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ORIGINAL RESEARCH

Sleep Timing May Predict Congestive Heart Failure: A Community-Based Cohort Study

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BACKGROUND: Previous studies have suggested that sleep timing is associated with cardiovascular risk factors. However, there is no evidence on the relationship between sleep timing and congestive heart failure (CHF). We aimed to examine this relationship in this study.

METHODS AND RESULTS: We recruited 4765 participants (2207 men; mean age, 63.6±11.0 years) from the SHHS (Sleep Heart Health Study) database in this multicenter prospective cohort study. Follow-up was conducted until the first CHF diagnosis between baseline and the final censoring date. Sleep timing (bedtimes and wake-up times on weekdays and weekends) was based on a self-reported questionnaire. Cox proportional hazard models were constructed to investigate the association between sleep timing and CHF. During the mean follow-up period of 11 years, 519 cases of CHF (10.9%) were reported. The multivariable Cox proportional hazards models revealed that participants with weekday bedtimes >12:00 AM (hazard ratio [HR], 1.56; 95% CI, 1.15–2.11; *P*=0.004) and from 11:01 PM to 12:00 AM (HR, 1.25; 95% CI, 1.00–1.56; *P*=0.047) had an increased risk of CHF compared with those with bedtimes from 10:01 PM to 11:00 PM. After stratified analysis, the association was intensified in participants with a self-reported sleep duration of 6 to 8 hours. Furthermore, wake-up times >8:00 AM on weekdays (HR, 1.53; 95% CI, 1.07–2.17; *P*=0.018) were associated with a higher risk of incident CHF than wake-up times ≤6:00 AM.

CONCLUSIONS: Delayed bedtimes (>11:00 PM) and wake-up times (>8:00 AM) on weekdays were associated with an increased risk of CHF.

Key Words: bedtime ■ congestive heart failure ■ sleep timing ■ wake-up time

Congestive heart failure (CHF) is one of the major causes of mortality, morbidity, and hospitalization worldwide.[1] The incidence and cost of CHF are steadily increasing, despite related mortality declining in many countries.[2] Thus, identifying risk factors is vital for prevention and early treatment of CHF. Sleep duration, usually determined by sleep timing (including bedtime and wake-up time), whether long or short, has been associated with high risk for cardiovascular disease (CVD).[3–6] Previous studies have also showed that late sleep timing is also correlated with obesity, poor glycemic control, and depressive symptoms, which are considered risk factors for CVD.[7–9] However, the relationship between late sleep timing and CHF remains unknown, and the most suitable timing for individual sleep requires further exploration. Therefore, we conducted this study using the SHHS (Sleep Heart Health Study) database to explore the relationship between sleep timing (bedtime, wake-up time, and sleep midpoint) and the incidence of CHF.

METHODS

Participants and Study Design

The data that support the findings of this study are available from the corresponding author on

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CLINICAL PERSPECTIVE

What Is New?

- A later bedtime (>11:00 PM) on weekdays may increase the risk of congestive heart failure, especially in those with a sleep duration of 6 to 8 hours.
- A later wake-up time (>8:00 AM) on weekdays also serves as a risk factor for congestive heart failure.

What Are the Clinical Implications?

- Community populations at risk for heart failure may benefit from a bedtime at 10:01 PM to 11:00 PM and wake-up time at ≤8:00 AM on weekdays, if proved by randomized controlled trials.

Nonstandard Abbreviations and Acronyms

AHI	apnea-hypopnea index
SHHS	Sleep Heart Health Study

reasonable request. The SHHS is a prospective, multicenter, community-based cohort study, which aims to investigate the association between cardiovascular outcomes and sleep-disordered breathing (ClinicalTrials.gov identifier: NCT00005275). Details about the SHHS design have been previously described.[10] Written informed consent was provided by all participants, and the study protocol was approved by the institutional review board at all field sites. We had access to the SHHS database through a signed agreement with Brigham and Women's Hospital. Participants in the SHHS, who were at least 40 years of age, had no history of treatment of sleep apnea and tracheostomy, and had no current home oxygen therapy, were enrolled from a "parent" cohort, including those of the ARIC (Atherosclerosis Risk in Communities) Study, the CHS (Cardiovascular Health Study), the Framingham Offspring and Omni Study, the SHS (Strong Heart Study), the Tucson Epidemiological Study of Obstructive Lung Disease, the cohort studies of respiratory disease in Tucson, and cohort studies of hypertension in New York. All participants in the current investigation were from the SHHS cohort and underwent electroencephalography-based overnight polysomnography (P-Series; Compumedics, Abbotsville, Australia) at home and completed sleep habits questionnaire by trained and certified technicians in the baseline examination of the SHHS.[11] Besides, there was a clear and rigorous Data Quality Assurance and Control system in each "parent" study. Furthermore, the Comparability Committee was in charge of comparing data to determine the existing data collected by the parent studies to be used. Cardiovascular outcomes data were monitored and adjudicated by parent cohorts between baseline and 2011.

In the present study, all SHS participants were excluded because of sovereignty issues. Exclusion criteria were as follows: individuals with (1) a history of CHF; (2) missing follow-up data; (3) missing data on bedtime or wake-up time; or (4) night shift work. Finally, 4765 participants were included (Figure 1).

