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Association between sleep duration and hip fracture risk among the older adults: a cross-sectional study based on the NHANES

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Abstract

Background There has been sharp increase in the incidence of hip fractures (HFs) with the increasing aging globally. However, it remains ambiguous regarding the association between HF risk and sleep duration. This study intended to explore the association between sleep duration and HF risk among the older adults.

Methods The study assessed a cohort of 7,540 participants aged at least 60 years old using data from the National Health and Nutrition Examination Survey (NHANES) from 2005 to 2010, as well as from 2013 to 2014. Two distinct groups of HF and non-HF were constructed on the basis of their history of HFs. Based on the self-reported sleep duration through a structured questionnaire, multivariate logistic regression analyses were conducted to examine the relationship between sleep duration and HF risk. In addition, restricted cubic splines (RCS) were used to assess linearity. The receiver operating characteristic (ROC) curve was used to explore the threshold of sleep duration for HF risk.

Results HFs were found in 129 patients among the 7,540 participants over 60 years of age with mean age of 70.17 ± 7.1 years. Significant differences in sleep duration were observed between the HF and non-HF groups (7.73 ± 1.68 h vs. 7.11 ± 1.42 h; $p = 0.006$). The multivariate analysis was adjusted for sociodemographic, behavioral lifestyle, and comorbidities. A 1-h increase in sleep duration was associated with higher odds of having prior hip fractures in unadjusted models [odds ratio (OR) = 1.36; 1.11, 1.67; $p = 0.004$], minimally adjusted models (OR = 1.23; 1.03, 1.48; $p = 0.025$), second adjusted models (OR = 1.22; 1.02,1.45; $p = 0.026$) and fully adjusted models (OR = 1.22; 1.03,1.45; $p = 0.026$). The relationship remained consistent across all four models, indicating the correlation of a longer sleep duration with an elevated HF risk. RCS analysis revealed a statistically linear relationship between sleep duration and HF risk (p-nonlinear = 0.244, p-overall < 0.01). In addition, the identified threshold of sleep duration linked to HF risk was determined to be 7.5 h among the older adults (AUC = 0.611).

Conclusion This study suggests an linear association between sleep duration and the risk of HFs. Further research is needed to validate these findings and more clearly identify the clinical relevance of this potential relationship.

Keywords Hip fractures, Sleep duration, NHANES, Older adults

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Introduction

Hip fractures (HFs) are prevalent, particularly among the older adults, showing significant increase in their incidence owing to the intensified aging globally [1, 2]. The incidence of of HFs was 1.31 million in 1990, which is expected to rise to 6.26 million worldwide by 2050 [3–5]. Owing to serious complications as well as high mortality and disability rates, HFs are among the leading causes

of loss of disability-adjusted life years among the older adults [5]. Even within a year of injury, the mortality rate is approximately 30% [1].

Sufficient and adequate sleep is essential for maintaining optimal health and safety, whereas variations in sleep duration and timing may trigger metabolic, cardiovascular, endocrine, and neurological disorders [6–8]. Circadian rhythmicity and sleep behaviors are documented to be associated with bone health [9–11]. With disrupted circadian rhythms and impeded bone formation, sleep disorders can further increase the likelihood of fractures [12, 13]. Existing animal experiments have shown that long-term sleep restriction can hinder bone remodeling in laboratory rats [14, 15]. Therefore, disturbances in sleep physiology and the circadian rhythm may adversely affect bone health.

So far, there are still insufficient observational studies on the relationship between sleep behaviors and HF risk, and existing studies report conflicting results as well [16–18]. Meanwhile, people who sleep longer were reported to be more prone to falls and fractures compared with those with shorter sleep duration [16, 17]. Furthermore, a U-shaped relationship has been documented prospectively between sleep duration and fracture risk [19]. Therefore, it highlights the significance of recognizing modifiable risk factors, including sleep duration, for reducing the incidence of HFs, particularly among the older adults. In view of the above interpretation, this study sought to explore the association between sleep duration and the incidence of HFs in individuals aged at least 60 years old.

