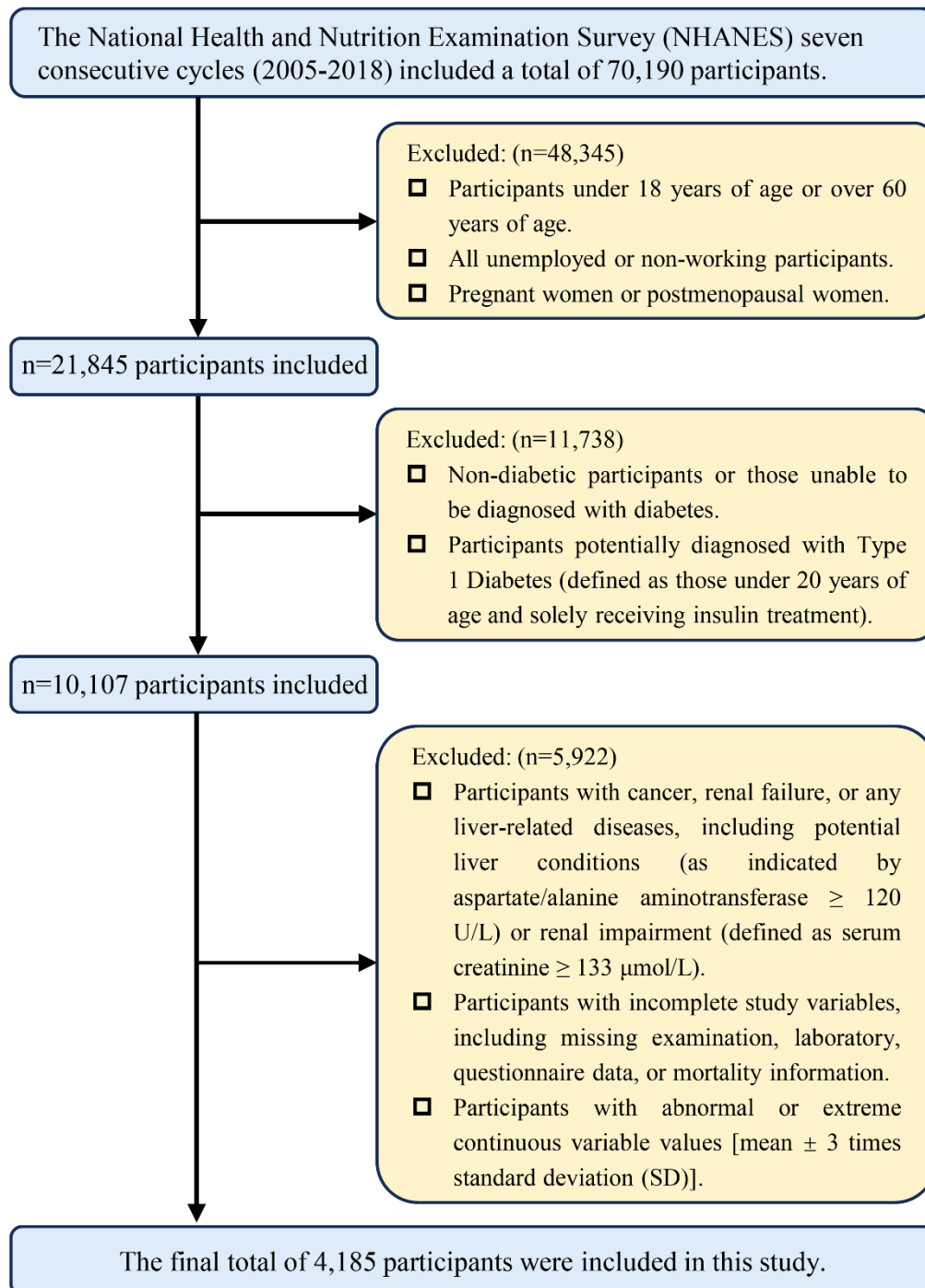