Assessment of Bedtimes and Wake-Up Times

Bedtimes and wake-up times on weekdays and weekends were assessed using sleep habit questionnaires based on affirmative answers to questions, such as, "At what time do you usually fall asleep or wake up on weekdays or workdays (hour, minute, AM or PM)?" and "At what time do you usually fall asleep or wake up on weekends or your nonwork days (hour, minute, AM or PM)?" Bedtimes on weekdays or weekends were categorized as follows: ≤10:00 PM, 10:01 to 11:00 PM, 11:01 PM to 12:00 AM, and >12:00 AM. Wake-up times were categorized as follows: ≤6:00 AM, 6:01 to 7:00 AM, 7:01 to 8:00 AM,

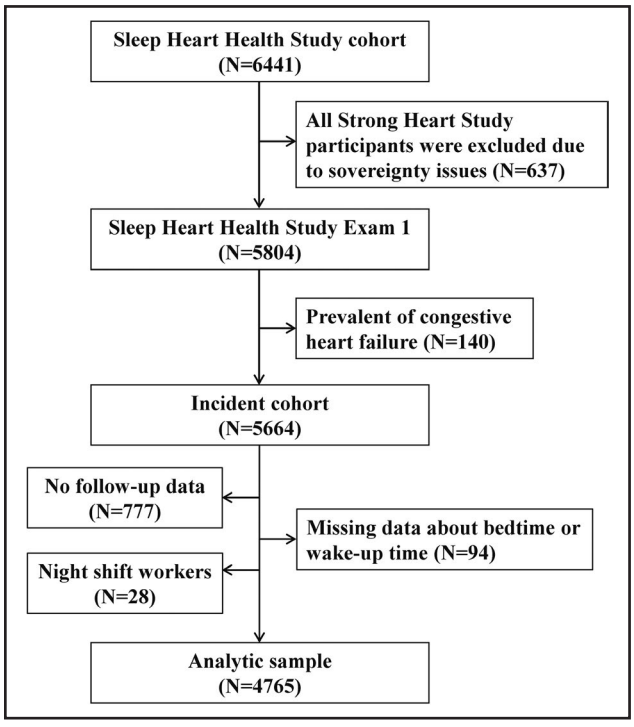

Figure 1. Flow diagram of participant selection.

and >8:00 AM. The sleep midpoint was calculated as the middle point between the bedtime and wake-up time.

Covariate Measurements

Information on age, sex, race, sleep duration, smoking status, history of diabetes mellitus and hypertension, and body mass index (BMI) was acquired from the baseline investigations of the SHHS. Self-reported sleep duration was acquired from a self-reported sleep habit questionnaire and defined as the length of sleep time between the bedtime and wake-up time. Sleep efficiency was calculated as the ratio of the total time spent sleeping/the time spent in bed. The apnea-hypopnea index (AHI), defined as the number of apnea and hypopnea occurrences per hour of sleep, accompanied by at least a 4% oxygen desaturation,[12] was measured by polysomnography monitoring.

Outcome Assessment

The primary outcome of this study was the incidence of clinical CHF, which was evaluated in the parent cohorts with explicit protocols that have been previously described.[13,14] Survival time was calculated as the time from investigation baseline to the first occurrence of CHF or the final censoring date during the follow-up period.

Statistical Analysis

ANOVA and the χ^2 test were used for continuous and categorical variables, which are presented as the mean±SD or the frequency and percentage, respectively. Unadjusted and multiple covariates adjusted Kaplan-Meier plots were performed for sleep timing with CHF. Univariable and multivariable Cox proportional hazards models were also used to assess the association between sleep timing and CHF. Adjustments were made for age, sex, race, smoking, BMI, diabetes mellitus, hypertension, AHI, sleep efficiency, and self-reported sleep duration. All variables in the Cox proportional hazards model meet the proportional hazards assumption. Interaction analyses were conducted between sleep timing and clinically relevant factors, including age (≥60 or <60 years), sex (men or women), smoking status (current, former, or never), race (White race, Black race, or other [Asian, American Indian or Alaskan Native, and Native Hawaiian or Other Pacific Islander]), BMI (≥30, 25–29.9, or 18–24.9 kg/m^2), diabetes mellitus (yes or no), hypertension (yes or no), AHI level (<5, ≥5–<15, ≥15–<30, or ≥30 events/h), sleep efficiency (≥85% or <85%), and self-reported sleep duration (<6, ≥6–≤8, or >8 hours). According to the results of interaction analyses, stratified analysis was then conducted to further investigate the correlation between sleep timing and CHF. Besides, a restricted cubic spline regression analysis was also used to assessed potential nonlinear trends between sleep timing and CHF, in which sleep timing was transformed into a continuous numerical variable. All analyses were performed using SPSS version 24.0 (SPSS Inc, Chicago, IL) and SAS version 9.4 (SAS Institute, Inc, Cary, NC). A 2-sided $P<0.05$ was considered statistically significant.

