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The association of sexual frequency with cardiovascular diseases incidence and all-cause mortality

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Sexual activity exists in a complex relationship with human health. This study aims to elucidate the correlation between the sexual frequency and the incidence of cardiovascular diseases (CVD) and all-cause mortality among young and middle-aged adults of the United States. We analyzed 17,243 participants from the National Health and Nutrition Examination Survey(NHANES)(2005–2016), comparing CVD incidence and all-cause mortality risks across sexual frequencies using multivariable Logistic and Cox regression models. Kaplan-Meier curves assessed survival probability stratified by sexual frequency, and a restricted cubic spline regression examined the nonlinear relationship between sexual frequency, CVD and survival status. We also established a nomogram and validated it by ROC and calibration curves. Over a median follow-up period of 106 months, 443 patients (2.57%) died. After adjusting for confounders, sexual frequency was found to be associated with CVD incidence and all-cause mortality among young and middle-aged individuals. Those with sexual acts less than 12 times/year faced the highest risks of CVD incidence and all-cause mortality, as frequency increased, the risks gradually decreased, reaching a nadir at approximately 52–103 times/year, but then a negative correlation began to emerge. A nomogram predicting survival rates based on sexual frequency achieved ROC areas of 0.782, 0.807, and 0.803 for 3, 5, and 10 years, with a calibration curve matching the ideal generally. Sexual frequency was associated with the incidence of CVD and all-cause mortality among young and middle-aged adults. Both excessive and infrequent sexual frequency may be detrimental to health.

Keywords Sexual frequency, Cardiovascular diseases, All-cause mortality, NHANES, Young and middle-aged adults

Abbreviations

CVD	Cardiovascular diseases
JACC	The Journal of the American College of Cardiology
NHANES	National Health and Nutrition Examination Survey
BMI	Body mass index
PHQ-9	Patient Health Questionnaire-9
eGFR	Estimated glomerular filtration rate
PIR	Poverty income ratio
TG	Total cholesterol
HbA1c	Glycated hemoglobin
RCS	Restricted cubic spline
ED	Erectile dysfunction

Background

Cardiovascular diseases (CVD), primarily ischemic heart disease and stroke, are the leading causes of death and disability worldwide[1]. The Journal of the American College of Cardiology (JACC) published a report on

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the global burden of CVD from 1990 to 2022, indicating that CVD caused approximately 19.8 million deaths worldwide, resulting in the loss of 396 million years of life and 44.9 million years lived with disability[2]. Over the past 20 years, despite improvements in cardiovascular health among older adults, the rate of CVD in young adults has increased, driven by both traditional and emerging risk factors[3,4]. Age, hypertension, dyslipidemia (particularly cholesterol and low-density lipoprotein cholesterol levels), diabetes, overweight or obesity, smoking, and alcohol consumption are all independent risk factors for CVD. The incidence of these diseases among young and middle-aged people (aged 20 to 59) has remained stable and has even slightly increased. Therefore, it is urgent to identify new predictors for CVD among young people[5].

The World Health Organization characterizes sexual health as an encompassing condition of physical vitality, emotional balance, mental well-being, and societal harmony, all intricately linked to one's sexuality, transcending mere freedom from illness, dysfunction, or weakness[6]. Studies have indicated that more frequent sexual activity is associated with better physical health[7]. Frequent sexual intercourse has been linked to a lower risk of fatal coronary heart disease, breast cancer, prostate cancer, and depression, additionally, it enhances life enjoyment, improves quality of life, increases happiness, and boosts cognitive function, indicating a potential protective effect of sexual activity[8–11]. Luo et al. identified a significant link between lower sexual frequency and increased all-cause mortality rates among hypertensive individuals, even after accounting for established risk factors[12]. Studying sexual frequency can provide researchers, clinicians, and public health professionals with valuable insights into the complex interactions between sexual activity and overall health. This enables them to better predict disease risk, assess psychological health and well-being, and ultimately identify patients who require treatment (including psychological and physical therapy) more quickly.

However, to date, no research has examined the relationship between sexual frequency and the incidence CVD incidence and mortality among young and middle-aged adults. Earlier research has suggested that engaging in sexual activity may offer protective benefits for overall health. However, there is an ancient Chinese legend that emperors who indulged excessively in sexual pleasures often died prematurely. Does excessive sexual intercourse really benefit physical health? Whether there is a dose-response relationship between sexual frequency and CVD or all-cause mortality remains controversial. In this study, we hypothesize that a "U-shaped" correlation exists between sexual frequency and the incidence and mortality of CVD in young and middle-aged adults, indicating that both excessive and infrequent sexual frequency are detrimental to health. The aim of this study is to examine this hypothesis by analyzing data from the National Health and Nutrition Examination Survey from 2005 to 2016.

Methods

Study population

The NHANES is a comprehensive, nationally representative set of surveys and physical examinations administered by the Centers for Disease Control and Prevention, encompassing a broad range of health and nutritional indicators. One of its chief goals is to attain a holistic comprehension of contemporary illness trends and provide valuable perspectives for the formulation of public health policies. Information about the surveys and the corresponding death index are available at www.cdc.gov/nchs/nhanes and www.cdc.gov/nchs/ndi/. We integrated datasets from 2005 to 2016, focusing on individuals aged 20 to 59. After excluding individuals with intellectual disabilities, inability to communicate normally, and a lack of relevant data, this study included a total of 17,243 participants (Fig. 1). The study protocol was approved by the NCHS Research Ethics Review Board, and all participants gave written informed consent.

Measurement of sexual frequency

During the physical examination, participants utilized an Audio Computer-Assisted Self-Interview system in a private room within the mobile examination center to fill out the questionnaire. Participants were required to answer the following questions: "Have you ever had vaginal, anal, or oral sex?" and "In the past 12 months, about how many times have you had vaginal or anal sex?". Our primary focus was on the second question, which provided several options including: Never, Once, 2–11 times, 12–51 times, 52–103 times, 104–364 times, 365 times or more. We excluded individuals who responded with "refused," "don't know," or had missing responses to this question.

Assessment of cardiovascular disease

Cardiovascular disease status was determined based on self-reported physician diagnoses collected through a customized interview using a standardized health survey. Participants were asked whether a medical professional had ever diagnosed them with congestive heart failure, coronary artery disease, angina pectoris, myocardial infarction, or stroke. Those who answered "yes" to any of these questions were classified as having CVD.

Clinical outcome

"All-cause mortality," defined as death from any cause until December 31, 2019, was the primary outcome measure in our study. We compiled these data using publicly accessible mortality files from the NHANES covering the years 2005 to 2019. Our analysis focused on assessing the time elapsed from participant enrollment (which coincided with the interview date) to mortality occurrence or the end of the study's observation period. Individuals without a recorded death were presumed alive throughout the follow-up period.