Materials and methods

Data and participants

The National Health and Nutrition Examination Survey represents a nationally representative cross-sectional study combining individual interviews, medical examinations and laboratory tests across diverse populations of America, orchestrated by the National Center for Health Statistics (NCHS) [20]. NHANES-sourced data have been approved by the NCHS Ethics Review Committee, and detailed statistics can be found at https://www.cdc.gov/nchs/nhanes/.

Owing to the lack of data on hip fracture of patients in 2011–2012, this study collected 50,966 subjects from NHANES during 2005–2010 and 2013–2014. Finally, 7,540 participants were identified based on rigorous exclusion criteria: (1) under 60 years of age, (2) missing sleeping duration data, (3) missing fractured hip data, and (4) the occurrence of fracture at the age of less than 60 years (Fig. 1). Finally, among the 7,540 eligible individuals enrolled in this study, 7,411 did not suffer from HFs, while 129 sustained HFs after age 60.

HFs

This study obtained data related to self-reported HF history and age at first HF provided in the NHANES interviews. Participants were asked to answer, "Has a doctor ever told you that you had broken or fractured hip?" Patients with HF history were asked the following questions “How old were you when you fractured your hip the first time?” Cases of HFs were included if they had HFs and were older than 60 years of age for the first time [21, 22].

Sleep duration

The sleep duration of the included participants was self-reported by answering the question of “How much sleep do you usually get at night on weekdays or workdays?” The recorded duration was a continuous variable and served as an independent variable [23].

Covariates

The NHANES was searched to acquire self-reported demographic data such as age, sex, race/ethnicity, education, marital status, and poverty-to-income ratio (PIR). Covariates included common risk factors, such as body mass index (BMI; normal, < 25 kg/m^2; overweight, 25–30 kg/m^2; and obesity: > 30 kg/m^2), alcohol consumption, and smoking. The smoking status was classified as either “smoker” or “non-smoker” by a questionnaire. Alcohol consumption was measured by a question “During the past 12 months, on those days that drank alcoholic beverages, on the average, how many drinks did you have?” Physical activity (PA) was converted to metabolic equivalent (MET, min), depending on the type of exercise, The recommended MET values for each PA are proposed by the NHANES according to the Global Physical Activity Questionnaire. The assessment of PA was determined by considering the MET values associated with the type, frequency, and duration of PA performed each week, which was calculated using the following formula: PA (MET-min/week) = MET × weekly frequency × duration of each PA [24, 25]. Diabetes was determined if any of the following criteria were met by the participants: a self-reported history of diabetes, a history of diabetes medication (DM), a fasting blood glucose > 7.0 mmol/L, a random blood glucose > 11.0 mmol/L, a glycosylated hemoglobin > 6.5%, and a 2-h OGTT glucose level > 11.1 mmoL/L [26, 27]. Meanwhile, hypertension would exist if participants had self-reported history of hypertension, history of medication for hypertension, three times of mean diastolic blood pressure > 90 mmHg, or three times of the mean systolic blood pressure > 140 mmHg [26, 28]. In addition, cardiovascular