RESULTS

Participant Characteristics

There were 4765 participants included in our final analysis. The mean age of the included individuals was 63.6±11.0 years, with 2207 (46.3%) men. In the present study, most of the population was White race (n=4166 [87.4%]), and the most common self-reported sleep duration was 6 to 8 hours (n=3443 [72.3%]). Table 1 shows the participants' characteristics, according to weekday bedtime categories. Participants with a bedtime >12:00 AM on weekdays (n=441) were more likely to be a current smoker and have a history of diabetes mellitus or hypertension than those with bedtimes from 11:01 PM to 12:00 AM (n=1306), 10:01 to 11:00 PM (n=1837), and ≤10:00 PM (n=1181). In addition, participants with CHF tended to have later bedtimes, later wake-up times, and delayed sleep midpoints when compared with controls (Table 2).

Association Between Weekday Bedtime and CHF

After a mean follow-up period of 10.8±2.9 years, 519 (10.9%) cases of CHF had been reported. As shown in Table 3, participants with late bedtimes (>12:00 AM) on weekdays had the highest incidence of CHF when compared with those with bedtimes from 11:01 PM to 12:00 AM, 10:01 to 11:00 PM, or ≤10:00 PM (15.6%, 12.7%, 7.0%, and 13.2%, respectively; $P<0.001$).

When compared with the reference group (10:01–11:00 PM), bedtimes >12:00 AM (hazard ratio [HR], 2.04; 95% CI, 1.54–2.71; $P<0.001$), from 11:01 PM to 12:00 AM (HR, 1.55; 95% CI, 1.25–1.93; $P<0.001$), and ≤10:00 PM (HR, 1.34; 95% CI, 1.06–1.69; $P=0.014$) were related with an increased risk of CHF in the univariate Cox proportional hazards model. After adjusting for age, sex, race, smoking status, BMI, diabetes mellitus, hypertension, AHI, sleep efficiency, and self-reported sleep duration, bedtimes >12:00 AM (HR, 1.56; 95% CI, 1.15–2.11; $P=0.004$) and from 11:01 PM to 12:00 AM (HR, 1.25; 95% CI, 1.00–1.56; $P=0.047$) were still associated with a higher risk of CHF (Table 3). Besides, the multivariable Kaplan-Meier analysis showed the rate of CHF to be increased in participants with weekday bedtimes >12:00 AM (Figure 2A).

Table 1. Subject Characteristics by Weekday Bedtime Categories

Characteristics	Total (n=4765)	Weekday Bedtime				*P* Value
		≤10:00 PM (n=1181)	10:01 to 11:00 PM (n=1837)	11:01 PM to 12:00 AM (n=1306)	>12:00 AM (n=441)	
Age, y	63.6±11.0	62.1±10.7	62.8±11.6	65.2±10.6	66.9±10.6	<0.001
Sex, n (%)						0.109
Men	2207 (46.3)	576 (48.8)	857 (46.7)	574 (44.0)	200 (45.4)	…
Women	2558 (53.7)	605 (51.2)	980 (53.3)	732 (56.0)	241 (54.6)	…
Race, n (%)						<0.001
White	4166 (87.4)	1018 (86.2)	1651 (89.9)	1124 (86.1)	373 (84.6)	…
Black	294 (6.2)	86 (7.3)	116 (6.3)	71 (5.4)	21 (4.8)	…
Other*	305 (6.4)	77 (6.5)	70 (3.8)	111 (8.5)	47 (10.6)	…
Body mass index, kg/m^2	28.3±5.1	28.2±4.9	28.2±5.2	28.3±5.0	28.5±5.5	0.712
Smoking status, n (%)						<0.001
Current smoker	453 (9.5)	121 (10.3)	153 (8.3)	111 (8.6)	68 (15.4)	…
Former smoker	2083 (43.9)	546 (46.4)	810 (44.2)	547 (42.1)	180 (40.8)	…
Never smoker	2215 (46.6)	509 (43.3)	872 (47.5)	641 (49.3)	193 (43.8)	…
Diabetes mellitus, n (%)	328 (6.9)	104 (8.8)	78 (4.2)	97 (7.4)	49 (11.1)	<0.001
Hypertension, n (%)	1845 (38.7)	458 (38.8)	639 (34.8)	560 (42.9)	188 (42.6)	<0.001
Self-reported sleep duration, n (%)						<0.001
<6 h	379 (7.9)	15 (1.3)	84 (4.6)	127 (9.7)	153 (34.7)	…
6–8 h	3443 (72.3)	723 (61.2)	1436 (78.2)	1040 (79.6)	244 (55.3)	…
>8 h	943 (19.8)	443 (37.5)	317 (17.2)	139 (10.6)	44 (10.0)	…
Sleep efficiency, %	83.0±10.4	82.7±10.5	83.7±9.8	82.9±10.5	81.4±11.4	<0.001
AHI, n (%)						0.195
<5.0	2343 (49.2)	566 (47.9)	937 (51.0)	643 (49.2)	197 (44.7)	…
5.0–14.9	1447 (30.4)	358 (30.3)	547 (29.8)	385 (29.5)	157 (35.6)	…
15.0–29.9	639 (13.4)	166 (14.1)	228 (12.4)	190 (14.6)	55 (12.5)	…
≥30.0	336 (7.0)	91 (7.7)	125 (6.8)	88 (6.7)	32 (7.2)	…
Follow-up time, y	10.8±2.9	11.1±2.8	10.7±3.0	10.8±2.7	10.1±3.2	<0.001

Results are presented as mean±SD or number (percentage). The *P* values represent the difference between 4 groups. AHI indicates apnea-hypopnea index.
*Asian, American Indian or Alaskan Native, and Native Hawaiian or Other Pacific Islander.

