Heliyon 10 (2024) e28240

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

The association between night shift work and osteoporosis risk in adults: A cross-sectional analysis using NHANES

Yu Qian [a,b], Jianchun Mao [a,b,*]

[a] Shanghai University of Traditional Chinese Medicine, NO.1200 Cai Lun Road, Pudong New District, Shanghai, 201203, People's Republic of China
[b] Department of Rheumatology, Longhua Hospital Shanghai University of Traditional Chinese Medicine, NO.725 South Wan Ping Road, Xuhui District, Shanghai, 200032, People's Republic of China

ARTICLE INFO

Keywords:
Night work
Bone mineral density
Osteoporosis
Life style
NHANES

ABSTRACT

Purpose: Through this study, we assess whether night shift work increases the risk of osteoporosis, and explore the effects of age, gender, or lifestyle differences.
Methods: This cross-sectional study included the collection of data from a sample of the US adults who participated in the National Health and Nutrition Examination Survey (NHANES) over a 7.3-year period (2007–2008, 2009–2010, 2017–March2020), including 4408 participants (2351 [52.8%] men and 2057[47.2%] women), with an age range of 20–80 years. The primary variables, health status, nutrition, harmful lifestyle habits, and bone mineral density (BMD), were segregated, and analyzed according to different work schedules. Linear regression models were conducted to evaluate correlations of night shift work and T-scores. Associations between night shift work and osteoporosis were examined using logistic regression analyses. All regression models were stratified by gender and age ≥50 years. Osteoporosis was defined as BMD at the femoral neck or total spine equal to or less than 2.5 standard deviations below the mean for youthful people of the same gender. All data were obtained using questionnaires and examinations collected in mobile examination center (MEC) from NHANES.
Results: After multivariate adjustment, night shift work was related to statistically significant decreases of the total spine in T-scores of females aged ≥50 years. Furthermore, night shift work of the overall population (OR = 2.31 [95% CI, 1.03–5.18]; P = 0.043) and females aged ≥50 years (OR = 4.6 [95% CI, 1.21–17.54]; P = 0.025) was related to an increased prevalence of osteoporosis.
Conclusion: Night shift work correlates with a higher risk of osteoporosis in the population of the US adults, with the combined effect of age, gender, and harmful lifestyle.

1. Introduction

Osteoporosis is a crucial worldwide problem of public health since it increases the risk of fracture and bone fragility [1]. Among the US adults aged ≥50 years, the prevalence of osteoporosis reported in the literature varied between 6% and 11% (approximately 7–12 million adults) [2]. Moreover, there are many risk variables for osteoporosis, including aging, gender (females more than males), ethnicity (non-Hispanic blacks > non-Hispanic whites > Hispanic > other races), low Body Mass Index (BMI), nutrient-poor status,

* Corresponding author. Shanghai University of Traditional Chinese Medicine, NO.1200 Cai Lun Road, Pudong New District, Shanghai 201203, People's Republic of China.
E-mail address: mjczyczx@shutcm.edu.cn (J. Mao).

https://doi.org/10.1016/j.heliyon.2024.e28240
Received 14 October 2023; Received in revised form 11 March 2024; Accepted 14 March 2024
Available online 15 March 2024

current cigarette smoking, heavy alcohol consumption, previous major fractures, low physical activity, and many other uncontrollable or lifestyle factors [3–6]. Besides, diseases that affect bone metabolism such as diabetes and chronic kidney disease (CKD) are also risk factors for osteoporosis [7,8]. Fracture caused by osteoporosis is a major reason for morbidity and mortality in older adults [9].

Working night shifts is a common occupational factor. About 26.5% of the working population in America are engaged in night shift work [10]. The working time of the night shift includes evening (18:00 to 22:00), night (23:00 to 3:00), and early morning (4:00 to 8:00). Literature reports have demonstrated that night shift work leads to insufficient sunlight exposure and disturbance of the endogenous circadian system [11,12]. Furthermore, some epidemiological and laboratory studies provide evidence that night shift work is related to an increased risk for some chronic illnesses, including different types of cancer, coronary heart disease (CHD), metabolic diseases, and sleep disorders [13–15].

Currently, the association between night shift work and the risk of osteoporosis or fracture is open to debate. Some recent researches suggest that rotating night shift work may bring about low bone mineral density (BMD), osteoporosis, and risk of hip or wrist fractures with a significantly higher bone turnover rate [16–19]. Some other literatures have not substantiated a correlation between night shift schedule and the onset of osteoporosis [20]. From these studies, many recognized methods for osteoporosis risk include BMD obtained at femoral neck, total femur, or lumbar spine (L1–L4) using dual-energy X-ray absorptiometry (DXA), and self-reported fracture [16–20]. However, the osteoporosis clinical criteria used the BMD at total spine or femoral neck areas [21].

Most of the research was cross-sectional, community-based, and focused on a group of people restricted to gender or age so that they represented only a small portion of the population [16–20]. As the accuracy of the findings is based on the sample size, we would like to conduct our study by using nationwide population-based data from the National Health and Nutrition Examination Survey (NHANES).

Osteoporosis and osteoporotic fractures are relevant to age and gender. After the age of 50, osteoporosis is significantly more prevalent in women than in males [22]. The incidence of hip fractures in the US has been reckoned at 17% for white women and 6% for white men after age 50 [23]. Besides, it is also vital for males because of a higher prevalence of secondary osteoporosis and mortality after a fracture [24]. Therefore, age 50 years and gender are two essential risk factors for bone health.

To this end, our study aimed to evaluate the association between T-scores at femoral neck or total spine, and osteoporosis risk with night shift work in a cohort representative of the US population from 3.6 cycles of the NHANES (2007–2008, 2009–2010, 2017–March2020), and explore age, gender, or lifestyle differences.

