Am J Transl Res 2023;15(3):2207-2219
www.ajtr.org /ISSN:1943-8141/AJTR0147515

Original Article

Development and validation of a model to predict the risk of hypertension using anthropometric indicators in the Chinese population: a retrospective cohort study

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Received November 3, 2022; Accepted February 15, 2023; Epub March 15, 2023; Published March 30, 2023

Abstract: Background: The prevalence of hypertension and obesity in China has sharply increased in recent decades. We aimed to develop and validate a novel model for predicting the risk of hypertension based on anthropometric indicators relating to obesity in the general population of China. Methods: In this retrospective study, 6196 participants from the China Health and Nutrition Survey (CHNS) during the 2009-2015 waves were included. Risk factors for hypertension were assessed by LASSO regression combined with multivariate logistic regression analysis. A nomogram was developed as a predictive model based on the screening prediction factors. The discrimination and calibration of the model were evaluated by receiver operating curve (ROC) and calibration plots, respectively. Decision curve analysis (DCA) was used to evaluate the clinical application value of the model. Results: A total of 6196 participants were divided into two sets at a ratio of 7:3, using computer-generated random numbers: 4337 individuals were assigned to the training set and 1859 to the validation set. The training set was divided into a hypertension group (n = 1016) and a non-hypertension group (n = 3321) based on the follow-up outcomes for hypertension. Predictive factors of hypertension included age, drinking, body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR) and arm-to-height ratio (AHtR) at baseline as predictors. The area under the ROC curve (AUC) for the training and validation sets was 0.906 (95% CI: 0.897-0.915) and 0.905 (95% CI: 0.887-0.922), respectively. In bootstrap validation, the C-index was 0.905 (95% CI: 0.888-0.921). The model also had good predictive accuracy according to the calibration plot. DCA demonstrated that people would benefit more when the threshold probability was between 5% and 80%. Conclusion: A nomogram model was successfully established to effectively predict the risk of hypertension based on anthropometric indicators. The model could be a feasible tool for hypertension screening in the general population of China.

Keywords: Anthropometric indicator, hypertension, waist-hip ratio (WHR), waist-height ratio (WHtR), arm-to-height ratio (AHtR)

Introduction

Hypertension (HTN) is a major risk factor for cardiovascular disease (CVD), premature death and all-cause mortality worldwide [1, 2]; moreover, it is a risk factor for stroke, chronic kidney disease and dementia [3, 4]. Currently, one-third of the population suffers from HTN worldwide, while the number of hypertensive patients is estimated to be more than approximately 245 millions in China [5]. However, the rates of awareness, treatment and control of HTN are still very low [6, 7]. HTN has now led to a significant economic burden and has become a major public health problem [8].

Essential HTN comprised ~95% of all HTN cases, which is closely related to obesity, sedentary lifestyle and excessive diet-salt intake. Body mass index (BMI), the most common indicator of obesity, has been associated with arterial blood pressure elevation and HTN. In addition, waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR), indicators related to fat distribution and central adiposity, were also well-studied in hyperten-

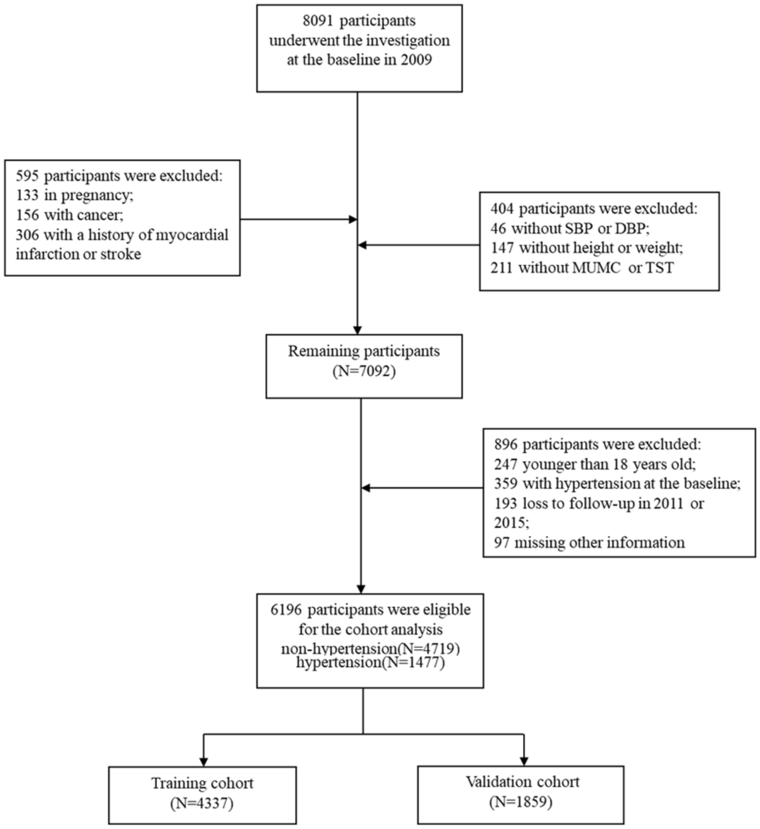

Figure 1. Flowchart of the study population.

sion prediction [9, 10]. Recently, other novel anthropometric indicators of obesity have been evaluated in HTN, such as mid-upper-arm circumference (MUAC) and arm-to-height ratio (AHtR) [11, 12]. It has been reported that MUMC and AHtR are strongly correlated with BMI, WC and WHtR [13]. Recently, Liu et al. demonstrated that mid-upper arm muscle circumference (MAMC) could accurately estimate lean body mass and is associated with the elevation of blood pressure [14]. Since these anthropometric indicators are easily accessible in routine health examinations, utilizing these indicators for HTN risk prediction seems to be a feasible and economic method in the general population of China.