A statistically significant interaction stratified by self-reported sleep duration (<6, 6–8, or >8 hours) was observed for the incidence of CHF ($P_{interaction}$=0.019). Therefore, a stratified analysis was performed to explore the association between weekday bedtimes and the incidence of CHF, classified by self-reported sleep

Table 2. Comparison of Bedtime, Wake-Up Time, and Sleep Midpoint in CHF and Non-CHF

Variable	Total	CHF	Non-CHF	*P* Value
Weekday				
Bedtime	10:56 PM±65 min	11:04 PM±70 min	10:55 PM±64 min	0.004
Wake-up time	6:17 AM±71 min	6:32 AM±78 min	6:15 AM±70 min	<0.001
Sleep midpoint	2:31 AM±51 min	2:40 AM±54 min	2:30 AM±50 min	<0.001
Weekend				
Bedtime	11:10 PM±65 min	11:08 PM±72 min	11:10 PM±65 min	0.650
Wake-up time	6:53 AM±76 min	6:47 AM±80 min	6:54 AM±76 min	0.088
Sleep midpoint	3:01 AM±60 min	2:58 AM±64 min	3:02 AM±60 min	0.203

The *P* values represent the difference between 2 groups. CHF indicates congestive heart failure.

Table 3. HRs and 95% CIs for Sleep Timing (Bedtime, Wake-Up Time, and Sleep Midpoint) Associated With CHF on Weekdays

Variable	Individuals, N	Person-Years	Event, n (%)	Morbidity Rate*	Univariate Models		Multivariable Adjusted†		Multivariable Adjusted‡		Multivariable Adjusted§	
					HR (95% CI)	*P* Value	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
Sleep timing	4765	49 791.6	519 (10.9)	10.4								
Bedtime												
>12:00 AM	441	4278.7	69 (15.6)	16.1	2.04 (1.54–2.71)	<0.001	1.46 (1.09–1.94)	0.010	1.43 (1.08–1.91)	0.014	1.56 (1.15–2.11)	0.004
11:01 PM to 12:00 AM	1306	13 514.4	166 (12.7)	12.3	1.55 (1.25–1.93)	<0.001	1.20 (0.96–1.50)	0.105	1.21 (0.97–1.52)	0.085	1.25 (1.00–1.56)	0.047
10:01–11:00 PM	1837	19 826.3	128 (7.0)	7.9	1 (Reference)		1 (Reference)		1 (Reference)		1 (Reference)	
≤10:00 PM	1181	12 172.3	156 (13.2)	12.8	1.34 (1.06–1.69)	0.014	1.28 (1.01–1.62)	0.041	1.26 (1.00–1.60)	0.054	1.17 (0.92–1.50)	0.194
Wake-up time												
>8:00 AM	229	2057.6	45 (19.7)	21.9	2.65 (1.92–3.66)	<0.001	1.70 (1.23–2.35)	0.001	1.65 (1.19–2.28)	0.002	1.53 (1.07–2.17)	0.018
7:01–8:00 AM	627	6209.5	89 (14.2)	14.3	1.73 (1.35–2.21)	<0.001	1.25 (0.98–1.61)	0.079	1.22 (0.95–1.57)	0.121	1.16 (0.88–1.51)	0.290
6:01–7:00 AM	1485	15 515.6	171 (11.5)	11	1.33 (1.09–1.63)	0.005	1.11 (0.90–1.36)	0.331	1.10 (0.89–1.34)	0.385	1.08 (0.87–1.32)	0.494
≤6:00 AM	2424	26 009.0	214 (8.8)	8.2	1 (Reference)		1 (Reference)		1 (Reference)		1 (Reference)	
Sleep midpoint					1.30 (1.17–1.44)	<0.001	1.11 (1.00–1.23)	0.052	1.11 (1.00–1.23)	0.060	1.09 (0.98–1.21)	0.099

CHF indicates congestive heart failure; and HR, hazard ratio.

*Crude event rate per 1000 person-years.

†Adjusted by age, sex, race, smoking, body mass index, diabetes mellitus, hypertension, and apnea-hypopnea index.

‡Adjusted by age, sex, race, smoking, body mass index, diabetes mellitus, hypertension, apnea-hypopnea index, and sleep efficiency.

§Adjusted by age, sex, race, smoking, body mass index, diabetes mellitus, hypertension, apnea-hypopnea index, sleep efficiency, and self-reported sleep duration.