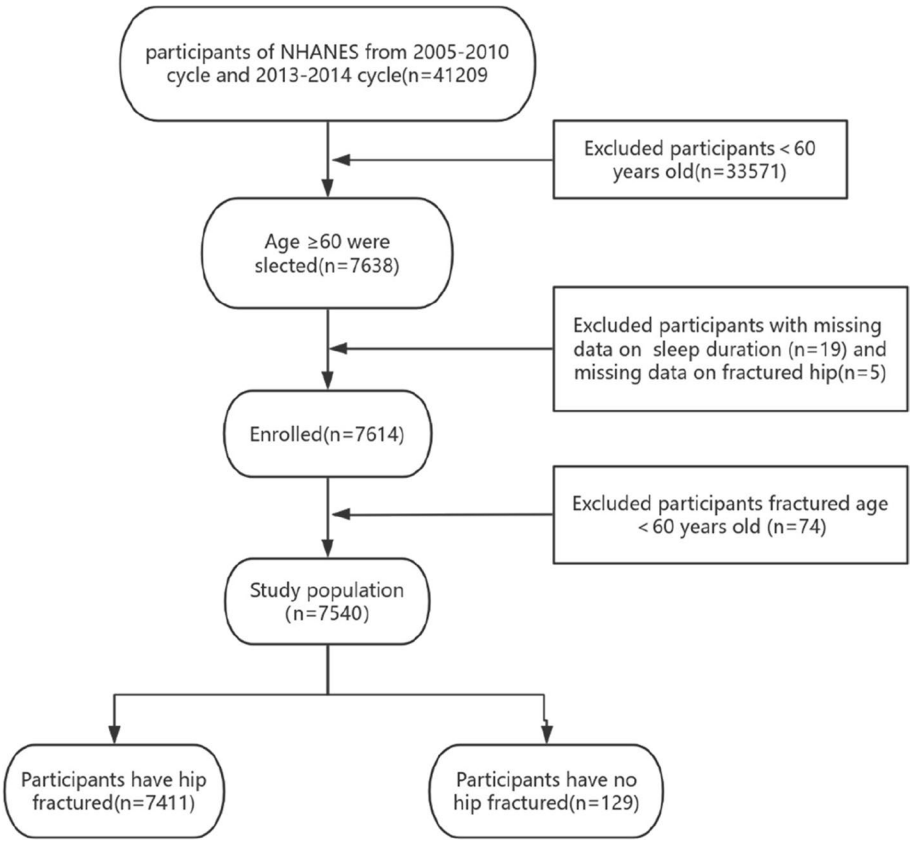

Fig. 1 Screening procedure flowchart

disease (CVD) included self-reported congestive coronary heart disease, heart failure, stroke, heart attack, and angina.

Statistical analysis

Given the complex multistage sampling design of the NHANES, weighted analyses were appropriately conducted via the R survey package to better represent the overall characteristics of the U.S. population. According to the NHANES recommended Two-Year Sample Weights for MEC Examination (WTMEC2YR) records, sample weights of individuals were determined by WTMEC2YR/4. Statistical analyses in this study were completed by utilizing R 4.3.0 and SPSS 29. Normally distributed continuous variables were reported as mean ± standard deviation (SD) and compared using two independent samples t-test between groups. Categorical variables were represented as n (%), and compared by chi-square test or Fisher's exact test. The p value of < 0.05 was considered statistically significant.

In the multivariable regression analyses, Model 1 was adjusted for covariates such as age, sex, education, marital status, race/ethnicity, and PIR. Based on Model 1, Model 2 incorporated adjustments for BMI, smoking, PA and alcohol consumption. Finally, Model 3 was additionally adjusted for diabetes, hypertension, and CVD. Furthermore, the optimal cutoff value for sleep duration was determined by receiver operating characteristic (ROC) curve analyses. Based on the computation of the area under the curve (AUC), an AUC value of ≥ 0.81, 0.71–0.80, 0.61–0.70, and ≤ 0.6 indicated high, fair, poor accuracy, and a lack of discriminatory capability, respectively [29]. The Youden index was used to determine the optimal threshold for distinguishing patients if the AUC exceeded 0.60. In addition, a restricted cubic spline (RCS) with four nodes at the 5th, 35th, 65th, and 95th percentiles was employed to identify a linear or nonlinear relationship between sleep duration and HF risk.