2. Methods

2.1. Participants and data acquisition

NHANES program consists of ongoing, comprehensive, cross-sectional, population-based surveys to collect data about the health, nutritional status, and health behaviors of the non-institutionalized civilian resident population of the United States conducted by the

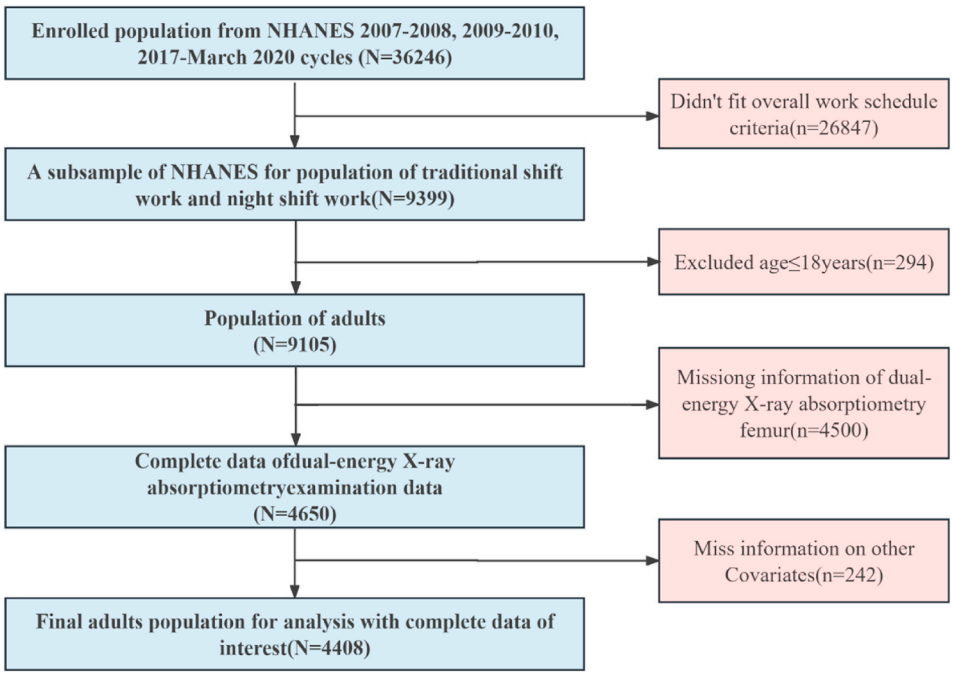

Fig. 1. The selection process of the population from 2007 to 2008, 2009–2010, 2017–March2020 NHANES database.
Abbreviation: NHANES, National Health and Nutrition Examination Survey.

National Center for Health Statistic of the Centers for Disease Control and Prevention (CDC) since the early 1960s [25]. It was approved by the National Center for Health Statistics Research Ethics Review Board and underwent annual review. These interviews, physical exams, and laboratory testing were conducted at mobile examination center (MEC) or home.

In this cross-sectional research, initial consideration was given to 36,246 potential participants from 3.6 cycles of NHANES (2007–2008, 2009–2010, and 2017–March 2020). After excluding 31,838 participants with missing covariate data who did not meet the criteria, this study population included 2351 male and 2057 female adults, with an age range of 20–80 years. The overall work schedule was structured based on response by survey participants ("Evening or nights" and "Early mornings" for night shift work and "Traditional 9 a.m. to 5 p.m. day" for traditional shift work). The study followed related guidelines and regulations. Subjects with incomplete dietary data, examination data, or questionnaires were excluded from the study. Fig. 1 illustrates the research population selection procedure.

2.2. BMD, osteoporosis, and osteoporotic fractures criteria

BMD (g/cm2) at the femoral neck or total spine areas was examined by a DXA scan (Hologic, Bedford, MA, USA), with femoral neck testing on the left hip, unless there was a history of previous fracture or surgery in which case the right hip was used; additionally, BMD at the total spine areas was the average of measurements from L1 to L4 [26]. All DXA machines routinely conducted quality control. We define osteoporosis according to World Health Organization criteria, which is BMD at the femoral neck or total spine equal to or less than 2.5 standard deviations below the mean for youthful people of the same gender [27]. To determine the fractured history, when asked "Has a doctor ever told you that you had a broken or fractured hip/wrist/spine?", if the participants answered "yes", the subjects were recorded as positive. In the study, we stratified the subjects by gender and age 50 years.

2.3. Other covariates

Covariates, including epidemiological characteristics, health status, nutrition, and harmful lifestyle habits, were obtained using questionnaires and examinations collected in MEC from NHANES.

Among others, nutrition has a crucial role as a modifiable factor in influencing bone health. High ingestion of vegetables, fruits, poultry, fish, whole grains, milk, and dairy products was related to a reduced risk of low BMD and fracture [28]. Thus, energy, carbohydrate, protein, fat, calcium, and Vitamin D included in "Total Nutrient Intakes, First Day" and milk consumption included in "Diet Behavior & Nutrition" were obtained as covariates. Milk consumption was divided into five groups: often (every day or more), sometimes (weekly or more often, but less frequently than daily), rarely (less than weekly), never, and varied.

We should pay attention to the influence of harmful lifestyle habits, including alcoholic behavior, on their risk of osteoporosis, which is adaptable to some extent [29]. A high loading of alcohol consumption is related to a decrease in BMD, which results in an increased liability of fractures [30]. Alcoholic behavior included in "Alcohol Use" is categorized into three groups: every day, rarely (less than monthly), regular (monthly or more often, but less frequently than daily), and never.

Other covariates were also included: age, gender, ethnicity, BMI, blood pressure, diabetes, Hemoglobin A1C (HbA1c), CKD, estimated glomerular filtration rate (eGFR), and caffeine intake. Diabetes is categorized into three groups: yes, no, and borderline. CKD included in "Kidney Conditions - Urology" was divided into yes or no, based on response.