Although BMI, WHtR, WHR, MUMC and triceps skinfold thickness (TST) have been reported in HTN prediction [14-16], these results mostly came from small-sample or cross-sectional studies, and no comprehensive model has integrated these indicators. Here, we used the CHNS data to establish and validate a novel model for predicting HTN based on anthropometric indicators in the general population of China.

Methods

Study design and population

The CHNS, an open longitudinal cohort, aims to research the effects of socioeconomic transformation on nutrition, behaviors and health outcomes among Chinese general residents [14]. The survey started in 1989 and 10 rounds of follow-up were completed in 2015 [17]. The respondents came from 15 provinces or autonomous regions of China [18]. Since the 2009 wave, the biochemical results were first collected. Here, data from three consecutive waves (2009, 2011 and 2015) were selected. Participants without self-reported HTN at baseline in 2009 were included, and outcomes during follow-up in 2011 or 2015 were extracted according to their assigned ID. The study met the standards for the ethics of participants, and it was approved by the institutional review boards of the University of North Carolina at Chapel Hill; the China-Japan Friendship Hospital, Ministry of Health of the People's Republic of China; and the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention. The inclusion criteria were as follows: (1) age ≥18 years old; (2) never been diagnosed with HTN before in 2009 wave; (3) not currently taking any antihypertensive medications; and (4) follow-up data were available during the 2011 or 2015 survey. The exclusion criteria were as follows: (1) acute or chronic abnormal liver function, moderate or severe renal function injury, and acute cerebrovascular disease; (2) severe arrhythmia, myocardial infarction, heart failure, and malignant tumor; and (3) pregnancy status or data deficiencies. The screening process of the study population is shown in **Figure 1**. In this retrospective study, 6,196 participants were eventually enrolled in the study, of whom 1477 developed HTN during the follow-up. All participants were divided into two sets at a ratio of 7:3, using computer-generated random numbers: 4337 participants were assigned to the training set and 1859 to the validation set. The prevalence rates of HTN in the two cohorts were 23.4% and 24.8%, respectively. The training cohort was divided into an HTN group (n = 1016) and a non-HTN group (n = 3321) based on the follow-up outcomes of HTN.

Measurement and definition of anthropometric indicators

Height, weight, WC, hip circumference (HC), MUMC and TST were measured by trained health care staff at each survey follow-up according to standardized protocols [19]. Height was measured by a portable stadiometer to the nearest 0.1 cm. Weight was measured by a calibrated beam scale to the nearest 0.1 kg with no shoes and only lightweight clothing. WC was measured by a nonelastic tape to the nearest 0.1 cm at a point midway between the lowest rib and the iliac crest in a horizontal plane. HC was measured to the nearest 0.1 cm around the widest part of the buttocks. MUAC was measured by a metric scale at the midpoint of the mid-upper arm with the elbow fully extended, and was recorded to the nearest 0.1 cm. TST was measured between the tip of the olecranon process of the ulna and the acromion process of the scapula, and the results were recorded to the nearest 0.5 mm. The averages of three times above all indictors were used for subsequent analysis. BMI, WHtR, WHR, AHtR and MAMC were calculated according to the relevant formulas: BMI (kg/m^2) = weight (kg)/ height ^ 2 (m^2), WHtR = WC (cm)/height (cm), WHR = WC (cm)/HC (cm), AHtR = MUMC (cm)/ height (cm), MAMC (cm) = MUAC (cm) - π *TST (mm)/10. Smoking and drinking status were recorded for each subject using a questionnaire. Based on the ROC curve, WHtR and WHR were divided into two groups by cutoff points: WHtR = 0.525 with AUC = 0.671, and WHR = 0.875 with AUC = 0.633. According to WHO recommendations for Asian populations, BMI was divided into four categories: underweight (BMI <18.5 kg/m^2), normal weight (18.5 to 24.9 kg/m^2), overweight (25 to 29.9 kg/m^2) and obese (≥30 kg/m^2). Furthermore, abdominal obesity was defined as WC ≥90.0 cm for males and ≥85.0 cm for females.

Selection of variables

Based on published papers, predictive variables correlated with HTN were included: age, smoking, drinking, education background, BMI, WHtR, WHR, AHtR, abdominal obesity, TST and MAMC. In addition, those risk factors for HTN were assessed by least absolute shrinkage and selection operator (LASSO) coupled with logistic regression analysis.

Measurement and definition of outcome

Blood pressure was measured using standard mercury sphygmomanometers after a 15-minute rest in the seated position with no alcohol, tea or coffee [16]. The average of three measurements was used for further analysis. HTN was diagnosed when a subject's systolic blood pressure (SBP) was ≥140 mmHg and/or diastolic blood pressure (DBP) was ≥90 mmHg or when taking antihypertensive medications [8].

Model development

The nomogram was built based on regression coefficients using multivariate logistic regression analysis. The model is derived using the formula:

$$\text{Probability (HTN)} = \frac{e^{(\beta 0 + \beta 1x1 + \beta 2x2 + \cdots)}}{1 + e^{(\beta 0 + \beta 1x1 + \beta 2x2 + \cdots)}}$$

Where β are the regression coefficients and x are the reported values of the predictors.

