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Evaluating the potential of waist-to-BMI ratio, a body shape index, and other anthropometric parameters in predicting cardiovascular disease mortality: evidence from NHANES III

Thung-Lip Lee[1,2], Fang-Ju Lin[3,4], Chih-Fan Yeh[5], Yu-Chung Hsiao[5], Kai-Chien Yang[5,6], Chin-Feng Hsuan[1,7,8,10*] and Chau-Chung Wu[5,9]

Abstract

Background Anthropometric measures can be obtained easily and quickly and have the potential for prognostic stratification in the context of cardiovascular disease (CVD). This study evaluates the prognostic value of the waist-to-BMI ratio, a body shape index (ABSI), body roundness index (BRI), waist circumference (WC), and body mass index (BMI) for CVD mortality prediction in the general population, compared with the Framingham risk score (FRS).

Methods Data of participants from the United States Third National Health and Nutrition Examination Survey (NHANES III) (1988 to 1994), aged 40–79 years with complete data were extracted and analyzed. Cox regression, receiver operating characteristic (ROC) curve analysis, and the C-index were used to determine the predictive value of the anthropometric parameters for CVD mortality, with follow-up through the end of 2019 via the National Center for Health Statistics (NCHS) Linked Mortality File.

Results After applying inclusion and exclusion criteria, 6,746 individuals (mean age 57.6 years) were analyzed. Cox regression indicated significant associations between BMI, WC, waist-to-BMI ratio, BRI, ABSI, and increased CVD mortality risk (adjusted hazard ratios [aHR] = 1.11, 1.19, 1.07, 1.12, and 1.13, respectively). ROC analysis revealed that FRS had the best performance for predicting 10-year CVD mortality (AUC = 0.7252), followed by ABSI (0.6407) and waist-to-BMI ratio (0.6120). Time-dependent AUC analyses confirmed FRS had the highest C-index (0.7004), followed by ABSI (0.6358) and waist-to-BMI ratio (0.5807).

Conclusions Our study suggests that, among the anthropometric measures studied, ABSI and waist-to-BMI ratio may offer predictive capability for CVD mortality in the general US population. The simplicity of measuring and calculating the waist-to-BMI ratio enhances its practicality, making it a potentially useful tool, particularly when other clinical factors are not available.

*Correspondence:
Chin-Feng Hsuan
calvin.hsuan@msa.hinet.net

Full list of author information is available at the end of the article

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Keywords Body mass index, waist-to-BMI ratio, waist-to-hip ratio, A body shape index, Body roundness index, Framingham risk score, cardiovascular disease risk, anthropometric parameters

Background

Cardiovascular disease (CVD) is a leading cause of death globally, with approximately 18 million people dying from CVD each year [1, 2]. Although CVD is typically thought of as a disease of middle-aged to older persons, recent evidence indicates that in developed countries the prevalence of CVD risk factors such as obesity, physical inactivity, and poor diet are increasing in individuals 18 to 50 years of age, and this is followed by an increase in the prevalence of CVD in this age group [1].

While there are many factors associated with an increased risk of CVD and CVD mortality, approximately 20% of CVD cases can be attributed to overweight and obesity [3, 4]. Other factors known to be associated with increased risk of CVD and CVD mortality include unhealthful dietary intake, physical inactivity, dyslipidemia, pre-diabetes/diabetes, high blood pressure, older age, race/ethnicity, being male, smoking, kidney dysfunction, and genetics/familial hypercholesterolemia [5–7].

Body mass index (BMI) is the most widely used measure of excess body weight and obesity, and an increased BMI is associated with increased CVD risk [3, 4, 8, 9]. However, BMI has limitations, particularly in its ability to differentiate between muscle and fat mass [3, 4, 8, 9]. Other anthropometric measures, such as body roundness index (BRI), a body shape index (ABSI), waist-to-BMI ratio, and waist-to-hip ratio (WHR), have been proposed as alternatives to BMI for predicting CVD risk and mortality [8, 10, 11]. These measures take into account different aspects of body composition and may provide more accurate estimates of CVD risk and mortality [8, 10, 11].

However, studies that examined the aforementioned anthropometric measures have reported inconsistent results [11]. For example, some reports suggested that WHR is a better predictor of CVD risk than BMI, whereas other reports have found no notable difference in the predictive ability of the 2 measures [11]. To date, few studies have directly compared the predictive ability of different anthropometric measures.

It is important to identify persons at increased risk of CVD and mortality due to CVD, especially those in high-risk populations so that targeted interventions to reduce CVD risk can be administered [4, 5, 8–11]. Many models for predicting CVD risk and mortality rely on laboratory testing (e.g., serum cholesterol, blood glucose) [5–7]. Anthropometric measures are non-laboratory based and can be obtained easily and quickly during an outpatient visit. As such, it is necessary to determine the anthropometric measure with the best performance for identifying increased CVD risk and predicting CVD mortality.

Therefore, this study aimed to evaluate and compare the predictive value of different anthropometric measures for assessing CVD risk and mortality using data from a nationally representative cohort of the United States. We hypothesize that among the anthropometric measures studied, ABSI and the waist-to-BMI ratio will demonstrate superior predictive performance for CVD mortality compared to BMI and other conventional measures and that these indices may serve as practical alternatives in clinical settings, particularly when laboratory-based risk assessments are unavailable.

Methods

Study design and data source

This was a population-based, cohort study that used data from the Third National Health and Nutrition Examination Survey III (NHANES III), a nationally representative survey of the non-institutionalized civilian population of the US. NHANES is conducted by the National Center for Health Statistics (NCHS) at preset intervals. NHANES III was conducted from 1988 to 1994, and data collected included patient demographic data, medical history, and physical examination and laboratory testing findings.

The NHANES survey uses a stratified, multistage probability design to select participants from all 50 states and the District of Columbia. Oversampling of certain subpopulations is conducted to ensure adequate representation. The survey data are collected through interviews conducted in participants' homes, and physical examinations conducted in mobile examination centers. NHANES III data are publicly available, and have been extensively used in research on various health topics. The NHANES III survey was approved by the NCHS Institutional Review Board, and informed consent was obtained from all participants before the data collection. Details about the NHANES III design, questionnaires, and data collection can be found at http://www.cdc.gov/nchs/nhanes/nhanes3.htm. Mortality data of NHANES survey participants were obtained from the death certificate records from the National Death Index (NDI).