2.4. Statistical analysis

All statistical analyses were performed using STATA, version 17.0 for Windows. Categorical data are expressed as percentage frequency (95% CI), and continuous variables as mean (95% CI). Differences in the pattern of groups were evaluated using the $\chi 2$ test for categorical data and the T-test for continuous variables. The multiple interpolation for missing values of covariates was performed using the R package mice (3.16.0, https://cran.r-project.org/web/packages/mice/mice.pdf). Because of the NHANES study's sophisticated survey design, each analysis was appropriately weighted for representation of the United States population. All cycles use the data from the sample with completed day 1 24-h dietary recall, so we use Dietary day 1 sample weights. To combine survey cycles, the survey weights of 2017–March 2020 were multiplied by 3.2/7.2, and 2007–2008 and 2009–2010 were multiplied by 2/7.2 [31]. Linear regression analyses were utilized to estimate the correlations between night shift work and T-scores at the femoral neck and total spine, and results were reported by β (95% CI). The effects of night shift work on osteoporosis were performed to evaluate by logistic regression, which was calculated as odds ratios (95% CI). All model 1 was adjusted for age, gender, ethnicity, BMI, blood pressure, HbA1c, diabetes, eGFR, and CKD, and all model 2 was further adjusted for nutrient intakes, milk or alcohol consumption, and work hours. In all tests, $P < 0.05$ was considered statistically significant.

3. Results

3.1. Characteristics of participants

After excluding participants with missing covariate data, 4408 adults (average age, 43.52 [95% CI, 42.98–44.06]; 2351[52.8%] men and 2057[47.2%] women) were incorporated in this study, with 671 cases of night shift work and 3737 cases of traditional shift work (Fig. 1).

Table 1 describes the basic characteristics of the study participants by overall work schedule type in adult populations of

Americans. Night shift workers were predominantly Non-Hispanic Black, older, and had higher alcoholic consumption (all $P < 0.001$). They had elevated systolic blood pressure and HbA1c levels (all $P < 0.001$). However, they had less intake of calcium, milk, protein, and caffeine (all $P < 0.05$). There were more subjects with osteoporosis, a history of wrist fracture, and diabetes in night shift workers

Table 1
Characteristics of survey participants according to the overall work schedule in the adults population of NHANES (N = 4408).

Characteristic	No. reported	Overall	Overall work schedule		p-value
			Traditional shift work	Night shift work	
Age, Mean (95% CI), year	4408	43.52(42.98,44.06)	43.45(42.89,44.01)	43.94(42.19,45.69)	<0.0001
Gender, % (95% CI)	4408				
Male	2351	52.8(50.67,54.92)	52.6(50.32,54.87)	54(48.04,59.85)	0.443
Female	2057	47.2(45.08,49.33)	47.39(45.13,49.68)	46(40.15,51.96)	
Ethnicity, % (95% CI)	4408				
Mexican American	907	8.99(8.23,9.82)	9.1(8.28,10)	8.31(6.49,10.59)	<0.0001
Other Hispanic	550	5.69(5,6.36)	5.42(4.79,6.14)	7.31(5.62,9.47)	
Non-Hispanic White	1834	69.1(67.42,70.74)	70.61(68.84,72.32)	59.9(54.6,64.98)	
Non-Hispanic Black	808	9.55(8.75,10.42)	8.33(7.53,9.19)	17.08(14.15,20.47)	
Other Race	309	6.66(5.75,7.7)	6.54(5.56,7.68)	7.39(5.2,10.41)	
BMI, Mean (95% CI), kg/m2	4408	27.86(27.63,28.09)	27.84(27.59,28.09)	27.98(27.4,28.56)	0.1075
SBP, Mean (95% CI), mmHg	4408	117.71(117,118.43)	117.311(116.54,118.09)	120.15 (118.31,121.99)	<0.0001
DBP, Mean (95% CI), mmHg	4408	67.19(66.58,67.79)	67.02(66.37,67.68)	68.22(66.64,69.79)	0.0006
Diabetes, %(95% CI)	4408				
Yes	310	5.19(4.34,6.2)	4.85(3.96,5.93)	7.28(5.02,10.44)	0.012
No	4028	93.50(92.40,94.44)	93.84(92.65,94.85)	91.36(88.08,93.81)	
Borderline	70	1.31(0.93,1.86)	1.31(0.89,1.92)	1.36(o.66,2.78)	
HbA1c, %	4408	5.52(5.49,5.55)	5.51(5.48,5.54)	5.61(5.52,5.7)	<0.0001
CKD, %(95% CI)	4408				
Yes	48	0.91(0.58,1.41)	0.81(0.5,1.32)	1.48(0.54,4)	0.279
No	4360	99.09(98.59,99.42)	99.19(98.68,99.5)	98.52(96,99.46)	
eGFR, Mean (95% CI), mL/min/1.73m2	4408	92.98(92.05,93.91)	92.74(91.75,93.73)	94.47(91.84,97.1)	0.1832
Protein intake per day, Mean (95% CI), g/kg	4408	1.12(1.1,1.14)	1.13(1.11,1.15)	1.06(0.98,1.13)	0.0113
Calorie intake, Mean (95% CI), kcal/day/kg	4408	29.01(28.45,29.57)	29.16(28.57,29.74)	28.08(26.33,29.83)	0.0941
Calorie intake, Mean (95% CI), kcal/day	4408	2262.95 (2222.53,2303.37)	2279.06 (2236.46,2321.66)	2164.39 (2045,2283.78)	0.0507
% from carbohydrate, Mean (95% CI)	4408	48.15(47.7,48.61)	48.12(47.63,48.61)	48.36(47.11,49.6)	0.3009
% from protein, Mean (95% CI)	4408	15.82(15.62,16.01)	15.9(15.69,16.11)	15.32(14.76,15.87)	0.0378
% from fat, Mean (95% CI)	4408	3.76(3.72,3.8)	3.75(3.71,3.79)	3.83(3.71,3.95)	0.1883
Vitamin D intake per day, Mean (95% CI), mcg/kg	4408	4.73(4.5,4.95)	4.79(4.55,5.03)	4.34(3.81,4.87)	0.0786
Calcium intake per day, Mean (95% CI), mg/kg	4408	13.07(12.72,13.41)	13.16(12.81,13.52)	12.49(11.39,13.59)	0.0131
Caffeine intake per day, Mean (95% CI), mg/kg	4408	2.49(2.35,2.61)	2.56(2.42,2.71)	2.02(1.72,2.31)	0.0019
Alcohol intake per day, Mean (95% CI), gm/kg	4408	0.16(0.14,0.17)	0.16(0.14,0.18)	0.14(0.11,0.18)	0.2506
Past 12 months alcoholic behavior, %(95% CI)	2372				
Never	372	12.16(10.53,14)	12.18(10.36,14.28)	19.49(15.56,24.11)	<0.0001
Rarely- less than monthly	1667	72.23(69.32,74.96)	74.54(71.36,77.47)	60.29(54.38,65.92)	
Regular - monthly or more often, but less frequently than daily	281	13.07(10.83,15.71)	10.46(8.19,13.25)	19.02(14.44,24.62)	
Everyday	52	2.54(1.62,3.94)	2.82(1.75,4.53)	1.21(0.51,2.83)	
Milk consumption, %(95% CI)	4408				
Never	782	16.45(14.98,18.03)	16.46(14.87,18.17)	16.42(12.8,20.82)	0.004
Rarely - less than weekly	722	15.29(13.82,16.89)	14.51(13.02,16.15)	20.07(15.43,25.69)	
Sometimes - weekly or more often, but less frequently than daily	1317	31.44(29.44,33.51)	31.27(29.13,33.5)	32.44(27.1,38.27)	
Often - every day or more	1579	36.59(34.58,38.64)	37.49(35.32,39.71)	31.07(25.96,36.68)	
Varied	8	0.23(0.09,0.59)	0.27(0.1,0.69)	NA	
Working hours per week, Mean (95% CI), h	4408	40.48(39.93,41.03)	40.69(40.09,41.3)	39.17(37.85,40.5)	0.0507
Femoral neck BMD, Mean (95% CI)	4408	0.85(0.85,0.86)	0.85(0.85,0.86)	0.86(0.84,0.87)	0.2701
Femoral neck T-score, Mean (95% CI)	4408	−0.28(-0.33,-0.23)	−0.28(-0.33,-0.23)	−0.27(-0.42,-0.13)	0.2701
Total spine BMD, Mean (95% CI)	4408	1.04(1.04,1.05)	1.04(1.04,1.05)	1.03(1.02,1.05)	0.2923
Total spine T-score, Mean (95% CI)	4408	−0.18(-0.23,-0.13)	−0.16(-0.21,-0.11)	−0.26(-0.41,-0.12)	0.2923
Osteoporosis, %(95% CI)	4408				
Yes	162	3.14(2.48,3.97)	2.59(2.02,3.31)	6.5(3.81,10.9)	0.012
No	4246	96.6(96.03,97.52)	97.41(96.69,97.98)	93.5(89.1,96.19)	
Broken or fractured	400				
Hip, %(95% CI)	22	0.65(0.36,1.16)	0.72(0.39,1.31)	0.23(0.07,0.8)	0.836
Wrist, %(95% CI)	326	9.3(8.01,10.79)	9.19(7.77,10.84)	10.04(7.38,13.54)	0.047
Spine, %(95% CI)	52	1.6(1.07,2.4)	1.26(1.03,2.54)	1.47(0.68,3.15)	0.674