Model performance

Receiver operating characteristic (ROC) curve analysis was utilized to illustrate the diagnostic performance of the nomogram model constructed. Delong validation was used to compare the areas under the curve (AUCs) in the training set and validation set and determine whether they differed significantly. We also constructed a nomogram for the effective prediction model to provide a more direct way for the clinician to assess the possibility of HTN. Calibration curves were adopted to analyze the diagnostic performance of the nomogram in both the training and the validation cohorts. Decision curve analysis (DCA) was conducted to determine the clinical usefulness of the nomogram by quantifying the net benefits at different threshold probabilities in the entire cohort.

Statistical analysis

Continuous variables are described by the mean ± standard deviation, and a t test was performed to compare the differences between the non-hypertension and hypertension groups. Categorical variables are described by proportions, and the Pearson chi-square test was used to compare the differences between groups. The independent predictors of HTN were screened by LASSO regression, multivariate stepwise regression and Akaike information criterion (AIC), and then the estimated odds ratio (OR) and 95% confidence interval (CI) were obtained. The choice of variables in the regression model was driven by those factors with a *P* value <0.10 in the logistic regression analysis, with the goal of the greatest explanatory power while minimizing overfitting. The rms package was used to construct a nomogram of the prediction model. Bootstrap resampling was performed 100 times for internal validation. ROC curve was plotted to analyze the predictive ability of the nomogram model for the risk of HTN. The area under the ROC curve (AUC) or concordance index (C-index) was used to evaluate the discrimination degree of the model. When the AUC or C index was <0.7, the discrimination was considered to be poor, 0.7-0.9 was good, and >0.9 was high. Difference in the AUCs between the development and validation cohorts was compared using the Delong test. A calibration curve was plotted to prove the accuracy of the model (the closer the curve is to the diagonal line, the higher the accuracy of the model). DCA was performed to evaluate the clinical practicability of the model. Improvements in the predictive accuracy of our new model were estimated by calculating the relative integrated discrimination improvement (IDI) and the net reclassification improvement (NRI). *P*<0.05 was considered statistically significant. All data were analyzed using SPSS version 18.0 and R (http://www.r-project.org/) version 4.1.3.

Results

Baseline characteristics of the study population

A total of 6196 participants were enrolled in this study and 4337 subjects were divided into the training cohort and 1859 subjects were divided into the validation cohort. There were 1016 and 461 HTN subjects in the training and validation cohorts, respectively. There were no significant differences in BMI, WC, WHtR, WHR, AHtR, MUMC, MAMC and the proportion of general obesity and abdominal obesity (all *P*>0.05). Moreover, there was no difference in the prevalence of hypertension between the two groups (P = 0.245) (**Table 1**).

As shown in **Table 2**, the prevalence of drinking and diabetes in the HTN group was higher than that in the non-HTN group in the training cohort (31.2% vs. 23.3%, *P*<0.001; 3.5% vs. 1.4%, *P*<0.001). The levels of SBP, DBP, BMI, WC, MUMC, TST, WHR, WHtR, AHtR and MAMC in HTN group were higher than those in non-HTN group (123.89 ± 11.33 mmHg vs. 116.25 ± 11.37 mmHg, *P*<0.001; 81.41 mmHg ± 8.13 vs. 76.27 ± 8.09 mmHg, *P*<0.001; 24.35 ± 3.55 kg/m^2 vs. 22.77 ± 3.18 kg/m^2, *P*<0.001; 86.42 ± 9.95 cm vs. 80.68 ± 9.62 cm, *P*<0.001; 27.87 ± 5.06 cm vs. 26.92 ± 4.63 cm, *P*<0.001; 16.70 ± 7.67 mm vs. 16.22 ± 7.64 mm, *P* = 0.033; 0.90 ± 0.07 vs. 0.87 ± 0.08, *P*<0.001; 0.54 ± 0.06 vs. 0.50 ± 0.06, *P*<0.001; 0.17 ± 0.03 vs. 0.16 ± 0.02, *P*<0.001; 22.63 ± 4.80 cm vs. 21.83 ± 4.60 cm, *P*<0.001, respectively), and the proportions of overweight, general obesity, abdominal obesity, high WHtR (>0.525) and high WHR (>0.875) group were larger than those in non-HTN group (overweight: 35.3% vs. 20.9%, *P*<0.001; general obesity: 6.4% vs. 2.1%, *P*<0.001; abdominal obesity: 50.4 vs. 29.3%, *P*<0.001; high WHtR: 57.7% vs. 33.3%, *P*<0.001; high WHR: 63.7% vs. 42.3%, *P*< 0.001).

