



Article



Prevalence and Determinants of Pre-Hypertension among Adults in Fujian Province, China: A Large-Scale Cross-Sectional Study

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Abstract: Background: Prehypertension is a critical precursor to cardiovascular diseases, posing a significant public health burden. This study investigated its prevalence, determinants, and predictive modeling among adults in Fujian Province, China. Methods: A population-based cross-sectional survey was conducted from August 2020 to April 2021. Using multi-stage stratified random sampling, 9455 adults (≥ 18 years) were recruited. Prehypertension was defined according to JNC 7 guidelines (SBP 120–139 and/or DBP 80–89 mmHg) without antihypertensive medication. Determinants were identified via multivariable logistic regression, and a nomogram was developed and validated. Univariate analysis identified smoking and alcohol consumption as potential correlates, while multivariate analysis was used to determine independent predictors. Results: The weighted prevalence of prehypertension was 37.35%. Independent risk factors included older age, rural residence, central obesity, family history of hypertension, dyslipidemia, tea consumption, and elevated triglyceride-glucose (TyG) index. Notably, smoking was associated with a lower odds ratio in the multivariate model ($OR = 0.737$), a finding likely attributable to residual confounding or reverse causality rather than a true protective effect. The nomogram demonstrated robust predictive performance (AUC: 0.755 in training; 0.746 in validation). Conclusion: Prehypertension is highly prevalent among adults in Fujian Province. The identified



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risk factors and validated nomogram provide a scientific foundation for precise primary prevention and early intervention strategies.

Keywords: pre-hypertension; public health; risk prediction; nomogram; cross-sectional study

1. Introduction

Hypertension is the third leading risk factor for disability globally and a primary precursor to cardiovascular, cerebrovascular, and renal diseases. Approximately 49% of myocardial infarctions and 62% of strokes are attributable to hypertension [1]. Therefore, effective blood pressure management is crucial for mitigating the rising morbidity and mortality associated with cardiovascular and cerebrovascular diseases [2]. According to the Report on Cardiovascular Health and Diseases in China 2022, the prevalence of cardiovascular disease (CVD) and associated mortality in China continues to rise [3]. Hypertension remains widespread, with a prevalence of 27.9% (weighted: 23.2%) among Chinese adults in 2018, exhibiting a consistent upward trend. Concurrently, awareness, treatment, and control rates remain suboptimal at 41.0%, 34.9%, and 11.0%, respectively, underscoring the escalating burden of hypertension on public health in China [3].

Even before reaching the diagnostic threshold for hypertension, blood pressure elevations are associated with increased cardiovascular risk. Individuals with blood pressure above normal but below the hypertension diagnostic threshold face a 45% higher risk of cardiovascular events compared to those with normal blood pressure [4]. In 2003, the Seventh Report of the Joint National Committee (JNC 7) first defined pre-hypertension as a systolic blood pressure (SBP) of 120–139 mmHg and/or diastolic blood pressure (DBP) of 80–89 mmHg [5]. The 2005 Chinese Guidelines for Prevention and Treatment of Hypertension adopted a similar definition. However, the 2017 American College of Cardiology/American Heart Association (ACC/AHA) guidelines reclassified SBP of 130–139 mmHg and DBP of 80–89 mmHg as stage 1 hypertension [6]. In contrast, the 2024 Chinese Guidelines retained the previous definition for pre-hypertension, citing insufficient evidence for the efficacy and safety of drug therapy in this population [7]. Pre-hypertension is a precursor to overt hypertension, with a progression rate of approximately 40% within five years [8–10].

Pre-hypertension is a global health concern, affecting an estimated 25–50% of adults worldwide [8,11,12]. Prevalence varies significantly across regions, with developing countries generally experiencing higher rates compared to developed nations. For instance, studies report prevalences of 36.8% in South Korea [13], 32.9–56.8% in Africa [14], and 28.2% in the United States [15]. In China, the most recent data indicate a crude prevalence of 39.1% and a weighted prevalence of 41.3%, representing approximately 435 million individuals [3].

Emerging evidence links pre-hypertension to various adverse health outcomes, including cardiovascular diseases, metabolic syndrome, cardiac injury, and chronic kidney disease. Pathophysiological mechanisms involve increased carotid intima-media thickness, reduced vascular elasticity, and endothelial dysfunction [16,17], which may lead to myocardial ischemia and infarction [18–20]. Additionally, pre-hypertension is associated with dysregulation of the renin-angiotensin-aldosterone system (RAAS), heightened adrenergic tone, and inflammatory cascades that promote atherosclerosis and lipid imbalance [21]. A meta-analysis further suggests that pre-hypertension increases the risk of chronic kidney disease (relative risk: 1.28, 95% CI: 1.13–1.45), establishing it as an independent risk factor for incident chronic kidney disease [22].

In China, regional disparities in the prevalence of pre-hypertension are evident, with reported rates of 30.8% in the Northeast [23], 27.4% in Central China [24], 29.0% in Southern China [25], and 41.3% in high-altitude regions [26]. However, epidemiological data specific to Fujian Province, a southeastern coastal region, remain scarce. Given the escalating burden of hypertension, evaluating the prevalence and determinants of pre-hypertension in this population is imperative. Such insights are vital for developing tailored prevention and control strategies and hold significant public health implications for the primary prevention of hypertension and associated cardiovascular and cerebrovascular diseases. Therefore, this study aims to assess the epidemiological characteristics and determinants of pre-hypertension among adults in Fujian Province and to develop a nomogram prediction model.

2. Materials and Methods

2.1. Study Design and Data Source

This study employed a cross-sectional design utilizing data from the national “Cardiovascular Disease and Risk Factors Surveillance Investigators” project, coordinated by the Bureau of Disease Prevention and Control, National Health Commission. The National Center for Cardiovascular Diseases and Fuwai Hospital, Chinese Academy of Medical Sciences, provided scientific oversight and developed the technical protocols. The project

aims to establish a nationally representative surveillance system to monitor the epidemiological profile and trends of cardiovascular diseases (CVD) and their key risk factors, thereby providing an evidence base for public health policy formulation and evaluation.

2.2. Sampling and Study Population

2.2.1. Sampling Strategy and Survey Sites

A baseline survey was conducted nationwide from August 2020 to April 2021, covering 31 provincial-level administrative divisions. A multi-stage stratified random cluster sampling method was employed, stratified by administrative division, urban/rural classification, and economic development level to ensure national and provincial representativeness. A total of 262 representative districts/counties were initially selected as primary sampling units. Within each unit, two townships/sub-districts were randomly chosen, followed by three villages/residential communities per selected township. Permanent residents aged ≥ 18 years who had lived in the selected area for at least six months were eligible for recruitment.