Covariates

We extracted covariates from NHANES for analysis. The categorical variables were: age (20–30, 31–43, 44–59years old), gender (male, female), race (white, black, others), educational level (below high school, high school, above high school), partnered status (partnered, unpartnered), exercise (light, vigorous/moderate), homosexual

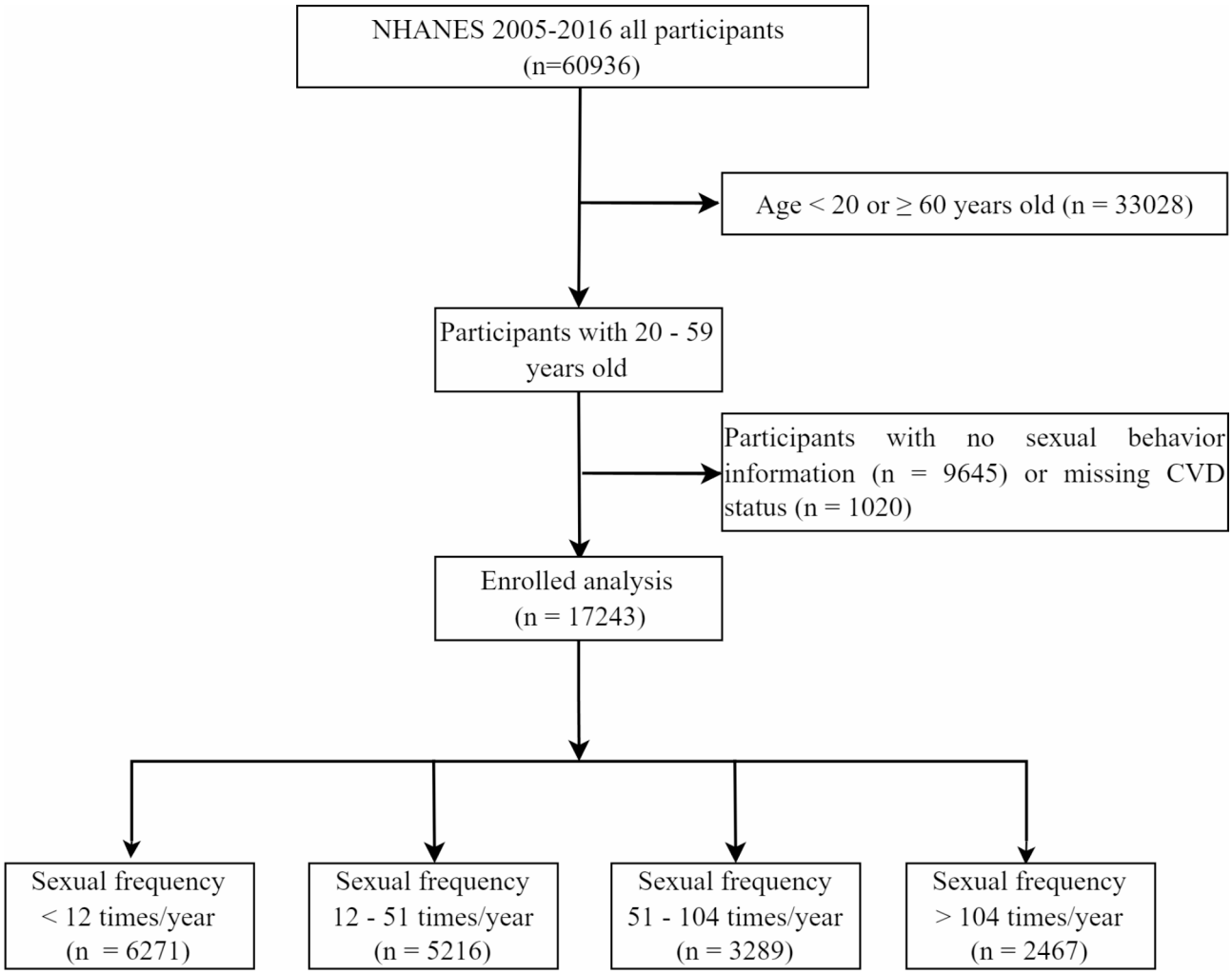

Fig. 1. A detailed flowchart of participant recruitment.

behavior, medication use (β-blockers, erectile dysfunction agents, contraceptives), Body Mass Index(BMI, < 25, 25–30, > 30 kg/m²), drinking (none, 1–5 times/month, > 5 times/month), patient health questionnaire-9(PHQ-9, 0–9, 10–14, ≥ 15), neutrophil–lymphocyte ratio(NLR, < 1.43, 1.44–2.5, > 2.5), estimated glomerular filtration rate (eGFR, < 60, 60–90, > 90 ml/min/1.73 m²), and smoking, hypertension, diabetes. Additionally, age, family poverty income ratio (PIR), BMI, Systolic blood pressure, diastolic blood pressure, and lab indicators were treated as continuous variables. Lab tests determined total cholesterol (TC), glycated hemoglobin (HbA1c), white blood cell count, neutrophil count, lymphocyte count, and creatinine using standardized procedures. Participants were categorized as smokers if they had smoked more than 100 cigarettes in total, irrespective of their current smoking behavior. We used the CKD-EPI model to estimate eGFR, considering age, gender, race/ethnicity, and serum creatinine levels. For the assessment on exercise, homosexual behavior and medication use please refer to the Supplementary material.

Statistical methods

During our analysis, we accounted for the sample weights of different research periods due to the complex sampling methods used in the NHANES. Some respondents were missing demographic data. To avoid biases from excluding these cases, we used multiple imputation to handle the missing data, ensuring representativeness and accuracy. Continuous variables were reported as means (SD), while categorical variables were given as counts (percentages), where the counts were based on unweighted values. Differences in baseline characteristics among participants with different sexual frequencies were analyzed using the Student's t-test and chi-square test.

We separately used multivariate logistic regression and Cox regression analyses to evaluate the relationships between sexual frequency and CVD incidence as well as all-cause mortality. Our models included an unadjusted model and three adjusted models: Model I (adjusted for age, sex, and race), Model II (further adjusted for diabetes, hypertension, PHQ-9, NLR, eGFR, cancer, chronic bronchitis, smoking and drinking), and Model III (further adjusted for partnered status, exercise, PIR, education level, homosexual behavior, medication use including β-blockers, erectile dysfunction agents and contraceptives). Notably, both Model II and Model III include CVD as an additional adjustment factor when predicting mortality. During subgroup analysis, variables

without distribution or those exhibiting collinearity may be removed as necessary. Specifically, in the Female subgroup, the erectile dysfunction agents variable was excluded, and in the Male subgroup, the contraceptives variable was removed. The final model showed no signs of multicollinearity. The survival outcomes of patients with varying sexual frequencies were evaluated using segmented Kaplan-Meier analysis, with differences determined using Log-Rank tests.

To investigate the nonlinear relationship between sexual frequency and CVD as well as survival status, we used a multivariate restricted cubic spline (RCS) analysis. Subgroup analyses assessed the stability of the association across age, sex, race, BMI, depression (PHQ-9 $\geq$ 10), education level, PIR, BMI, smoking, Drinking, diabetes, and hypertension. We developed a nomogram to predict prognosis based on key variables related to sexual frequency. Participants were randomly assigned to training and validation groups at a 1:1 ratio using a random number table. Model performance was evaluated with ROC curves and calibration curves, ensuring the reliability and accuracy of the assessment.

Statistical analyses were performed using R software version 4.3.3, with significance assessed based on a P-value of less than 0.05.