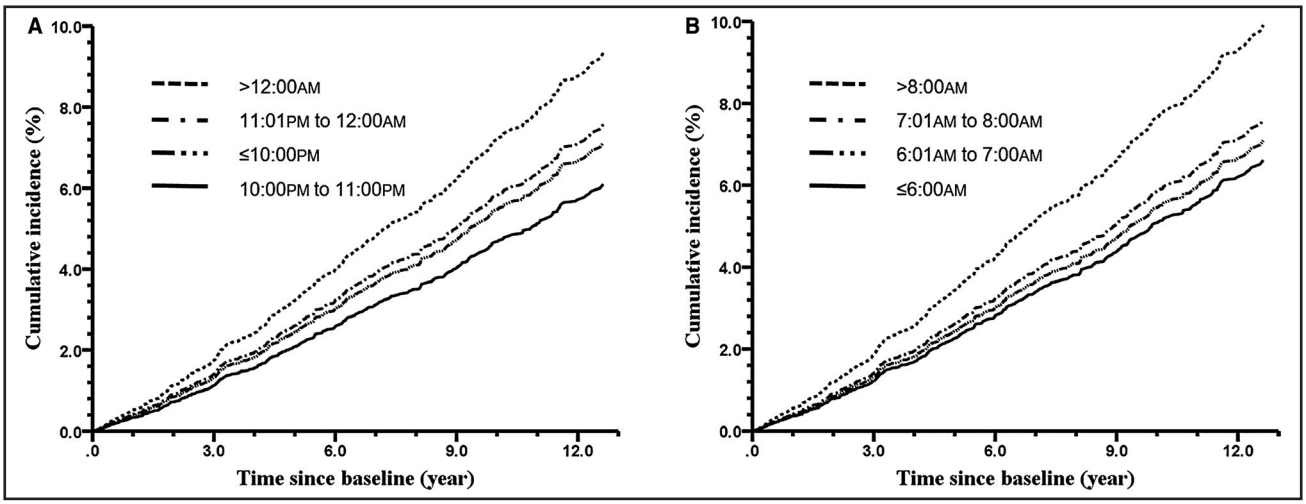

Figure 2. Multivariable Kaplan-Meier plots of the cumulative risk for congestive heart failure, stratified by bedtime.
A, Bedtime (≤10:00 pm, 10:01–11:00 pm, 11:01 pm to 12:00 am, and >12:00 am). B, Wake-up time (≤6:00 am, 6:01–7:00 am, 7:01–8:00 am, and >8:00 am).

duration. The multivariable Cox proportional hazards model revealed that weekday bedtimes >12:00 AM (HR, 2.09; 95% CI, 1.45–3.01; P<0.001), from 11:01 PM to 12:00 AM (HR, 1.49; 95% CI, 1.14–1.95; P=0.004), and ≤10:00 PM (HR, 1.50; 95% CI, 1.09–2.07; P=0.013) were associated with an increased risk of CHF in participants with sleep durations of 6 to 8 hours when compared with bedtimes from 10:01 PM to 11:00 PM (Table 4). Restricted cubic spline regression analysis also revealed a nonlinear J-shaped effect of weekday bedtime on the incidence of CHF in participants with sleep durations of 6 to 8 hours (P=0.016; Figure 3). No significant association was found between weekday bedtime and CHF in the subgroup analysis of those with sleep durations >8 or <6 hours.

In addition, there was no interaction effect on the association between weekday bedtimes and CHF stratified by age ($P_{interaction}$=0.812), sex ($P_{interaction}$=0.774), smoking status ($P_{interaction}$=0.420), race ($P_{interaction}$=0.963), BMI ($P_{interaction}$=0.380), a history of diabetes mellitus ($P_{interaction}$=0.240) or hypertension ($P_{interaction}$=0.429), AHI level ($P_{interaction}$=0.219), or sleep efficiency ($P_{interaction}$=0.167).

Association Between Wake-Up Times on Weekdays and CHF

The 4 wake-up time categories (>8:00 AM, 7:01–8:00 AM, 6:01–7:00 AM, and ≤6:00 AM) revealed varying incidences of CHF (19.7%, 14.2%, 11.5%, and 8.8%, respectively; P<0.001). In addition, the multivariable Kaplan-Meier analysis showed an increased incidence of CHF in participants with wake-up times >8:00 AM on weekdays (Figure 2B). In addition, the multivariable Cox proportional hazards model showed that a wake-up time >8:00 AM on weekdays was associated with an increased risk of CHF (HR, 1.53; 95% CI, 1.07–2.17; P=0.018) compared with the reference group (≤6:00 AM) (Table 3). Furthermore, there was no interaction effect between wake-up weekday times and the above clinically relevant factors.

Association Between Sleep Timing on Weekends and CHF

We also investigated the association between weekend sleep timing and CHF, as well as the role of weekend wake-up time, bedtime, and sleep midpoint in the incidence of CHF. Our results showed that weekend bedtime, wake-up time, and sleep midpoint were not associated with the incidence of CHF (Table S1).

DISCUSSION

CHF, a type of CVD, has become a major public health concern, as it results in shorter length of life, severely impacted function, and reduced quality of life.[15] As a lifestyle behavior, sleep timing is closely related to healthy sleep.[16] Numerous studies have shown that sleep timing had an impact on sleep duration and CVD risk factors.[7,9,17–19] However, there is little evidence on the effect of sleep timing on the incidence of CHF. In this large community-based study, we found that a late weekday bedtime was associated with the incidence of CHF in individuals who reported sleep durations of 6 to 8 hours. A delayed wake-up time on weekdays was also a risk factor for CHF.