2.2.2. Sample Size Calculation

The initial sample size was estimated using the formula for simple random sampling for a population proportion:

$$n_{SRS} = \frac{Z_{\alpha/2}^2 \times \pi \times (1 - \pi)}{\delta^2}$$

where, π is the overall probability; type I error probability $\alpha = 0.05$, $Z_{\alpha/2} = 1.96$; absolute maximum allowable error $\delta = 0.1p$, p is the estimated value of π , and the hypertension prevalence rate of 23.2% was taken in this project.

Due to the complex sampling adopted in the study, the design effect (deff) should also be considered. The actual required sample size is: $n = deff \times n_{SRS}$, where $deff = \frac{v_p(\hat{\theta})}{v_{srs}(\hat{\theta})}$, $v_p(\hat{\theta})$ is the variance estimator of the estimator under the actual sampling design ($p(\cdot)$), and $v_{srs}(\hat{\theta})$ is the variance estimator of the estimator under the SRS design. $deff$ measures the estimation efficiency or effect of the estimator under the actual sampling design, and $deff = 2$ was taken in this project.

Consequently, the target sample size for each primary sampling unit (monitoring district/county) was set at 1200 individuals. To account for an anticipated non-response rate, the recruitment target was adjusted to approximately 1800 eligible individuals per district/county. For this study, data from 8 monitoring sites in Fujian Province were extracted, yielding a final analytical sample of 9455 adults. The planned allocation per district is detailed in Table 1.

Table 1. Planned sample allocation and recruitment targets per monitoring district/county.

Age Group (Year)	National Population Composition (%)	Number of People to Survey = 1200 × Population Composition	Adjusted Number of People to Survey	Estimated Non-Response Rate	Required Sample Size (Male/Female)
18–24	17.02	204	200	30	286 (143/143)
25–34	26.75	321	250	40	416 (208/208)
35–44	20.70	248	230	40	384 (192/192)
45–54	16.24	195	200	30	286 (143/143)
55–64	9.62	115	120	30	172 (86/86)
65–74	6.60	79	100	20	126 (63/63)
≥ 75	3.06	38	100	20	126 (63/63)
Total	100	1200	1200		1796

2.2.3. Fujian Province Sub-Study

Participants and Criteria: For the present analysis, data from 8 monitoring sites in Fujian Province were extracted: 3 urban districts (Meilie, Sanming; Xiangcheng, Zhangzhou; Jianyang, Nanping) and 5 rural counties/cities (Luoyuan County & Fuqing City, Fuzhou; Anxi County, Quanzhou; Nanjing County, Zhangzhou; Zhangping City, Longyan). A total of 9736 individuals were initially surveyed.

Inclusion criteria were: (1) age ≥ 18 years; (2) permanent resident with local residence ≥ 6 months; (3) provision of written informed consent. Exclusion criteria were: (1) age < 18 years; (2) pregnant or lactating; (3) known history of severe cardiovascular/cerebrovascular disease, malignancy, or severe mental disorder; (4) known secondary hypertension. Additionally, participants with missing blood pressure measurements or incomplete key covariate data ($n = 281$) were excluded, resulting in a final analytic sample of 9455 adults.

2.3. Data Collection and Measurements

2.3.1. Questionnaire Survey

Trained investigators conducted face-to-face interviews using a standardized electronic questionnaire on tablet devices. Data collected included socio-demographics (age, sex, education, occupation, marital status), personal and family medical history (hypertension, diabetes, CVD events), and lifestyle habits (smoking, alcohol and tea consumption, diet, physical activity, sleep).

2.3.2. Physical Examination

Standardized protocols and calibrated equipment were used. Height, weight, and waist circumference were measured with participants in light clothing. Height was measured to the nearest 0.1 cm. Weight and body composition were measured using a bioelectrical impedance analyzer (InBody H20B). Waist circumference was measured at the midpoint between the lowest rib and the iliac crest. Central obesity: Waist circumference < 85 cm for males and < 80 cm for females is normal; 85 cm ≤ waist circumference < 90 cm for males and 80 cm ≤ waist circumference < 85 cm for females is pre-central obesity; waist circumference ≥ 90 cm for males and ≥ 85 cm for females is central obesity [27]. Blood pressure (BP) was measured by trained staff using a validated automatic oscillometric device (Omron HBP-1120U). After a 5-min rest, three consecutive BP readings were taken on the right arm with a 1-min interval; the average of the second and third readings was recorded. The average of these readings from a single visit was used as the individual's final BP value. Room temperature was maintained at 22–25 °C.

2.3.3. Laboratory Tests

Fasting venous blood and urine samples were collected. Serum was separated on-site and stored at –20 °C. Samples were transported via cold chain for centralized analysis. Measured parameters included fasting blood glucose, glycosylated hemoglobin (HbA1c), lipid profile (total cholesterol, triglycerides, high-density lipoprotein cholesterol [HDL-C], low-density lipoprotein cholesterol [LDL-C]), serum creatinine, and uric acid [28,29].

2.4. Definition of Key Variables

Blood Pressure Categories: Based on the 2024 Chinese Hypertension Guidelines and measured in the absence of antihypertensive medication: Normal: systolic blood pressure (SBP) < 120 mmHg and diastolic blood pressure (DBP) < 80 mmHg. Pre-hypertension: SBP 120–139 mmHg and/or DBP 80–89 mmHg. Hypertension: SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg, or self-reported diagnosis, or current medication.

Obesity Indices: Body mass index (BMI) = weight (kg)/height² (m²). Categories: underweight (<18.5 kg/m²), normal (18.5–23.9 kg/m²), overweight (24.0–27.9 kg/m²), obesity (≥28.0 kg/m²).

Other Health Conditions: Diabetes, dyslipidemia, and hyperuricemia were defined per contemporary Chinese guidelines. Family history of hypertension was defined as having at least one parent with hypertension.

Lifestyle Factors: Smoking: having smoked in the past month. Alcohol drinking: having consumed alcohol in the past year. Tea consumption: having drunk tea in the past. Physical activity: engaging in moderate/vigorous activity ≥5 days/week and ≥30 min/day in the past month [30]. Regular sleep: average nightly sleep duration 7–9 h (calculated as a weighted average of weekday and weekend sleep) [31].

Triglyceride-glucose (TyG) index: Calculated as $\text{Ln} [\text{fasting triglycerides (mg/dL)} \times \text{fasting plasma glucose (mg/dL)} / 2]$ [32].

2.5. Quality Control

A comprehensive quality control system was implemented throughout the survey cycle. It covered pre-survey (protocol training, material preparation), on-site (standardized procedures, data collection verification, sample handling), and post-survey (data review, entry, cleaning) phases. Electronic data capture via tablet ensured real-time logic checks. Data were centrally managed, cleaned, and backed up. External supervision was conducted to ensure adherence to protocols.