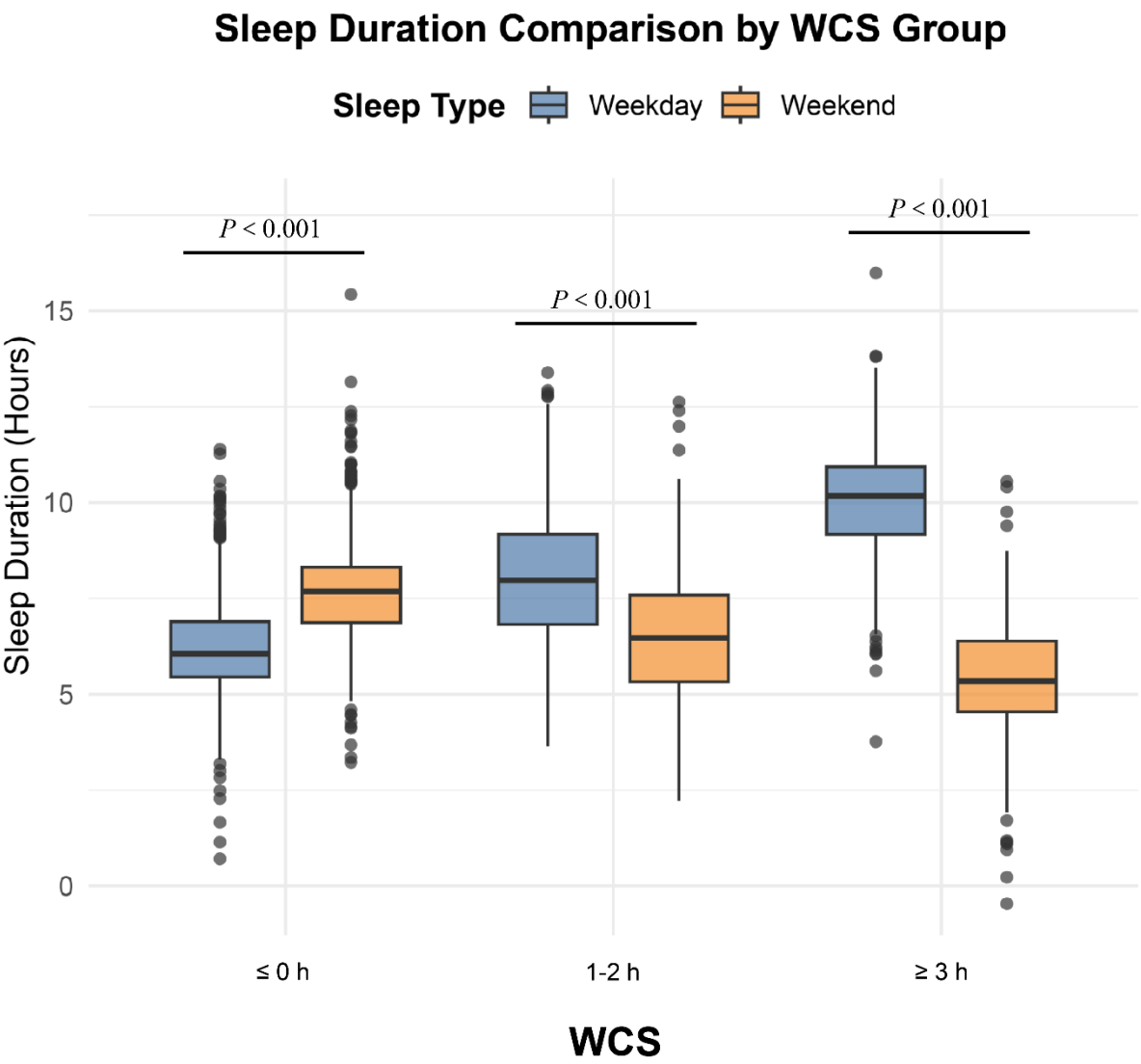