Logistic regression analysis and LASSO regression

The risk predictors for HTN were screened by univariate and multivariate logistic stepwise regression analysis and AIC. Multivariate regression analysis showed that age (40-59: OR = 3.48, 95% CI: 2.22-5.45 and ≥60: OR = 6.89, 95% CI: 4.27-11.12, both *P*<0.001), drinking (OR = 1.34, 95% CI: 1.02-1.76, *P* = 0.033), baseline SBP (OR = 1.04, 95% CI: 1.03-1.04, *P*<0.001), baseline DBP (OR = 1.03, 95% CI: 1.02-1.05, *P*<0.001) and AHtR (OR = 6.86, 95% CI: 4.15-7.09, *P*<0.001) were risk factors of HTN. Moreover, BMI (OR = 1.06, 95% CI: 0.97-1.15), categorical WHR (OR = 1.32, 95% CI: 1.00-1.75) and categorical WHtR (OR = 1.04, 95% CI: 0.72-1.50) were included (*P*<0.10)

Table 1. Baseline characteristics of all subjects

Characteristics	Total (n = 6196)	Training cohort (n = 4337)	validation cohort (n = 1859)	*P* value
Age (years)				0.181
18-40	1548 (25.0)	1103 (25.4)	445 (23.9)	
41-60	3175 (51.2)	2229 (51.4)	946 (50.9)	
>60	1473 (23.8)	1005 (23.2)	468 (25.2)	
Gender, no (%)				0.598
Male	2898 (46.8)	2038 (47.0)	860 (46.3)	
Female	3298 (53.2)	2299 (53.0)	999 (53.7)	
Smoke, no (%)				0.389
No	4275 (69.0)	2978 (68.7)	1297 (69.8)	
Yes	1921 (31.0)	1359 (31.3)	562 (30.2)	
Drink, no (%)				0.087
No	4632 (74.8)	3238 (74.7)	1394 (75.0)	
Yes	1564 (25.2)	1099 (25.3)	465 (25.0)	
Diabetes, no (%)				0.338
No	6084 (98.2)	4254 (98.1)	1830 (98.4)	
Yes	112 (1.8)	83 (1.9)	29 (1.6)	
Education, no (%)				0.935
low	4762 (76.9)	3332 (76.8)	1430 (76.9)	
high	1434 (23.1)	1005 (23.2)	429 (23.1)	
SBP (mmHg)	121.86 ± 16.45	121.83 ± 16.31	121.92 ± 16.77	0.852
DBP (mmHg)	79.23 ± 10.25	79.20 ± 10.26	79.30 ± 10.23	0.707
Urea (mmol/L)	5.42 ± 1.58	5.41 ± 1.56	5.43 ± 1.59	0.654
Cr (umol/L)	86.17 ± 21.87	86.13 ± 21.86	86.25 ± 21.88	0.836
UA (umol/L)	301.59 ± 107.04	302.20 ± 108.80	300.15 ± 102.81	0.488
TC (mmol/L)	4.83 ± 1.03	4.82 ± 1.01	4.82 ± 1.05	0.969
TG (mmol/L)	1.63 ± 1.47	1.61 ± 1.47	1.66 ± 1.47	0.283
LDL-C (mmol/L)	2.95 ± 0.97	2.95 ± 0.96	2.94 ± 1.00	0.850
HDL-C (mmol/L)	1.44 ± 0.46	1.44 ± 0.44	1.45 ± 0.48	0.595
Lp(a) (mg/L)	153.44 ± 214.90	152.53 ± 217.70	155.55 ± 208.25	0.612
FBG (mmol/L)	5.33 ± 1.46	5.34 ± 1.45	5.29 ± 1.47	0.227
HbA1c (%)	5.53 ± 1.02	5.55 ± 1.06	5.50 ± 0.93	0.096
ALT (U/L)	22.56 ± 18.67	22.69 ± 19.07	22.25 ± 17.68	0.397
Anthropometric indicators				
BMI (kg/m^2)	23.15 ± 3.34	23.12 ± 3.31	23.20 ± 3.41	0.409
WC (cm)	82.05 ± 10.00	82.02 ± 9.94	82.11 ± 10.13	0.725
MUMC (cm)	27.15 ± 4.75	27.16 ± 4.89	27.13 ± 4.38	0.856
TST (mm)	16.33 ± 7.65	16.30 ± 7.64	16.40 ± 7.66	0.620
WHR	0.87 ± 0.08	0.87 ± 0.08	0.87 ± 0.07	0.339
WHtR	0.51 ± 0.06	0.51 ± 0.06	0.51 ± 0.06	0.204
AHtR	0.17 ± 0.03	0.17 ± 0.03	0.17 ± 0.03	0.587
MAMC (cm)	22.02 ± 4.66	22.03 ± 4.80	21.98 ± 4.30	0.660
General obesity, no (%)				0.498
underweight	4085 (65.9)	2882 (66.5)	1203 (64.7)	
normal	409 (6.6)	284 (6.5)	125 (6.7)	
overweight	1505 (24.3)	1040 (24.0)	465 (25.0)	
obesity	197 (3.2)	131 (3.0)	66 (3.6)	

Abdominal obesity, no (%)				0.254
No	4287 (69.2)	2985 (68.8)	1302 (70.0)	
Yes	1909 (30.8)	1352 (31.2)	557 (30.0)	
WHtR group, no (%)				0.420
low	3757 (60.6)	2644 (61.0)	1113 (59.9)	
high	2439 (39.4)	1693 (39.0)	746 (40.1)	
WHR group				0.294
low	3236 (52.2)	2284 (52.7)	952 (51.2)	
high	2960 (47.8)	2053 (47.3)	907 (48.8)	
Outcome, no (%)				0.245
Non-hypertension	4719 (76.2)	3321 (76.6)	1398 (75.2)	
hypertension	1477 (23.8)	1016 (23.4)	461 (24.8)	

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; Cr, creatinine; UA, uric acid; TC, total cholesterol; TGs, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; FBG, fasting blood glucose; ALT, alanine transaminase; BMI, body mass index; WC, waist circumference; MUMC, mid-upper arm circumference; TST, triceps skinfold thickness; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; AHtR, arm-to-height ratio; MAMC, mid-upper arm muscle circumference; 95% CI, 95% confidence interval.