Study population

Adults 40 to 79 years old who participated in NHANES III between 1988 and 1994 were eligible for inclusion in the current study. Participants without complete data of

study covariates and variables of interest were excluded: i.e., education level, poverty index, smoking status, estimated glomerular filtration rate (eGFR), systolic blood pressure (SBP), diastolic blood pressure (DBP), serum total cholesterol (TC), serum low-density lipoprotein-cholesterol (LDL-C), serum high-density lipoprotein-cholesterol (HDL-C), glycated-hemoglobin (HbA1c), fasting plasma glucose (FPG), BMI, waist circumference (WC), and death status.

Study variables

Body mass index (BMI)

BMI was calculated as body weight (kilograms) divided by height (meters squared) (kg/m^2). Body weight was measured using an electronic load cell scale, and standing height was measured with a fixed stadiometer.

Waist-to-BMI ratio

The waist-to-BMI ratio was calculated as waist circumference (cm) divided by BMI. This index integrates overall body mass with central adiposity, offering a refined assessment of fat distribution. Unlike BMI alone, which does not distinguish between fat and lean mass, the waist-to-BMI ratio provides additional insight into visceral fat accumulation [12], a key factor in cardiovascular disease risk.

Body roundness index (BRI)

BRI was calculated by the equation published by Thomas et al. [13] The WC and height (both in cm) were extracted from the NHANES III database, and BRI was calculated as: $BRI = 364.2–365.5 \times (1- [(0.5 \times WC/\pi)^2 / (0.5 \times height)^2])^{1/2}$.

A body shape index (ABSI)

ABSI was developed by Krakauer and Krakauer, which was based on the allometric power law analysis to adjust WC for weight and height [14]. It was defined as: $ABSI = WC/(BMI^{2/3} \times height^{1/2})$.

Framingham risk score (FRS)

Coronary heart disease (CHD) risk at 10 years in percent can be calculated with the FRS. The FRS is calculated based on 6 cardiovascular disease (CVD) risk factors: age, sex, serum total cholesterol, HDL-C, SBP, and smoking habit [15]. The cutoffs for calculating FRS are: TC < 160, 160–199, 200–239, 240–279, and ≥ 280 mg/dL; for systolic blood pressure: < 120, 120–129, 130–139, 140–159, and ≥ 160 mmHg; and for HDL-C: < 40, 40–49, 50–59, and ≥ 60 mg/dL. Ten-year risk in percentage is calculated by total points (1 point 6%, 2 points 8%, 3 points 10%, 4 points 12%, 5 points 16%, 6 points 20%, 7 points 25%, 10 points or more > 30%). Absolute CVD risk percentage over 10 years is classified as low risk (< 10%), intermediate risk (10–20%), and high risk (> 20%).

Ascertainment of CVD death

Through December 31, 2019, NCHS provided the NHANES Public-Use Linked Mortality File, which was linked to the NDI and contained all death records in the US. The International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10) was used to distinguish the participants' underlying reasons of death. CVD mortality was identified through death from heart disease and cerebrovascular disease (ICD10: I00–I09, I11, I13, I20–I51, and I60–I69). The number of months from the interview date to the death date, or through December 31, 2019, for individuals with no incident, was used to establish the follow-up period. The details can be found at: https://www.cdc.gov/nchs/data-linkage/mortality-public.htm.

Covariates

The age and sex of participants were obtained by standard questionnaires through in-person home interviews conducted by trained interviewers using the Family and Sample Person Demographics questionnaires, and the Computer-Assisted Personal Interviewing (CAPI) system (Confirmit Corp. New York, USA). Collected data were weighted according to the NHANES protocol. Diabetes was defined by the answer to the question: "Other than during pregnancy, have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?" or "Are you now taking insulin" or "Are you now taking diabetic pills to lower your blood sugar? These are sometimes called oral agents or oral hypoglycemic agents." Diabetes was also defined as a HbA1c ≥ 6.5% or FBG > 7 mmol/L.

The estimated glomerular filtration rate (eGFR) was determined from a re-calibrated serum creatinine level using the 4-variable Modification of Diet in Renal Disease (MDRD) Study equation. Here we use the IDMS-traceable MDRD Study equation that uses standardized creatinine: $eGFR = 175 \times (\text{standardized serum creatinine})^{-1.154} \times (\text{age})^{-0.203} \times 0.742$ (if the subject is a woman) × 1.212 (if the subject is black). Participants were considered to have chronic kidney disease (CKD) if the eGFR was < 60 ml/min/1.73 m^2.

Statistical analysis

Categorical variables were expressed as count and percentage, and compared with the chi-squared test. Continuous variables were expressed as mean ± standard deviation, and compared with Student's t-test. Pearson correlation analysis was used to examine the correlations between FRS and the 5 anthropometric parameters (BMI, WC, waist-to-BMI ratio, BRI, ABSI). Univariate and

multivariable Cox proportional hazard regressions were performed to calculate the hazard ratio (HR) and 95% confidence interval (CI) of FRS and the 5 anthropometric parameters for CVD mortality. Multivariable Cox proportional hazards models adjusted for age to examine the independent associations between the anthropometric indices and CVD mortality. Harrell's concordance index (C-index) [16] was calculated, and receiver operating characteristic (ROC) curves were performed to examine the accuracy of FRS and the 5 anthropometric parameters for predicting 10-year CVD mortality. Harrell's C-index is a goodness of fit measure for models which produce risk scores. The area under the ROC curve (AUC) is the same as Harrel's C-index for binary outcomes. It is commonly used to evaluate risk models in survival analysis, where data may be censored. Time-dependent AUCs plot was furtherly conducted and summarized by the C-statistics, whereas C-statistics provide overall measures of predictive accuracy, time-dependent ROC curves and AUC functions summarize the predictive accuracy at specific times. In addition, restricted cubic spline models with 3 knots (10th, 50th, and 90th percentiles) were used to investigate the dose-response association between the 6 anthropometric parameter exposures and CVD mortality [17].