Supplementary Material

Supplemental Figure 1. Flowchart of the detailed screening process for participants.



Supplemental Figure 2. Boxplots of weekday and weekend sleep duration across the three WCS categories defined in the main analysis, illustrating the distribution of sleep duration and differences between groups.



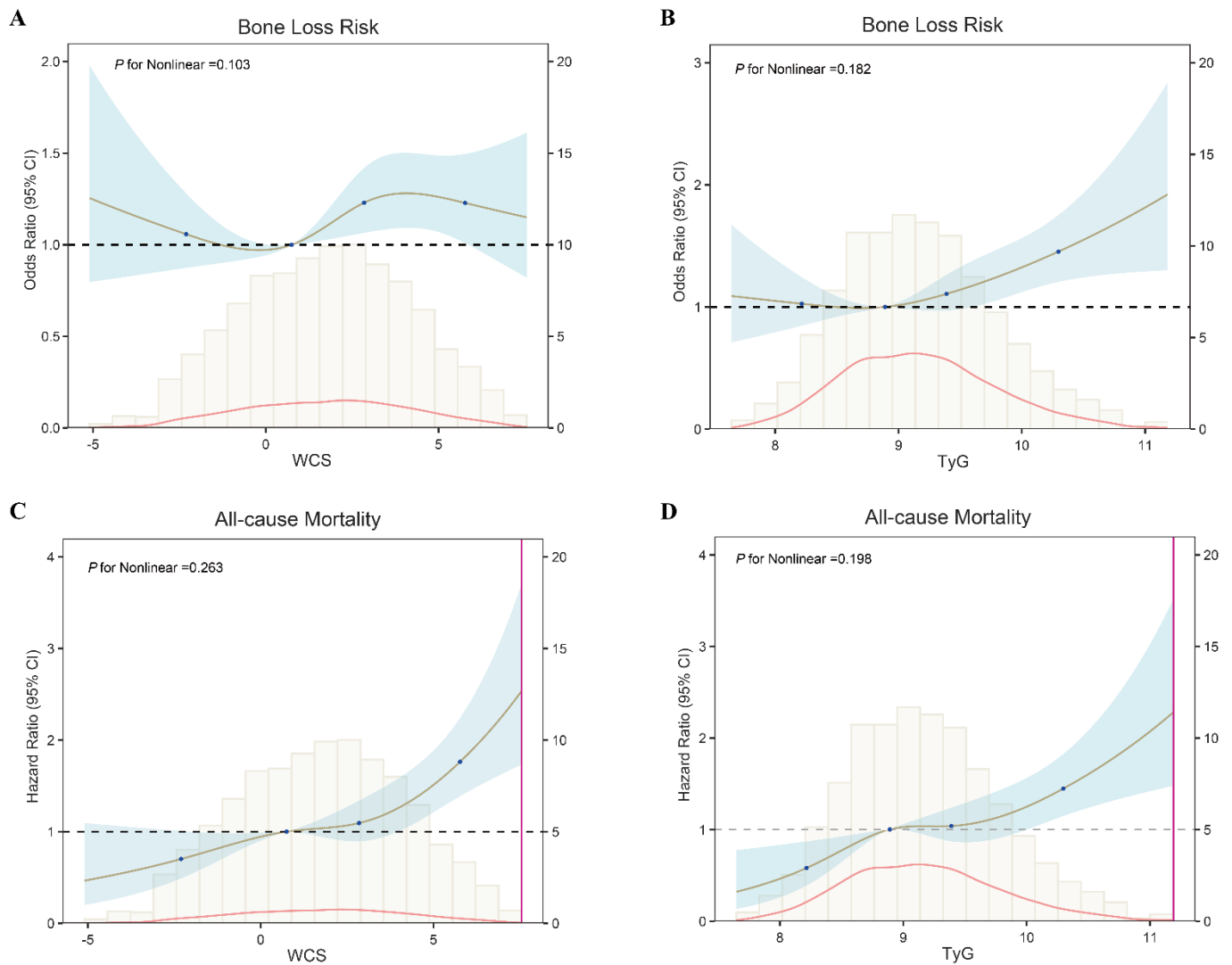
Supplemental Figure 3. RCS analysis on the non-linear association between predictors and the risk of bone loss and all-cause mortality in employed U.S. adults aged 18–60 with T2DM.