Result

Characteristics of the study population

This study initially included 60,936 participants from the NHANES (2005–2016). Following the inclusion and exclusion criteria, 17,243 adults who completed the sexual behavior and CVD questionnaires were enrolled, representing 42.9 million US residents (Fig. 1). The average age of the study population was 39.0 years, with just over half (51%) being male. Differences exist in many characteristics among groups with varying sexual frequencies, including demographic factors (age, gender, race, education) and lifestyle factors (smoking, drinking, marital status, anxiety), as well as health conditions (hypertension, diabetes, renal insufficiency, coronary heart disease). Patients with a sexual frequency of less than 12 times/year had a higher proportion of CVD (4.83%) and the highest risk of death during follow-up (4.39%). Over a median follow-up of 106 months, 443 patients (2.57%) died from various causes (Table 1).

Association between sexual frequency and CVD and all-cause mortality

To compare the incidence of CVD and all-cause mortality among participants with different sexual frequencies, multivariable logistic and Cox regression models were used. In the unadjusted model, compared to a sexual frequency of less than 12 times/year, both the incidence of CVD and the risk of all-cause mortality were significantly lower for those with sexual frequencies of 12–51 times/year and more than 51 times/year. After adjusting for confounders in Models I, II, and III, the protective effects associated with sexual frequencies of 12–51 times/year and 52–103 times/year remained stable, indicating consistent benefits in reducing risks. However, for individuals with a sexual frequency exceeding 103 times/year, the protective effect was no longer significant in the adjusted models (Fig. 2). Kaplan-Meier curves show worst survival prognosis for $<$12 times/year sex, better for 52–103 times/year (Fig. 3).

Nonlinear relationship between sexual frequency, CVD, and mortality

Further evaluation using restricted cubic splines revealed a nonlinear relationship between sexual frequency and both CVD incidence and mortality, exhibiting a slightly rising U-shaped curve. As sexual frequency increased, the incidence of CVD and mortality decreased significantly, reaching inflection points at 52–103 times/year, indicating the greatest protective effect. However, a negative correlation emerged thereafter (Figs. 4A and 5A).

Additionally, we performed restricted cubic splines analysis for subgroups based on sex, age, and race. We found that, except for the 44–59 age group, the relationship between sexual frequency and CVD was generally nonlinear, exhibiting statistically significant U-shaped or L-shaped patterns (Fig. 4B-I). Similarly, in the relationship between sexual frequency and mortality, U-shaped or L-shaped patterns were observed in most subgroups, except for 31–43 age group and Race-Other (Fig. 5B-I).

Subgroup analysis on the association of sexual frequency with CVD and all-cause mortality

To further investigate the impact of sexual frequency on CVD and mortality, considering the nonlinear relationship, participants were categorized into more detailed subgroups based on sexual frequency: 0, 1, 2–11, 12–51, 52–103, 104–364, and $\geq$365 times/year. The group with the best prognosis (52–103 times/year) served as the reference in the models. Multivariable regression analysis, after adjustment in Model III, showed that the relationship between sexual frequency and CVD remained stable in the overall population. Specifically, for CVD risk, the HR for a sexual frequency of 0 was 1.61 (1.06, 2.37), and for $\geq$365 times/year, it was 2.35 (1.03, 5.39). For mortality risk, the HR for 0 sexual frequency was 2.36 (1.48, 3.78), and for $\geq$365 times/year, it was 2.82 (1.28, 6.23) (Fig. 6). Additionally, the relationship between sexual frequency and CVD showed interactions in certain subgroups, with Black and other racial groups, older age, smoking, alcohol consumption, diabetes, BMI $>$ 30, and depression being more strongly influenced by sexual frequency. In contrast, the relationship with mortality risk remained relatively stable (Table S1).

Nomogram for survival analysis

Based on the results of Cox regression analysis and its clinical significance, we have successfully developed a nomogram for predicting survival models (Fig. 7A). In the training group(n = 8621), the areas under the ROC curves for 3-year, 5-year, and 10-year survival rates were 0.782, 0.807, and 0.803, respectively, in the validation group(n = 8622), these were 0.760, 0.770, and 0.763, respectively (Fig. 7B, C). Calibration curves indicate a high level of agreement between predicted and observed 10-year survival rates (Fig. 7D, E). The nomogram shows a 50-year-old black male with no sexual activity and concurrent CVD. According to our model, his 5-year survival