Results

Study population

There were 9,616 persons aged 40–79 years old identified in the NHANES III database between 1988 and 1994. Persons with incomplete data of covariates ($n = 2,565$), death ($n = 2$), BMI ($n = 12$), and WC ($n = 291$) were excluded. Finally, a total of 6,746 individuals were included in the analyses, of which 1,424 (21.1%) died due to CVD (Fig. 1).

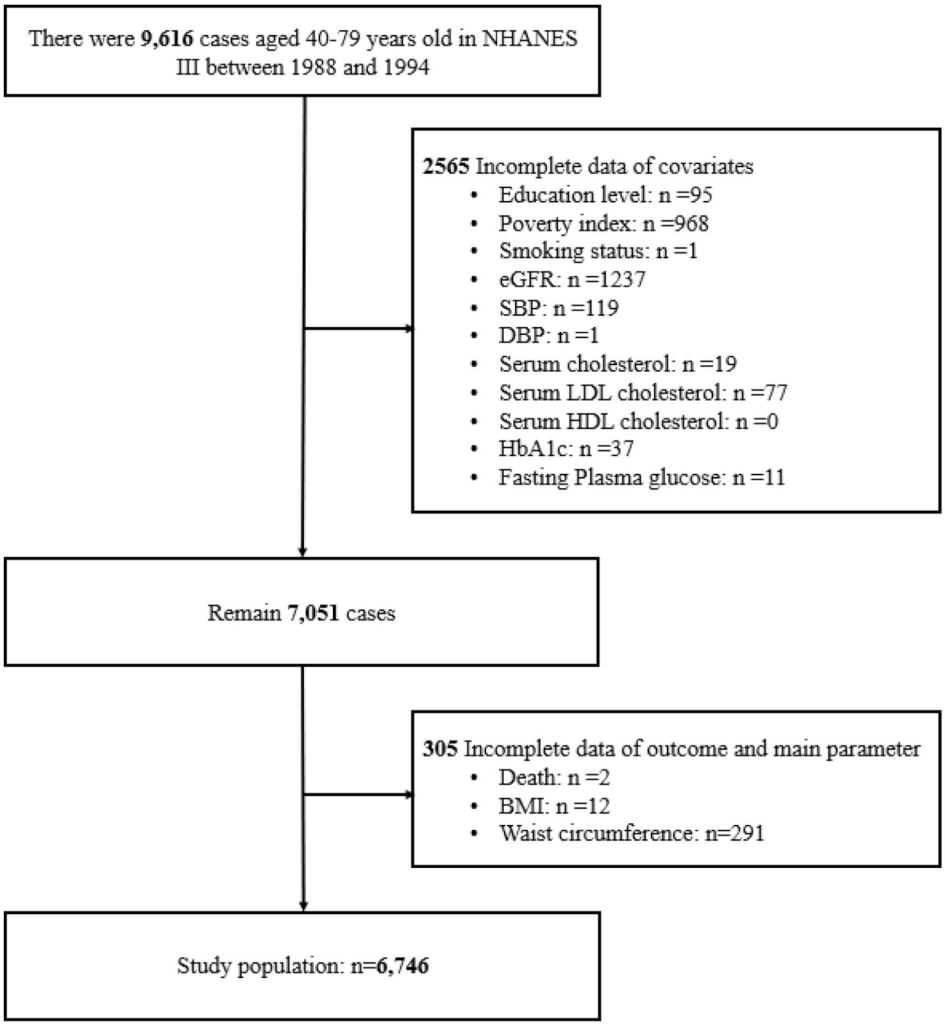

Fig. 1 Flow Chart of study population selection
BMI, body mass index; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HDL, high-density lipoprotein; HbA1c, glycosylated hemoglobin; LDL, low-density lipoprotein

Baseline characteristics of individuals who died from CVD and those who did not die

The characteristics of the study population and persons who died from CVD or not are summarized in Table 1. The mean age of all persons was 57.6 ± 11.5 years, with 3,280 males (48.6%) and 3,466 females (51.4%). The majority of persons were non-Hispanic white (48.3%), received an education of more than 12 years (56.9%), had a poverty-income ratio ≥ 1 (81.2%), had hypertension (62.9%) or an eGFR ≥ 60 mL/min/1.73 m^2 (61.4%). The mean follow-up time was 20.3 ± 8.8 years.

Persons who died due to CVD had a greater FRS (13.7 ± 9.2 vs. 8.9 ± 8.4, $p < 0.001$), BMI (28.2 ± 5.6 vs. 27.8 ± 5.6 kg/m^2, $p < 0.001$), WC (99.4 ± 13.8 vs. 96.5 ± 13.5 cm, $p < 0.001$), waist-to-BMI ratio (3.58 ± 0.35 vs. 3.52 ± 0.35 cm·m^2/kg, $p < 0.001$), BRI (5.5 ± 1.9 vs. 5.1 ± 1.9, $p < 0.001$), and ABSI (0.0837 ± 0.0049 vs. 0.0819 ± 0.0050 $m^{11/6}$/$kg^{2/3}$, $p < 0.001$).

Besides, persons who died from CVD were older (64.7 ± 9.9 vs. 55.7 ± 11.1 years, $p < 0.001$), were more likely to be male (52.2% vs. 47.7%, $p < 0.001$), were White and Black (52.1% vs. 47.3% and 25.4% vs. 24.4%, respectively, $p < 0.001$), had a lower education level (< 12 y: 53.2% vs. 40.4%, $p < 0.001$), were poor (21.1% vs. 18.2%, $p = 0.012$), and were more likely to be former smokers (36.7% vs. 31.9%, $p = 0.002$). Persons who died due to CVD had a higher percentage of comorbidities, including diabetes, chronic obstructive pulmonary disease (COPD), hypertension, and CKD (all $p < 0.001$). Persons who died due to CVD also had higher SBP, TC, LDL-C, HbA1c, and FPG (all $p < 0.001$), and lower HDL-C ($p = 0.046$).

Correlations between the anthropometric parameters and FRS

The correlations between FRS and the 5 anthropometric parameters examined are summarized in Table 2. Of the anthropometric parameters, ABSI had the strongest correlation with FRS (Pearson correlation coefficient $r = 0.34$), while the waist-to-BMI ratio exhibited the second highest correlation ($r = 0.29$). In addition, WC and BMI, BRI and BMI, and BRI and WC were strongly correlated ($r > 0.85$).