(A). The RCS analysis on the association between WCS and bone loss risk.

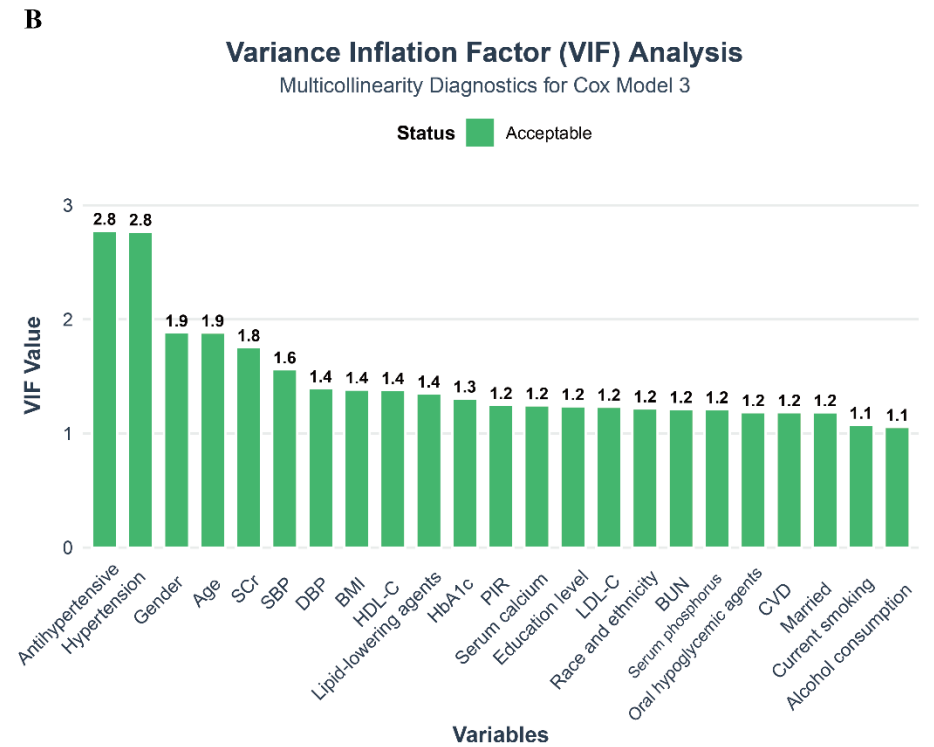
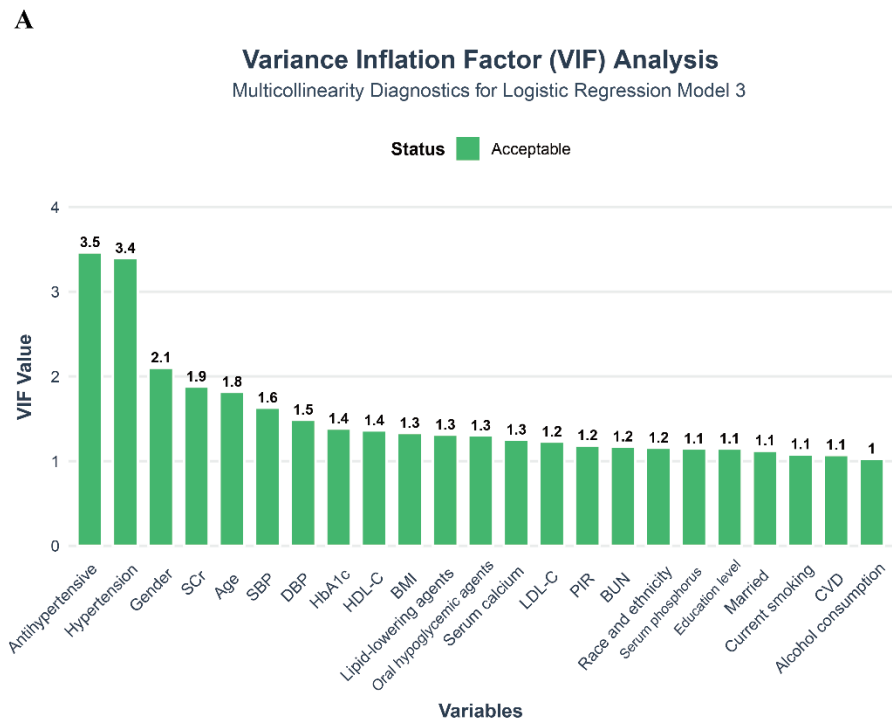
(B). The RCS analysis on the association between TyG and bone loss risk.

