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Development and validation of a nomogram model for predicting the risk of H-type hypertension with pulse diagram parameters

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ABSTRACT

Objective To develop an onset risk prediction nomogram for patients with homocysteine-type (H-type) hypertension (HTH) based on pulse diagram parameters to assist early clinical prediction and diagnosis of HTH.

Methods Patients diagnosed with essential hypertension and admitted to Shanghai Shuguang Hospital Affiliated to Shanghai University of Traditional Chinese Medicine, Shanghai Hospital of Traditional Chinese Medicine, and Shanghai Hospital of Integrated Traditional Chinese and Western Medicine from July 6th 2020 to June 16th 2021, and from August 11th 2023 to January 22nd 2024, were enrolled in this retrospective research. The baselines and clinical biochemical indicators of patients were collected. The SMART-I TCM pulse instrument was applied to gather pulse diagram parameters. Multivariate logistic regression was adopted to analyze the risk factors for HTH. RStudio was employed to construct the nomogram model, receiver operating characteristic (ROC) curve, and calibration curve (bootstrap self-sampling 200 times), and clinical decision curve were drawn to evaluate the model's discrimination and clinical effectiveness.

Results A total of 168 hospitalized patients with essential hypertension were selected and divided into non-HTH group (n = 29) and HTH group (n = 139). Compared with non-HTH group, HTH group had a lower body mass index (BMI), and higher proportions of male patients and drinkers (P < 0.05). The ventricular wall thickening (VWT) could not be determined. The proportions of left common carotid intima-media wall thickness (LCCIMWT) and serum creatinine (SCR) were higher in HTH group (P < 0.05). The pulse diagram parameter As was significantly higher, and H4/H1 and T1/T were lower in HTH group (P < 0.05). Gender, alcohol consumption, serum creatinine, and the pulse diagram parameter H4/H1 were identified as independent risk factors for HTH (P < 0.05). The nomogram's area under the ROC curve (AUC) was 0.795 [95% confidence interval (CI): (0.706 6, 0.882 8)], with a specificity of 0.724 and sensitivity of 0.799. After 200 times repeated bootstrap self-samplings, the calibration curve showed that the simulated curve fits well with the actual curve (x^2 = 9.500 2, P = 0.301 9). The clinical decision curve indicated that the nomogram's applicability was optimal when the threshold for predicting HTH was between 0.38 and 1.00.

Conclusion The nomogram model could be valuable for predicting the onset risk of HTH and pulse diagram parameters can facilitate early screening and prevention of HTH.

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1 Introduction

Hypertension, a globally prevalent chronic condition, represents a significant risk factor for cardiovascular and cerebrovascular diseases. In China, the prevalence of hypertension stands at a relatively high level, reaching 31.6% [1]. Homocysteine, a sulfur-containing amino acid intermediate [plasma homocysteine (Hcy)], is of particular interest. Hyperhomocysteinemia, recognized as an independent risk factor for atherosclerosis, is closely related to cardiovascular and cerebrovascular disorders [2]. Hypertension accompanied by hyperhomocysteinemia, also known as homocysteine-type (H-type) hypertension (HTH), significantly increases the onset risk of cardiovascular and cerebrovascular disorders due to the synergistic effect of both conditions [3]. Studies have shown that three-quarters of hypertension cases in China are HTH [4,5].

Traditional Chinese medicine (TCM) employs the four diagnostic methods as the foundation for syndrome differentiation and treatment. Pulse diagnosis, a unique clinical diagnostic method in TCM, has advanced in parallel with the development of various pulse diagnosis instruments. Time domain analysis of pulse diagram parameters is widely used in relevant research. Study has shown that pulse patterns in hypertensive patients are correlated with their cardiovascular status [6]. Elevated homocysteine levels are associated with vascular endothelial injury, and pulse diagnosis techniques can detect the degree of vascular injury and hardening. However, there is currently a lack of systematic research exploring the diagnostic value of pulse diagnosis in evaluating Hcy-related vascular injury, highlighting the urgent need for further investigation in this field. Thus, the correlation between pulse diagram parameters and vascular function in patients with HTH calls for further exploration. This study aims to construct a risk prediction nomogram model for HTH based on pulse diagram parameters through retrospective analysis, furnishing a TCM-based reference for the prevention and treatment.