Cox regression analysis of the associations between FRS, the anthropometric parameters, and CVD mortality

The results of the univariate and multivariable Cox regression analyses on the associations between FRS and the anthropometric parameters (in z-score) and CVD mortality are summarized in Table 3. A unit increase of FRS z-score was associated with an increased risk of CVD mortality (HR = 1.83, 95% CI: 1.75–1.92, $p < 0.001$). After adjusting for age, the following variables were associated with an increased risk of CVD mortality: BMI, WC, waist-to-BMI ratio, BRI, and ABSI (adjusted HR [aHR] = 1.11, 1.19, 1.07, 1.12, and 1.13, respectively, all $p < 0.001$, except waist-to-BMI ratio with $p = 0.019$).

The predictive performance of the anthropometric parameters for 10-year CVD mortality

Results of the ROC analysis of the anthropometric parameters in predicting 10-year CVD mortality are shown in Fig. 2. FRS had the highest performance for predicting 10-year CVD mortality (AUC = 0.7252), followed by ABSI (AUC = 0.6407), and waist-to-BMI ratio (AUC = 0.6120) (Fig. 2A, F and D, respectively). The AUCs of BMI, WC, and BRI were all < 0.55. Similar results were found when time-dependent AUCs were examined (Fig. 3). FRS had the highest C-index of 0.7004, followed by ABSI (C-index = 0.6358), and waist-to-BMI ratio (C-index = 0.5807) (Fig. 3A, F and D, respectively).

Dose response relations between the anthropometric parameters and CVD mortality

The dose response curves of the 6 anthropometric parameters with respect to CVD mortality are shown in Fig. 4. FRS, BRI, and ABSI were non-linearly associated with CVD mortality ($p < 0.001$, < 0.001, and 0.032, respectively, Fig. 4A, E and F, respectively). The waist-to-BMI ratio exhibited a borderline non-linear association with CVD mortality ($p = 0.053$, Fig. 4D).

Discussion

In this study, we used a nationally representative database of the US to investigate a range of anthropometric measures with predictive value for death from CVD. Our analysis suggests that, among the anthropometric measures studied, ABSI and the waist-to-BMI ratio appear to have a relatively higher predictive ability for CVD mortality. Given its simplicity and accessibility, the waist-to-BMI ratio could serve as a practical tool for CVD risk assessment, especially in settings where laboratory-based evaluations are limited. Its ease of use makes it ideal for primary care and community health programs, enabling early risk identification and better resource allocation in underserved populations.

Prevention of CVD is simpler and more effective than treatment, and thus it is important to determine a person's risk for developing CVD such that interventions can be performed early to reduce the risk of developing CVD [18–20]. The FRS is the most validated model for predicting the risk of developing CVD [19]. However, the FRS was developed 3 decades ago, and although the model has been updated over these decades the variables and calculations used can be complicated and the results are not always consistent with other models for predicting the risk of developing CVD [18, 19]. A recent review and meta-analysis found that the FRS in general overestimates the risk of developing CVD, and this is

Table 1 Baseline characteristics of individuals who died from CVD and those who did not die

Variables	All (*N* = 6,746)	CVD mortality		*p*-value
		Yes (*n* = 1,424)	No (*n* = 5,322)	
Follow-up time, years	20.3 ± 8.8	14.2 ± 7.8	21.9 ± 8.3	**< 0.001**
FRS	9.9 ± 8.8	13.7 ± 9.2	8.9 ± 8.4	**< 0.001**
BMI, kg/m^2	27.9 ± 5.6	28.2 ± 5.6	27.8 ± 5.6	**0.035**
Waist circumference, cm	97.1 ± 13.6	99.4 ± 13.8	96.5 ± 13.5	**< 0.001**
Waist-to-BMI ratio, cm · m^2/kg	3.53 ± 0.35	3.58 ± 0.35	3.52 ± 0.35	**< 0.001**
BRI	5.2 ± 1.9	5.5 ± 1.9	5.1 ± 1.9	**< 0.001**
ABSI, m$^{11/6}$/kg$^{2/3}$	0.0822 ± 0.050	0.0837 ± 0.0049	0.0819 ± 0.0050	**< 0.001**
Age, years	57.6 ± 11.5	64.7 ± 9.9	55.7 ± 11.1	**< 0.001**
40–49	2091 (31.0)	156 (11.0)	1935 (36.4)	**< 0.001**
50–59	1512 (22.4)	205 (14.4)	1307 (24.6)	
60–69	1818 (26.9)	514 (36.1)	1304 (24.5)	
70–79	1325 (19.6)	549 (38.6)	776 (14.6)	
Sex				**0.002**
Male	3280 (48.6)	744 (52.2)	2536 (47.7)	
Female	3466 (51.4)	680 (47.8)	2786 (52.3)	
Race/ethnicity				**< 0.001**
Non-Hispanic white	3257 (48.3)	742 (52.1)	2515 (47.3)	
Non-Hispanic black	1658 (24.6)	361 (25.4)	1297 (24.4)	
Mexican-American	1566 (23.2)	288 (20.2)	1278 (24.0)	
Other	265 (3.9)	33 (2.3)	232 (4.4)	
Education level				**< 0.001**
< 12 years	2908 (43.1)	758 (53.2)	2150 (40.4)	
≥ 12 years	3838 (56.9)	666 (46.8)	3172 (59.6)	
Poverty index				**0.012**
Poor (< 1)	1266 (18.8)	300 (21.1)	966 (18.2)	
Not poor (≥ 1)	5480 (81.2)	1124 (78.9)	4356 (81.8)	
Smoking status				**0.002**
Non-smoker	2883 (42.7)	568 (39.9)	2315 (43.5)	
Former smoker	2219 (32.9)	523 (36.7)	1696 (31.9)	
Current smoker	1644 (24.4)	333 (23.4)	1311 (24.6)	
DM	1215 (18.0)	384 (27.0)	831 (15.6)	**< 0.001**
CVD history	723 (10.7)	336 (23.6)	387 (7.3)	**< 0.001**
COPD	605 (9.0)	160 (11.2)	445 (8.4)	**< 0.001**
HTN	4245 (62.9)	1105 (77.6)	3140 (59.0)	**< 0.001**
eGFR, mL/min/1.73 m^2				**< 0.001**
< 60	2605 (38.6)	712 (50.0)	1893 (35.6)	
≥ 60	4141 (61.4)	712 (50.0)	3429 (64.4)	
SBP, mm Hg	130.1 ± 20.8	138.5 ± 22.2	127.8 ± 19.9	**< 0.001**
DBP, mm Hg	74.9 ± 11.4	74.9 ± 12.2	74.9 ± 11.2	0.926
Total cholesterol, mg/dL	217.9 ± 43.4	223.7 ± 43.9	216.3 ± 43.2	**< 0.001**
LDL-C, mg/dL	135.1 ± 39.7	140.3 ± 40.8	133.8 ± 39.3	**< 0.001**
HDL-C, mg/dL	50.7 ± 16.4	50.0 ± 16.6	50.9 ± 16.3	**0.046**
HbA1c, %	5.8 ± 1.3	6.1 ± 1.6	5.7 ± 1.2	**< 0.001**
Fasting plasma glucose, mg/dL	108.3 ± 44.0	117.1 ± 55.1	106.0 ± 40.2	**< 0.001**

ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; DBP, diastolic blood pressure; DM, diabetes mellitus; eGFR, estimated glomerular filtration rate; FRS, Framingham risk score; HbA1c, glycated hemoglobin; HDL-C, high-density lipoprotein cholesterol; HTN, hypertension; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure

Continuous variables are presented as mean ± standard deviation; categorical variables are presented as count (%)

P-value < 0.05 are shown in bold

Table 2 Correlation between the 5 anthropometric parameters and FRS (*N* = 6,746)

	Pearson Correlation Coefficients					
	FRS	**BMI**	**WC**	**Waist-to-BMI ratio**	**BRI**	**ABSI**
FRS	1	0.02	0.25	0.29	0.07	0.34
BMI		1	0.86	-0.71	0.89	-0.11
WC			1	-0.28	0.90	0.35
Waist- to-BMI ratio				1	-0.44	0.70
BRI					1	0.29
ABSI						1

ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; FRS, Framingham risk score; WC, waist circumference

All $p < 0.001$, except the correlation between FRS and BMI ($p = 0.182$)

Table 3 Cox regression analysis of the associations between the anthropometric parameters, FRS, and CVD mortality (*N* = 6,746)

	Univariate		**Multivariable**	
	HR (95% CI)	***p*-value**	**aHR (95% CI)** [a]	***p*-value**
FRS	1.83 (1.75–1.92)	**< 0.001**	-	
Anthropometric parameters				
BMI	1.03 (0.98–1.09)	0.195	1.11 (1.06–1.18)	**< 0.001**
WC	1.24 (1.18–1.30)	**< 0.001**	1.19 (1.13–1.26)	**< 0.001**
Waist-to-BMI ratio	1.31 (1.24–1.38)	**< 0.001**	1.07 (1.01–1.13)	**0.019**
BRI	1.22 (1.17–1.28)	**< 0.001**	1.12 (1.06–1.18)	**< 0.001**
ABSI	1.58 (1.51–1.66)	**< 0.001**	1.13 (1.07–1.19)	**< 0.001**

ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; CI, confidence interval; CVD, cardiovascular disease; FRS, Framingham risk score; HR, hazard ratio; aHR, adjusted HR; WC, waist circumference

[a] Adjusted for age

FRS and the anthropometric parameters were standardized into z-scores. *P*-value < 0.05 results are shown in bold

especially prominent in high-risk populations [19]. Other study has reported the same overestimation in a Japanese population [21]. Interestingly, another systematic review found "there is an over-abundance of CVD risk prediction models", and few have been externally validated [18]. Another recent review (2022) also found that while there are a large number of CVD risk models, few have been externally validated [20]. Thus, a simple model that uses readily available anthropometric measures and has a high predictive ability would be very useful clinically [22, 23].

Our results showed that ABSI has the highest predictive value for CVD and mortality from CVD among all anthropometric measures. A previous study of ABSI for the prediction of CVD risk in individuals with obesity found that ABSI was correlated with FRS, pooled cohort equations risk calculator (PRCAE) score, and systematic coronary risk evaluation (SCORE) score [24]. Another study of children and adolescents with obesity by Mameli et al. reported similar results—that ABSI was correlated with CVD risk markers [25]. A recent NHANES study of adults with diabetes that used data from 2003 to 2014 found that ABSI exhibited a linear and positive relation with total and CVD mortality risk, and that the relation was especially prominent in men and persons younger than 60 years [26]. The results of a study performed in Korea found similar results to the aforementioned studies; the z-score of the log-transformed ABSI was strongly correlated with CVD risk, and the correlation was stronger than that of BMI or WC alone [27]. Similarly, a study in the US using NHANES 1999 to 2014 data showed that the z-score of the log-transformed ABSI was strongly associated with all-cause and CVD mortality [28]. However, ABSI can be difficult to calculate making it difficult to use in general clinical practice [10, 25].

Compared to BMI, the waist-to-BMI ratio appeared to be a more sensitive and specific predictor of CVD mortality. This is evident in the AUC values of 0.53 for BMI and 0.61 for waist-to-BMI ratio, which indicate that the waist-to-BMI ratio is better able to discriminate between patients who are at risk of CVD mortality and those who are not. The stronger predictive ability of waist-to-BMI ratio may be attributed to its ability to capture central adiposity, which is metabolically more active and strongly associated with cardiovascular risk factors such as insulin resistance, systemic inflammation, and dyslipidemia [29, 30]. In contrast, BMI does not distinguish between fat and lean mass, potentially limiting its predictive value in individuals with different body compositions [31, 32].