(**Table 3**). Based on published literature, smoking, sex and diabetes were also included as predictive factors. Ultimately, 19 risk factors were included and LASSO regression analysis was performed to identify the predictors by adjusting the penalty coefficient λ. When $0.0027 \leq \lambda \leq 0.0177$, the estimated error range of the model was acceptable (**Figure 2**). Therefore, we finally identified 8 independent risk factors for HTN: age (40-59 and >60), drinking, BMI, baseline SBP, baseline DBP, AHtR, WHtR (≥0.525) and WHR (≥0.875).

Construction nomogram

A nomogram was constructed using the 8 identified predictors (**Figure 3**). Each risk factor was assigned a specific point and total points were acquired from the sum of all factors. Total points corresponded to the probability of HTN. In addition, the total points of the nomogram model ranged from 121 to 210 and the predictive value ranged from 0.1 to 0.9.

Evaluation of the nomogram model

The AUC or C-index was used to evaluate the discrimination, and a calibration plot was generated to evaluate the accuracy of the model. The AUCs of the training and validation cohorts were 0.906 (95% CI: 0.897-0.915) and 0.905 (95% CI: 0.887-0.922), respectively (**Figure 4A** and **4B**). The Delong test manifested that there was no difference in the training set and validation set with a *p* value of 0.882. The C-index of bootstrap resampling was 0.905 (95% CI: 0.888-0.921), which indicated that the model was able to distinguish hypertensive and non-hypertensive patients. Calibration curves were close to the 45° line in the internal and external validation (**Figure 5A** and **5B**), indicating that the model's predicted probability was in line with the actual probability.

In addition, the DCA certified that the application of the model to predict HTN generated a higher net benefit than the "intervention for all patients" or "no intervention for all patients" methods, which suggested that the nomogram could be used in making clinical decisions when the threshold probability of a person developing HTN was 5% to 80% (**Figure 6**).

Comparison of our nomogram and the previous model

To further verify the superiority of our model, we compared our nomogram with the old model [20]. The NRI and IDI values in our new nomogram were 0.103 (95% CI: 0.051-0.172, $P<0.001$) and 0.009 (95% CI: 0.006-0.013, $P = 0.047$). These results indicate that our new model exhibited superior predictive performance compared to the previous model.

Discussion

The prevalence and incidence of HTN are accelerating worldwide. It is well established that obesity substantially increases the risk of HTN,

Table 2. Comparison of characteristics between the non-hypertension and hypertension groups in the training cohort

	Non-hypertension (n = 3321)	Hypertension (n = 1016)	*P* value
Age (years)			<0.001
18-40	1026 (30.9)	77 (7.6)	
41-60	1707 (51.4)	522 (51.4)	
>60	588 (17.7)	417 (41.0)	
Gender, no (%)			0.197
Male	1491 (44.9)	470 (46.3)	
Female	1830 (55.1)	546 (53.7)	
Smoke, no (%)	1012 (30.5)	347 (34.2)	0.524
Drink, no (%)	774 (23.3)	325 (31.2)	<0.001
Diabetes, no (%)	47 (1.4)	36 (3.5)	<0.001
Education, no (%)			0.035
low	2491 (75.0)	840 (82.7)	
high	830 (25.0)	176 (17.3)	
SBP (mmHg)	116.25 ± 11.37	123.89 ± 11.33	<0.001
DBP (mmHg)	76.27 ± 8.09	81.41 ± 8.13	<0.001
BMI (kg/m^2)	22.77 ± 3.18	24.35 ± 3.55	<0.001
WC (cm)	80.68 ± 9.62	86.42 ± 9.95	<0.001
MUMC (cm)	26.92 ± 4.63	27.87 ± 5.06	<0.001
TST (mm)	16.22 ± 7.64	16.70 ± 7.67	0.033
WHR	0.87 ± 0.08	0.90 ± 0.07	<0.001
WHtR	0.50 ± 0.06	0.54 ± 0.06	<0.001
AHtR	0.16 ± 0.02	0.17 ± 0.03	<0.001
MAMC (cm)	21.83 ± 4.60	22.63 ± 4.80	<0.001
General obesity, no (%)			<0.001
underweight	252 (7.6)	36 (3.5)	
normal weight	2304 (69.4)	557 (54.8)	
overweight	694 (20.9)	359 (35.3)	
obesity	71 (2.1)	64 (6.4)	
Abdominal obesity, no (%)	973 (29.3)	512 (50.4)	<0.001
WHtR group, no (%)			<0.001
low	2214 (66.7)	430 (42.3)	
high	1107 (33.3)	586 (57.7)	
WHR group, no (%)			<0.001
low	1015 (57.7)	369 (36.3)	
high	1406 (42.3)	647 (63.7)	

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; WC, waist circumference; MUMC, mid-upper arm circumference; TST, triceps skinfold thickness; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; AHtR, arm-to-height ratio; MAMC, mid-upper arm muscle circumference; 95% CI, 95% confidence interval.

and exerts a great impact on the morbidity and mortality of patients. BMI is extensively utilized to define overweight or general obesity, and WHtR, WHR, and AHtR are used to measure abdominal fat distribution in research and practice. These anthropometric indices are crucial for the early recognition of obesity which may lead to HTN [21, 22]. Currently, a few models for predicting HTN have been established; however, they are not associated with anthropometric indicators in the East Asian population, especially in the Chinese Han population. Here, we established a novel nomogram model to predict HTN based on anthropometric indica-