2 Materials and methods

2.1 Study participants

Patients with essential hypertension, admitted to Shuguang Hospital Affiliated to Shanghai University of Traditional Chinese Medicine, Shanghai Hospital of Traditional Chinese Medicine, and Shanghai Hospital of Integrated Traditional Chinese and Western Medicine from July 6th 2020 to June 16th 2021, and from August 11th 2023 to January 22nd 2024, were enrolled in this retrospective study. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Medical Ethics Committee of Shanghai University of Traditional Chinese Medicine (2023-3-10-08-08), and informed consent was obtained from all participants.

2.2 Diagnostic criteria

2.2.1 Essential hypertension The diagnostic criteria for essential hypertension were based on 2018 Chinese Guidelines for the Management of Hypertension (Revised Edition) [7].

2.2.2 HTH According to clinical Hcy levels, patients were divided into HTH group (Hcy $\geqslant$ 10 μmol/L) and non-HTH group (Hcy < 10 μmol/L) [8].

2.3 Inclusion and exclusion criteria

2.3.1 Inclusion criteria (i) Patients aged 22 – 85 years. (ii) Patients with symptoms meeting the diagnostic criteria of essential hypertension. (iii) Patients who voluntarily consented to participate in the study and signed the informed consent form.

2.3.2 Exclusion criteria (i) Patients with secondary hypertension. (ii) Patients with congenital heart disease, pulmonary heart disease, or pleural effusion. (iii) Patients with severe hepatic or renal dysfunction. (iv) Patients with pregnancy. (v) Patients with mental illness or dementia. (vi) Patients with malignant tumors. (vii) Patients with incomplete medical records or clinically collected indexes.

2.4 Data collection and measurement

2.4.1 Clinical data The common risk factors of hypertension were identified according to 2018 Chinese Guidelines for the Management of Hypertension (Revised Edition) [7]. Patients' baseline characteristics including gender, age, body mass index (BMI), smoking, alcohol consumption, the blood pressure index, blood biochemical index, and ultrasound index were recorded. Data on left ventricular hypertrophy (LVH), left ventricular internal diameter enlargement (LVIDE), ventricular wall thickening (VWT), ejection fraction (EF), left ventricular end-diastolic diameter (LVEDD), interventricular septal thickness (IST), left ventricular posterior wall thickness (LVPWT), left ventricular mass index (LVMI), arterial plaque (AP), left common carotid diameter (LCCD), left common carotid intima-media wall thickness (LCCIMWT), left common carotid peak systolic flow velocity (LCCPSFV), and left common carotid resistance index (LCCRI) were included. Blood biochemical indicators including triglyceride (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), serum uric acid (SUA), serum creatinine (SCR), serum urea (SU), glycosylated hemoglobin (GHB), Hcy, and albumin (ALB) were identified.

2.4.2 Collection of pulse diagram parameters The SMART-I TCM pulse instrument was used to collect pulse information from the patient's left hand. Each patient rested for at least 5 min before the examination in a relaxed sitting or lying position. During collection, the left forearm was kept level with the heart, relaxed with the palm up and fingers slightly curled. A pulse pillow was placed under the patient's wrist to help them relax. The pressure sensor was fine-tuned to find the optimal pulse-taking location and pressure, then 60 s of data were collected for pulse diagram parameter analysis.

2.4.3 Time domain parameters of the pulse diagram The SMART-I TCM pulse instrument automatically analyzed pulse time domain parameters, including H1, H3, H4, H5, T1, T4, T5, T, W1, W2, As, Ad, As/Ad, H3/H1, H4/H1, H5/H1, T1/T, T1/T4, T5/T4, W1/T, and W2/T [4] (Figure 1).