Previous research has shown that sleep timing was correlated with CVD risk factors. Asarnow et al[18] found that a later bedtime was correlated with an increase in BMI over time from adolescence to adulthood. Reutrakul et al[8] revealed that bedtime, as a continuous

Table 4. HRs and 95% CIs for Weekday Bedtime Associated With CHF in Subgroup Analysis With Different Self-Reported Sleep Duration

Variable	Individuals, N	Person-Years	Event, n (%)	Morbidity Rate*	Univariate Models		Multivariable Adjusted†		Multivariable Adjusted‡	
					HR (95% CI)	*P* Value	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
Bedtime										
6–8 h	3443	36 715	331 (9.6)	9.0						
>12:00 AM	244	2340.6	43 (17.6)	18.4	3.03 (2.11–4.34)	<0.001	2.18 (1.51–3.14)	<0.001	2.09 (1.45–3.01)	<0.001
11:01 PM to 12:00 AM	1040	10 853.3	129 (12.4)	11.9	1.98 (1.52–2.58)	<0.001	1.48 (1.13–1.94)	0.004	1.49 (1.14–1.95)	0.004
10:01–11:00 PM	1436	15 796.6	94 (6.5)	6.0	1 (Reference)		1 (Reference)		1 (Reference)	
≤10:00 PM	723	7724.4	65 (9.0)	8.4	1.43 (1.04–1.96)	0.026	1.50 (1.09–2.07)	0.013	1.50 (1.09–2.07)	0.013
>8 h	943	9227.2	141 (15.0)	15.3						
>12:00 AM	44	384.2	9 (20.5)	23.4	1.37 (0.68–2.79)	0.382	1.43 (0.68–2.99)	0.346	1.47 (0.70–3.07)	0.308
11:01 PM to 12:00 AM	139	1405.6	21 (15.1)	14.9	0.92 (0.55–1.52)	0.735	0.80 (0.48–1.33)	0.387	0.81 0.48–1.35)	0.418
10:01–11:00 PM	317	3129	51 (16.1)	16.3	1 (Reference)		1 (Reference)		1 (Reference)	
≤10:00 PM	443	4308.4	60 (13.5)	13.9	0.87 (0.60–1.26)	0.449	0.84 (0.58–1.23)	0.378	0.84 (0.58–1.23)	0.368
<6 h	379	3849.5	47 (12.4)	12.2						
>12:00 AM	153	1553.9	17 (11.1)	10.9	0.90 (0.42–1.92)	0.784	0.61 (0.27–1.38)	0.235	0.63 (0.28–1.43)	0.271
11:01 PM to 12:00 AM	127	1255.5	16 (12.6)	12.7	1.04 (0.48–2.24)	0.924	0.80 (0.36–1.80)	0.591	0.85 (0.37–1.91)	0.685
10:01–11:00 PM	84	900.7	11 (13.1)	12.2	1 (Reference)		1 (Reference)		1 (Reference)	
≤10:00 PM	15	139.4	3 (20)	21.5	1.21 (0.34–4.32)	0.775	1.23 (0.30–5.08)	0.776	1.14 (0.27–4.81)	0.862
$P_{interaction}$=0.019										

CHF indicates congestive heart failure; and HR, hazard ratio.
*Crude event rate per 1000 person-years.
†Adjusted by age, sex, race, smoking, body mass index, diabetes mellitus, hypertension, and apnea-hypopnea index.
‡Adjusted by age, sex, race, smoking, body mass index, diabetes mellitus, hypertension, apnea-hypopnea index, and sleep efficiency.