Results

Table 1 presents significant inter-group differences concerning various demographic and lifestyle factors. On average, individuals in the HF group were older than those in the control group (76.93 ± 6.13 years vs. 70.17 ± 7.10 years; $p < 0.001$). The HF group included a significantly greater percentage of female participants (71.13% vs. 55.20%; $p = 0.002$). Meanwhile, compared to the control group, the HF group presented a longer

Table 1 Participant characteristics in NHANES (2005–2010 and 2013–2014)

Variables	Total, *N* = 7,540	Control, *N* = 7,411	Case, *N* = 129	*P* value
Age,Mean ± SD	70.17 ± 7.10	70.07 ± 7.07	76.93 ± 6.13	< 0.001
Sleep h,Mean ± SD	7.11 ± 1.42	7.11 ± 1.42	7.73 ± 1.68	0.006
Alcohol consumption,Mean ± SD	0.93 ± 1.34	0.94 ± 1.34	0.49 ± 0.94	< 0.001
Gender, n (%)				0.002
Male	3,680 (44.55)	3,629 (44.80)	51 (28.87)	
Female	3,860 (55.45)	3,782 (55.20)	78 (71.13)	
Race, n (%)				0.269
Non-hispanic white	4,118 (79.74)	4,022 (79.67)	96 (84.06)	
Non-hispanic black	1,482 (8.88)	1,469 (8.94)	13 (4.88)	
Mexican American	1,005 (4.27)	991 (4.26)	14 (4.54)	
Other Hispanic	558 (2.63)	558 (2.67)	0 (0)	
Other	377 (4.48)	371 (4.45)	6 (6.52)	
Education, n (%)				0.013
College graduate or above	1,403 (25.01)	1,389 (25.22)	14 (11.75)	
High school grade	1,825 (25.78)	1,793 (25.73)	32 (28.86)	
9-11th grade	1,220 (13.05)	1,192 (12.96)	28 (19.09)	
Some college or AA degree	1,758 (26.47)	1,725 (26.48)	33 (26)	
Less than 9th grade	1,334 (9.69)	1,312 (9.62)	22 (14.31)	
DM, n (%)				0.185
No	5,114 (72.24)	5,011 (72.12)	103 (80.09)	
Yes	2,426 (27.76)	2,400 (27.88)	26 (19.91)	
CVD, n (%)				< 0.001
No	5,630 (75.95)	5,553 (76.16)	77 (62.56)	
Yes	1,910 (24.05)	1,858 (23.84)	52 (37.44)	
PIR, n (%)				0.217
≤ 1.0	1,261 (9.87)	1,240 (9.83)	21 (12.60)	
1.0–3.0	3,653 (44.42)	3,583 (44.32)	70 (50.65)	
≥ 3.0	2,626 (45.71)	2,588 (45.85)	38 (36.74)	
BMI group, n (%)				< 0.001
Normal	1,864 (26.26)	1,811 (25.95)	53 (46)	
Overweight	3,088 (38.11)	3,028 (38.04)	60 (42.56)	
Obesity	2,588 (35.62)	2,572 (36.01)	16 (11.44)	
Smoking, n (%)				0.656
No	6,618 (89.04)	6,505 (89.06)	113 (87.50)	
Yes	922 (10.96)	906 (10.94)	16 (12.50)	
Hypertension, n (%)				0.102
No	2,225 (31.14)	2,192 (31.27)	33 (22.88)	
Yes	5,315 (68.86)	5,219 (68.73)	96 (77.12)	
Marital Status, n (%)				< 0.001
Married	4,142 (60.78)	4,094 (61.15)	48 (37.51)	
Widowed	1,802 (21.51)	1,736 (21.01)	66 (53.07)	
Divorced	921 (11.34)	911 (11.43)	10 (5.61)	
Separated	178 (1.19)	177 (1.19)	1 (0.69)	
Living with partner	154 (1.64)	154 (1.67)	0 (0)	
Never married	343 (3.55)	339 (3.56)	4 (3.12)	
MET,Mean ± SD	2,426.87 ± 3,933.12	2,443.37 ± 3,950.85	1,379.28 ± 2,351.66	< 0.001

average sleep duration (7.73 ± 1.68 h vs. 7.11 ± 1.42 h; $p = 0.006$), and a lower level of alcohol consumption (0.49 ± 0.94 vs. 0.94 ± 1.34 glasses/day; $p < 0.001$). Moreover, the control group had higher MET than the HF group (2,443.37 ± 3,950.85 min vs. 1,379.28 ± 2,351.66 min; $p < 0.001$). Besides, the incidence of CVD was elevated in the HF group (37.44% vs. 23.84%; $p < 0.001$).