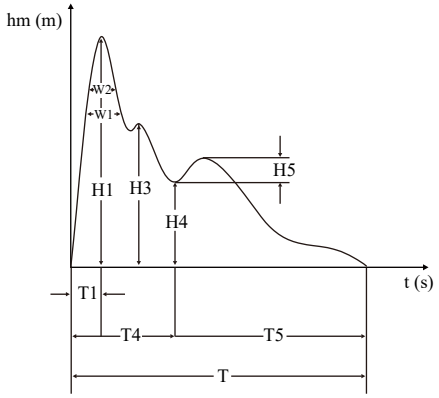

Figure 1 One representative cycle of a pulse waveform and time domain parameters of the pulse diagram

2.5 Statistical methods

Data were entered into Excel 2013 and analyzed using SPSS 25.0 with a two-person entry verification method. Data of basic information, such as age, gender, and BMI, were analyzed. The next step was a univariate analysis. Since the measurement data did not meet the normality and homogeneity of variance, the non-parametric rank sum test (Mann-Whitney *U* test) was used for inter-group comparison and represented by median (Q1, Q3). The counting data were expressed as the number of cases *n* (%), and the Chi-square test was applied for inter-group comparison. Differences were considered statistically significant with $P < 0.05$, from which statistical variables were screened. In multivariate logistic regression analysis (backward stepwise), the dependent variable was HTH (yes = 1, no = 0), and the statistically significant physical and chemical indexes and pulse diagram parameters from the previous analysis were used as independent variables. According to World Health Organization (WHO) classification, BMI was divided into three groups: 1 [underweight (< 18.5)], 2 [normal (18.5 – 24.9)], and 3 [overweight (≥ 25.0)]. The remaining continuous variables were classified into three grades using the SPSS visual split box. The graded variables were converted into dummy variables, and compared with the first grade to identify risk factors independently associated with HTH. The pulse diagram parameters independently associated with HTH were identified. Logistic regression model was adopted to generate a nomogram model based on the risk factors and pulse diagram parameters in RStudio. The bootstrap method was employed for repeated sampling 200 times. The receiver operating characteristic (ROC) curve was used to evaluate the model's discrimination. The Hosmer-Lemeshow goodness-of-fit test was used to evaluate the model's calibration, and the decision analysis curve was adopted to evaluate the clinical practicability of the model.

3 Results

3.1 Comparison of the general information

A total of 526 patients were enrolled initially. After excluding 358 patients with incomplete medical records and missing physical and chemical indexes, 168 patients were finally enrolled in the study, with 80 male patients and 88 female patients. These patients were divided into HTH group (n = 139) and non-HTH group (n = 29) (Figure 2).

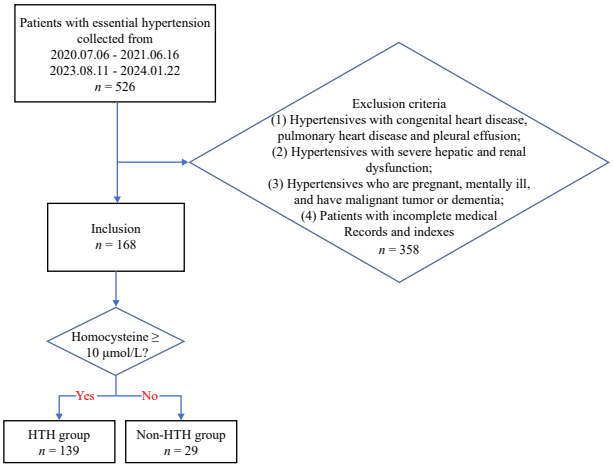

Figure 2 Flow diagram of the inclusion process of study subjects

There were no significant differences between HTH and non-HTH groups in age, smoking status, LVH, LVIDE, EF, LVEDD, IST, LVPWT, AP, LCCD, LCCPSFV, LCCRI, TG, HDL-C, LDL-C, SUA, SU, GHB, and ALB ($P > 0.05$). Compared with non-HTH group, HTH group had a lower BMI and higher proportions of males and drinkers ($P < 0.05$). In HTH group, VWT (no), and the values of LCCIMWT and SCR were significantly higher ($P < 0.05$) (Table 1).