(C). The RCS analysis on the association between WCS and all-cause mortality.

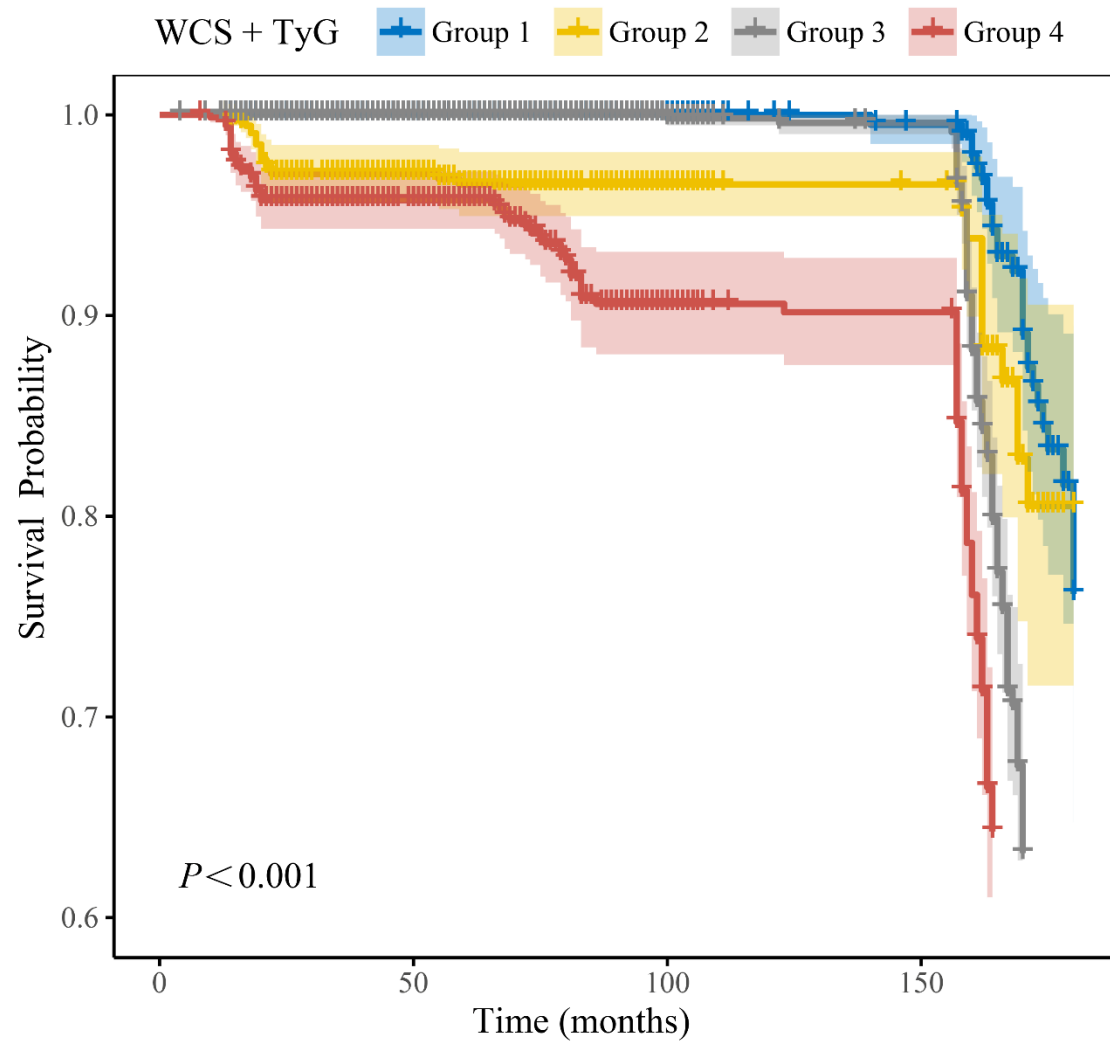
(D). The RCS analysis on the association between TyG and all-cause mortality.