Furthermore, four logistical regression models were constructed to clarify the correlation between sleep duration and HF risk among the older adults. As presented in Table 2, longer sleep duration correlated with an increased risk of HFs in the crude model [odds ratio (OR) = 1.36, (1.11,1.67); $p = 0.004$]. Consistently, longer sleep duration was associated with an increased risk of HFs in the adjusted Model 1 [OR = 1.23(1.03,1.48); $p = 0.025$], Model 2 [OR = 1.22(1.02,1.45); $p = 0.026$], and Model 3 [OR = 1.22(1.03,1.45); $p = 0.026$]. After adjustment for confounding variables, the OR values of the three models decreased compared with those of the crude model, yet with the same association remained.

The ROC curve analysis (Fig. 2) revealed an AUC of 0.611, indicating that sleep duration had a low predictive accuracy for HF risk. The optimal threshold was determined to be 7.5 h, resulting in a Youden index of 0.192, corresponding to a sensitivity of 0.597 and a specificity of 0.595. In addition, RCS curves were plotted to examine the potential nonlinearity in the studied relationship. The generated approximate U-shaped image suggested that either long or short sleep duration would increase the risk of HFs. However, the RCS curve (Fig. 3) still showed a linear association (p-overall = 0.002, p-nonlinear = 0.218).

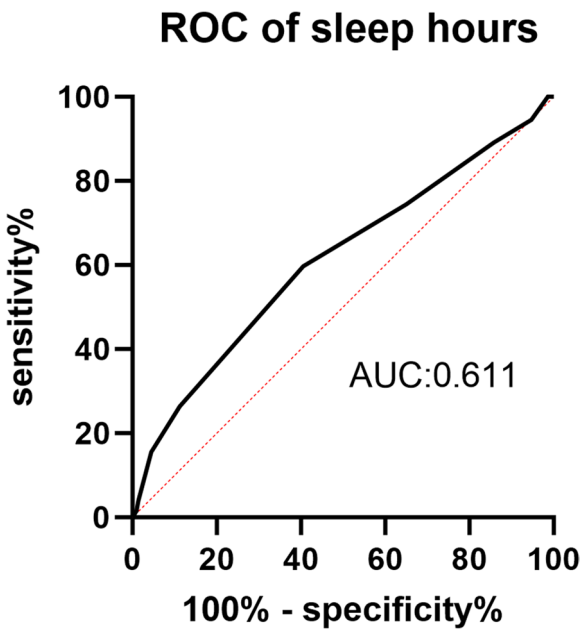

Fig. 2 ROC curves for sleep duration with poor accuracy (AUC:0.61–0.7) for distinguishing between controls and HF patients

Discussion

In this population-based retrospective cross-sectional study, sleep duration was associated with HF risk among the older adults according to analyses based on logistic regression models. There was a linear correlation between sleep duration and HF risk, as supported by multiple logistic regression analysis and the RCS curve. This association remained consistent across the three models that accounted for confounding factors. The threshold of sleep duration was 7.5 h, which, however, cannot be used as a diagnostic criterion owing to a low reliability in our study.

These findings have crucial clinical implications. Longer sleep duration is an independent risk factor for HFs according to existing epidemiological studies. For instance, in a study on osteoporotic fractures by including 8,101 postmenopausal women, significantly increased risk of HFs was observed in postmenopausal women who slept longer than 10 h [17]. In our study, women accounted for a greater proportion of HFs among the older adults, which was in line with the findings of this study. A substantial prospective cohort study from the China Health and Retirement Longitudinal Study indicated a mitigated risk of HFs by integrating brief sleep duration with afternoon napping [30]. A recent meta-analysis in China also revealed a significant correlation of both insufficient and excessive sleep duration with the incidence of falls, with a notably stronger association between prolonged sleep duration and falls in the white population [31]. HFs are caused mainly by falls among the older adults, which, to some extent, explain the increased risk of HFs in case of prolonged sleep duration