Table 1 Analysis of the baseline data and general data of HTH and non-HTH groups

Group	Age (year)	BMI (kg/m²)	Gender [*n* (%)]		IST (mm)	LVPWT (mm)	EF (%)	LVEDD (mm)
			Male	Female				
Non-HTH	67 (59, 73.5)	27.34 (23.06, 30.39)	9 (31)	20 (69)	10 (9, 10)	10 (9, 10)	66 (61, 67)	49 (47, 51)
HTH	69 (65, 73)	24.80 (22.66, 27.27)	71 (51.1)	68 (48.9)	10 (9, 10)	10 (9, 10)	65 (62, 69)	49 (45, 52)
Z/X^2 value	*Z* = – 0.983	*Z* = – 2.05	X^2 = 3.865a		*Z* = – 0.942	*Z* = – 1.485	*Z* = – 0.85	*Z* = – 0.474
P value	0.325	0.040	0.049		0.346	0.138	0.395	0.636

Group	Smoking [*n* (%)]		Alcohol consumption [*n* (%)]		LCCD (mm)	LCCIMWT (mm)	LCCPSFV (cm/s)	LCCRI
	Yes	No	Yes	No				
Non-HTH	8 (27.6)	21 (72.4)	6 (20.7)	23 (79.3)	6.9 (6.4, 7.5)	0.8 (0.7, 0.9)	67 (57.5, 85.5)	0.73 (0.665, 0.79)
HTH	65 (46.8)	74 (53.2)	63 (45.3)	76 (54.7)	6.8 (6.3, 7.5)	0.8 (0.7, 1)	68 (51, 79)	0.75 (0.7, 0.78)
Z/X^2 value	X^2 = 3.591a		X^2 = 6.016a		*Z* = – 0.24	*Z* = – 2.157	*Z* = – 1.096	*Z* = – 1.398
P value	0.058		0.014		0.811	0.031	0.273	0.162

Group	LVH [*n* (%)]		LVIDE [*n* (%)]		TG (mmol/L)	HDL-C (mmol/L)	LDL-C (mmol/L)	SUA (μmol/L)
	Yes	No	Yes	No				
Non-HTH	11 (37.9)	18 (62.1)	11 (37.9)	18 (62.1)	1.59 (1, 2.255)	1.12 (0.9, 1.34)	2.63 (1.795, 3.27)	3 219.1 (244.9, 390.35)
HTH	44 (31.7)	95 (68.3)	44 (31.7)	95 (68.3)	1.37 (1.07, 1.88)	1.03 (0.9, 1.26)	2.56 (1.93, 3.31)	348.6 (278.5, 421.2)
Z/X^2 value	X^2 = 0.429a		X^2 = 0.429a		*Z* = – 0.789	*Z* = – 0.544	*Z* = – 0.048	*Z* = – 1.419
P value	0.512		0.512		0.430	0.587	0.962	0.156

Group	VWT [*n* (%)]		AP [*n* (%)]		SCR (μmol/L)	SU (mmol/L)	GHB (%)	ALB (g/L)
	Yes	No	Yes	No				
Non-HTH	7 (24.1)	22 (75.9)	17 (58.6)	12 (41.4)	62 (54.7, 70.3)	5.2 (4.11, 6.345)	6 (5.45, 6.5)	40 (38.3, 42.75)
HTH	13 (9.4)	126 (90.6)	91 (65.5)	48 (34.5)	71 (60, 86.6)	5.6 (4.7, 6.9)	5.9 (5.5, 6.7)	40.4 (37, 43.7)
Z/X^2 value	X^2 = 5.001a		X^2 = 0.490a		*Z* = – 2.984	*Z* = – 1.393	*Z* = – 0.246	*Z* = – 0.162
P value	0.025		0.484		0.003	0.163	0.806	0.872

a, the regression coefficient, the weight of influence on a variable.

3.2 Comparison of the pulse diagram parameters between HTH and non-HTH groups

The pulse diagram parameter As in HTH group were significantly higher than those in non-HTH group ($P < 0.05$). Additionally, the pulse diagram parameters H4/H1 and T1/T in HTH group were lower than those in non-HTH group ($P < 0.05$) (Table 2). There were no significant differences between HTH and non-HTH groups in H1, H3, H4, H5, T1, T4, T5, T, W1, W2, Ad, As/Ad, H3/H1, H5/H1, T1/T4, T5/T4, W1/T, or W2/T ($P > 0.5$).