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); SBP, systolic blood pressure; DBP, diastolic blood pressure; HbA1c, Hemoglobin A1C; CKD, Chronic kidney disease; eGFR, estimated glomerular filtration rate; BMD, bone mineral density; NHANES, National Health and Nutrition Examination Survey; CI, confidence interval.

(all $P < 0.05$).

3.2. Associations bone parameters with night shift work

Linear regression models demonstrating the association of night shift work and T-scores at total spine and the femoral neck are summarized in Table 2. In all models, night shift work was correlated with statistically significant decreases in total spine T-scores of females and females aged ≥50, but not females aged <50. At the same time, night shift work was associated with statistically significant decreases in total spine T-scores of females aged ≥50 years and statistically significant increases in femoral neck T-scores of females aged <50 years in unadjusted models. After the multiple adjustments of basic characteristics for potential confounders, these associations did not fade. Besides, the decreases in femoral neck T-scores of females aged ≥50 years and total spine in T-scores became statistically significant associated with night shift work. Nevertheless, these associations mostly faded following the multivariate adjustments of living habits except total spine in T-scores of females aged ≥50 years.

Across the entire study, gender (β = −0.53 [95% CI, −0.75 to −0.3]; $P < 0.001$), advancing age (β = −0.03 [95% CI, −0.04 to −0.03]; $P < 0.001$), less protein intake (β = −0.54 [95% CI, −0.89 to −0.2]; $P = 0.002$), and CKD (β = −0.97 [95% CI, −1.45 to

Table 2
Association of night shift work with T-Scores in NHANES 2007–2008, 2009–2010, and 2017–March.

Variable	Unadjusted model		Model 1[a]		Model 2[b]	
	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p-value
Femoral neck t score						
Overall						
Traditional shift works	REF		REF		REF	
Night shift works	0.01(-0.14,0.16)	0.905	−0.04(-0.16,0.09)	0.543	−0.04(-0.2,0.12)	0.615
Male						
Traditional shift works	REF		REF		REF	
Night shift works	0.01(-0.18,0.2)	0.901	−0.02(-0.19,0.16)	0.808	0.02(-0.16,0.2)	0.842
Female						
Traditional shift works	REF		REF		REF	
Night shift works	−0.01(-0.24,0.22)	0.926	−0.06(-0.23,0.11)	0.02	−0.18(-0.48,0.12)	0.248
Age<50, male						
Traditional shift works	REF		REF		REF	
Night shift works	0.16(-0.07,0.4)	0.166	0.11(-0.12,0.34)	0.345	0.13(-0.11,0.37)	0.296
Age<50, female						
Traditional shift works	REF		REF		REF	
Night shift works	0.32(0.08,0.57)	0.01	0.27(0.04,0.49)	0.022	NA	NA
Age ≥ 50, male						
Traditional shift works	REF		REF		REF	
Night shift works	−0.08(-0.36,0.2)	0.587	−0.05(-0.3,0.19)	0.667	−0.05(-0.32,0.21)	0.703
Age ≥ 50, female						
Traditional shift works	REF		REF		REF	
Night shift works	−0.19(-0.44,0.07)	0.153	−0.28(-0.52,-0.04)	0.021	−0.22(-0.51,0.08)	0.144
Total spine t score						
Overall						
Traditional shift works	REF		REF		REF	
Night shift works	−0.1(-0.25,0.05)	0.202	−0.13(-0.27,0.02)	0.08	−0.05(-0.23,0.12)	0.553
Male						
Traditional shift works	REF		REF		REF	
Night shift works	0.04(-0.14,0.22)	0.66	0.02(-0.16,0.2)	0.818	0.1(-0.07,0.28)	0.253
Female						
Traditional shift works	REF		REF		REF	
Night shift works	−0.27(-0.51,-0.03)	0.025	−0.29(-0.48,-0.1)	0.003	−0.44(-0.76,-0.12)	0.008
Age<50, male						
Traditional shift works	REF		REF		REF	
Night shift works	0.01(-0.21,0.22)	0.941	0(-0.2,0.2)	0.987	0.08(-0.12,0.29)	0.424
Age<50, female						
Traditional shift works	REF		REF		REF	
Night shift works	−0.02(-0.27,0.22)	0.852	−0.03(-0.23,0.18)	0.776	NA	NA
Age ≥ 50, male						
Traditional shift works	REF		REF		REF	
Night shift works	0.07(-0.25,0.39)	0.663	0.18(-0.13,0.49)	0.268	0.27(-0.04,0.59)	0.09
Age ≥ 50, female						
Traditional shift works	REF		REF		REF	
Night shift works	−0.37(-0.68,-0.07)	0.016	−0.45(-0.75,-0.16)	0.003	−0.53(-0.85,-0.21)	0.001