2.6. Statistical Analysis

Continuous variables with normal distribution are presented as mean ± standard deviation (SD) and compared using Student's *t*-test or ANOVA; otherwise, median (interquartile range) and non-parametric tests were used. Categorical variables are presented as *n* (%) and compared using chi-square or Fisher's exact tests.

Univariable logistic regression identified factors associated with pre-hypertension (vs. normal BP). Variables with $p < 0.10$ in univariable analysis or deemed clinically important were entered into a multivariable logistic regression model. Results are expressed as odds ratios (OR) with 95% confidence intervals (CI).

A nomogram was developed based on the final multivariable model to predict individual pre-hypertension risk. The total sample was randomly split into a training set (70%) for model development and a validation set (30%) for internal validation. Model performance was evaluated by discrimination (area under the receiver operating characteristic curve, AUC), calibration (calibration plot with 1000 bootstrap samples), and clinical utility (decision curve analysis, DCA). All analyses were performed using SPSS 25.0 and R 4.4.2 software, with a two-tailed $p < 0.05$ considered statistically significant.

3. Results

3.1. Baseline Characteristics of the Study Population

Of the 9736 individuals initially surveyed, 9455 met the inclusion criteria and had complete data, yielding a valid response rate of 97.11%. The mean age of the study population was 44.61 ± 18.03 years. The largest proportion of participants was in the 25–34 years (19.45%) and 35–44 years (19.09%) age groups. The population consisted of 4670 males (49.39%) and 4785 females (50.61%). Regarding residence, 3486 (36.87%) participants resided in urban areas and 5969 (63.13%) in rural areas, reflecting a predominance of rural residents. Rural residents outnumbered urban residents across all age strata, with the disparity being most pronounced in the 18–24 years age group (63.51% rural vs. 36.49% urban).

Regarding socioeconomic status, the highest educational attainment was college/university or above (28.15%), followed by junior high school (23.36%) and high school/technical secondary school (18.60%). A highly significant association was observed between age group and educational level ($\chi^2 = 5258.184$, $p < 0.001$); the proportion of participants with no schooling or primary education increased with age, whereas those with higher education decreased. Self-assessed economic status was predominantly medium (66.05%), followed by low (30.10%) and high (3.85%). Increasing age was significantly associated with lower self-assessed economic status ($\chi^2 = 262.128$, $p < 0.001$). The detailed baseline characteristics are summarized in Table 2.

Table 2. Baseline demographic and socioeconomic characteristics of the study population ($n = 9455$).

Characteristics	Total n (%)
Age, years	44.61 ± 18.03 *
Gender	
Male	4670 (49.39)
Female	4785 (50.61)
Residence	
Urban	3486 (36.87)
Rural	5969 (63.13)
Educational Attainment	
No Schooling	1178 (12.46)
Primary School	1647 (17.42)
Junior High School	2209 (23.36)
High School/Vocational	1759 (18.60)
College or above	2662 (28.15)
Self-Assessed Economic Status	
Low	2846 (30.10)
Medium	6245 (66.05)
High	364 (3.85)

Note: Data are presented as n (%) unless otherwise specified. * Mean $\pm$ standard deviation. Significant associations were observed between age groups and educational level ($\chi^2 = 5258.184$, $p < 0.001$) and economic status ($\chi^2 = 262.128$, $p < 0.001$).

3.2. Prevalence of Pre-Hypertension

3.2.1. Overall Prevalence

Among the 9455 participants, 3545 (37.49%) were identified with pre-hypertension, while 2869 (30.34%) had normal blood pressure and 3041 (32.16%) had hypertension. The age-standardized prevalence of pre-hypertension was 37.57%, and the weighted prevalence was 37.35%.

3.2.2. Prevalence by Gender and Age

The crude prevalence of pre-hypertension was significantly higher in males (42.48%) than in females (32.62%) ($p < 0.001$). After age standardization, the rates were 41.98% for males and 33.35% for females. The prevalence exhibited an inverted U-shaped trend across age groups, peaking in the 45–54 years age group (40.98%) before declining in older ages (Table 3). Stratified by gender, males showed a significant decreasing trend after peaking in younger age groups ($p < 0.001$), whereas females showed an increasing trend until 54 years of age followed by a decline. Notably, prevalence was higher in males than females among participants aged <45 years, while this pattern reversed in those aged ≥ 45 years.

Table 3. Prevalence of pre-hypertension by age and gender.

Age Group (Years)	Overall Population			Male			Female			p^*
	Survey Count	Detected Cases	Detection Rate (%)	Survey Count	Detected Cases	Detection Rate (%)	Survey Count	Detected Cases	Detection Rate (%)	
18–24	1477	577	39.07	756	387	51.19	721	190	26.35	<0.001
25–34	1839	706	38.39	911	464	50.93	928	242	26.08	<0.001
35–44	1805	738	40.89	908	420	46.26	897	318	35.45	<0.001
45–54	1657	679	40.98	797	312	39.15	860	367	42.67	<0.001
55–64	1077	390	36.21	501	172	34.33	576	218	37.85	0.231
65–74	825	266	32.24	412	130	31.55	413	136	32.93	0.672
≥ 75	775	189	24.39	385	99	25.71	390	90	23.08	0.393
Total	9455	3545	37.49	4670	1984	42.48	4785	1561	32.62	<0.001
$p^{\&}$			<0.001			<0.001			0.009	

Note: * Comparison of pre-HTN in males and females of the same age group; & indicates comparison of pre-HTN in different age groups of the same sex.

3.2.3. Prevalence by Urban and Rural Residence

The crude prevalence of pre-hypertension was comparable between urban (37.18%) and rural (37.68%) areas ($p = 0.628$). However, significant disparities were observed in specific subgroups. Among females, the prevalence was significantly higher in rural areas (33.84%) than in urban areas (30.51%) ($p = 0.018$). Age-stratified analysis revealed that prevalence was higher in rural areas among participants aged 18–54 years, whereas urban areas showed higher rates among those aged ≥ 55 years (Table 4). Additionally, significant interactions were observed with adiposity measures; for instance, among individuals with pre-central obesity, urban residents had a higher prevalence than rural residents (44.83% vs. 37.95%, $p = 0.005$).

Table 4. Prevalence of pre-hypertension by residence and selected characteristics.