Table 3. Univariate and multivariate logistic regression analysis

Index	Univariate		Multivariate	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Age (years)				
18-39	reference			
40-59	6.21 (4.03-9.57)	<0.001	3.48 (2.22-5.45)	<0.001
≥60	14.11 (9.11-21.86)	<0.001	6.89 (4.27-11.12)	<0.001
Gender				
male	reference		-	-
female	0.88 (0.74-1.06)	0.183	-	-
Smoke				
no	reference		-	-
yes	1.07 (0.88-1.30)	0.519	-	-
Drink				
no	reference		reference	
yes	1.45 (1.18-1.76)	<0.001	1.34 (1.02-1.76)	0.033
SBP (mmHg)	1.06 (1.05-1.07)	<0.001	1.04 (1.03-1.04)	<0.001
DBP (mmHg)	1.09 (1.08-1.10)	<0.001	1.03 (1.02-1.05)	<0.001
BMI (kg/m^2)	1.16 (1.13-1.19)	<0.001	1.06 (0.97-1.15)	0.086
WC (cm)	1.06 (1.05-1.07)	<0.001	0.99 (0.97-1.02)	0.658
MUMC (cm)	1.04 (1.02-1.05)	<0.001	0.03 (0.01-12.96)	0.602
TST (mm)	1.02 (1.02-1.03)	0.010	2.93 (0.05-16.83)	0.604
AHtR	5.47(4.12-7.27)	<0.001	6.86 (4.15-7.09)	<0.001
MAMC (cm)	1.03 (1.01-1.04)	0.002	3.04 (0.01-1.22)	0.604
Central obesity				
no	reference		reference	
yes	2.54 (2.11-3.06)	<0.001	0.99 (0.68-1.44)	0.960
General obesity				
normal weight	reference		reference	
underweight	0.51 (0.30-0.89)	0.018	0.69 (0.35-1.35)	0.279
overweight	2.38 (1.95-2.90)	<0.001	1.40 (0.96-2.05)	0.083
obesity	3.76 (2.54-5.58)	<0.001	1.21 (0.56-2.63)	0.630
WHtR				
<0.525	reference		reference	
≥0.525	2.85 (2.36-3.44)	<0.001	1.04 (0.72-1.50)	0.066
WHR				
<0.875	reference		reference	
≥0.875	2.44 (2.01-2.96)	<0.001	1.32 (1.00-1.75)	0.051

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; WC, waist circumference; MUMC, mid-upper arm circumference; TST, triceps skinfold thickness; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; AHtR, arm-to-height ratio; MAMC, mid-upper arm muscle circumference.

tors related to obesity among the general population of China.

Based on the large-scale, multicenter cohort study data of the CHNS, we developed a quantifiable and concise nomogram model to predict the risk of HTN. In both the training and validation cohorts, our model performed well, as indicated by a high C-index as well as a good calibration curve with excellent consistency. DCA proved that patients would benefit from this model when applied into practice. Using these inexpensive, simple, fast and noninvasive indices, clinicians could effectively identify individuals with a high risk of HTN during health examinations.

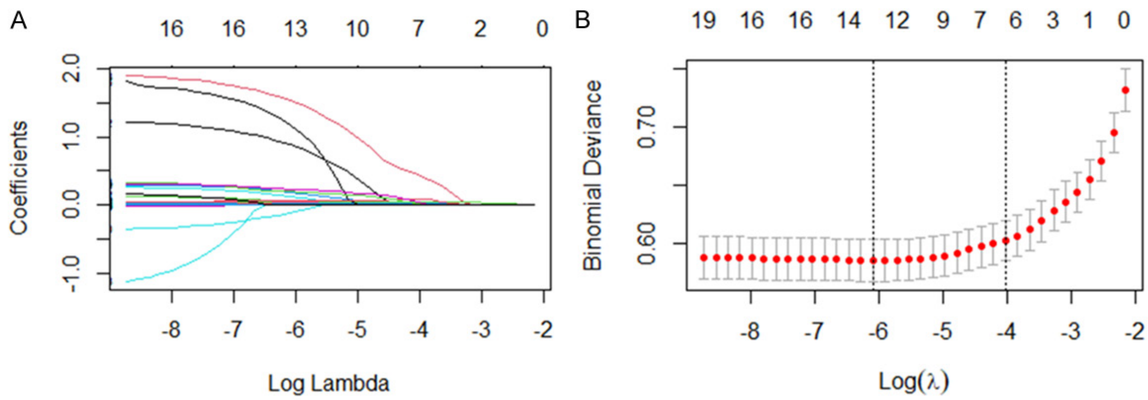

Figure 2. Predictors were selected by the LASSO binary regression model. A: The distribution of 19 risk factors for the LASSO coefficient. A coefficient contour plot was drawn against the log (lambda) sequence. B: The number of factors and optimal parameter (lambda) selection.