The waist-to-BMI ratio is a simple and practical measure to calculate in clinical practice. This is unlike other measures, such as ABSI, which require more complex calculations. Our results are consistent with those of prior studies. A study using NHANES data from 1999 to 2014 reported that waist-to-BMI ratio was independently associated with overall and CVD mortality, and was a better discriminator of mortality (AUC = 0.637)

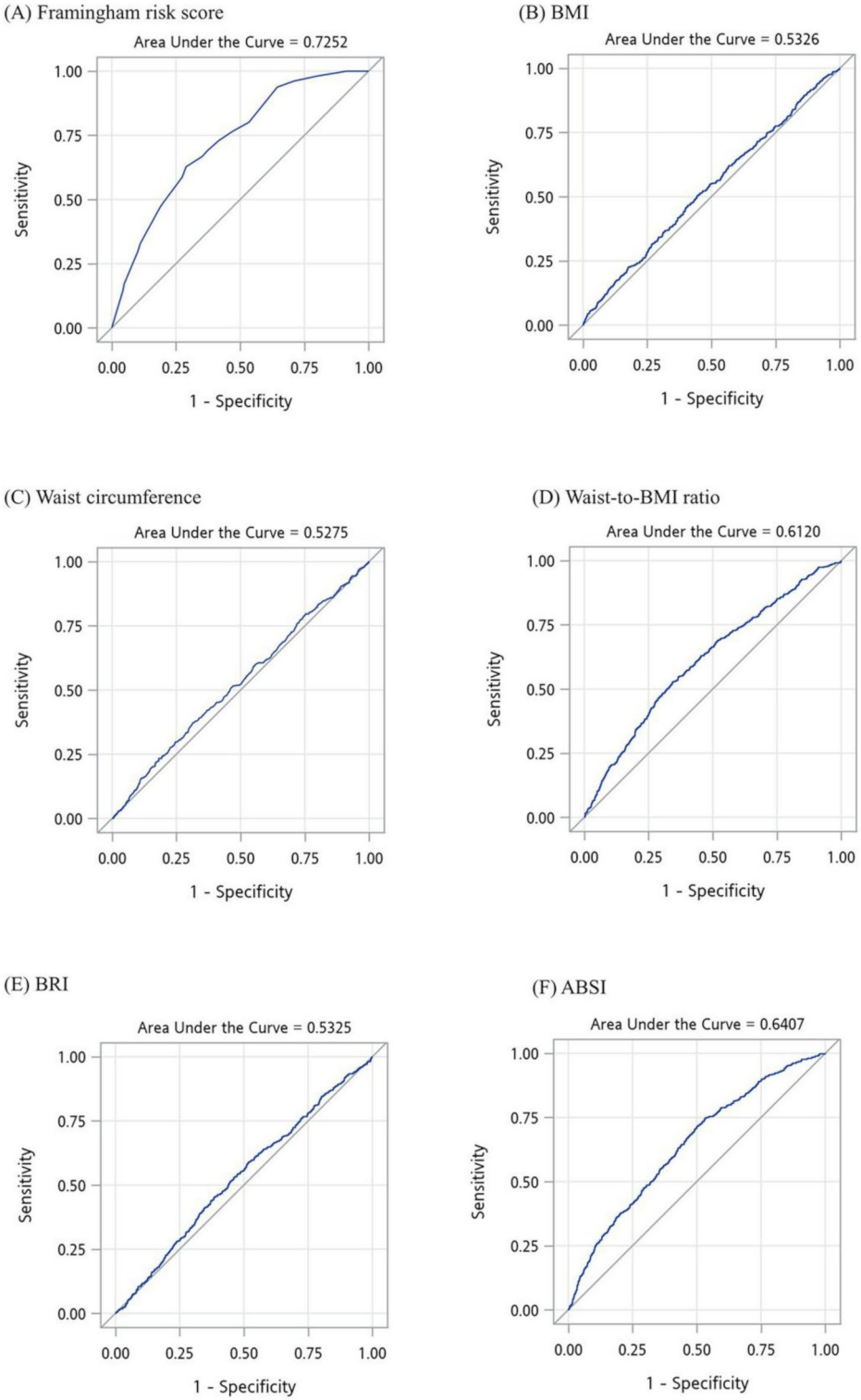

Fig. 2 ROC curves for 10-year CVD mortality of (**A**) FRS, (**B**) BMI, (**C**) WC, (**D**) Waist-to-BMI ratio, (**E**) BRI, and (**F**) ABSI
ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; CVD, cardiovascular disease; ROC, receiver operating characteristic; WC, waist circumference

