R., Maitland, L. A., Kido, T. H., Krasnow, M. B., & Hayes, W. C. (1994). Trochanteric bone mineral density is associated with type of hip fracture in the elderly. *Journal of Bone and Mineral Research*, *9*(12), 1889–1894.

Grijsen, M. L., Vrouenraets, S. M., Wit, F. W., Stolte, I. G., Prins, M., Lips, P., … Prins, J. M. (2013). Low bone mineral density, regardless of HIV status, in men who have sex with men. *The Journal of Infectious Diseases*, *207*(3), 386–391.

Haraldsen, I. R., Haug, E., Falch, J., Egeland, T., & Opjordsmoen, S. (2007). Cross-sex pattern of bone mineral density in early onset gender identity disorder. *Hormones and Behavior*, *52*, 334–343.

Hatzenbuehler, M. L., & Pachankis, J. E. (2016). Stigma and minority stress as social determinants of health among lesbian, gay, bisexual, and transgender youth: Research evidence and clinical implications. *Pediatric Clinics*, *63*(6), 985–997.

Havens, P. L., Perumean-Chaney, S. E., Patki, A., Cofield, S. S., Wilson, C. M., Liu, N., … Mulligan, K. (2020). Changes in bone mass after discontinuation of preexposure prophylaxis with tenofovir disoproxil fumarate/emtricitabine in young men who have sex with men: Extension phase results of adolescent trials network protocols 110 and 113. *Clinical Infectious Diseases*, *70*(4), 687–691.

Heaney, R. P., Abrams, S., Dawson-Hughes, B., Looker, A., Marcus, R., Matkovic, V., & Weaver, C. (2000). Peak bone mass. *Osteoporosis International*, *11*(12), 985–1009.

Hernandez, M., & Gibb, J. K. (2020). Culture, behavior and health. *Evolution, Medicine, and Public Health*, *2020*(1), 12–13.

Holick, M. F. (1996). Vitamin D and bone health. *The Journal of Nutrition*, *126*(S4), 1159S–1164S.

Johnell, O., & Kanis, J. (2005). Epidemiology of osteoporotic fractures. *Osteoporosis International*, *16*(2), S3–S7.

Juster, R. P., Hatzenbuehler, M. L., Mendrek, A., Pfaus, J. G., Smith, N. G., Johnson, P. J., … Lupien, S. J. (2015). Sexual orientation modulates endocrine stress reactivity. *Biological Psychiatry*, *77*(7), 668–676.

Juster, R. P., Vencill, J. A., & Johnson, P. J. (2017). Impact of stress and strain on current LGBT health disparities. In K. Eckstrand & J. Potter (Eds.), *Trauma, resilience, and health promotion in LGBT patients*. Cham: Springer.

Kandola, A., Ashdown-Franks, G., Hendrikse, J., Sabiston, C. M., & Stubbs, B. (2019). Physical activity and depression: Towards understanding the antidepressant mechanisms of physical activity. *Neuroscience & Biobehavioral Reviews*, *107*, 525–539.

Kanis, J. A. (2002). Diagnosis of osteoporosis and assessment of fracture risk. *The Lancet*, *359*, 1929–1936.

Kanis, J. A., McCloskey, E. V., Johansson, H., Oden, A., Melton, L. J., III, & Khaltaev, N. (2008). A reference standard for the description of osteoporosis. *Bone*, *42*(3), 467–475.

Krall, E. A., & Dawson-Hughes, B. (1999). Smoking increases bone loss and decreases intestinal calcium absorption. *Journal of Bone and Mineral Research*, *14*(2), 215–220.

Kroenke, K., Spitzer, R. L., & Williams, J. B. (2001). The PHQ-9: validity of a brief depression severity measure. *Journal of general internal medicine*, *16*(9), 606–613.

Kroenke, K., & Spitzer, R. L. (2002). The PHQ-9: A new depression diagnostic and severity measure. *Psychiatric Annals*, *32*(9), 509–515.

Lampl, M., & Schoen, M. (2017). How long bones grow children: Mechanistic paths to variation in human height growth. *American Journal of Human Biology*, *29*(2), e22983.

Lick, D. J., Durso, L. E., & Johnson, K. L. (2013). Minority stress and physical health among sexual minorities. *Perspectives on Psychological Science*, *8*(5), 521–548.

Lorentzon, M., & Cummings, S. R. (2015). Osteoporosis: the evolution of a diagnosis. *Journal of internal medicine*, *277*(6), 650–661.