3.3 Multivariate logistic regression analysis

The results showed that gender and alcohol consumption were independent risk factors for HTH. In the classification of H4/H1, grade 3 was a protective factor against HTH compared with grade 1 (OR = 0.198, $P < 0.05$), while grade 2 was not statistically significant compared with grade 1 ($P > 0.05$). For SCR, the incidence of HTH for grade 3 was 8.077 times higher than for grade 1 (OR = 8.077, $P < 0.05$), while grade 2 was not statistically significant compared with grade 1 ($P > 0.05$) (Table 3 and Figure 3).

Table 2 Comparison of the pulse diagram parameters of HTH and non-HTH groups

Group	H4/H1	As	T1/T
Non-HTH	0.42 (0.35, 0.51)	140 412 (72 125.55, 264 732.94)	0.18 (0.16, 0.20)
HTH	0.38 (0.29, 0.44)	233 104 (91 972.7, 332 324)	0.17 (0.15, 0.19)
Z value	– 2.172	– 2.042	– 1.977
P value	0.030	0.041	0.048

Table 3 Multivariate logistic regression analysis for risk factors of HTH

Factor	Alcohol consumption	[BMIWHO]2	[BMIWHO]3	TVW
B	2.787	– 0.045	– 1.160	– 1.036
SE	1.000 89	1.271 28	1.246 47	0.608 21
OR	16.228	0.956	0.313	0.355
95% CI	16.220 (2.272 – 125.4)	0.956 (0.040 – 8.991)	0.313 (0.013 – 2.697)	0.354 (0.107 – 1.199)
Z value	2.784	– 0.035	– 0.931	– 1.703
P value	0.005	0.972	0.352	0.089

Factor	[SCR]2	[SCR]3	[H4/H1]2	[H4/H1]3	Gender
B	0.445	2.089	– 0.823	– 1.618	2.410
SE	0.528 94	0.779 4 5	0.651 6 6	0.638 91	0.999 6
OR	1.560	8.077	0.439	0.198	11.134
95% CI	1.560 (0.559 – 4.531)	8.077 (1.978 – 45.08)	0.439 (0.112 – 1.515)	0.198 (0.051 – 0.652)	11.130 (1.569 – 86.81)
Z value	0.841	2.680	– 1.263	– 2.532	2.411
P value	0.400	0.007	0.206	0.011	0.016

B represents the regression coefficient, and SE is the standard error. [BMIWHO]2, [BMIWHO]3, [SCR]2, [SCR]3, [H4/H1]2, and [H4/H1]3 are transformed grading variables, referring to the Section 2.5 for further details.

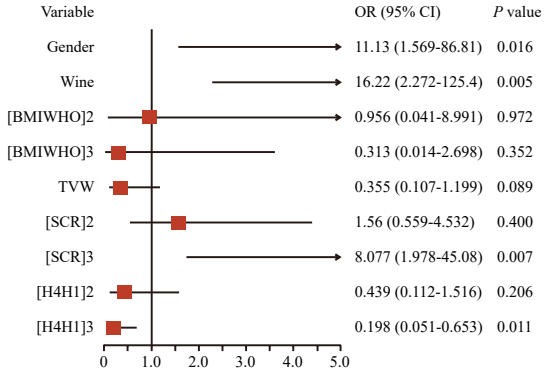

Figure 3 Forest plot of multifactor logistic regression analysis for risk factors of HTH

3.4 Establishment and evaluation of the nomogram model

A nomogram model was constructed based on independent predictors (gender, alcohol consumption, BMI, SCR, and H4/H1) identified by multivariate logistic regression analysis (Figure 4). Each variable's influence on the outcome variable was quantified in the nomogram model: gender (level 1 = 0 points, level 2 = 86 points), alcohol consumption (level 1 = 100 points), SCR (level 1 = 0 points, level 2 = 16 points, level 3 = 75 points), and H4/H1 (level 1 = 58 points, level 2 = 29 points, level 3 = 0 points). The total score for each case of essential hypertension was calculated by summing the points for all variables, and the probability of HTH was derived from the total score.