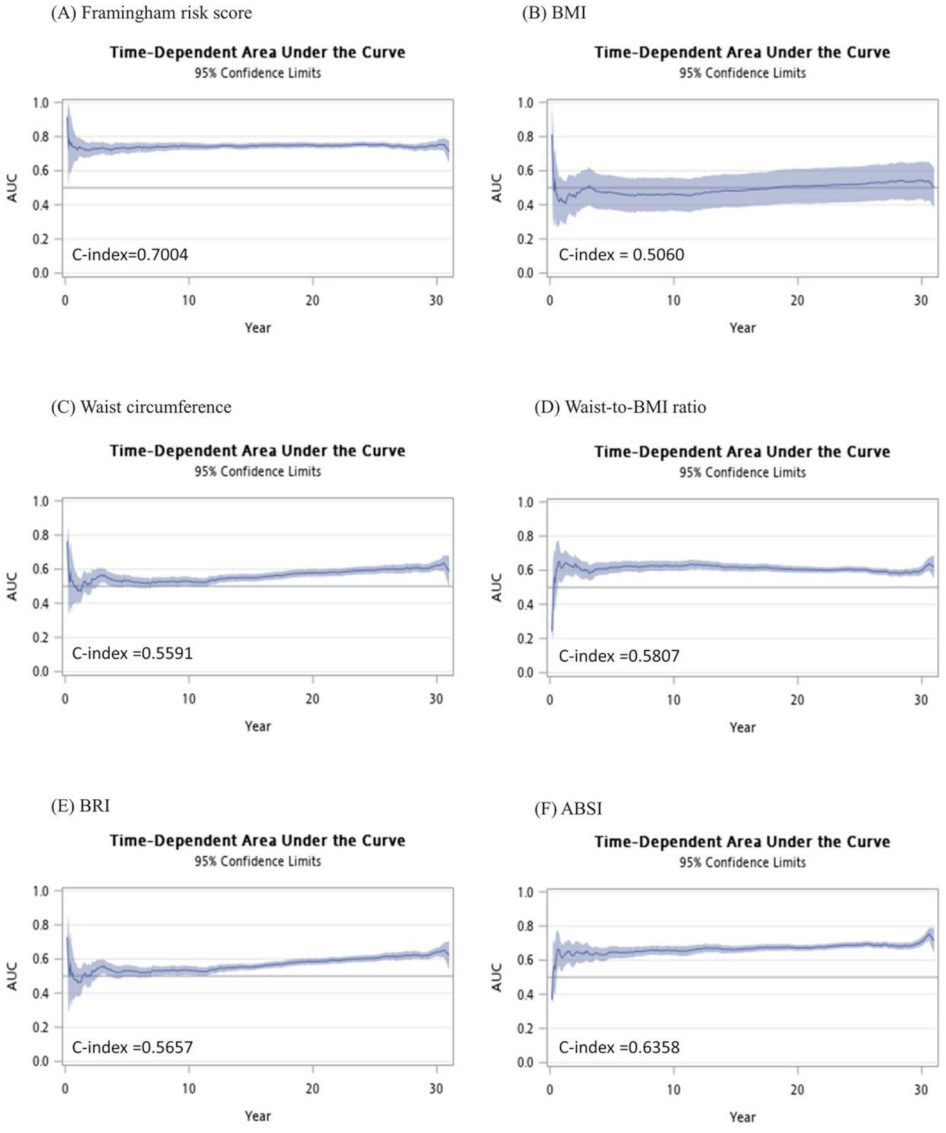

Fig. 3 Time-dependent AUCs for cause-specific survival of (**A**) FRS, (**B**) BMI, (**C**) WC, (**D**) Waist-to-BMI ratio, (**E**) BRI, and (**F**) ABSI
ABSI, a body shape index; AUC, area under the ROC curve; BMI, body mass index; BRI, body roundness index; CVD, cardiovascular disease; FRS, Framingham risk score; ROC, receiver operating characteristic; WC, waist circumference

than BMI, WC, or waist-to-height ratio [12]. Another study of patients with known atherosclerotic CVD also reported that waist-to-BMI ratio was a predictor of major adverse cardiovascular events (cardiovascular death, nonfatal myocardial infarction, stroke, and cardiac arrest) [33]. Although the waist-to-BMI ratio was not specifically addressed, a Consensus Statement from the IAS and ICCR Working Group on Visceral Obesity recommended that WC be included as a "vital sign" in clinical practice and be used in addition to BMI for CVD risk stratification [21]. Given the growing recognition of central adiposity as a key driver of cardiovascular risk, incorporating waist-to-BMI ratio into routine clinical assessment may improve risk stratification, particularly in resource-limited settings where laboratory-based evaluations are not readily available. Based on the evidence, we recommend that the waist-to-BMI ratio be used in addition to BMI to assess CVD risk in clinical practice. Nonetheless, the optimal cutoff values for waist-to-BMI ratio remain to be determined, and future studies should validate its predictive performance across different populations.

Dose-response analysis showed that FRS, BRI, and ABSI had a strong, non-linear association with CVD mortality, with a sharp increase in risk at higher levels of exposure. Waist-to-BMI ratio also had a borderline non-linear association with CVD mortality, suggesting that even modest reductions may be beneficial. The sigmoidal

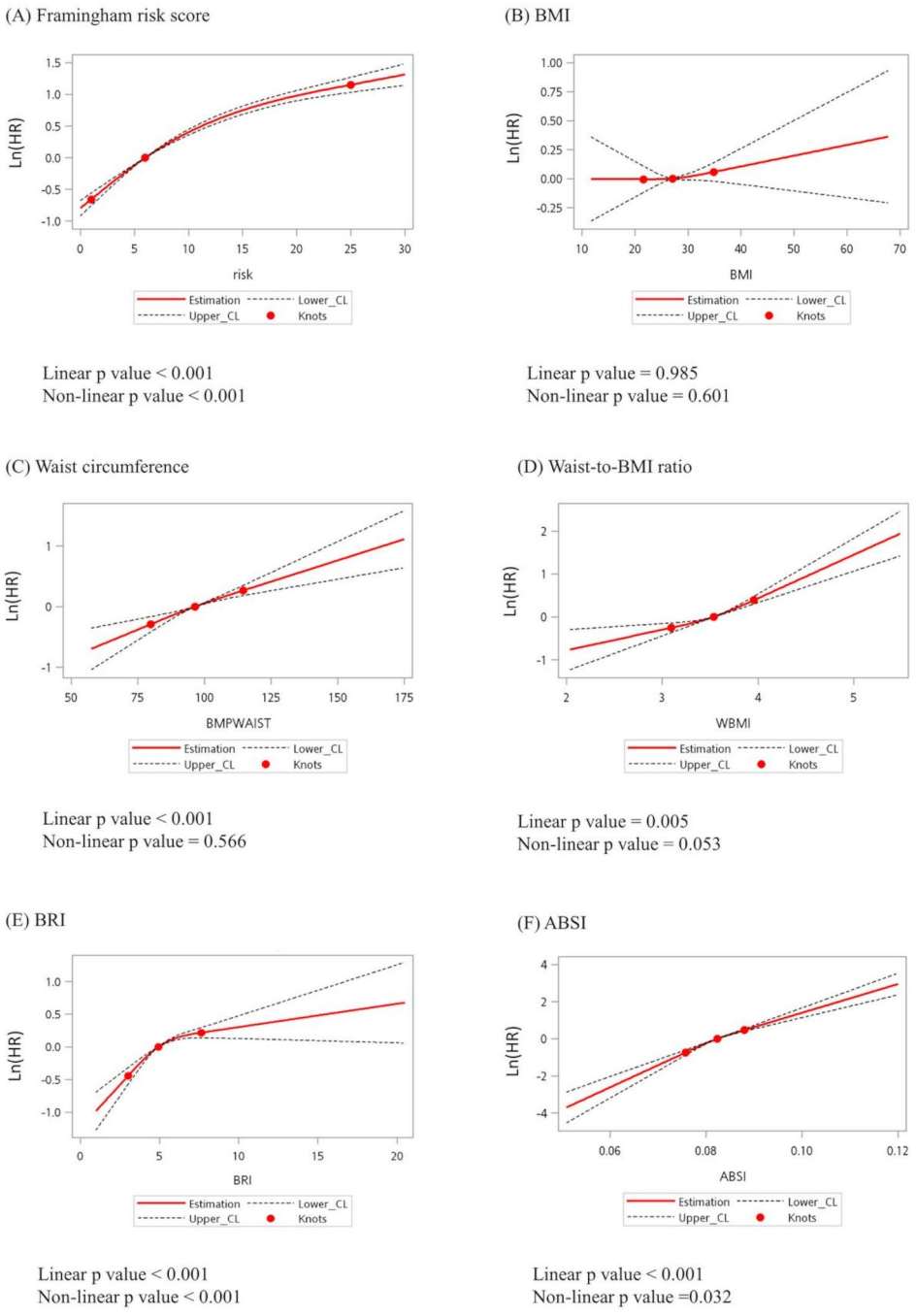

Fig. 4 Dose response curves of (**A**) FRS, (**B**) BMI, (**C**) WC, (**D**) Waist-to-BMI ratio, (**E**) BRI, and (**F**) ABSI on the risk of CVD mortality
ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; CVD, cardiovascular disease; FRS, Framingham risk score; WC, waist circumference