Characteristic	Overall ($n=17243$)	Sexual frequency, times/year				*P* value
		< 12($n=6271$)	12–51($n=5216$)	52–103 ($n=3289$)	> 103 ($n=2467$)	
Age, years						< 0.001***
20–30	5263 (29.5%)	1706 (26%)	1430 (25.4%)	1107 (33.4%)	1020 (41.2%)	
31–43	5910 (32.8%)	1767 (27.2%)	1905 (35%)	1271 (35.6%)	967 (36.8%)	
44–59	6070(37.1)	2798 (46.7%)	1881 (39.6%)	911 (31%)	480 (22%)	
Sex-male	8649 (51%)	3326 (53.5%)	2462 (49.1%)	1622 (50.5%)	1239 (50.7%)	< 0.001***
Race						< 0.001***
White	7027 (65.2%)	2184 (59.2%)	2324 (69.7%)	1451 (68.2%)	1068 (64.4%)	
Other	6556 (23.1%)	2523 (25.8%)	1816 (19.9%)	1254 (22.4%)	963 (25.4%)	
Black	3660 (11.7%)	1564 (15.1%)	1076 (10.5%)	584 (9.4%)	436 (10.2%)	
Education level						< 0.001***
Below high school	3700 (14.9%)	1750 (19.8%)	840 (11.3%)	566 (11.9%)	544 (16%)	
High school	3892 (21.9%)	1477 (23.3%)	1069 (20.6%)	731 (20.1%)	615 (24%)	
Above high school	9651 (63.3%)	3044 (56.9%)	3307 (68.1%)	1992 (68%)	1308 (60%)	
Marital status	9070 (56.9%)	2617 (46%)	3120 (64.4%)	1977 (62.8%)	1356 (56.4%)	< 0.001***
BMI, Kg/m^2						0.2
<25	5360 (32.5%)	1894 (31.6%)	1709 (32.9%)	1020 (33.2%)	737 (32.3%)	
25–30	5584 (32.7%)	2008 (31.9%)	1664 (33%)	1102 (34%)	810.00 (32%)	
>30	6299 (34.8%)	2369 (36.5%)	1843 (34.1%)	1167 (32.8%)	920 (35.7%)	
Hypertension	3928 (22%)	1684 (25.1%)	1196 (23%)	619 (18.4%)	429 (17.4%)	< 0.001***
Diabetes	1641 (7.5%)	844 (10.5%)	421 (6.8%)	237 (5.8%)	139 (4.5%)	< 0.001***
Smoking	7223 (43%)	2583 (42.7%)	2079 (41%)	1355 (41.7%)	1206 (50.1%)	< 0.001***
Drinking						< 0.001***
Never	4253 (19.7%)	1872 (24.2%)	1216 (18.8%)	708 (17.2%)	457(15%)	
1-5times/month	8873 (51.5%)	,089 (51.4%)	2728 (50.9%)	1725 (51.5%)	1,331 (53%)	
> 5times/month	4117 (28.8%)	1310 (24.4%)	1272 (30.3%)	856 (31.4%)	679 (32%)	
PHQ-9						< 0.001***
0–9	15,716 (92.5%)	5570 (90.2%)	4818 (93.7%)	3074 (93.9%)	2254 (92.9%)	
10–14	950 (4.72%)	420 (6.1%)	256 (4.2%)	143 (3.8%)	131 (4.3%)	
> 15	577 (2.8%)	281 (3.8%)	142 (2.2%)	72 (2.3%)	82 (2.9%)	
NLR						0.054
< 1.43	4320 (22.4%)	1642 (22.7%)	1271 (21.7%)	847 (23.5%)	560 (21.8%)	
1.44–2.5	8641 (52.2%)	3032 (50.6%)	2640 (52.4%)	1654 (53.1%)	1315 (54.4%)	
> 2.5	4282 (25.4%)	1597 (26.7%)	1305 (25.9%)	788 (23.4%)	592 (23.8%)	
eGFR, ml/min/1.73m^2						< 0.001***
< 60	242 (1.4%)	133 (2%)	66 (1.29%)	30 (1.1%)	13 (0.4%)	
60–90	3548 (24.6%)	1415 (26.7%)	1147 (26.25%)	581 (21.5%)	405 (20.6%)	
> 90	13,453 (74%)	4723 (71.4%)	4003 (72.45%)	2678 (77.4%)	2049 (79%)	
Partnered	11,093 (68.5%)	3,193 (54.7%)	3,626 (73.3%)	2,459 (77.3%)	1,815 (74.8%)	< 0.001***
Exercise, vigorous/moderate	9,850 (71.4%)	3,381 (67.2%)	3,021 (70.3%)	1,934 (73.7%)	1,514 (76.6%)	< 0.001***
Homosexual behavior	1,230 (7.7%)	459 (8.6%)	351 (7.0%)	211 (6.8%)	209 (8.9%)	0.008**
β-blockers	715 (4.1%)	341 (5.4%)	232 (4.6%)	79 (2.2%)	63 (2.6%)	< 0.001***
Contraceptives	684 (5.4%)	151 (3.5%)	244 (6.1%)	162 (6.3%)	127 (6.7%)	< 0.001
Erectile dysfunction agents	30 (0.2%)	7 (< 0.1%)	13 (0.3%)	5 (0.2%)	5 (0.3%)	0.2
CVD	663 (3.2%)	360 (4.8%)	157 (2.77%)	74 (1.9%)	72 (2.4%)	< 0.001***
CVD-mortality	120 (0.5%)	77 (1%)	32 (0.4%)	5 (0.1%)	6 (0.2%)	< 0.001***
All-cause mortality	565 (2.8%)	327 (4.6%)	127 (2%)	56 (1.6%)	55 (2.4%)	< 0.001***
Cancer	650 (4.8%)	266 (5.3%)	206 (5.3%)	107 (4.3%)	71 (3.4%)	0.020*
Chronic bronchitis	799 (4.8%)	306 (5%)	251 (5.2%)	115 (3.3%)	127 (5.4%)	0.008**
Age, years	38.69 (11.31)	40.68 (11.98)	39.46 (10.92)	37.02 (10.76)	34.70 (9.97)	< 0.001***
PIR	3.03 (1.67)	2.80 (1.69)	3.32 (1.61)	3.04 (1.64)	2.84 (1.67)	< 0.001***
BMI, Kg/m^2	28.73 (6.88)	29.07 (7.32)	28.60 (6.67)	28.50 (6.64)	28.56 (6.60)	0.026*
SBP, mmHg	118.04 (14.05)	119.78 (15.53)	117.55 (13.69)	117.05 (12.87)	116.55 (12.43)	< 0.001***
DBP, mmHg	70.90 (11.23)	71.11 (11.82)	71.25 (10.94)	70.62 (10.73)	69.97 (11.13)	< 0.001***
Cr, ummol/L	76.20 (26.30)	77.40 (32.66)	75.94 (25.51)	75.07 (18.25)	75.65 (20.65)	0.083
Continued						

Characteristic	Overall ($n=17243$)	Sexual frequency, times/year				P value
		< 12($n=6271$)	12–51($n=5216$)	52–103 ($n=3289$)	> 103 ($n=2467$)	
HbA1c, %	5.46 (0.86)	5.59 (1.01)	5.42 (0.77)	5.39 (0.73)	5.35 (0.78)	< 0.001***
HDL, mmol/L	1.36 (0.42)	1.35 (0.42)	1.38 (0.43)	1.36 (0.42)	1.33 (0.39)	0.007**
TC, mmol/L	5.02 (1.06)	5.03 (1.06)	5.06 (1.10)	4.99 (1.02)	4.93 (1)	< 0.001***
NE, $\times 10^9$	4.37 (1.74)	4.36 (1.80)	4.34 (1.73)	4.36 (1.68)	4.44 (1.69)	0.013*
LY, $\times 10^9$	2.19 (0.82)	2.18 (0.77)	2.16 (0.98)	2.21 (0.67)	2.24 (0.69)	< 0.001***
WBC, $\times 10^9$	7.35 (2.21)	7.33 (2.26)	7.30 (2.27)	7.37 (2.11)	7.49 (2.11)	< 0.001***
eGFR, ml/min/1.73m^2	101.65 (18.53)	100.46 (19.45)	100.67 (18.20)	103.22 (17.84)	104.44 (17.59)	< 0.001***

Table 1. Clinical characteristics of the study population grouped by sexual frequency. Data are n (%), or mean (SD), the percentages (%) and SD are calculated from weighted data. BMI, body mass index; PHQ, Patient Health Questionnaire; NLR, neutrophil–lymphocyte ratio; PIR, poverty income ratio; SBP, systolic blood pressure; DBP, diastolic blood.; Cr, creatinine; HbA1c, glycated hemoglobin; HDL-C, high-density lipoprotein cholesterol; TC, total cholesterol; NE, neutrophils; LY, lymphocytes; WBC, white blood cells; eGFR, estimated glomerular filtration rate; *P value < 0.05, **P value < 0.01, ***P value < 0.001.