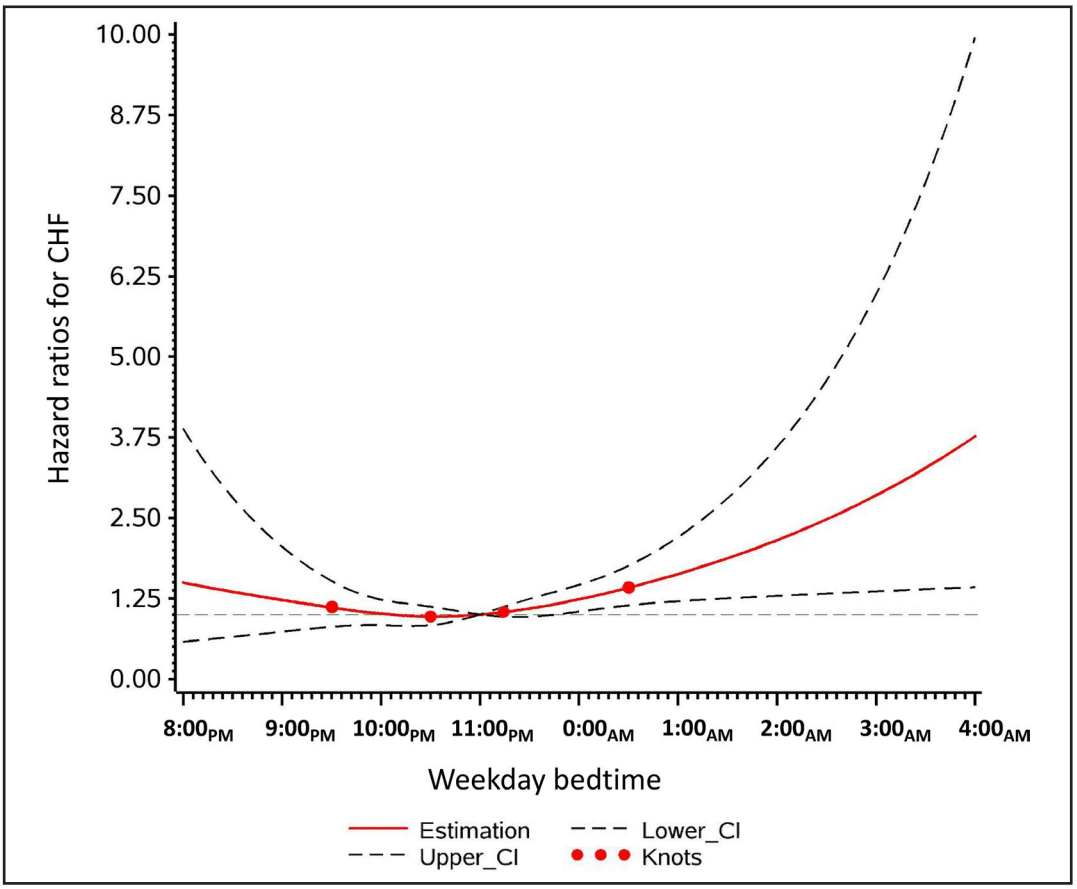

Figure 3. Multivariable-adjusted restricted spline curves for the association between weekday bedtime and the incidence of congestive heart failure (CHF) in participants with self-reported sleep durations of 6 to 8 hours.

variable, was negatively associated with glycemic control in patients with type 2 diabetes mellitus, whereas no association was observed between wake-up time and glycemic control. Moreover, Japanese workers with bedtimes ≥1:00 AM and from 11:00 to 11:59 PM have had an increased prevalence of depressive symptoms.[9] A late bedtime (>12:00 AM), but not a late wake-up time, has been found to increase the risk of obesity in Japanese people.[7] However, the relationship between sleep timing and CHF remains unknown. Our findings showed that late bedtimes, >12:00 AM and from 11:01 PM to 12:00 AM, on weekdays were associated with an increased risk of CHF when compared with the reference group (10:01–11:00 PM). We also investigated the relationship between late bedtimes on weekends and CHF, but no significant association was found. This may be because of the different bedtime habits on weekdays and weekends. In this study, we also found a high incidence of CHF among people with wake-up times later than 8:00 AM on weekdays. These findings indicate that late bedtimes and delayed wake-up times may increase the risk of CHF.

Sleep duration could be acquired from polysomnography or actigraphy objectively and self-report questionnaire subjectively. Reinhard et al found that there was a linear association between short objective sleep duration by polysomnography and increased mortality.[20] King et al also demonstrated that longer sleep duration monitored with wrist actigraphy is related with elevated risk of coronary artery calcification incidence.[21] Besides, U-shaped associations of self-reported sleep duration with CVD and all-cause mortality (6–8 hours was considered as a normal sleep duration) were detected.[22] Compared with self-report sleep duration, objectively measured sleep duration may provide more accurate sleep time during the night and could avoid the recalling bias. Multiple polysomnography and wrist actigraphy levels were useful measurements to evaluate the human bedtime during the nighttime. However, in SHHS, there was only one-night polysomnography measurement. Although the entire monitoring process with in-home polysomnography tried to make participants consistent with their usual sleep, the effect on sleep, such as first night effect for polysomnography, cannot be avoided. Therefore, the single-night polysomnography monitoring may not fully reflect the habitual sleep duration, and sleep duration was obtained from the sleep-habit questionnaires in SHHS.

We also performed an interaction analysis to explore the role of bedtime on the incidence of CHF ($P_{interaction}$=0.019). The stratified analysis revealed that the association between weekday bedtime and CHF was intensified in individuals with sleep durations of 6 to 8 hours, whereas no significant association was observed between bedtime and CHF in participants with sleep durations of <6 or >8 hours. Our results indicate that a bedtime from 10:01 to 11:00 PM may be the most suitable for people with sleep durations of 6 to 8 hours to decrease the risk of CHF. An interaction analysis was also performed between wake-up time and sleep duration, and no significant interaction was found ($P_{interaction}$=0.243). That suggested that the relationship of wake-up time with CHF will not change in individuals with different sleep duration. Besides, previous studies have reported that high level of AHI was associated with an increased risk of heart failure using SHHS cohort.[13,23] Thus, we added AHI into multivariable proportional hazard models. Furthermore, the interaction analysis of weekday bedtime with AHI was conducted, and no significant interaction was found ($P_{interaction}$=0.219).