Abbreviations: NHANES, National Health and Nutrition Examination Survey; NA, not applicable; REF, reference; CI, confidence interval. Unreliable estimates are due to insufficient result observations.

[a] Adjusted for age, sex, ethnicity, BMI, blood pressure, HbA1c, diabetes, eGFR, and CKD.

[b] Adjusted for nutrient intakes, milk or alcohol consumption, and work hours.

−0.48]; P < 0.001) were the statistically significant covariates related to diminished femoral neck T-scores. Besides, lower total spine in T-scores did not correlate with advancing age but diabetes (β = −1.22 [95% CI, −1.69 to −0.75]; P < 0.001).

3.3. Associations osteoporosis with night shift work

Table 3 summarizes the correlation between night shift work and the prevalence of osteoporosis within the research population. In the unadjusted investigation, night shift work was associated with a higher prevalence of osteoporosis (OR = 2.62 [95% CI, 1.41–4.85]; P = 0.002). Besides, male night shift workers aged ≥50 years had the highest-odds of osteoporosis (OR = 5.64 [95% CI, 1.75–18.23]; P = 0.004). In model 1, there were statistically significant associations of night shift work with adding odds of osteoporosis (OR = 2.57 [95% CI, 1.25–5.28]; P = 0.01). Moreover, males aged ≥50 years had a higher odds of osteoporosis (OR = 4.93 [95% CI, 1.28–19.04]; P = 0.021). With the multivariate adjustment of living habits in model 2, night shift work was correlated with a higher prevalence of osteoporosis (OR = 2.31 [95% CI, 1.03–5.18]; P = 0.043). Furthermore, females aged ≥50 had the greatest-odds of osteoporosis (OR = 4.6 [95% CI, 1.21–17.54]; P = 0.025). In univariate or multivariate analyses, night shift workers of males aged <50 years were not related to heightened risk of osteoporosis (Table 3). Moreover, no increased risk of osteoporotic fractures was observed as a result (data not shown).

4. Discussion

In our study, we revealed that night shift work, especially for females aged ≥50 years, substantially raised the risk of osteoporosis compared with traditional shift work. Despite statistically significant associations of advancing-age and gender with lower total spine BMD or osteoporosis, our findings draw emphasis on the effect of harmful lifestyles.

The correlation between night shift schedule, BMD, and osteoporosis differs in literatures. In an investigation, a cohort of postmenopausal nurses aged ≥50 in Chile showed that the rotating shift work was relevant to the decrease of BMD in femoral neck or lumbar spine, and the increased prevalence of osteopenia, compared with the traditional shift work [16]. The consequences of our research are in line with these findings. In order to explore age or gender differences, we expanded the survey population to defined adults. However other studies did not reveal an effect of the same outcome as mentioned. Two of them were cross-sectional and population-based. One involved 3005 adults aged ≤50 analyzing the data from Fourth Korea National Health and Nutrition Examination Survey 2009 [17]. The other was carried out among 500 adults aged ≥50 from the NHANES (2010–2011) [32]. A cross-sectional study of 194 female blue-collar workers aged >40 years with subgroups of premenopausal and postmenopausal women also revealed negative results [20]. The sample size, population, lifetime duration for night shift work, work type, and measurement have contributed to these different outcomes. To clarify the impact of the night shift work on bone health, a sizable population foundation with standard measurements such as NHANES and more cycles combinations are provided to prevent this type of partiality.

Table 3
Associations of night shift works with osteoporosis in NHANES, 2007–2008, 2009–2010, and 2017–March2020.

Variable	Unadjusted model		Model 1[a]		Model 2[b]	
	OR(95% CI)	p-value	OR(95% CI)	p-value	OR(95% CI)	p-value
Overall						
Traditional shift works	REF					
Night shift works	2.62(1.41,4.85)	0.002	2.57(1.25,5.28)	0.01	2.31(1.03,5.18)	0.043
Male						
Traditional shift works	REF		REF		REF	
Night shift works	4.03(1.48,10.95)	0.006	2.76(0.85,8.95)	0.092	2.04(0.77,5.37)	0.151
Female						
Traditional shift works	REF		REF		REF	
Night shift works	2.31(1.06,5.06)	0.036	2.33(0.91,5.94)	0.077	4.52(1.07,19.16)	0.041
Age<50, male						
Traditional shift works	REF		REF		REF	
Night shift works	0.7(0.19,2.67)	0.605	0.59(0.15,2.31)	0.446	0.15(0.01,2.04)	0.155
Age<50, female						
Traditional shift works	REF		REF		REF	
Night shift works	1.41(0.18,11.12)	0.741	1.41(0.13,15.24)	0.777	NA	NA
Age ≥ 50, male						
Traditional shift works	REF		REF		REF	
Night shift works	5.64(1.75,18.23)	0.004	4.93(1.28,19.04)	0.021	3.26(0.93,11.49)	0.065
Age ≥ 50, female						
Traditional shift works	REF		REF		REF	
Night shift works	2.16(0.9,5.18)	0.084	2.52(0.99,6.47)	0.054	4.6(1.21,17.54)	0.025

Abbreviations: NHANES, National Health and Nutrition Examination Survey; OR, odds ratio; NA, not applicable; REF, reference; CI, confidence interval.