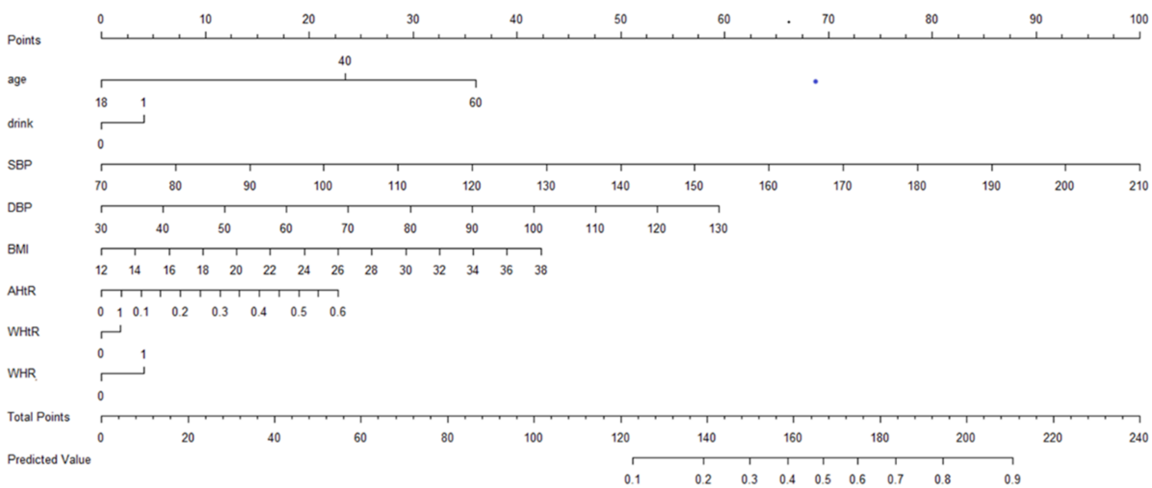

Figure 3. Nomogram for predicting hypertension in the healthy Chinese population. The nomogram included 8 risk factors: age (years), drinking, SBP (mmHg), DBP (mmHg), BMI (kg/m^2), AHtR, WHtR and WHR. SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; AHtR, mid-upper arm circumference-to-height ratio; WHtR, waist-to-height ratio; WHR, waist-to-hip ratio. (A value of "1" was assigned to those who were WHtR ≥0.525 or WHR ≥0.875 and a value of "0" was assigned to those who were WHtR <0.525 or WHR <0.875).

Our prediction models included age, drinking status, baseline SBP, baseline DBP, BMI, WHtR, WHR and AHtR. These variables identified as risk factors for HTN were consistent with previous studies [23-27]. Several HTN risk models have been developed in different populations. Deng et al. constructed a nomogram model of HTN including age, family history, baseline SBP, DBP, BMI and triglycerides in Hebei Province, China [23]. Lim NK et al. established a prediction model including SBP, DBP, family history of HTN, age, smoking and sex in a Korean population [28]. Otsuka T and colleagues demonstrated that age, BMI, SBP, current smoking status, excessive alcohol intake and parental history of HTN were independent predictors of HTN, which were included in a model for screening high-risk group in Japanese male population [29]. Xu et al. designed a nomogram model consisting of sex, age, SBP, DBP, smoking, family history, BMI, salt intake, oil intake, yak-butter intake, and blood lipids, for HTN prediction in Xinjiang Kazakh populations [30]. Consistent with these studies, age, alcohol consumption, baseline SBP, DBP and BMI were also included as predictors in this study. Baseline SBP and DBP were the strongest predictors of HTN in this model, as proven by others. It has been

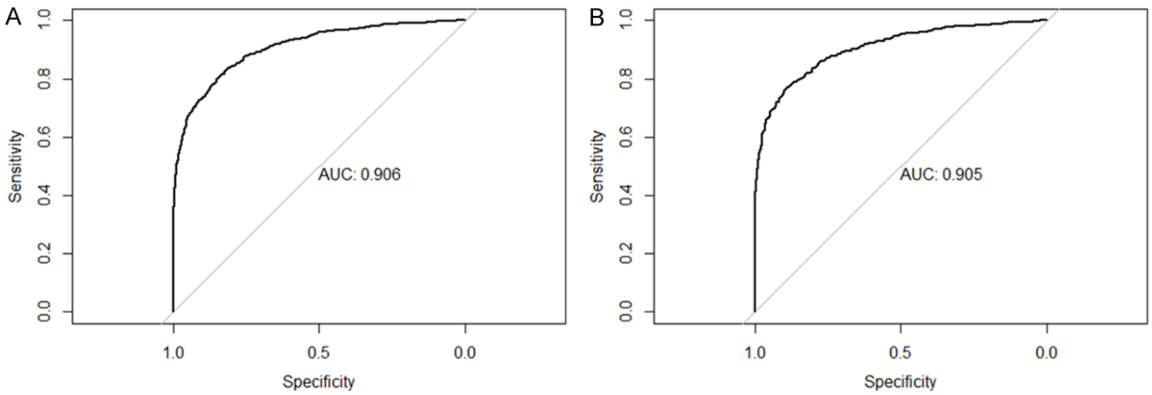

Figure 4. ROC curves of hypertension in the general population nomogram in the training cohort (A) and validation cohort (B). The AUCs for hypertension in the training and validation cohorts both surpassed 0.900, which indicated that the nomogram model had the ability to discriminate who will develop hypertension in general populations. ROC: receiver operating characteristic; AUC: area under the ROC curve.