Characteristic	Stratification	Urban ($n = 3486$)			Rural ($n = 5969$)			p
		Survey Count	Detected Cases	Detection Rate (%)	Survey Count	Detected Cases	Detection Rate (%)	
Age (years)	18–24	539	205	38.03	938	372	39.66	0.538
	25–34	688	250	36.34	1151	456	39.62	0.162
	35–44	671	273	40.69	1134	465	41.01	0.894
	45–54	599	229	38.23	1058	450	42.53	0.087
	55–64	413	153	37.05	664	237	35.69	0.653
	65–74	293	104	35.49	532	162	30.45	0.138
	≥ 75	283	82	28.98	492	107	21.75	0.024
Gender	Male	1739	763	43.88	2931	1221	41.66	0.138
	Female	1747	533	30.51	3038	1028	33.84	0.018
BMI (kg/m^2)	BMI < 18.5	208	63	30.29	355	116	32.68	0.557
	$18.5 \leq \text{BMI} < 24.0$	1739	618	35.54	3071	1156	37.64	0.146
	$24.0 \leq \text{BMI} < 28.0$	1067	418	39.18	1879	734	39.06	0.952
	BMI ≥ 28.0	472	197	41.74	664	243	36.60	0.080
Central Obesity	Yes	933	343	36.76	1236	428	34.63	0.304
	Pre-central Obesity	687	308	44.83	946	359	37.95	0.005
	No	1866	645	34.57	3787	1462	38.61	0.003
Total		3486	1296	37.18	5969	2249	37.68	0.628

3.2.4. Prevalence by BMI and Waist Circumference

The prevalence of pre-hypertension varied significantly by combinations of BMI and waist circumference (WC) (Table 5). In males, the highest prevalence (52.86%) was observed in those with BMI $\geq 28.0 \text{ kg}/\text{m}^2$ and WC 85–90 cm. In females, the highest prevalence (49.23%) was found in those with BMI $\geq 28.0 \text{ kg}/\text{m}^2$ and WC 80–85 cm. Generally,

within fixed BMI categories, prevalence tended to vary with WC, though the trend was not linear across all subgroups. Higher BMI was consistently associated with increased prevalence, particularly in females (p for trend = 0.001).

Table 5. Prevalence of pre-hypertension by BMI and waist circumference.

Waist Circumference (cm)	BMI (kg/m ²)									<i>p</i>
	<24.0			24.0–28.0			≥28.0			
	Survey Count	Detected Cases	Detection Rate (%)	Survey Count	Detected Cases	Detection Rate (%)	Survey Count	Detected Cases	Detection Rate (%)	
Male										
<85	2044	894	43.74	518	233	44.98	30	13	43.33	0.876
85–90	282	119	42.20	536	233	43.47	70	37	52.86	0.266
≥90	68	28	41.18	565	213	37.7	557	214	38.42	0.850
Subtotal	2394	1041	43.48	1619	679	41.94	657	264	40.18	0.273
<i>p</i>			0.823			0.036			0.063	
Female										
<80	2582	784	30.36	453	171	37.75	26	12	46.15	0.002
80–85	282	95	33.69	398	151	37.94	65	32	49.23	0.061
≥85	115	33	28.70	476	151	31.72	388	132	34.02	0.527
Subtotal	2979	912	30.61	1327	473	35.64	479	176	36.74	0.001
<i>p</i>			0.465			0.083			0.037	

3.3. Univariate Analysis of Factors Associated with Pre-hypertension

3.3.1. Comparison of Characteristics between Normotensive and Pre-hypertensive Groups

Participants were categorized into normotensive ($n = 2869$) and pre-hypertensive ($n = 3545$) groups. Univariate analysis revealed statistically significant differences between the two groups across all demographic, anthropometric, clinical, and lifestyle variables (Table 6). Compared to the normotensive group, the pre-hypertensive group had a higher proportion of males, older participants, rural residents, and those with lower educational attainment. Additionally, participants with pre-hypertension exhibited higher BMI, waist circumference, and prevalence of comorbidities (diabetes, dyslipidemia, hyperuricemia), as well as higher rates of smoking, alcohol consumption, and tea consumption.

Table 6. Univariate analysis of factors associated with pre-hypertension.

Characteristics	Category	Normotensive ($n = 2869$)	Pre-Hypertension ($n = 3545$)	t / χ^2	p -Value
		n (%) or Mean $\pm$ SD	n (%) or Mean $\pm$ SD		
Gender	Male	895 (31.20)	1984 (55.97)	393.295	<0.001
	Female	1974 (68.80)	1561 (44.03)		
Age (years)	18–24	769 (26.80)	577 (16.28)	398.895	<0.001
	25–34	863 (30.08)	706 (19.92)		
	35–44	630 (21.96)	738 (20.82)		
	45–54	336 (11.71)	679 (19.15)		
	55–64	143 (4.98)	390 (11.00)		
	65–74	79 (2.75)	266 (7.50)		
	≥75	49 (1.71)	189 (5.33)		
Residence	Urban	1164 (40.57)	1296 (36.56)	10.801	0.001
	Rural	1705 (59.43)	2249 (63.44)		
Education Level	No Schooling	122 (4.25)	368 (10.38)	247.963	<0.001
	Primary School	260 (9.06)	594 (16.76)		
	Junior High School	644 (22.45)	838 (23.64)		
	High School/Technical Secondary	596 (20.77)	729 (20.56)		
	College/Undergraduate or Above	1247 (43.46)	1016 (28.66)		
Self-rated Economic Status	Low	699 (24.36)	1023 (28.86)	16.326	<0.001
	Medium	2050 (71.45)	2380 (67.13)		
	High	120 (4.18)	142 (4.01)		
Height (cm) *		160.66 $\pm$ 8.35	162.84 $\pm$ 9.12	97.316	<0.001
Weight (kg) *		57.25 $\pm$ 10.00	63.54 $\pm$ 12.33	487.459	<0.001
BMI (kg/m ²) *		22.14 $\pm$ 3.21	23.88 $\pm$ 3.64	400.831	<0.001
	BMI < 18.5	308 (10.74)	179 (5.05)	336.706	<0.001
	18.5 ≤ BMI < 24.0	1862 (64.90)	1774 (50.04)		
	24.0 ≤ BMI < 28.0	572 (19.94)	1152 (32.50)		
	BMI ≥ 28.0	127 (4.43)	440 (12.41)		
Waist Circumference (cm) *		74.18 $\pm$ 9.39	80.23 $\pm$ 10.46	580.634	<0.001
	Normal	2309 (80.48)	2107 (59.43)	333.928	<0.001
	Pre-central Obesity	299 (10.42)	667 (18.82)		
	Central Obesity	261 (9.10)	771 (21.75)		

Table 6. Cont.