The underlying mechanisms of the relationship between sleep timing and CHF remain unclear, but some sleep-related biological mechanisms may explain the phenomenon. On the one hand, circadian disruption occurs when endogenous circadian rhythms are not in synchrony with external environment. For example, wake up, sleep, and meals are not at an appropriate time that depends on the internal circadian clock. Individuals with late sleep timing has tended to have a shift in the timing of meals and have a longer duration of light exposure, which may lead to circadian disruption.[24–26] Circadian disruption has also been found to be associated with increased risks of obesity, diabetes mellitus, and CVD.[25,27,28] One the other hand, previous studies have shown that a late bedtime was associated with unhealthy dietary habits, including consuming excess calories at dinner, increased snacking behavior, and reduced fruit and vegetable consumption.[25,26] Therefore, late sleepers were prone to be obese and have a high BMI.[7,26] Besides, late sleepers had a late meal timing, which might increase the risk of obesity.[26] Furthermore, late sleep timing was closely related to CVD risk factors, such as diabetes mellitus, depression, lack of physical activity, and short sleep duration.[8,9,19]

There are both strengths and weaknesses in the present study. To our knowledge, this is the first study to investigate the role of sleep timing in the incidence of CHF. Our investigation was based on a large community population, which allows for us to generalize our findings. We used bedtime and wake-up time as new predictors for CHF, and our results suggest that a suitable bedtime and wake-up time may help decrease the risk of CHF. However, the participants in our study were middle-aged or older, and most were White race. Therefore, it might not be possible to extend our findings to the younger population or to all race/ethnic groups. No association was found between bedtime and CHF in participants with a sleep duration of <6 or >8 hours; this may be attributable to its relatively small study sample. Moreover, SHHS was an existing data set, and we did not obtain some potential factors, such as occupation, social economic status, shift work patterns, meal timings, hyperlipidemias, season, geographic region, and information collection sites. We also lacked the data about the treatment for sleep apnea. All these were limitations for the present study. In future studies, we will enlarge the sample size, enroll younger participants, and cover more confounders to further explore the relationship between sleep timing and CVD in Chinese population.

CONCLUSIONS

In summary, we found that individuals with late bedtimes on weekdays were at greater risk of CHF. To decrease this risk, a bedtime from 10:01 to 11:00 PM may be most suitable for individuals with a sleep duration of 6 to 8 hours. Delayed wake-up times (>8:00 AM) on weekdays also were associated with increased incidence of CHF.

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Disclosures

None.

Supplementary Material

Table S1

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SUPPLEMENTAL MATERIAL

Table S1. H Rs and 95% CIs for sleep timing (bedtime, wake time, sleep midpoint) associated with CHF on weekends

	Persons (N)	Person-years	Event, n (%)	Morbidity rate*	Univariate Models HR (95%CI)	*P*	Multivariable adjusted† HR (95%CI)	*P*	Multivariable adjusted‡ HR (95%CI)	*P*	Multivariable adjusted§ HR (95%CI)	*P*
Sleep timing	4,751	49,624	516	10.4								
Bedtime												
>12:00 AM	596	5,987.7	73 (12.2)	12.2	1.39 (1.06-1.84)	0.018	1.20 (0.91-1.59)	0.201	1.19 (0.90-1.58)	0.212	1.25 (0.94-1.67)	0.124
11:01 PM to 12:00 AM	1,525	16,026	170 (11.1)	10.6	1.21 (0.98-1.50)	0.077	1.08 (0.87-1.34)	0.497	1.10 (0.88-1.37)	0.397	1.13 (0.91-1.41)	0.273
10:01 PM to 11:00 PM	1,751	18,786.6	164 (9.4)	8.7	1(Ref)		1(Ref)		1(Ref)		1(Ref)	
≤10:00 PM	879	8,823.7	109	12.4	1.42	0.005	1.19	0.172	1.17	0.215	1.11	0.415

			(12.4)		(1.11-1.81)		(0.93-1.52)		(0.91-1.50)		(0.86-1.43)	
Wake-up time												
			68		1.03		1.26		1.23		1.10	
>8:00 AM	564	5,649.1	(12.1)	12	(0.78-1.37)	0.813	(0.95-1.67)	0.108	(0.93-0.63)	0.155	(0.80-1.50)	0.566
			108		0.78		0.98		0.98		0.90	
7:01 AM to 8:00 AM	1,118	11,794.7	(9.7)	9.2	(0.62-0.99)	0.043	(0.77-1.25)	0.856	(0.77-1.24)	0.845	(0.69-1.17)	0.439
			163		0.82		0.88		0.89		0.86	
6:01 AM to 7:00 AM	1,597	17,050.6	(10.2)	9.6	(0.66-1.01)	0.062	(0.71-1.09)	0.245	(0.72-1.10)	0.284	(0.69-1.08)	0.195
≤6:00 AM	1,472	15,129.7	177	11.7	1(Ref)		1(Ref)		1(Ref)		1(Ref)	
					0.94		1.00		1.00		1.00	
Sleep midpoint					(0.87-1.03)	0.202	(0.92-1.09)	0.980	(0.92-1.09)	0.966	(0.91-1.09)	0.923

CHF, congestive heart failure; 95% CI, 95% confidence interval; HR, hazard ratio.
* Crude event rate per 1,000-person years
† adjusted by age, sex, race, smoking, BMI, diabetes mellitus, hypertension and AHI
‡ adjusted by † + sleep efficiency
§ adjusted by ‡ + sleep duration