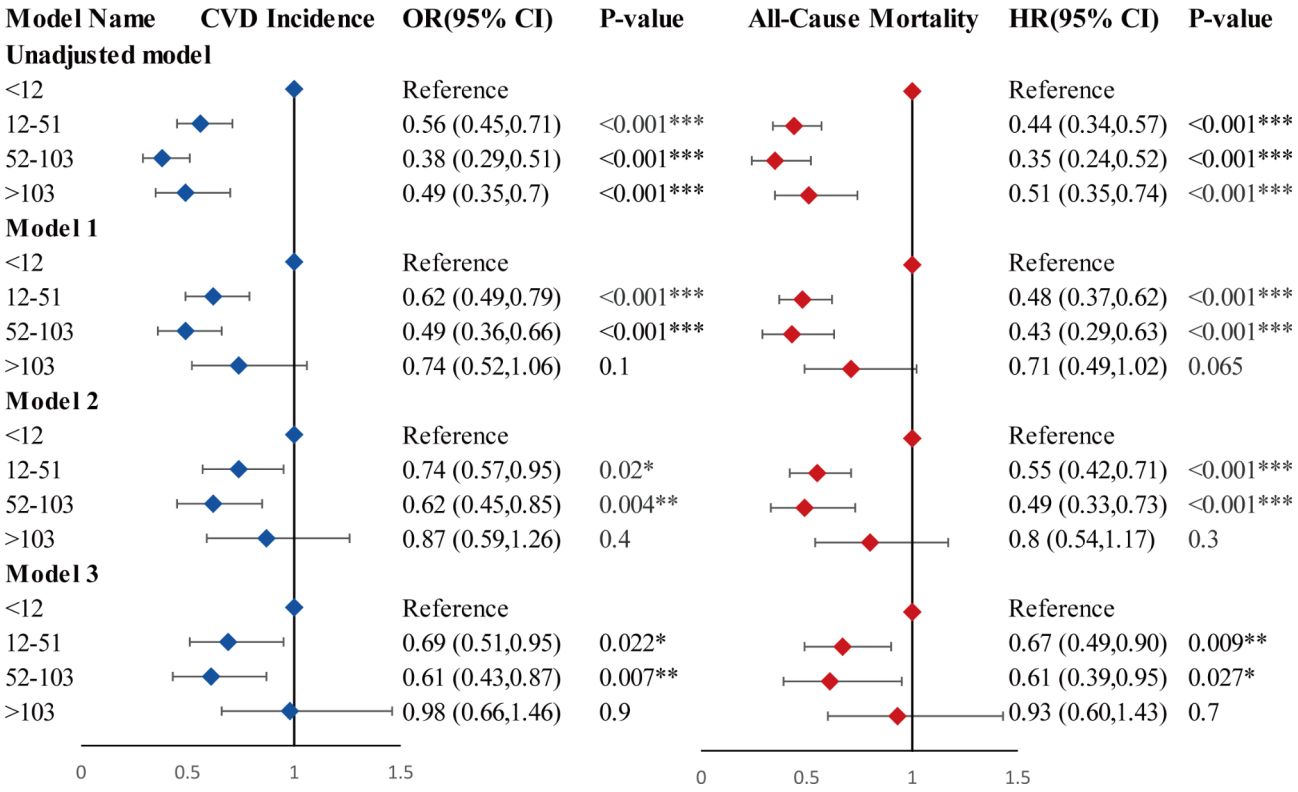

Fig. 2. Weighted Regression analysis of the association between sexual frequency and cardiovascular disease risk, as well as all-cause mortality; Model I adjusted for age, sex, and race; Model II further adjusted for PHQ-9, NLR, eGFR, cancer, chronic bronchitis, smoking, drinking, diabetes, and hypertension. Model III further adjusted for partnered status, exercise, PIR, education level, homosexual behavior, medication use. Notably, both Model II and Model III include CVD when predicting mortality.
*P value < 0.05, **P value < 0.01, ***P value < 0.001.

probability is around 0.6, and his 10-year survival probability is around 0.28. NHANES data indicate his actual survival time was about 7.5 years.

Discussion

This study examined the relationship between sexual frequency, the incidence of CVD, and all-cause mortality among individuals aged 20 to 59 in the United States, using data from the NHANES database. Previous studies have shown that frequent sexual intercourse is associated with better enjoyment of life, improved quality of life, and higher well-being[13]. Decreased libido, inability to reach orgasm, and difficulties with sexual intercourse

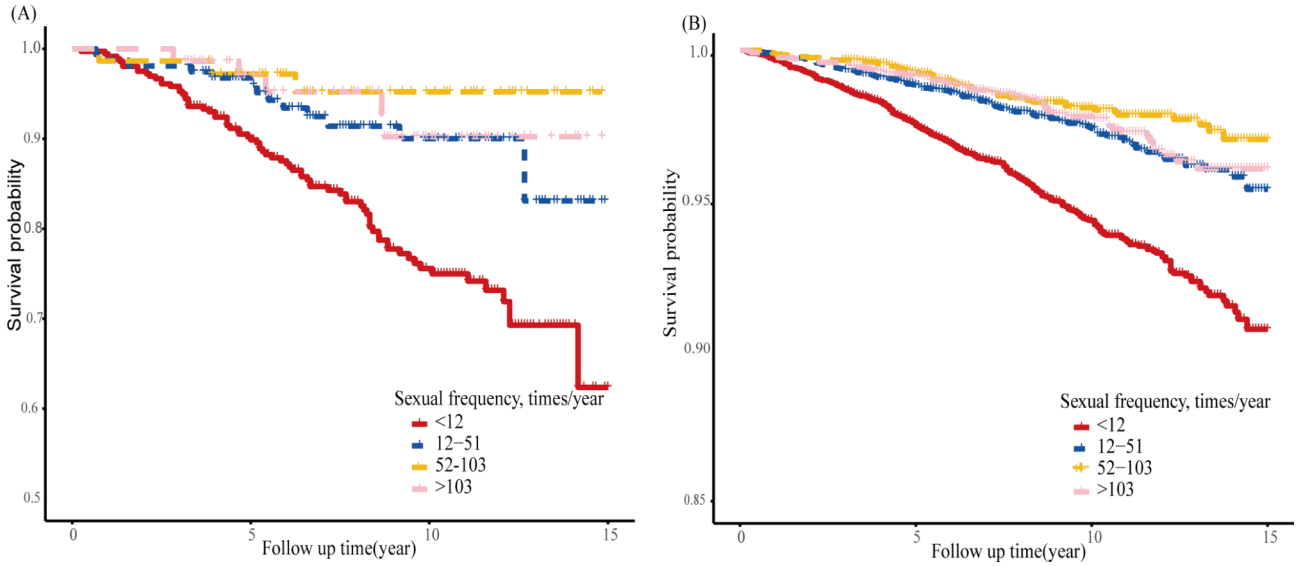

Fig. 3. Survival probability stratified by sexual frequency in (**A**) CVD participants and (**B**) All participants.