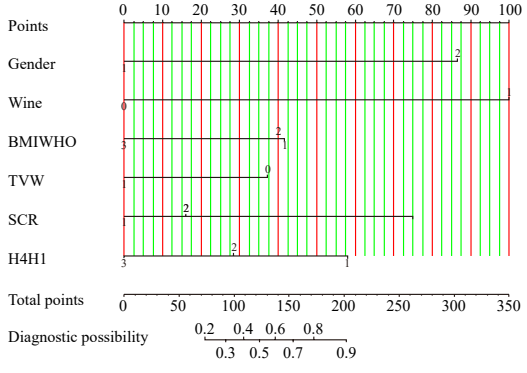

Figure 4 HTH onset risk prediction nomogram model

The ROC curve was used to evaluate the nomogram model's discrimination. An area under the ROC curve (AUC) of 0.795 with 95% CI = (0.706 6 – 0.882 8), a specificity of 0.724, and a sensitivity of 0.799 indicated good differentiation and diagnostic efficacy (Figure 5).

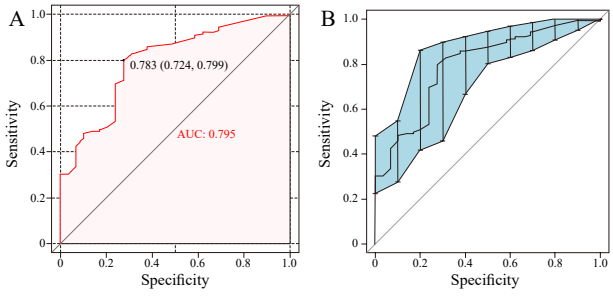

Figure 5 ROC curve of the nomogram model

A, ROC curve of the training set. B, ROC curve of the internal verification set.

Calibration curves were used to assess the model's accuracy, with the bootstrap method applied for 200 repeated samplings to internally validate the model. The Hosmer-Lemeshow goodness-of-fit test showed good calibration (x^2 = 9.500 2, P = 0.301 9). The calibration curve closely matched the ideal curve when predicted probability values were greater than 0.5, indicating that the predicted values were consistent with the measured values and the model's prediction accuracy was acceptable (Figure 6).

The clinical decision curve indicated that the nomogram model's applicability was optimal when the threshold for predicting HTH was between 0.38 and 1.00 (Figure 7).

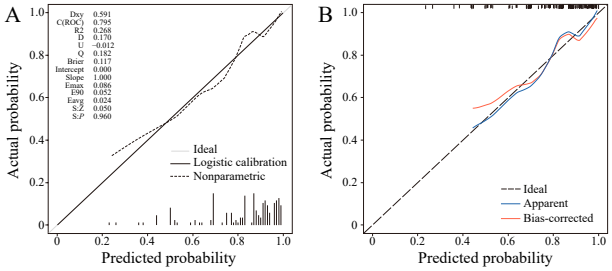

Figure 6 Calibration curve of the nomogram model

A, calibration curve of the training set. B, calibration curve of the internal verification set.

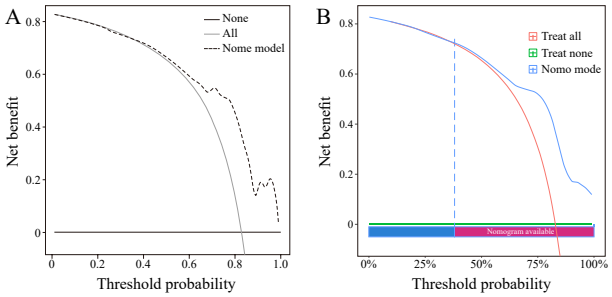

Figure 7 Decision analysis curve of the nomogram model

A, decision analysis curve of the training set. B, decision analysis curve of the internal verification set.

4 Discussion

HTH represents the most prevalent form of hypertension (three-quarters of all cases). In China, the incidence of HTH has been on an annual upward trend and is a significant risk factor for stroke [9]. This is likely associated with the damage to the brain and cardiovascular system caused by the release of catecholamines, which is induced by homocysteine [10]. Patients with HTH experience a higher frequency of cardiovascular events with stroke risk increased by 12-fold, particularly in women [11]. Therefore, early screening, along with accurate prevention and treatment of HTH, is of utmost importance in reducing the risk of hypertensive stroke.