Unreliable estimates are due to insufficient result observations.

[a] Adjusted for age, sex, ethnicity, BMI, blood pressure, HbA1c, diabetes, eGFR, and CKD.

[b] Adjusted for nutrient intakes, milk or alcohol consumption, and work hours.

This is the first report to evaluate the associations among night shift work, BMD, and osteoporosis in a cross-sectional, population-based survey, especially for the US adult population, and to explore age, gender, or lifestyle differences.

There is a great deal of evidence that indicates a significant necessity to consider age and gender when assessing bone health [2,33–35]. With advancing age, the intricate balance between bone formation and bone resorption went into disorder, related to osteoporosis [33]. The loss of hormonal and increase in oxygen species were crucial drivers of bone loss [34,35]. Because of menopause, females suffer more than males. Epidemiologic research demonstrated that women (16.5%) have a higher prevalence of femoral neck and/or lumbar spine osteoporosis than men (5.1%) based on NHANES (2013–2014) data [2]. Consequently, we led a subgroup analysis of age and gender. Our research did not find night shift work correlated with either total femoral neck or total spine T-score in the overall population but with total spine T-score in females. Besides, compared to the overall female group, females aged ≥50 years make a greater contribution to low BMD in the total spine, while females aged <50 years reveal no effect. Furthermore, the relationship between night shift work and osteoporosis is significant in females aged ≥50 years after the full adjustment, but not in females aged <50 years or males. These findings may support the explanation for the effect of age or gender on bone health.

One interesting point in our study is that female night shift workers aged ≥50 years encounter a tremendously higher risk of osteoporosis after adjusting from the covariates of lifestyle habits. Still, we did not see this phenomenon in the unadjusted model and model 1. Contrary to females, male night shift workers had countervailing manifestations. In the group of adults aged <50 years, we did not observe this distinction. Most of females suffer from postmenopausal after aged 50 years, which led to the reduced protection of estrogen for bone health [36]. Besides, the bone loss increase in bone turnover in females with age is quite as much as males [37]. In our study, night shift work is significantly associated with decreased femoral neck or total spine T-score in females aged ≥50 years. That is more than enough to justify the close relationship between night shift work and osteoporosis in females aged ≥50. Furthermore, there is distinction in lifestyle habits by gender. In comparison to men, a higher percentage of women choose not to drink alcohol throughout their lifetime, drink less, and are less prone to problematic drinking behaviors [38]. More intake of vitamin D, calcium, protein, and dairy is good for protecting bone mass [39]. To our consideration, women aged ≥50 years seem to care more about their health status, so they have healthier lifestyles than men, which would be a protective factor. After changing lifestyle habits from harmful to healthy, males aged ≥50 may decrease the osteoporosis risk.

Night shift work results in harmful lifestyles and interferes with circadian rhythm. Moreover, it leads to more exposure to artificial light at night, which may decrease melatonin production resulting in bone loss [40,41]. The lack of sunlight exposure is common in night shift workers. Moreover, it may cause a low vitamin D level, contributing to osteoporosis or even osteoporotic fractures [42,43]. In addition, unhealthy lifestyles and night shift work were related to an increased probability of Diabetes mellitus type 2 and hypertension [44,45]. In our work, night shift workers tend to be more diabetic, and have higher blood pressure and HbA1c. A previous study showed that postmenopausal nurses who worked in rotating-shift schedules for over 10 years had a greater proportion of current smokers (48.7% vs. 32.2%) and coffee intake (66.6% vs. 16.4%). We found that less protein intake and diabetes separately or together accelerate bone mass loss. Therefore, it is imperative to address the necessity for lifestyle improvement in reducing the probability of low BMD or osteoporosis. In other words, more protein or calcium intake, regular milk consumption, and quitting alcoholic or smoking behavior presumably provide counteracting effects to the lifestyle risk factors depending on the results above.

5. Limitations

There are some limitations to our study. Because of the cross-sectional nature of the NHANES, neither long-term data on the participants nor a causal relationship could be determined. We didn't know the lifetime duration for night shift work, current daily work duration, and work type, so the cumulative effect or working intensity has not been discerned. Future studies require a validated questionnaire assessment of night shift work status, as such biases may result in an underestimation of the relationship between night shift work and BMD of osteoporosis. Owing to the missing data, we did not adjust lifestyle habits of physical activity, smoking behavior, osteoporotic parameters or sun-protective behaviors and examined serum 25-hydroxyvitamin D levels in the models. Moreover, nutrition data were collected from "Total Nutrient Intakes, First Day" taken at a point in time from NHANES, which wasn't the representative of the average nutrient intake and may have influenced study findings.

6. Conclusions

Results of this cross-sectional study indicated that night shift work was associated with a higher risk of osteoporosis in US adults, especially for women aged ≥50 years. Besides, night shift schedule was significantly related to an increased risk of low BMD among American women aged ≥50 years. Furthermore, harmful lifestyles have a combined impact on osteoporosis risk for male night-shift workers aged ≥50 years. Our findings contribute to the existing understanding of the relationships between bone health and the integrated effect of night shift work, age, gender, and lifestyle. Future research should pay attention to assessing the possible causal effects of this relationship accounting for lifetime duration of night shift work, current daily work duration, and work type.

Data availability statement

The datasets presented in this study are available at NHANES website: https://www.cdc.gov/nchs/nhanes/index.htm.

Ethics approval

Review and approval by an ethics committee was not needed for this study because the data in this study are from public databases.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Yu Qian: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jianchun Mao:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to give our heartfelt thanks to the editors and reviewers for their valuable comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28240.