Supplemental Figure 4. The VIFs for all covariates included in Model 3 of the logistic regression (A) and Cox proportional hazards models (B).



Supplemental Figure 5. Kaplan-Meier survival curves showing associations of the WCS + TyG combination with all-cause mortality.



Supplemental Figure 6. An online open-access risk stratification portal was developed at https://evosaber.shinyapps.io/wcs_bone_loss_app/.

(A)

Online Scale of WCS and TyG

Form

Result

Question 1: What is your age?

Age:

55

Question 2: What is your height (m)?

Height:

1.75

Question 3: What is your weight (kg)?

Weight:

75

Question 4: What is your gender?

Choose your answer:

☒ Female

☐ Male

Question 5: What is your Race?

Choose your answer:

☒ Non-Hispanic white

☐ Non-Hispanic black

☐ Hispanic

☐ Other race

Question 6: What time do you usually fall asleep on weekdays?

Bedtime:

24

Question 7: What time do you usually wake up on weekdays?

Wake-up time:

6

Question 8: What time do you usually fall asleep on weekends?

Bedtime:

23

Question 9: What time do you usually wake up on weekends?

Wake-up time:

8

Question 10: What is your TG (mg/dL)?

TG:

220

Question 11: What is your FBG (mg/dL)?

FBG:

130

Submit Scale

(B)

Online Scale of WCS and TyG

Form

Result

Scale result

BMI: 24.49

WCS: 3

TyG: 9.57

Risk Level: High risk (high WCS & high TyG)

Recommendation: This group represents the highest-risk population and requires immediate, two-pronged intervention. Risk is largely driven by a vicious cycle in which insufficient sleep exacerbates IR, which in turn further disrupts sleep. Clinicians should implement an integrated management plan addressing both sleep and metabolic control to break this cycle. The BMD testing should be performed without delay (e.g., DXA); if bone loss with high fracture risk is identified or diagnostic criteria for osteoporosis are met, pharmacotherapy should be initiated promptly to halt accelerated bone loss and substantially reduce short-term fracture risk.