Lotz, J. C., Cheal, E. J., & Hayes, W. C. (1995). Stress distributions within the proximal femur during gait and falls: Implications for osteoporotic fracture. *Osteoporosis International*, *5*(4), 252–261.

Manios, Y., Moschonis, G., Lambrinou, C. P., Mavrogianni, C., Tsirigoti, L., Hoeller, U., … Livingstone, K. M. (2018). Associations of vitamin D status with dietary intakes and physical activity levels among adults from seven European countries: The Food4Me study. *European Journal of Nutrition*, *57*(4), 1357–1368.

Marshal, M. P., Dietz, L. J., Friedman, M. S., Stall, R., Smith, H. A., McGinley, J., … Brent, D. A. (2011). Suicidality and depression disparities between sexual minority and heterosexual youth: A meta-analytic review. *Journal of Adolescent Health*, *49*(2), 115–123.

Maurel, D. B., Boisseau, N., Benhamou, C. L., & Jaffre, C. (2012). Alcohol and bone: Review of dose effects and mechanism. *Osteoporosis International*, *23*(1), 1–16.

Mays, V. M., Juster, R. P., Williamson, T. J., Seeman, T. E., & Cochran, S. D. (2018). Chronic physiologic effects of stress among lesbian, gay, and bisexual adults: Results from the National Health and Nutrition Examination Survey. *Psychosomatic Medicine*, *80*(6), 551–563.

Mulligan, K., Glidden, D. V., Anderson, P. L., Liu, A., McMahan, V., Gonzales, P., … Wang, F. (2015). Effects of emtricitabine/tenofovir on bone mineral density in HIV-negative persons in a randomized, double-blind, placebo-controlled trial. *Clinical Infectious Diseases*, *61*(4), 572–580.

Mustanski, B., Andrews, R., & Puckett, J. A. (2016). The effects of cumulative victimization on mental health among lesbian, gay, bisexual, and transgender adolescents and young adults. *American Journal of Public Health*, *106*(3), 527–533.

Mustanski, B. S., Garofalo, R., & Emerson, E. M. (2010). Mental health disorders, psychological distress, and suicidality in a diverse sample of lesbian, gay, bisexual, and transgender youths. *American Journal of Public Health*, *100*(12), 2426–2432.

Nanayakkara, D. D., Sun, X., Morris, S., Louie, S., Mulligan, K., Overton, T., … Dubé, M. P. (2019). Effect of vitamin D supplementation on bone turnover markers during HIV pre-exposure prophylaxis using tenofovir disoproxil fumarate-emtricitabine in men who have sex with men. *AIDS Research and Human Retroviruses*, *35*(7), 608–614.

National Institute of Health (NIH). (2018). *Osteoporosis overview*. Retrieved from https://www.bones.nih.gov.

Nyberg, C. H., Leonard, W. R., Tanner, S., McDade, T., Huanca, T., Godoy, R. A., & TAPS Bolivia Study Team. (2012). Diurnal cortisol rhythms and child growth: Exploring the life history consequences of HPA activation among the Tsimane. *American Journal of Human Biology*, *24*(6), 730–738.

Office of the Surgeon General (OSG). (2004). *Bone health and osteoporosis: A report of the Surgeon General*.

Plöderl, M., & Tremblay, P. (2015). Mental health of sexual minorities. A systematic review. *International Review of Psychiatry*, *27*(5), 367–385.

Premaor, M. O., & Compston, J. E. (2020). People living with HIV and fracture risk. *Osteoporosis International*, *31*, 1633–1644. https://doi.org/10.1007/s00198-020-05350-y.

R Meyer, I. H. (2003). Prejudice, social stress, and mental health in lesbian, gay, and bisexual populations: conceptual issues and research evidence. *Psychological bulletin*, *129*(5), 694.

Raphael-Mizrahi, B., & Gabet, Y. (2020). The cannabinoids effect on bone formation and bone healing. *Current Osteoporosis Reports*, *18*, 433–438. https://doi.org/10.1007/s11914-020-00607-1.

Rein, T., Ambrée, O., Fries, G. R., Rappeneau, V., Schmidt, U., & Touma, C. (2019). The hypothalamic-pituitary-adrenal Axis in depression: Molecular regulation, pathophysiological role, and translational implications. In *Neurobiology of depression* (pp. 89–96). Cambridge, Massachusetts, USA: Academic Press.

Rosen, H. N., Hamnvik, O. P. R., Jaisamrarn, U., Malabanan, A. O., Safer, J. D., Tangpricha, V., … Yeap, S. S. (2019). Bone densitometry in transgender and gender non-conforming (TGNC) individuals: 2019 ISCD official position. *Journal of Clinical Densitometry*, *22*, 544–553.