References

[1] B. Adejuyigbe, J. Kallini, D. Chiou, J.R. Kallini, Osteoporosis: molecular pathology, diagnostics, and therapeutics, Int. J. Mol. Sci. 24 (19) (2023) 14583, https://doi.org/10.3390/ijms241914583.
[2] A.C. Looker, N. Sarafrazi Isfahani, B. Fan, J.A. Shepherd, Trends in osteoporosis and low bone mass in older US adults, 2005-2006 through 2013-2014, Osteoporos. Int. 28 (6) (2017) 1979–1988, https://doi.org/10.1007/s00198-017-3996-1.
[3] A.J. Tsai, Disparities in osteoporosis by race/ethnicity, education, work status, immigrant status, and economic status in the United States, Eur. J. Intern. Med. 64 (2019) 85–89, https://doi.org/10.1016/j.ejim.2019.04.011.
[4] P.L. Xiao, A.Y. Cui, C.J. Hsu, et al., Global, regional prevalence, and risk factors of osteoporosis according to the World Health Organization diagnostic criteria: a systematic review and meta-analysis, Osteoporos. Int. 33 (10) (2022) 2137–2153, https://doi.org/10.1007/s00198-022-06454-3.
[5] E. Rentzeperi, S. Pegiou, I. Tsakiridis, et al., Diagnosis and management of osteoporosis: a comprehensive review of guidelines, Obstet. Gynecol. Surv. 78 (11) (2023) 657–681, https://doi.org/10.1097/OGX.0000000000001181.
[6] A.K. Anam, K. Insogna, Update on osteoporosis screening and management, Med. Clin. 105 (6) (2021) 1117–1134, https://doi.org/10.1016/j.mcna.2021.05.016.
[7] B.C. Mkhize, P. Mosili, P.S. Ngubane, et al., The relationship between renin-angiotensin-aldosterone system (RAAS) activity, osteoporosis and estrogen deficiency in type 2 diabetes, Int. J. Mol. Sci. 24 (15) (2023) 11963, https://doi.org/10.3390/ijms241511963.
[8] B. Kirk, J. Zanker, G. Duque, Osteosarcopenia: epidemiology, diagnosis, and treatment-facts and numbers, J Cachexia Sarcopenia Muscle 11 (3) (2020) 609–618, https://doi.org/10.1002/jcsm.12567.
[9] J.E. Compston, M.R. McClung, W.D. Leslie, Osteoporosis, Lancet 393 (10169) (2019) 364–376, https://doi.org/10.1016/S0140-6736(18)32112-3.
[10] H.R. Lieberman, S. Agarwal, J.A. Caldwell, V.L. Fulgoni, Demographics, sleep, and daily patterns of caffeine intake of shift workers in a nationally representative sample of the US adult population, Sleep 43 (3) (2020) zsz240, https://doi.org/10.1093/sleep/zsz240.
[11] M. Ward, D.J. Berry, C. Power, E. Hyppönen, Working patterns and vitamin D status in mid-life: a cross-sectional study of the 1958 British birth cohort, Occup. Environ. Med. 68 (12) (2011) 902–907, https://doi.org/10.1136/oem.2010.063479.
[12] L. Kervezee, M. Cuesta, N. Cermakian, D.B. Boivin, Simulated night shift work induces circadian misalignment of the human peripheral blood mononuclear cell transcriptome, Proc. Natl. Acad. Sci. U. S. A. 115 (21) (2018) 5540–5545, https://doi.org/10.1073/pnas.1720719115.
[13] B.S.C. Koritala, K.I. Porter, O.A. Arshad, et al., Night shift schedule causes circadian dysregulation of DNA repair genes and elevated DNA damage in humans, J. Pineal Res. 70 (3) (2021) e12726, https://doi.org/10.1111/jpi.12726.
[14] N. Wang, Y. Sun, H. Zhang, et al., Long-term night shift work is associated with the risk of atrial fibrillation and coronary heart disease, Eur. Heart J. 42 (40) (2021) 4180–4188, https://doi.org/10.1093/eurheartj/ehab505.
[15] Y.C. Lim, V.C.W. Hoe, A. Darus, N. Bhoo-Pathy, Association between night-shift work, sleep quality and metabolic syndrome, Occup. Environ. Med. 75 (10) (2018) 716–723, https://doi.org/10.1136/oemed-2018-105104.
[16] I. Quevedo, A.M. Zuniga, Low bone mineral density in rotating-shift workers, J. Clin. Densitom. 13 (4) (2010) 467–469, https://doi.org/10.1016/j.jocd.2010.07.004.
[17] B.K. Kim, Y.J. Choi, Y.S. Chung, Other than daytime working is associated with lower bone mineral density: the Korea National Health and Nutrition Examination Survey, 2009, Calcif. Tissue Int. 93 (6) (2013) 495–501, https://doi.org/10.1007/s00223-013-9779-6.
[18] D. Feskanich, S.E. Hankinson, E.S. Schernhammer, Nightshift work and fracture risk: the nurses' health study, Osteoporos. Int. 20 (4) (2009) 537–542, https://doi.org/10.1007/s00198-008-0729-5.
[19] A. Bukowska-Damska, E. Skowronska-Jozwiak, P. Kaluzny, A. Lewinski, Night shift work and osteoporosis - bone turnover markers among female blue-collar workers in Poland, Chronobiol. Int. 39 (6) (2022) 818–825, https://doi.org/10.1080/07420528.2022.2037626.
[20] A. Bukowska-Damska, E. Skowronska-Jozwiak, P. Kaluzny, A. Lewinski, B. Peplonska, Night shift work and osteoporosis among female blue-collar workers in Poland - a pilot study, Chronobiol. Int. 37 (6) (2020) 910–920, https://doi.org/10.1080/07420528.2020.1763381.