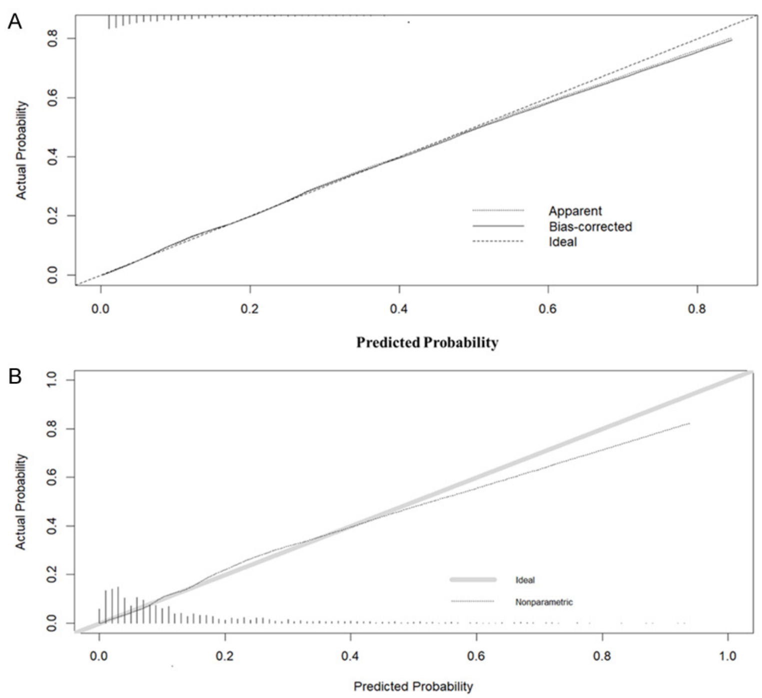

Figure 5. Calibration plots for evaluating the accuracy of the nomogram model in the bootstrap resampling (A) and validation set (B). The closer the distance of two lines, the higher the accuracy of the prediction model.

reported that BMI seemed to be the best indicator of hypertension in men, while WHtR was considered the best indicator of HTN in women [31]. In addition, other anthropometric indicators were also included in our model, such as WHtR, WHR and AHtR. Previous studies have demonstrated that WHtR and WHR are risk factors for HTN, whereas there is no prediction model comprised of these indictors. The link between AHtR and HTN has rarely been reported, however, our study confirmed that it was a risk index of HTN and could be used to effectively screen hypertension patients. Smoking and male sex are well-recognized risk factors for HTN and are frequently included in prediction models [32, 33]. Moreover, a low level of education or low socioeconomic status is often related to a higher risk of HTN compared with a well-educated population [34], even though other research has indicated that high education is associated with the prevalence of prehypertension [35]. However, our study failed to demonstrate the link of smoking or education level with the risk of HTN in either in males or females. These disagreements may be attributed to differences in research designs, study populations or living habits. The AUC and calibration plot revealed that the model had good discrimination and accuracy in both the training and validation sets. Thus, the model could be able to recognize people at high risk of HTN early during health examinations.

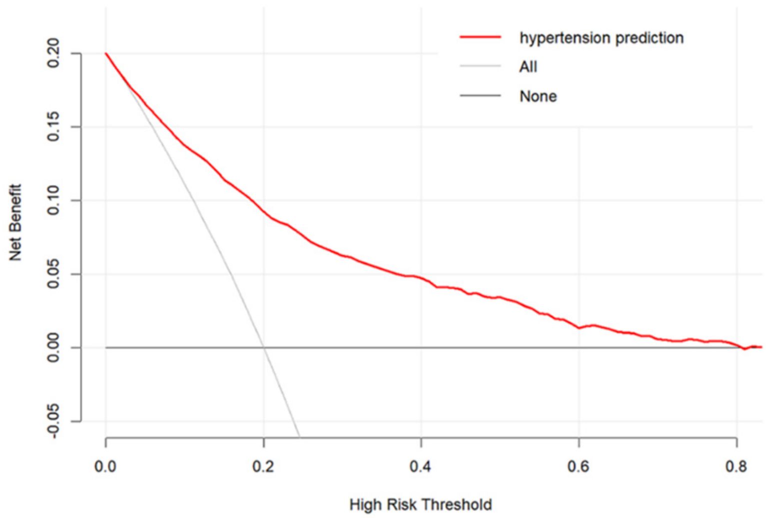

Figure 6. Decision curve analysis for evaluating the clinical practicability of the nomogram model. The black line and gray line represent the net benefit of not treating all patients and treating all patients, respectively. The red line represents a curve of the predictive model. The area under the three lines indicated the clinical practicability of the nomogram model.

Our study has some limitations. First, the nomogram model is based on a retrospective cohort study in which individuals with incomplete data are excluded, which may lead to selection bias. Second, although our analysis includes a wide range of potential predictors, there are still some factors that cannot be included, such as dietary salt intake and physical activities, which leads to the limited predictive power of the model. Finally, HTN is thought to be partly related to heredity, but the study did not investigate family history due to incomplete database information.

Conclusions

This study was the first to establish a nomogram for predicting the incidence of HTN in the general population of China using anthropometric indicators, including age, drinking, baseline SBP, baseline DBP, BMI, WHtR, WHR and AHtR. This predictive model may be a convenient tool for distinguishing high-risk groups of HTN in the general population during health examinations.

Acknowledgements

The data for this study come from the China Health and Nutrition Survey (CHNS). The CHNS is an international project. We truly appreciate contributions from the National Institute for Nutrition and Health (NINH), the Chinese Center for Disease Control and Prevention (CCDC), Beijing Center for Diseases Prevention and Control (BCDC), Chinese National Human Genome Center at Shanghai (CHGC), and the University of North Carolina at Chapel Hill (UNC-CH).

Disclosure of conflict of interest

None.

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