Table 2 Association between sleep duration and HF risk among the older adults

	Crude		Model 1		Model 2		Model 3	
	OR(95%CI)	*p*	OR(95%CI)	*p*	OR(95%CI)	*p*	OR(95%CI)	*p*
Sleep duration	1.36 (1.11, 1.67)	0.004	1.23 (1.03, 1.48)	0.025	1.22 (1.02, 1.45)	0.026	1.22 (1.03, 1.45)	0.026

Crude represents an unadjusted model. Model 1 was adjusted for age, gender, race, marital status, education, and PIR. Model 2 was adjusted for alcohol consumption past 12 months, smoking past 30 days, BMI groups and MET, based on Model 1. Model 3 was adjusted for diabetes, CVD, and hypertension, based on Model 2

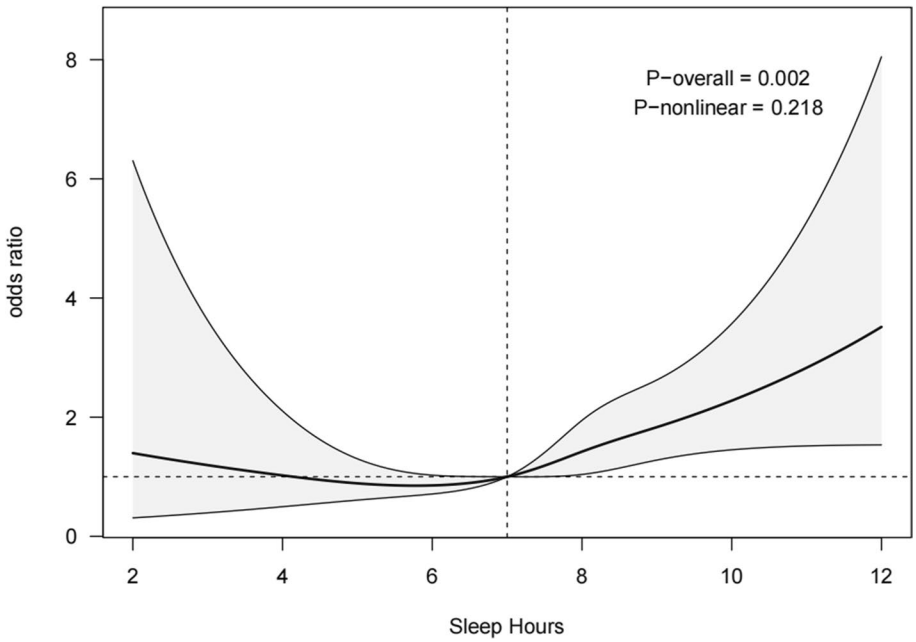

Fig. 3 The RCS curve of the association between sleep duration and HF risk among all the study participants. RCS regression was adjusted for age, gender, race, marital status, education, PIR, alcohol consumption, smoking, BMI, MET, diabetes, CVD, and hypertension

[32, 33]. HFs are significantly correlated with decreased bone mineral density (BMD) [34], which facilitated the elucidation of our findings. For example, Specker et al. conducted a cross-sectional investigation involving 1,146 participants, comprising both genders aged between 20 and 60 years. Individuals who reported a nightly sleep duration of under 6.5 h had lower BMD than those whose slept over 6.5 h per night. Nevertheless, no significant distinctions in BMD at the spinal or hip areas were identified between sleep-deprived individuals of either sexes. Additional cross-sectional analyses in Japan and China both indicated that individuals with self-reported sleep duration of over 8 h were at a greater risk of developing osteoporosis than those less than 8 h in sleeping [35–37].