Characteristics	Category	Normotensive (<i>n</i> = 2869)	Pre-Hypertension (<i>n</i> = 3545)	<i>t</i> / χ^2	<i>p</i> -Value
		<i>n</i> (%) or Mean $\pm$ SD	<i>n</i> (%) or Mean $\pm$ SD		
Family History of Hypertension	No	2366 (82.47)	2785 (78.56)	15.302	<0.001
	Yes	503 (17.53)	760 (21.44)		
Diabetes	No	2732 (95.22)	3222 (90.89)	44.785	<0.001
	Yes	137 (4.78)	323 (9.11)		
Dyslipidemia	No	2420 (84.35)	2443 (68.91)	206.076	<0.001
	Yes	449 (15.65)	1102 (31.09)		
Hyperuricemia	No	2260 (78.77)	2477 (69.87)	65.046	<0.001
	Yes	609 (21.23)	1068 (30.13)		
Smoking	No	2453 (85.50)	2683 (75.68)	95.763	<0.001
	Yes	416 (14.50)	862 (24.32)		
Alcohol Consumption	No	2116 (73.75)	2389 (67.39)	30.714	<0.001
	Yes	753 (26.25)	1156 (32.61)		
Tea Consumption	No	1560 (54.37)	1585 (44.71)	59.253	<0.001
	Yes	1309 (45.63)	1960 (55.29)		
Regular Sleep	No	989 (34.47)	1450 (40.90)	27.826	<0.001
	Yes	1880 (65.53)	2095 (59.10)		
Physical Activity	No	1310 (45.66)	1527 (43.07)	4.298	0.038
	Yes	1559 (54.34)	2018 (56.93)		
HbA1c (%)		5.38 $\pm$ 0.53	5.57 $\pm$ 0.75	127.584	<0.001
Triglyceride-Glucose Index		8.15 $\pm$ 0.60	8.48 $\pm$ 0.68	417.834	<0.001
Serum Creatinine (μ mol/L)		69.48 $\pm$ 22.10	75.75 $\pm$ 17.60	160.112	<0.001

Note: Count data were expressed as frequency (*n*) and percentage (%), and comparisons between groups were made using the χ^2 test or Fisher's exact probability method; * measurement data were expressed as mean $\pm$ standard deviation ($\bar{x} \pm s$), comparisons between two groups were made using the t-test, and comparisons between multiple groups were made using the one-way analysis of variance. BMI: body mass index.

3.3.2. Multivariate Logistic Regression Analysis

All variables significant in the univariate analysis ($p < 0.05$) were included in the initial multivariate logistic regression model. A forward stepwise selection method was used (entry criteria: $p < 0.05$; removal criteria: $p > 0.10$). Variables such as self-assessed economic status, BMI categories, diabetes, hyperuricemia, alcohol consumption, regular sleep, physical activity, height, glycosylated hemoglobin (HbA1c), and serum creatinine were excluded from the final model due to non-significance or collinearity.

The final multivariate model identified several independent factors associated with pre-hypertension (Table 7). Protective factors included female gender ($OR = 0.439$, 95% CI : 0.378–0.509), higher educational attainment (all $p < 0.05$ compared to no schooling), and smoking ($OR = 0.737$, 95% CI : 0.623–0.872). Risk factors included older age (with OR s increasing from 1.253 for 35–44 years to 3.559 for ≥ 75 years compared to 18–24 years), rural residence ($OR = 1.293$, 95% CI : 1.150–1.454), central obesity (including pre-central obesity), family history of hypertension ($OR = 1.207$, 95% CI : 1.048–1.391), dyslipidemia ($OR = 1.194$, 95% CI : 1.026–1.390), tea consumption ($OR = 1.181$, 95% CI : 1.054–1.324), higher body weight ($OR = 1.032$ per kg, 95% CI : 1.024–1.040), and elevated TyG index ($OR = 1.347$, 95% CI : 1.210–1.500).

Table 7. Univariate and multivariate logistic regression analysis of factors associated with pre-hypertension.

Variable	Category	Univariate Analysis		Multivariate Analysis	
		<i>OR</i> (95% <i>CI</i>)	<i>p</i>	<i>OR</i> (95% <i>CI</i>)	<i>p</i>
Gender	Male	Ref		Ref	
	Female	0.352 (0.311–0.399)	<0.001	0.439 (0.378–0.509)	<0.001
Age (years)	18–24	Ref		Ref	
	25–34	1.107 (0.928–1.321)	0.257	0.929 (0.787–1.096)	0.379
	35–44	1.693 (1.412–2.029)	<0.001	1.253 (1.046–1.502)	0.014
	45–54	2.632 (2.155–3.213)	<0.001	1.909 (1.547–2.355)	<0.001
	55–64	3.356 (2.577–4.370)	<0.001	2.275 (1.739–2.976)	<0.001
	65–74	4.908 (3.520–6.844)	<0.001	2.692 (1.940–3.736)	<0.001
	≥ 75	6.026 (3.976–9.133)	<0.001	3.559 (2.419–5.237)	<0.001
Residence	Urban	Ref		Ref	
	Rural	1.199 (1.062–1.353)	0.003	1.293 (1.150–1.454)	<0.001

Table 7. Cont.

Variable	Category	Univariate Analysis		Multivariate Analysis	
		OR (95% CI)	p	OR (95% CI)	p
Education	No Schooling	Ref		Ref	
	Primary School	0.808 (0.596–1.096)	0.171	0.751 (0.572–0.984)	0.038
	Junior High	0.415 (0.315–0.547)	<0.001	0.495 (0.377–0.650)	<0.001
	High School	0.383 (0.290–0.506)	<0.001	0.522 (0.393–0.693)	<0.001
	College or above	0.270 (0.207–0.353)	<0.001	0.449 (0.339–0.596)	<0.001
Central Obesity	No	Ref		Ref	
	Pre-central	2.314 (1.937–2.765)	<0.001	1.374 (1.153–1.638)	<0.001
	Yes	3.303 (2.752–3.965)	<0.001	1.236 (1.003–1.522)	0.047
Family History of HTN	No	Ref		Ref	
	Yes	1.380 (1.185–1.606)	<0.001	1.207 (1.048–1.391)	0.009
Dyslipidemia	No	Ref		Ref	
	Yes	2.408 (2.077–2.792)	<0.001	1.194 (1.026–1.390)	0.022
Smoking	No	Ref		Ref	
	Yes	1.808 (1.551–2.109)	<0.001	0.737 (0.623–0.872)	<0.001
Tea Consumption	No	Ref		Ref	
	Yes	1.449 (1.287–1.631)	<0.001	1.181 (1.054–1.324)	0.004
Weight (kg)	Continuous	1.054 (1.048–1.061)	<0.001	1.032 (1.024–1.040)	<0.001
HbA1c (%)	Continuous	1.813 (1.599–2.056)	<0.001	—	—
TyG Index	Continuous	2.253 (2.037–2.492)	<0.001	1.347 (1.210–1.500)	<0.001

Note: Variables excluded from the final multivariate model include: Self-rated economic status, BMI categories, Diabetes, Hyperuricemia, Alcohol consumption, Regular sleep, Physical activity, Height, HbA1c, and Serum Creatinine. OR: odds ratio; CI: confidence interval; HTN: hypertension; TyG: triglyceride-glucose; HbA1c: glycosylated hemoglobin.