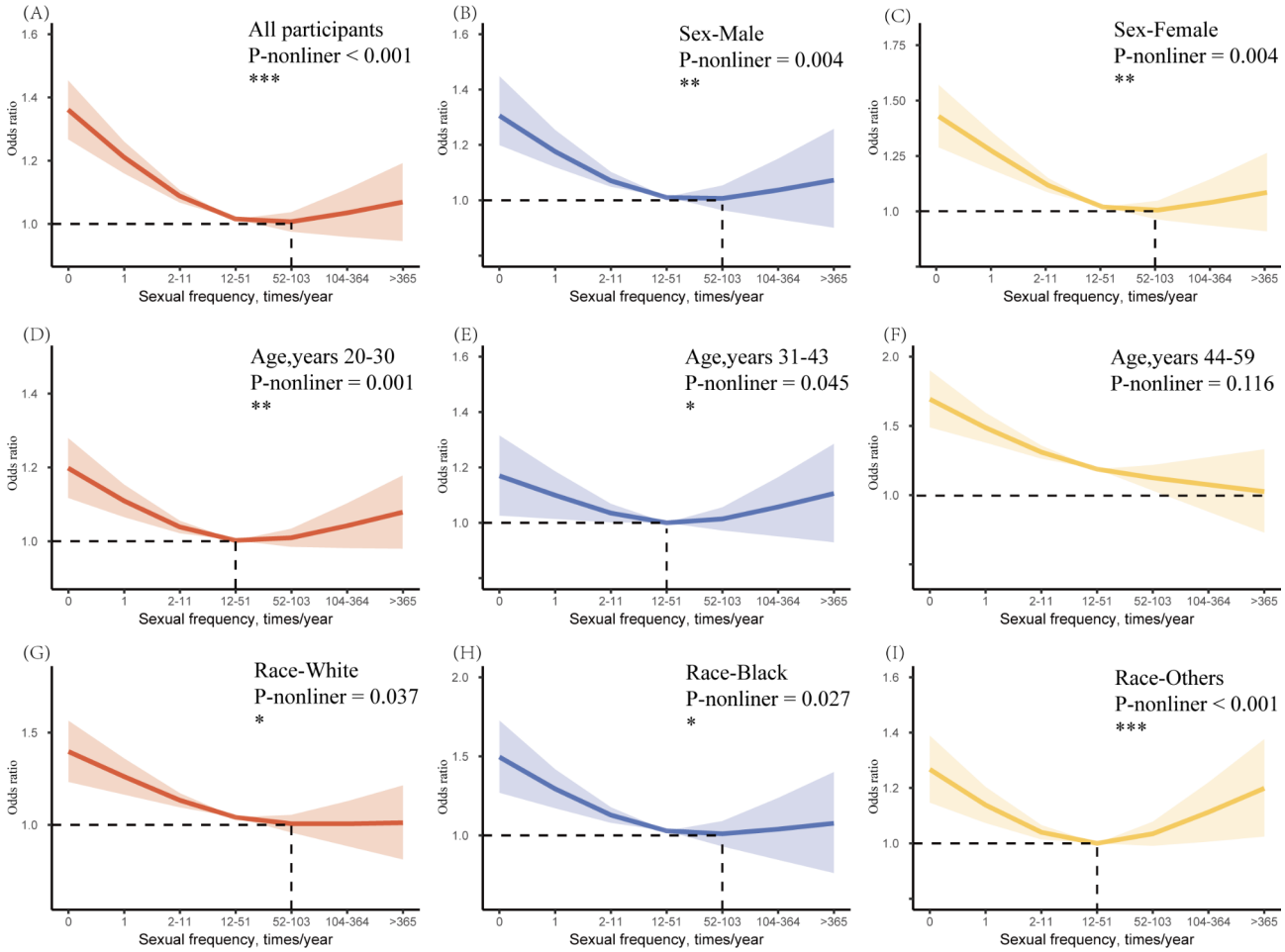

Fig. 4. Restricted cubic spline analyses for the association between sexual frequency with CVD. RCS was adjusted for age, sex, race.

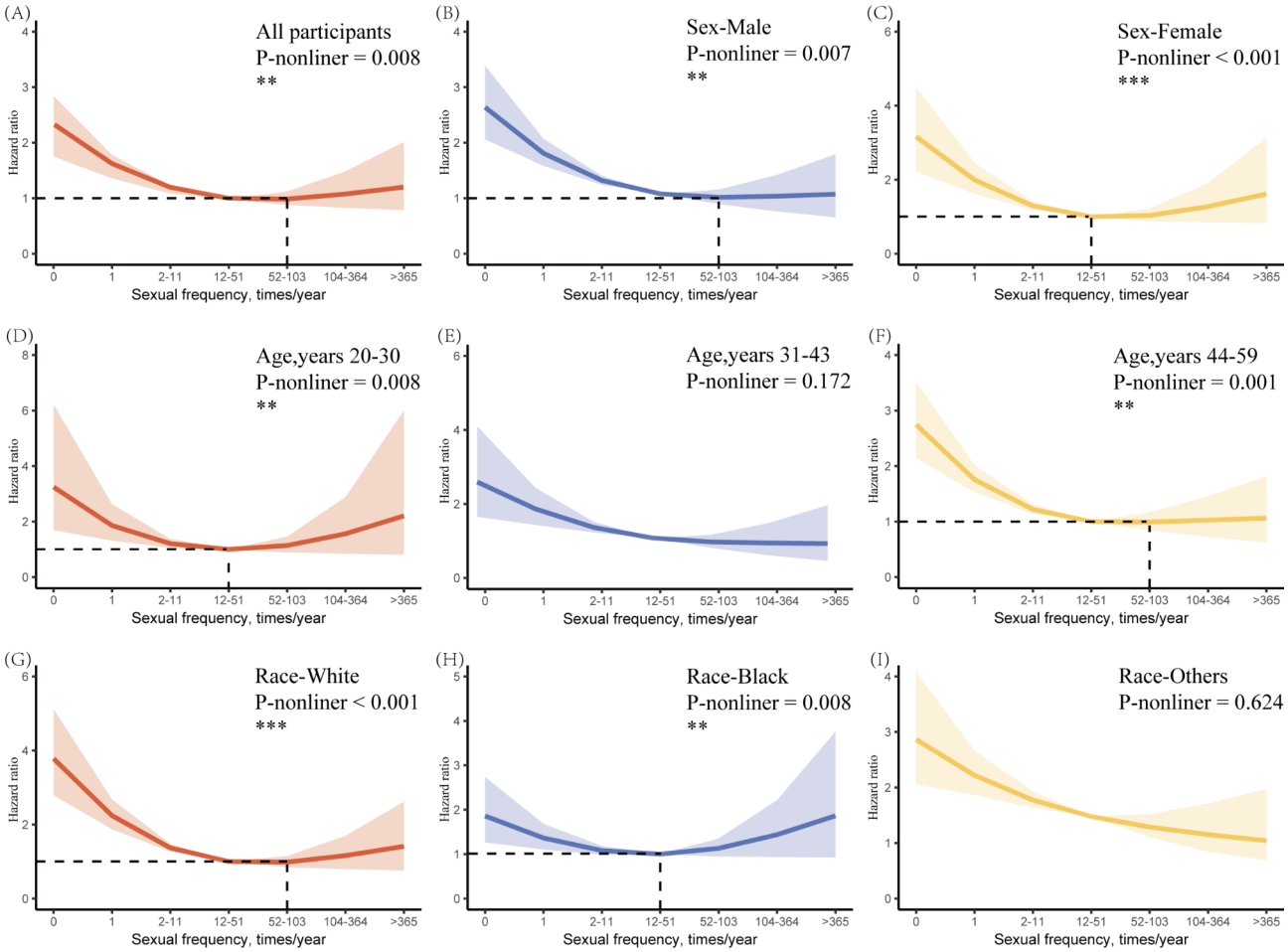

Fig. 5. RCS analyses for the association between sexual frequency with all-cause mortality. RCS was adjusted for age, sex, race, CVD.

independently predict adverse cardiovascular events[14]. Another study found that frequent orgasm in men and women with high sexual desire may reduce early mortality[15]. The subgroup analysis indicates that the association between sexual frequency and CVD is more pronounced in populations with older adults, diabetes, obesity, and depression, while it diminishes in groups without these risk factors. This suggests that abnormal sexual frequency may interact with traditional cardiovascular risk factors in a concerted manner. Overall, in the general population, the slightly rising U-shaped relationship remained consistent, including with cardiovascular disease incidence or mortality, suggesting that both higher (≥365 times/year) and lower (<2 times/year) sexual frequency can potentially be harmful. A sexual frequency of approximately 12–103 times/year appears optimal for health. The ranges of 2–11 and 104–364 times/year may be considered a gray area, where the health implications are less clear and the specific thresholds warrant further investigation.