shape of the curves indicates a threshold at which the risk of CVD mortality increases rapidly. This is important because it suggests that there are levels of exposure to these anthropometric parameters that are associated with a relatively low risk of CVD mortality, but above which the risk increases sharply.

Strengths

This study used NHANES III data and thus provides a large sample that is representative of the US population. For the most part, the data can be considered highly accurate, and the study period provides the opportunity to determine the variables examined for predicting long-term CVD mortality. Also, this was the first study to

compare the predictive value of FRS and 5 different body composition measures for predicting CVD mortality.

Limitations

Residual confounding from unmeasured or inadequately measured variables—such as detailed dietary intake patterns, physical activity levels, psychosocial stress, or medication use—could influence both anthropometric indices and cardiovascular outcomes, thereby biasing the associations. Second, the analysis focused on individuals with complete data, excluding those with missing key variables, which may introduce selection bias. Specifically, an amount of participants were excluded due to missing values on covariates or anthropometric measurements such as BMI or waist circumference. These excluded participants may differ systematically from those included in the analysis in terms of sociodemographic or health characteristics, which might result in biased estimates. Self-reported lifestyle factors such as smoking and dietary habits may be subject to recall bias. Third, NHANES III was chosen for its extended follow-up duration and comprehensive variables, however, it was collected between 1988 and 1994. Thus, lifestyle and environmental changes over time may limit its applicability to present-day populations. Additionally, the findings may not be generalizable to other populations or settings. The NHANES III cohort included only non-institutionalized U.S. adults, limiting applicability to institutionalized groups such as hospitalized or nursing home patients. Moreover, differences in demographics, healthcare systems, and lifestyle factors may reduce the generalizability to non-U.S. populations. Validation in diverse global and clinical settings is warranted. Fourth, the study did not account for gender-specific differences in anthropometric indices, which may affect predictive accuracy. Another limitation of this study is the minor differences in HR relative to their 95% CI. This raises concerns about over-interpreting these differences, especially in the absence of independent replication. Therefore, while our findings contribute to the existing body of knowledge, they should be approached with caution until further validated by additional studies.

Conclusions

Utilizing NHANES III data, among the anthropometric measures studied, our findings indicate that ABSI may be the most effective anthropometric measure for predicting CVD mortality within the general population of the US, with the waist-to-BMI ratio as a close second. Due to its simplicity in calculation, the waist-to-BMI ratio can be a practical indicator used for assessing the risk of CVD mortality, particularly when the other demographic and clinical factors are not available. Its integration into public health screening efforts could improve early risk detection, particularly in resource-limited or community-based settings.

Abbreviations

ABSI	A Body Shape Index
BRI	Body roundness index
WC	Waist circumference
BMI	Body mass index
FRS	Framingham risk score
ROC	Receiver operating characteristic
NHANES III	Third National Health and Nutrition Examination Survey

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Author contributions

Thung-Lip Lee: Conception and design; Drafting of the manuscript; Final approval of the manuscript; literature research. Fang-Ju Lin: Analysis and interpretation of data; Critical revision of the manuscript; Final approval of the manuscript; statistical analysisChih-Fan Yeh: Acquisition of data; Critical revision of the manuscript; Final approval of the manuscript. Yu-Chung Hsiao: Acquisition of data; Critical revision of the manuscript; Final approval of the manuscript. Kai-Chien Yang: Analysis and interpretation of data; Critical revision of the manuscript; Final approval of the manuscript. Chin-Feng Hsuan: Analysis and interpretation of data; Critical revision of the manuscript; Final approval of the manuscript; guarantor of integrity of the entire study; literature research; Supervision. Chau-Chung Wu: Analysis and interpretation of data; Critical revision of the manuscript; Final approval of the manuscript.

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Data availability

The data presented in this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate

The NHANES III survey was approved by the NCHS Institutional Review Board and in compliance with the Helsinki Declaration, and informed consent was obtained from all participants before the data collection. Details about the NHANES III design, questionnaires, and data collection can be found at http://www.cdc.gov/nchs/nhanes/nhanes3.htm. Mortality data of NHANES survey participants were obtained from the death certificate records from the National Death Index (NDI).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Division of Cardiology, Department of Internal Medicine, E-Da Hospital, I-Shou University, Kaohsiung 824005, Taiwan
[2]School of medicine for International Students, College of Medicine, I-Shou University, Kaohsiung 824005, Taiwan
[3]Graduate Institute of Clinical Pharmacy & School of Pharmacy, College of Medicine, National Taiwan University, Taipei 100233, Taiwan
[4]Department of Pharmacy, National Taiwan University Hospital, Taipei 100225, Taiwan
[5]Division of Cardiology and Cardiovascular Center, Department of Internal Medicine, National Taiwan University Hospital, Taipei 100225, Taiwan
[6]Department and Graduate Institute of Pharmacology, National Taiwan University College of Medicine, Taipei 100233, Taiwan
[7]Division of Cardiology, Department of Internal Medicine, E-Da Dachang Hospital, I-Shou University, Kaohsiung 807066, Taiwan

[8]School of Medicine, College of Medicine, I-Shou University, Kaohsiung 824005, Taiwan
[9]Graduate Institute of Medical Education & Bioethics, College of Medicine, National Taiwan University, Taipei 100233, Taiwan
[10]Division of Cardiology, Department of Internal Medicine, E-Da Dachang Hospital, No. 305, Dachang 1st Road, Sanmin District, Kaohsiung City 807066, Taiwan

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