Noticeably, even though there was a linear association between sleep duration and the risk of HFs, the RCS curve was close to a "U-shape". It can be observed with no obvious change in HF risk when the sleep duration was less than 7.5 h, but increased risk when the sleep duration was over 7.5 h. In contrast, Yu et al. reported a U-shaped correlation between sleep duration and HF risk, with the lowest HF risk detected in participants who slept 7–8 h daily [19]. These findings may indicate the unique nature of the association between HFs and sleep duration, which can vary according to fracture location [38].

Furthermore, the effect of sleep on HF risk involves many physiological and pathological processes, with unclear mechanism so far. Both short and long sleep durations are associated with the risk factors of HFs, such as osteoporosis, falls, psychological disorders, etc., all of which can mediate the effect on HF risk [10, 11, 39–41]. Specifically, patients with long sleep duration at night predispose to depression. Cizza et al. proposed that depressed patients might present with bone loss and osteoporosis symptoms, which could be explained primarily by specific immune responses and endocrine mechanisms [42]. We reckon that it may be one of the important reasons for the increased risk of HFs caused by longer sleep duration. Moreover, multiple risk factors for HFs, such as age, BMI, sex, and country, pose challenges to predict risk via a single variable, which may explain the limited predictive ability of ROC curve [34, 43].

This study for the first time explored the relationship between sleep duration and HF risk among the older adults based on recent extensive datasets. For a better representation of the overall characteristics of the U.S. population, this study utilized weights provided by NHANES to weight the sample data, in addition to data derived from a nationally representative sample. Therefore, the concluded results hold the potential to be generalized across the entire U.S. population. However, our study still has some limitations that must be acknowledged. First, this study was a cross-sectional study using the NHANES database, which was impossible to establish a causal link between sleep duration and HF risk among the older adults. Our analyses based on self-reported sleep duration might introduce recall bias and subjectivity. Furthermore, this large sample size

study might overstate the statistical effect, necessitating more clinical studies (e.g., using propensity matching analysis) to demonstrate the relationship between sleep duration and HFs in older adults. Moreover, the 2013–2014 NHANES data used in this study contained accelerometer data that has been used to derive multiple measures of sleep health (duration, efficiency, regularity, and timing) in recent work, which might compromise the consistency of sleep duration records in this study. Finally, sleep health is multi-dimensional, but this study used self-reported sleep data and only considered one measure of sleep health. Further studies are needed to explore the effects of sleep on HF risk by including more variables of sleep characteristics such as daytime naps, snoring, difficulty falling asleep, etc. [44, 45].

Conclusion

In summary, sleep duration is linearly associated with HF risk among the older adults based on a nationally representative study. However, further research is needed to validate these findings and more clearly identify the clinical relevance of this potential relationship.

Abbreviations

HFs	Hip fractures
HF	Hip fracture
NHANES	National Health and Nutrition Examination Survey
NCHS	National Center for Health Statistics
RCS	Restricted cubic splines
ROC	Receiver Operating Characteristic
PIR	Poverty-to-income ratio
BMI	Body mass index
PA	Physical activity
MET	Metabolic equivalent
CI	Confidence interval
AUC	Area under the curve
OR	Odds ratio
SD	Standard deviation
CVD	Cardiovascular disease
DM	Diabetes medication
CHARLS	China Health and Retirement Longitudinal Study
BMD	Bone mineral density

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Authors' contributions

Substantial contributions to study conception and design : HZ,ST,LT,BY. Substantial contributions to acquisition of data:HZ,LK,ST. Substantial contributions to analysis and interpretation of data: HZ,LK,ST. Drafting the article or revising it critically for important intellectual content:HZ,BY,QL. All authors read and approved the final manuscript. Final approval of the version of the article to be published:HZ,ST,LK,LT,BY,QL.

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Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate

Use of the dateset from the NHANES was approved by the National Center for Health. The study was conducted in accordance with the revised Declaration of Helsinki. All informed consents were obtained prior to data collection.

Consent for publication

Not applicable in the declarations section.

Competing interests

The authors declare no competing interests.

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