Several biological mechanisms underlying the association between sexual activity frequency and health have been previously suggested. People with low sexual frequency may partially suffer from erectile dysfunction (ED), which is an early manifestation of cardiovascular disease, and endothelial dysfunction is considered to be a common cause of ED[16]. Montorsi et al. found that 49% of patients with chest pain and angiographically confirmed coronary heart disease suffered from ED, while 67% of these reported that their ED preceded the onset of chest pain symptoms[17]. This temporal relationship is attributed to the hypothesis of penile artery size. The diameter of the penile artery is 1–2 mm, whereas the coronary artery has a diameter of 3–4 mm. Therefore, when atherosclerosis develops, occlusion of the penile artery occurs earlier[18]. Cristovh Kalka et al. concluded that ED is a cost-effective tool for screening cardiovascular risk factors in men[19]. Another possible mechanism may involve levels of testosterone hormone secretion. Low testosterone levels can result in elevated levels of total cholesterol, low-density lipoprotein cholesterol, and pro-inflammatory mediators, ultimately contributing to atherosclerosis. Epidemiological studies have demonstrated an association between low testosterone levels and a higher risk of cardiovascular disease and overall mortality[20]. Overall, individuals with lower sexual frequency are more susceptible to cardiovascular disease. Patients with cardiovascular disease often take medications like diuretics and beta-blockers, which are not conducive to sexual function, eventually leading to a vicious cycle[21].

Mental well-being is intricately connected to overall health. Radha Dhingra et al. used NHANES data to conclude that the burden of cardiovascular disease risk factors is associated with worsening depressive

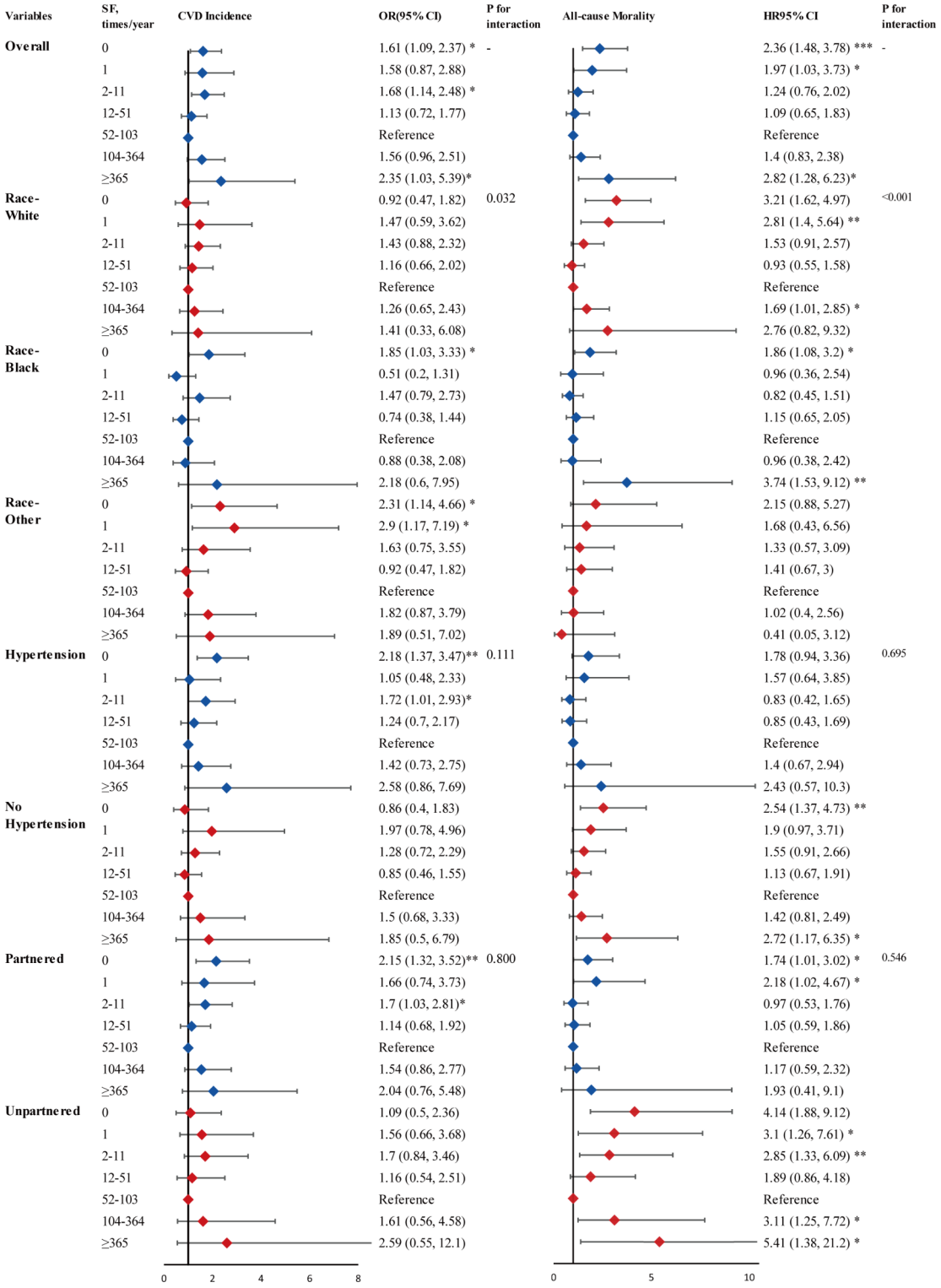

Fig. 6. Partial subgroup analyses exploring the association between sexual frequency and CVD incidence and all-cause mortality. SF, sexual frequency.

symptoms[22]. Both the Natsal study in the UK and the sexual study in Germany have found that self-reported general or poor health conditions, chronic diseases, disabilities impairing sexual desire are associated with reduced sexual frequency and lower sexual satisfaction. In summary, illnesses not directly related to sexual behavior can affect sexual health, and both physical and mental health issues can lead to a decline in sexual behavior[23]. This explains why a higher PHQ-9 is associated with a higher incidence of CVD. We summarize a physiological cycle: individuals often experience reduced sexual frequency due to factors such as erectile