According to TCM, vessels are the “palaces of blood”, governed by the heart. Pulse manifestations reflect the functions of the zang-fu organs and the balance of Yin, Yang, Qi, and blood. TCM-identified pulse characteristics, when linked to modern pulse wave analysis, can reveal physiological and pathological states of blood vessels. Time domain analysis, a common method for pulse diagram analysis, measures the amplitude and time values of pulse manifestations to analyze pulse wave characteristics [12]. The pulse diagram period aligns with the heartbeat cycle and includes the main wave, pre-beat wave, falling isthmus, and re-beat wave. The amplitude and timing of these waves reflect peripheral resistance, vascular structure, and arterial elasticity [13]. Thus, TCM pulse detection could serve as a clinical tool for evaluating vascular function in cardiovascular disease patients.

In this study, 168 patients were divided into HTH and non-HTH groups to explore risk factors of HTH. The results showed significant differences in alcohol consumption, gender, SCR, and H4/H1. Among them, the female gender was an independent risk factor for HTH, which is contrary to previous studies. The data did not show significant collinearity among the variables in the model, suggesting the potential presence of multiple confounding effects from gender, alcohol consumption, and BMI. SCR and the pulse diagram parameter H4/H1 were independent risk factors for HTH, where high SCR values and low H4/H1 values were positively correlated with the onset risk of HTH.

4.1 The correlation between pulse diagram parameters and the risk of HTH

In the presence of aortic valve insufficiency, blood backflow, an increased pulse pressure difference, or a sudden drop in blood volume, the heart compensates by increasing its beats, and H4/H1 may show a decreasing trend [12]. FESLER et al. [14] conducted a study and follow-up on 132 untreated primary hypertensive patients and found that the pulse pressure difference was negatively correlated with the decline in renal function in primary hypertensives, which corroborates the results of this article. From the perspective of TCM, the decline in renal function in hypertensive patients is related to the long-term imbalance of the Qi, blood, and Yin-Yang in the liver and kidneys, and the inadequate nourishment of the kidney meridians. This can ultimately result in the partial or complete loss of the kidney’s main function in regulating water and controlling its opening and closing for water excretion and retention [15]. Furthermore, study has shown that the average 24-h pulse pressure difference of HTH patients was significantly greater than that of non-HTH patients [16]. This might be related to the fact that Hcy promotes the proliferation and enlargement of the middle layer of vascular smooth muscle cells, leading to vessel wall stiffening and reduced elasticity [17]. Therefore, changes in pulse wave parameters are related to the onset risk of developing HTH.

4.2 The correlation between cardiovascular risk factors and HTH

Serum creatinine is formed through irreversible non-enzymatic dehydration, released into the blood, and excreted in urine, reflecting kidney function to some extent. Many patients with hypertension at different stages can have abnormal kidney function. The kidney is an important metabolic site for homocysteine, so serum creatinine is closely linked to homocysteine [18]. Declining renal function leads to the accumulation of homocysteine in the body. Studies have confirmed that homocysteine can

contribute to kidney disease through oxidative stress and other mechanisms, further reducing renal function [19]. Additionally, elevated homocysteine levels may induce renal vascular injury, and damage to the renal structure can promote the generation of homocysteine [20]. This study showed a positive correlation between serum creatinine and HTH, consistent with the positive correlation between serum creatinine and homocysteine reported by CHENG et al. [21]. LENG et al. [22] also found that creatinine was positively correlated with the incidence of HTH in women and was a risk factor.

4.3 The significance of the model

The nomogram model constructed in this study exhibited an AUC of 0.795, indicating that the model had good diagnostic efficiency and was capable of predicting the onset risk of HTH. The calibration curves and goodness-of-fit tests confirmed that the model had high predictive accuracy. The decision curve analysis showed that the model could provide clinical benefits to patients. To date, no nomogram for HTH has been reported. The development of this nomogram holds significant promise for clinical applications. It can facilitate early intervention in HTH, thereby improving prevention and treatment outcomes. Moreover, it can assist physicians in personalizing follow-up care, determining the appropriate frequency of follow-up visits, and deciding whether additional testing is required. Consequently, constructing a predictive model for HTH carries substantial potential value for clinical practice.