[21] Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Report of a WHO Study Group, World Health Organ Tech Rep Ser 843 (1994) 1–129.
[22] S. Xue, Y. Zhang, W. Qiao, et al., An updated reference for calculating bone mineral density T-scores, J. Clin. Endocrinol. Metab. 106 (7) (2021) e2613–e2621, https://doi.org/10.1210/clinem/dgab180.
[23] N.C. Wright, A.C. Looker, K.G. Saag, 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. 29 (11) (2014) 2520–2526, https://doi.org/10.1002/jbmr.
[24] S.R. Cummings, L.J. Melton, Epidemiology and outcomes of osteoporotic fractures, Lancet 359 (9319) (2002) 1761–1767, https://doi.org/10.1016/S0140-6736(02)08657-9.
[25] N. Ahluwalia, J. Dwyer, A. Terry, A. Moshfegh, C. Johnson, Update on NHANES dietary data: focus on collection, release, analytical considerations, and uses to inform public policy, Adv. Nutr. 7 (1) (2016) 121–134, https://doi.org/10.3945/an.115.009258.
[26] P.L. Xiao, C. Fuerwa, C.J. Hsu, et al., Socioeconomic status influences on bone mineral density in American men: findings from NHANES, 2011-2020, Osteoporos. Int. 33 (11) (2022) 2347–2355, https://doi.org/10.1007/s00198-022-06498-5.
[27] T. Vilaca, R. Eastell, M. Schini, Osteoporosis in men, Lancet Diabetes Endocrinol. 10 (4) (2022) 273–283, https://doi.org/10.1016/S2213-8587(22)00012-2.
[28] R. Fabiani, G. Naldini, M. Chiavarini, Dietary patterns in relation to low bone mineral density and fracture risk: a systematic review and meta-analysis, Adv. Nutr. 10 (2) (2019) 219–236, https://doi.org/10.1093/advances/nmy073.
[29] G. Hendrickx, E. Boudin, W. Van Hul, A look behind the scenes: the risk and pathogenesis of primary osteoporosis, Nat. Rev. Rheumatol. 11 (8) (2015) 462–474, https://doi.org/10.1038/nrrheum.2015.48.
[30] D.B. Maurel, N. Boisseau, C.L. Benhamou, C. Jaffre, Alcohol and bone: review of dose effects and mechanisms, Osteoporos. Int. 23 (1) (2012) 1–16, https://doi.org/10.1007/s00198-011-1787-7.
[31] C.D.C. PhysicsWeb, National Health and Nutrition Examination Survey, 2017–March 2020 Prepandemic File: Sample Design, Estimation, and Analytic Guidelines, 2022. Retrieved from, https://www.cdc.gov/nchs/data/series/sr_02/sr02-190.pdf. (Accessed 4 June 2023).
[32] P. Santhanam, R. Khthir, L. Dial, H.K. Driscoll, T.W. Gress, Femoral neck bone mineral density in persons over 50 Years performing shiftwork: an epidemiological study, J. Occup. Environ. Med. 58 (3) (2016) e63–e65, https://doi.org/10.1097/JOM.0000000000000662.
[33] A. Chandra, J. Rajawat, Skeletal aging and osteoporosis: mechanisms and therapeutics, Int. J. Mol. Sci. 22 (7) (2021) 3553, https://doi.org/10.3390/ijms22073553.
[34] S.C. Manolagas, From estrogen-centric to aging and oxidative stress: a revised perspective of the pathogenesis of osteoporosis, Endocr. Rev. 31 (3) (2010) 266–300, https://doi.org/10.1210/er.2009-0024.
[35] T.S. Agidigbi, C. Kim, Reactive oxygen species in osteoclast differentiation and possible pharmaceutical targets of ROS-mediated osteoclast diseases, Int. J. Mol. Sci. 20 (14) (2019) 3576, https://doi.org/10.3390/ijms20143576.
[36] R. Recker, J. Lappe, K.M. Davies, R. Heaney, Bone remodeling increases substantially in the years after menopause and remains increased in older osteoporosis patients, J. Bone Miner. Res. 19 (10) (2004) 1628–1633, https://doi.org/10.1359/JBMR.040710.
[37] A. Hannemann, H. Wallaschofski, Reference intervals for serum concentrations of three bone turnover markers for men and women, Bone 93 (2016) 216, https://doi.org/10.1016/j.bone.2015.06.020.
[38] A. Erol, V.M. Karpyak, Sex and gender-related differences in alcohol use and its consequences: contemporary knowledge and future research considerations, Drug Alcohol Depend. 156 (2015) 1–13, https://doi.org/10.1016/j.drugalcdep.2015.08.023.
[39] K.E. Ensrud, C.J. Crandall, Osteoporosis, Ann. Intern. Med. 167 (3) (2017) ITC17–ITC32, https://doi.org/10.7326/AITC201708010.
[40] T. Wei, C. Li, Y. Heng, et al., Association between night-shift work and level of melatonin: systematic review and meta-analysis, Sleep Med. 75 (2020) 502–509, https://doi.org/10.1016/j.sleep.2020.09.018.
[41] D.P. Cardinali, Melatonin as a chronobiotic/cytoprotective agent in bone. Doses involved, J. Pineal Res. 76 (1) (2024) e12931, https://doi.org/10.1111/jpi.12931.
[42] S. Rizza, A. Pietroiusti, A. Farcomeni, et al., Monthly fluctuations in 25-hydroxy-vitamin D levels in day and rotating night shift hospital workers, J. Endocrinol. Invest. 43 (11) (2020) 1655–1660, https://doi.org/10.1007/s40618-020-01265-x.
[43] P. Lips, N.M. van Schoor, The effect of vitamin D on bone and osteoporosis, Best Pract. Res. Clin. Endocrinol. Metabol. 25 (4) (2011) 585–591, https://doi.org/10.1016/j.beem.2011.05.002.
[44] Z. Shan, Y. Li, G. Zong, et al., Rotating night shift work and adherence to unhealthy lifestyle in predicting risk of type 2 diabetes: results from two large US cohorts of female nurses, BMJ 363 (2018) k4641, https://doi.org/10.1136/bmj.k4641.
[45] Z. Xiao, C. Xu, Q. Liu, et al., Night shift work, genetic risk, and hypertension, Mayo Clin. Proc. 97 (11) (2022) 2016–2027, https://doi.org/10.1016/j.mayocp.2022.04.007.