(C)

Low risk (low WCS & low TyG)		Management should primarily adhere to standard diabetes care, with emphasis on maintaining healthy sleep and metabolic function. Current guidelines should be followed, reinforcing lifestyle interventions such as a balanced diet with adequate calcium and vitamin D, regular physical activity, weight management, and consistent sleep patterns. The treatment goal is to prevent the development of new risk factors; apart from routine osteoporosis screening, no additional assessments or anti-osteoporotic pharmacotherapy are necessary.
Intermediate risk	Group A: low WCS & high TyG	This category is primarily driven by metabolic dysfunction. Management should focus on improving insulin sensitivity through a combination of pharmacologic and lifestyle interventions: (I) optimize glycemic control, giving preference to agents with potential benefits for weight, cardiovascular, renal, and bone health (e.g., metformin, GLP-1 receptor agonists), together with appropriate lipid management; (II) strengthen fundamental bone health measures, including sufficient calcium and vitamin D intake and regular weight-bearing exercise, with annual BMD reassessment. Anti-resorptive therapy should be initiated only when diagnostic criteria for osteoporosis are met.
	Group B: high WCS & low TyG	This group is primarily driven by sleep debt. Management should focus on sleep optimization: (I) provide structured sleep hygiene education and cognitive behavioral therapy for insomnia, and reduce weekday sleep debt to mitigate adverse metabolic and skeletal effects; (II) reinforce fundamental bone-health measures, identical to those recommended for intermediate-risk Group A.
High risk (high WCS & high TyG)		This group represents the highest-risk population and requires immediate, two-pronged intervention. Risk is largely driven by a vicious cycle in which insufficient sleep exacerbates IR, which in turn further disrupts sleep. Clinicians should implement an integrated management plan addressing both sleep and metabolic control to break this cycle. The BMD testing should be performed without delay (e.g., DXA); if bone loss with high fracture risk is identified or diagnostic criteria for osteoporosis are met, pharmacotherapy should be initiated promptly to halt accelerated bone loss and substantially reduce short-term fracture risk.

Supplemental Table 1. Associations of WCS with CVD in analyses stratified by weekday sleep duration (≤ 6 h vs > 6 h).

Variables		CVD risk			
		Unadjusted		Fully Adjusted*	
		OR (95% CI)	P	OR (95% CI)	P
Weekday sleep duration ≤ 6 h					
	≤ 0 h	1.000	Ref.	1.000	Ref.
WCS	1-2 h	0.439 (0.155-1.567)	0.152	0.318 (0.097-1.273)	0.075
	≥ 3 h	0.560 (0.210-1.941)	0.294	1.255 (1.098-1.434)	0.092
Weekday sleep duration > 6 h					
	≤ 0 h	1.000	Ref.	1.000	Ref.
WCS	1-2 h	1.099 (0.562-2.177)	0.782	1.156 (0.565-2.394)	0.690
	≥ 3 h	1.353 (0.589-2.964)	0.458	1.398 (0.579-3.224)	0.437

*The model incorporates age, gender, race and ethnicity, BMI, education level, married/living with a partner, family income to poverty, current smoking, alcohol consumption, hypertension, drug interventions, SBP, DBP, HDL-C, LDL-C, HbA1c, SCr, BUN, as well as serum calcium and phosphorus.

Supplemental Table 2. The sensitivity analysis was conducted using an alternative WCS threshold (≥ 2 h).

Variables	Bone loss risk				All-cause mortality			
	Unadjusted		Fully Adjusted*		Unadjusted		Fully Adjusted*	
	OR (95%CI)	P	OR (95%CI)	P	HR (95%CI)	P	HR (95%CI)	P
WCS								
< 2 h	1.000	Ref.	1.000	Ref.	1.000	Ref.	1.000	Ref.
≥ 2 h	1.240 (1.090-1.409)	<0.001	1.255 (1.098-1.434)	<0.001	1.425 (1.199-1.694)	<0.001	1.443 (1.212-1.719)	<0.001
TyG								
< 9.00	1.000	Ref.	1.000	Ref.	1.000	Ref.	1.000	Ref.
≥ 9.00	1.142 (1.002-1.301)	0.047	1.231 (1.054-1.437)	0.009	1.419 (1.179-1.707)	<0.001	1.445 (1.174-1.780)	<0.001
WCS + TyG								
Group 1: Low WCS and low TyG (WCS < 2 h and TyG < 9.00)	1.000	Ref.	1.000	Ref.	1.000	Ref.	1.000	Ref.
Group 2: Low WCS and high TyG (WCS < 2 h and TyG ≥ 9.00)	1.234 (1.027-1.484)	0.025	1.236 (1.005-1.521)	0.045	1.745 (1.311-2.324)	<0.001	1.812 (1.335-2.459)	<0.001
Group 3: High WCS and Low TyG (WCS ≥ 2 h and TyG < 9.00)	1.363 (1.114-1.669)	0.003	1.400 (1.134-1.729)	0.002	1.824 (1.337-2.490)	<0.001	1.828 (1.336-2.501)	<0.001
Group 4: High WCS and high TyG (WCS ≥ 2 h and TyG ≥ 9.00)	1.432 (1.190-1.725)	<0.001	1.443 (1.170-1.781)	<0.001	2.194 (1.657-2.905)	<0.001	2.338 (1.729-3.160)	<0.001