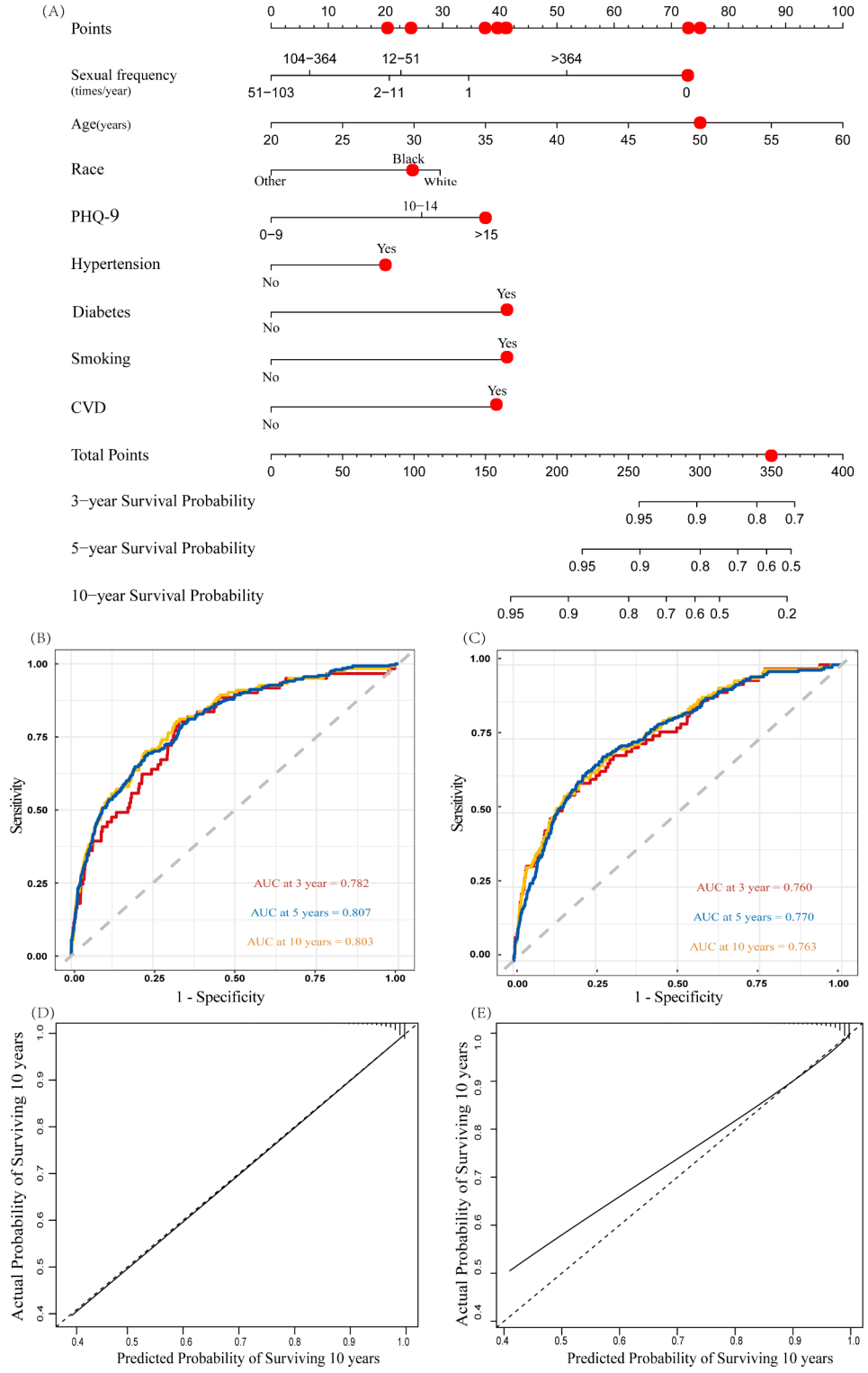

Fig. 7. Establishment and validation of a survival prediction model. (A) Nomogram Model; (B), (C) ROC curve of the model in the training group and validation groups; (D), (E) calibration curves of the model in the training group and validation groups.

dysfunction, testosterone deficiency, and physical weakness, which in turn increases the risk of CVD. Patients with CVD may also take medications or develop psychological issues such as inferiority complex and depression, further decreasing sexual frequency and creating a vicious cycle.

Additionally, we have found that excessive sexual frequency can be detrimental to health, which has rarely been mentioned in previous studies. It's often overlooked that sexual activity itself constitutes a form of physical

activity and aerobic exercise. Despite the well-established benefits of moderate physical activity, evidence suggests there may be a point of diminishing returns. In fact, high levels of aerobic exercise may detract from the significant health benefits observed with moderate levels or potentially lead to cardiotoxicity[24]. A cross-sectional study by Elisa Maseroli shows that women with sexual dysfunction can awaken libido through regular physical activity. However, excessive physical activity has a negative impact[25]. Intense sexual activity often triggers sympathetic overexcitement, leading to endothelial cell damage, platelet activation, accelerated ventricular remodeling, and atherosclerosis[26]. In fact, individuals with a sexual frequency of 365 times or more per year may be sex addicts. These sex addicts are characterized by hypersexuality and an inability to control their sexual behavior frequency despite experiencing negative psychological and physiological consequences, leading to excessive sexual behavior. Generally, a common threshold used to quantify "excessive sexual behavior" is having sexual climax at least 7 times or more per week, and this state needs to persist for at least 6 consecutive months. Sexual addiction can cause mental stress and symptoms of depression, which affect normal social and occupational functions. In terms of physical health, individuals with sexual addiction may suffer from injuries due to uncontrolled sexual behavior, such as an increased risk of sexually transmitted diseases and myocardial damage, ultimately leading to higher mortality rates[27]. In summary, both excessive and insufficient sexual activity can be detrimental to one's health.

Currently, sex education is generally inadequate, and epidemiological studies show that only one-fifth of men seek medical help for sexual dysfunction[28]. Many find it difficult to seek help, resulting in patients not receiving accurate diagnosis and treatment, ultimately causing irreversible damage. The highlight of this article is that it is the first time to verify that both excessively high and low sexual frequencies can increase the incidence of cardiovascular disease and the risk of all-cause mortality. Individuals with a sexual frequency of less than 52–103 times per year are encouraged to enjoy the benefits of a healthy sex life. Those with either excessively high or low frequencies should pay attention to the situation and seek medical attention if necessary.

However, this study has several limitations. Firstly, self-reported sexual behavior is prone to reporting bias, as individuals tend to underestimate or overestimate their sexual activity. Secondly, given the difficulty in accurately recalling annual sexual frequency, the raw data are categorized into multiple levels, inevitably leading to discrepancies between statistical outcomes and reality, which remains an inherent limitation. Additionally, the study lacks data on masturbation, oral sex frequency, and the duration of a single sexual activity, which may provide a more comprehensive understanding of sexual behavior. Furthermore, participants aged 60 and above were not included, which limits the generalizability of the findings to older populations. Furthermore, the presence of observational and unmeasured confounding factors in the study design hinders the determination of causality. Therefore, future research should adopt more rigorous methodologies to further confirm and reinforce these findings.

Conclusion

Sexual frequency was associated with the incidence of CVD and all-cause mortality among young and middle-aged adults. Both excessive and infrequent sexual frequency may be detrimental to health.

Data availability

Publicly available datasets were analyzed in this study. All the raw data used in this study are derived from the public NHANES data portal (https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx).

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Author contributions
H. Yu, and T. Teng were involved in the experiment design. T. Teng and J.Liu performed the data analysis and wrote the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version. All authors read and approved the final manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
This study exclusively utilized publicly available data for research and publication, thus exempting it from the need for ethical review and approval.

Consent for publication
All authors approved the final manuscript.

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