These results suggest that pulse diagram parameters can facilitate early screening and prevention of HTH. Furthermore, integrating the assessment of pulse diagram parameters into hypertension management programs can enhance the effectiveness and comprehensiveness of hypertension health management. The results represent an initial foray into ascertaining the efficacy of pulse diagram parameters in the self-management of HTH. These findings will lay the groundwork for future research on the translation of HTH risk factors within the framework of an internet-based group health administration model. The aim of this study is to improve the long-term lifestyle intervention compliance and reduce the incidence of HTH. The findings will strengthen the management of risk factors. This, in turn, will enable individuals to make well-informed decisions regarding their condition. However, the study has several limitations. First, being a retrospective study, it failed to establish the causal relationship with HTH. Second, as a single-center study, it may have potential selection bias. Third, confounding factors might have influenced the model. Fourth, only internal validation has been conducted, lacking external validation from other centers. Future research should focus on controlling the confounding factors with prospective studies. Additionally, multi-center data collection, expansion of sample sizes based on the population in different regions, and performance of external validation are necessary to improve the model. These endeavors would provide a stronger theoretical basis for the applications of pulse diagram parameters to assess the onset risk of cardiovascular diseases.

5 Conclusion

The onset risk of HTH was related to gender, alcohol consumption, serum creatinine, and the pulse diagram parameter H4/H1. Among these, H4/H1 emerged as an independent risk factor for HTH. The low value of H4/H1 not only mirrored the pathological manifestations of an increased pulse pressure difference in HTH but also indirectly indicated the pathological elevation of the SCR value in HTH. The findings will specifically improve health outcomes of chronic cardiovascular and cerebrovascular disease, enhance daily living functionality, and alleviate direct medical costs for families while optimizing inpatient resource allocation within the healthcare system.

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Competing interests

The authors declare no conflict of interest.

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基于脉图参数的 H 型高血压风险预测列线图模型构建与验证

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【摘要】目的 基于脉图参数构建 H 型高血压（HTH）发病风险预测列线图模型，为 HTH 的早期临床预测和诊断提供辅助依据。**方法** 研究选取 2020 年 7 月 6 日至 2021 年 6 月 16 日以及 2023 年 8 月 11 日至 2024 年 1 月 22 日期间在上海中医药大学附属曙光医院、上海市中医医院及上海市中西医结合医院住院的原发性高血压的患者。收集患者的一般信息和临床生化指标，并使用 SMART-I 中医脉象仪采集脉图参数。采用多因素逻辑回归分析 HTH 的危险因素，利用 RStudio 构建列线图，并绘制受试者工作特征（ROC）曲线、校准曲线（bootstrap 自助抽样 200 次）和临床决策曲线，评估模型的区分度和临床效能。**结果** 共纳入 168 例住院的原发性高血压患者，分为非 HTH 组（$n = 29$）和 HTH 组（$n = 139$）。H 型高血压组身体质量指数（BMI）显著低于非 HTH 组，男性患者比例和饮酒者比例显著高于非 HTH 组（$P < 0.05$）。HTH 组室壁增厚（VWT）、左颈总动脉内膜中层厚度（LCCIMWT）和血清肌酐（SCR）显著高于非 HTH 组（$P < 0.05$）。HTH 组脉图参数 As 显著高于非 HTH 组，H4/H1、T1/T 显著低于非 HTH 组（$P < 0.05$）。性别、饮酒、血清肌酐及脉图参数 H4/H1 是与 HTH 独立相关的危险因素（$P < 0.05$）。列线图模型的 ROC 曲线下面积（AUC）为 0.795 [95% 置信区间（CI）：（0.706 6，0.882 8）]，特异度为 0.724，敏感度为 0.799。bootstrap 自助抽样 200 次后，校准曲线显示模拟曲线与实际曲线拟合良好（$x^2 = 9.500\,2$，$P = 0.301\,9$）。临床决策曲线显示，列线图模型预测 HTH 的发生阈值在 0.38 – 1.00 之间时，该模型的适用性最佳。**结论** 基于脉图参数构建的列线图可为 HTH 的发病风险预测提供参考依据，脉图参数的检测有助于 HTH 的早期筛查和预防。

【关键词】H 型高血压；同型半胱氨酸；列线图；脉图参数；预测模型