*The model incorporates age, gender, race and ethnicity, BMI, education level, married/living with a partner, family income to poverty, current smoking, alcohol consumption, hypertension, CVD, drug interventions, SBP, DBP, HDL-C, LDL-C, HbA1c, SCr, BUN, as well as serum calcium and phosphorus.

Supplemental Table 3. The predictive performance of the WCS, TyG, and their combination for risk of bone loss and all-cause mortality as well as the incremental effects of incorporating the WCS and TyG into a traditional predictive model.

	Harrell's C-index	P value	*Adjusted Harrell's C-index
The incremental effects of composite WCS + TyG index			
<i>Bone loss risk</i>			
WCS + TyG vs. TyG	0.713 (0.697-0.729) vs. 0.613 (0.595-0.631)	<0.001	0.719 (0.703-0.735) vs. 0.620 (0.602-0.638)
WCS + TyG vs. WCS	0.713 (0.697-0.729) vs. 0.625 (0.607-0.643)	<0.001	0.719 (0.703-0.735) vs. 0.628 (0.611-0.646)
<i>All-cause mortality</i>			
WCS + TyG vs. TyG	0.744 (0.725-0.763) vs. 0.679 (0.655-0.702)	<0.001	0.755 (0.735-0.775) vs. 0.690 (0.667-0.713)
WCS + TyG vs. WCS	0.744 (0.725-0.763) vs. 0.693 (0.669-0.717)	<0.001	0.755 (0.735-0.775) vs. 0.699 (0.675-0.723)
The incremental effects of incorporating WCS and TyG into a traditional predictive model			
<i>Bone loss risk</i>			
^a Model	0.645 (0.628-0.663)	Ref.	0.648 (0.630-0.666)
Model + TyG	0.690 (0.673-0.707)	<0.001	0.693 (0.676-0.710)
Model + WCS	0.692 (0.675-0.709)	<0.001	0.694 (0.677-0.710)
Model + WCS + TyG	0.761 (0.746-0.777)	<0.001	0.763 (0.748-0.778)
<i>All-cause mortality</i>			
^a Model	0.647 (0.623-0.671)	Ref.	0.651 (0.627-0.676)
Model + TyG	0.734 (0.712-0.756)	<0.001	0.737 (0.714-0.759)
Model + WCS	0.736 (0.714-0.759)	<0.001	0.739 (0.717-0.761)
Model + WCS + TyG	0.795 (0.775-0.814)	<0.001	0.796 (0.777-0.816)

^aThe model incorporates age, gender, race and ethnicity, BMI, education level, married/living with a partner, family income to poverty, current smoking, alcohol consumption, hypertension, CVD, drug interventions, SBP, DBP, HDL-C, LDL-C, HbA1c, SCr, BUN, as well as serum calcium and phosphorus.

*Covariate-adjusted receiver operating characteristic curve analysis was adjusted for CVD, hypertension, and drug interventions.