3.3.3. Development and Validation of the Nomogram Prediction Model

Based on the 11 independent predictors identified in the multivariate logistic regression analysis (gender, age, residence, education, central obesity, family history of hypertension, dyslipidemia, smoking, tea consumption, body weight, and TyG index), a nomogram was constructed to predict the individual probability of pre-hypertension. The dataset was randomly split into a training set (70%) for model development and a validation set (30%) for internal validation.

In the nomogram, each predictor is assigned a score on the top scale. By summing the scores corresponding to an individual's variable values, a total point score is obtained. Drawing a vertical line from the total points scale to the probability scale allows for the estimation of the individual's risk of pre-hypertension (Figure 1).

The discriminative ability of the nomogram was evaluated using the area under the receiver operating characteristic curve (AUC). In the training set, the AUC was 0.755 (95% CI: 0.740–0.769), with an optimal cutoff probability of 0.028, yielding a sensitivity of 75.6% and a specificity of 62.7%. In the validation set, the AUC was 0.746 (95% CI: 0.724–0.768), with an optimal cutoff probability of 0.065, yielding a sensitivity of 71.3% and a specificity of 66.5%, indicating good predictive performance (Figure 2).

Internal validation was performed using the bootstrap resampling method (1000 repetitions). The bias-corrected C-index was consistent with the AUC values (0.755 for the training set and 0.746 for the validation set). The calibration curves showed excellent agreement between the predicted probabilities and the observed outcomes in both sets, indicating good calibration (Figure 3). Finally, decision curve analysis (DCA) demonstrated that the nomogram provided a higher net benefit across a wide range of threshold probabilities (approximately 0–60%) compared to the “treat-all” or “treat-none” strategies, confirming its clinical utility (Figure 4).

The area under the curve (AUC) values indicate the discriminative ability of the model. The X-axis represents 1-Specificity (False Positive Rate), and the Y-axis represents Sensitivity (True Positive Rate). The black dot on each curve represents the optimal cutoff probability determined by the Youden index. The values next to the black dot indicate the cutoff probability and the corresponding (Specificity, Sensitivity).

The X-axis represents the predicted probability of pre-hypertension, and the Y-axis represents the actual observed probability. The diagonal dashed line represents the ideal reference line (where predicted probability equals observed probability). The solid green line represents the bias-corrected performance of the nomogram using bootstrap resampling. Close alignment with the ideal line indicates good calibration.

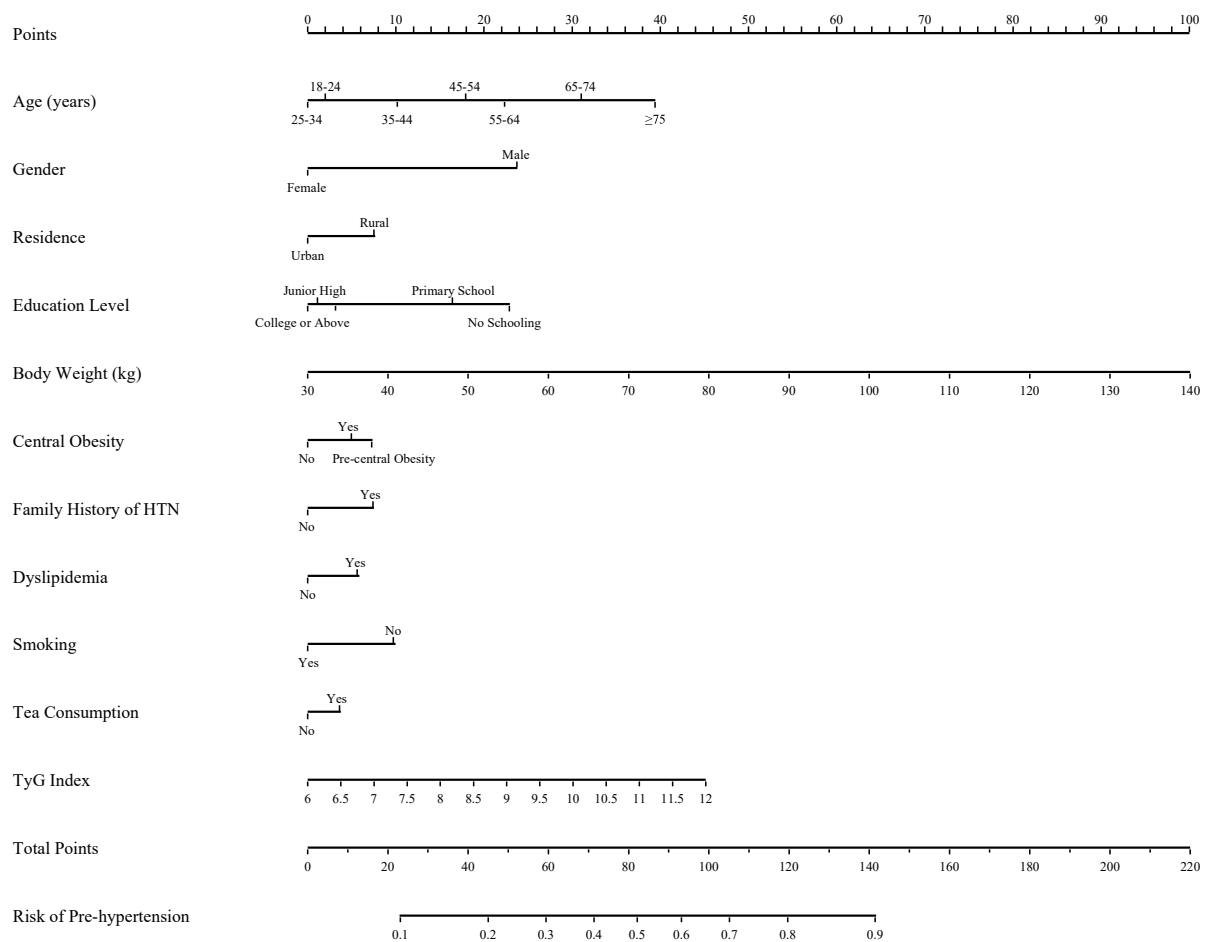


Figure 1. Line graph of predicted probability of detection of pre-HTN.