Ross, L. E., Dobinson, C., & Eady, A. (2010). Perceived determinants of mental health for bisexual people: A qualitative examination. *American Journal of Public Health*, *100*(3), 496–502.

Ross, L. E., Salway, T., Tarasoff, L. A., MacKay, J. M., Hawkins, B. W., & Fehr, C. P. (2018). Prevalence of depression

and anxiety among bisexual people compared to gay, lesbian, and heterosexual individuals: A systematic review and meta-analysis. *The Journal of Sex Research*, *55*(4-5), 435–456.

Russell, S. T., & Fish, J. N. (2016). Mental health in lesbian, gay, bisexual, and transgender (LGBT) youth. *Annual Review of Clinical Psychology*, *12*, 465–487.

Seeman, E. (2002). Pathogenesis of bone fragility in women and men. *The Lancet*, *359*, 1841–1850.

Slater, M. E., Godette, D., Huang, B., Ruan, W. J., & Kerridge, B. T. (2017). Sexual orientation-based discrimination, excessive alcohol use, and substance use disorders among sexual minority adults. *LGBT Health*, *4*(5), 337–344.

Sophocleous, A., Robertson, R., Ferreira, N. B., McKenzie, J., Fraser, W. D., & Ralston, S. H. (2017). Heavy cannabis use is associated with low bone mineral density and an increased risk of fractures. *The American Journal of Medicine*, *130*(2), 214–221.

Spinelli, M. A., Glidden, D. V., Anderson, P. L., Gandhi, M., McMahan, V. M., Defechereux, P., … Bekker, L. G. (2019). Impact of estimated pre-exposure prophylaxis (PrEP) adherence patterns on bone mineral density in a large PrEP demonstration project. *AIDS Research and Human Retroviruses*, *35*(9), 788–793.

Stevenson, M. O., & Tangpricha, V. (2019). Osteoporosis and bone health in transgender persons. *Endocrinology and Metabolism Clinics*, *48*(2), 421–427.

Stinson, S. (1985). Sex differences in environmental sensitivity during growth and development. *American Journal of Physical Anthropology*, *28*(S6), 123–147.

Teychenne, M., Ball, K., & Salmon, J. (2008). Physical activity and likelihood of depression in adults: A review. *Preventive Medicine*, *46*(5), 397–411.

Van Caenegem, E., & T'Sjoen, G. (2015). Bone in trans persons. *Current Opinion in Endocrinology, Diabetes and Obesity*, *22*, 459–466.

Vreeburg, S. A., Hoogendijk, W. J., van Pelt, J., DeRijk, R. H., Verhagen, J. C., van Dyck, R., … Penninx, B. W. (2009). Major depressive disorder and hypothalamic-pituitary-adrenal axis activity: Results from a large cohort study. *Archives of General Psychiatry*, *66*(6), 617–626.

Watson, L. B., Morgan, S. K., & Craney, R. (2018). Bisexual women's discrimination and mental health outcomes: The roles of resilience and collective action. *Psychology of Sexual Orientation and Gender Diversity*, *5*(2), 182–193.

Williams, L. J., Bjerkeset, O., Langhammer, A., Berk, M., Pasco, J. A., Henry, M. J., … Forsmo, S. (2011). The association between depressive and anxiety symptoms and bone mineral density in the general population: The HUNT study. *Journal of Affective Disorders*, *131*(1-3), 164–171.

Wong, P. K., Christie, J. J., & Wark, J. D. (2007). The effects of smoking on bone health. *Clinical Science*, *113*(5), 233–241.

World Health Organization. (1994). *Assessment of fracture risk and its application to screening for postmenopausal osteoporosis: report of a WHO study group*, Geneva, Switzerland: Author Retrieved from http://www.who.int/iris/handle/10665/39142

World Health Organization (WHO). (2017). *Policy brief: Consolidated guidelines on HIV prevention, diagnosis, treatment and care for key populations, 2016 update*. Geneva: World Health Organization.

Yoon, V., Maalouf, N. M., & Sakhaee, K. (2012). The effects of smoking on bone metabolism. *Osteoporosis International*, *23*(8), 2081–2092.

Zhu, K., Henley, D., Pennell, C., Herbison, C. E., Mountain, J., Lye, S., & Walsh, J. P. (2016). Associations between hypothalamic-pituitary-adrenal axis function and peak bone mass at 20 years of age in a birth cohort. *Bone*, *85*, 37–44.

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