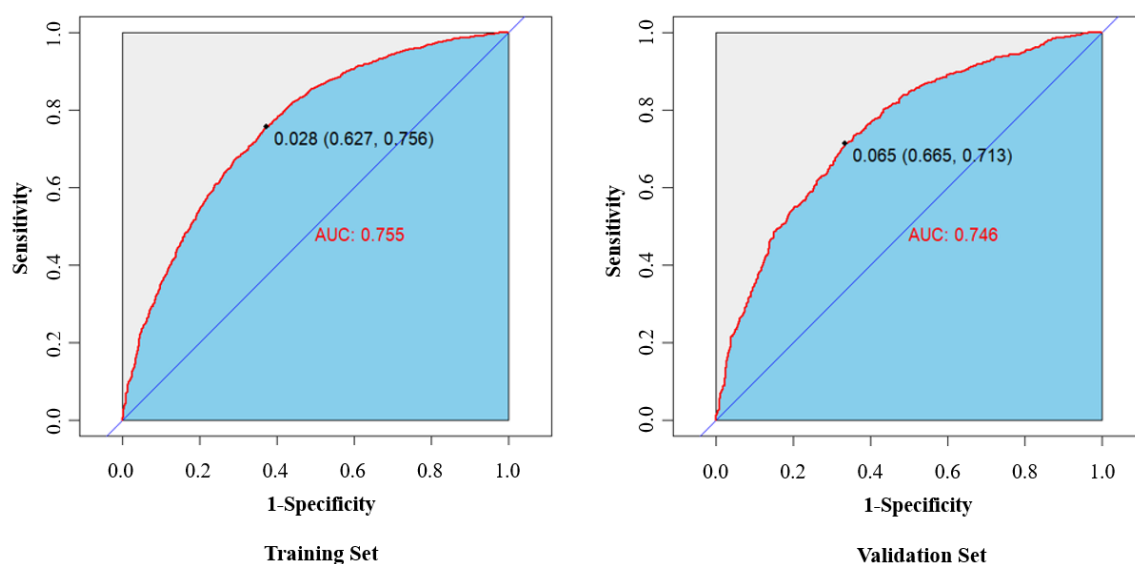


Figure 2. Receiver operating characteristic (ROC) curves for the nomogram in the training and validation sets.

The X-axis represents the threshold probability, and the Y-axis represents the standardized net benefit. The red line represents the nomogram model, the gray line represents the assumption that all patients have pre-hypertension (“All”), and the black line represents the assumption that no patients have pre-hypertension (“None”). The nomogram demonstrates a higher net benefit across a wide range of threshold probabilities (approximately 0–60%) compared to the treat-all or treat-none strategies, indicating good clinical utility.

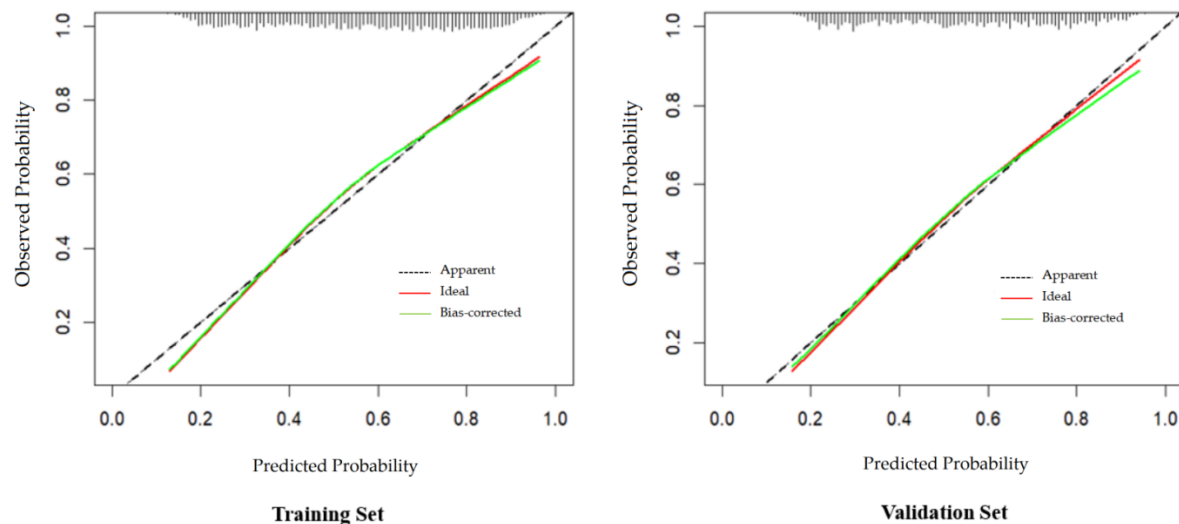


Figure 3. Calibration curves for the nomogram in the training and validation sets.

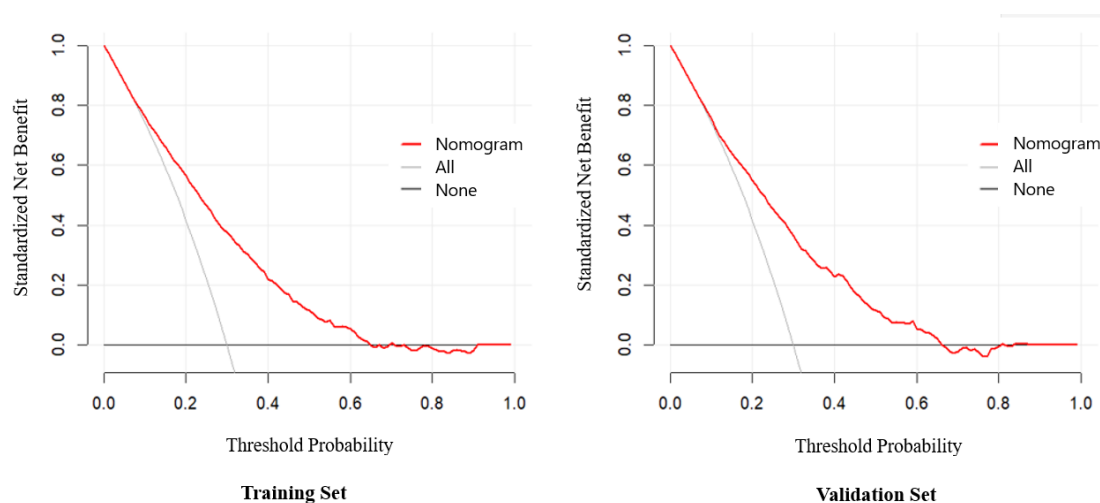


Figure 4. Decision curve analysis (DCA) for the nomogram in the training and validation sets.

4. Discussion

This study provides the first comprehensive epidemiological profile of pre-hypertension among adults in Fujian Province, China, based on a large, provincially representative sample. The key findings are threefold. First, the burden of pre-hypertension is substantial, with a crude prevalence of 37.49%. Second, we identified a distinct set of independent determinants, encompassing both non-modifiable (e.g., older age, male sex, family history) and, critically, modifiable factors (e.g., central adiposity, dyslipidemia, elevated TyG index, higher body weight). Third, a practical nomogram integrating these factors was developed and demonstrated good performance for individualized risk assessment.

Comparisons and Implications: The observed prevalence, while slightly lower than the latest national estimate for China (39.1%) [3], remains alarmingly high. It suggests that the ongoing epidemiological transition in Fujian—characterized by economic growth and lifestyle changes—has not effectively mitigated this cardiovascular risk precursor. The significant male predominance (42.48% vs. 32.62% in females) is consistent with global patterns and likely stems from a combination of biological factors (e.g., the vasoprotective role of estrogen [33,34]) and behavioral disparities (e.g., higher rates of adverse health behaviors among men) [15,35,36]. The concentration of cases in middle-aged adults (peak: males 18–44 years, females 35–54 years) underscores this demographic as a priority for targeted screening.

A notable finding is the absence of a significant urban-rural difference in crude prevalence. This convergence, also reported in other Chinese regions [35,37], may reflect two simultaneous trends: the gradual diffusion of urban lifestyles (including dietary and sedentary patterns) into rural areas, thereby increasing risk, alongside improvements in rural healthcare access and health awareness, potentially enhancing detection. The multivariate analysis identifying rural residence as an independent risk factor (adjusted $OR = 1.29$) after controlling for

demographics suggests that underlying risk profiles may be less favorable in rural settings, possibly due to factors like dietary sodium intake or health literacy gaps, warranting focused attention.

Our results highlight the central role of metabolic health in the pathogenesis of pre-hypertension. Central obesity (and pre-central obesity) and an elevated triglyceride-glucose (TyG) index—a robust marker of insulin resistance—emerged as strong, independent predictors. This aligns with the established pathophysiological continuum where visceral adiposity drives insulin resistance, inflammation, and endothelial dysfunction, collectively promoting blood pressure elevation [17,21,32]. The independent association of higher body weight and dyslipidemia further reinforces this metabolic syndrome paradigm. Interventions targeting this cluster, such as weight management and improvement of insulin sensitivity, are likely to be highly effective for primary prevention. Socioeconomic and Behavioral Factors: The protective effect of higher educational attainment is well-documented and likely mediated through multiple pathways, including greater health literacy, better socioeconomic conditions enabling healthier choices, and improved access to healthcare information [38]. The Complex Association with Tea Consumption: In contrast to some studies suggesting cardiovascular benefits of tea [39], we found tea consumption associated with a modestly increased risk (adjusted $OR = 1.18$). As Fujian is a major tea-producing region, local consumption habits (e.g., frequent intake of strong, concentrated Oolong tea, potentially with added sugars or alongside salty snacks) and the acute sympathetic activation from caffeine may explain this finding [40]. This underscores the importance of considering the cultural context, preparation method, and concomitant dietary behaviors when evaluating the health impact of tea. Critical Appraisal of the Smoking Association: A striking and counterintuitive finding was that current smoking was associated with a lower risk of pre-hypertension in the adjusted model ($OR = 0.74$). It is imperative to state unequivocally that this almost certainly represents a spurious association arising from the limitations of the cross-sectional design, not a true protective effect. Plausible explanations include: (1) Residual confounding: Despite adjustment, smoking is intricately linked to a complex web of social, behavioral, and psychological factors not fully captured, which may distort its apparent effect. (2) Survivor bias: Heavier smokers with advanced cardiopulmonary disease may be under-represented in a general population survey. (3) Reverse causality: Individuals diagnosed with high blood pressure are often advised to quit, leading to a lower prevalence of hypertension/pre-hypertension among current smokers. This finding reinforces the hazard of inferring causality from cross-sectional data and in no way diminishes the established, causal role of smoking in promoting cardiovascular disease [41,42].

The developed nomogram demonstrated good predictive performance ($AUC \sim 0.75$) and clinical net benefit. Its primary value lies in synthesizing demographic, anthropometric, metabolic (TyG index), and clinical data into a single, visual tool for risk stratification. In community or primary care settings, it could help identify asymptomatic individuals at high risk for pre-hypertension, who may benefit most from intensive lifestyle counseling and monitoring, thereby enabling a more efficient allocation of preventive resources. Prospective validation in independent cohorts is needed to confirm its generalizability and utility in improving health outcomes.

Major strengths include the large, representative sample from a national surveillance system, standardized data collection, and the development of a practical prediction tool. Key limitations must be acknowledged. First, the cross-sectional design precludes causal inference, as starkly illustrated by the smoking association. Second, the lack of detailed dietary data (e.g., sodium, potassium intake) is a significant omission, given its established link to blood pressure [43]. Third, blood pressure was measured during a single visit, which may overestimate true prevalence. Fourth, the model requires external validation. Finally, reliance on self-reported data for some variables may introduce bias.

5. Conclusions

In conclusion, this study reveals a high and concerning prevalence of pre-hypertension among adults in Fujian Province. The condition is strongly associated with a cluster of modifiable metabolic risk factors, particularly central obesity and insulin resistance (reflected by the TyG index). The constructed nomogram provides a useful tool for initial risk assessment. These findings call for integrated public health strategies that promote healthy lifestyles, with a focus on weight management and metabolic health, targeting middle-aged and rural populations. Future prospective studies are essential to confirm causal pathways and to evaluate the effectiveness of interventions guided by such risk prediction models.

Author Contributions

Resources: X.O., D.C., W.Q., X.Z. and D.L. Data curation: X.O., D.C., D.L. and B.H. Writing original draft: X.O., D.C. and X.Z. Formal analysis: D.L. and B.H. Validation: D.L. and B.H. Writing review and editing: L.X.,

Y.H. and X.-E.P. Conceptualization: L.X., Y.H. and X.-E.P. Methodology: Y.H. and X.-E.P. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study protocol received approval from the Ethics Committee of the Branch for Medical Research and Clinical Technology Application at The First Affiliated Hospital of Fujian Medical University (IEC-FOM-013-2.0). This study was conducted in accordance with the guidelines of the 1975 Declaration of Helsinki revised in 2013 and followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cross-sectional studies.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patients to publish this paper.

Data Availability Statement

The corresponding author can be contacted for reasonable requests regarding the analytical methods or code applied in this research.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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