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ORIGINAL RESEARCH

Development and Validation of a Risk Score Screening Tool to Identify People at Risk for Hypertension in Shanghai, China

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Purpose: This study aimed to develop a screening tool based on a risk scoring approach that could identify individuals at high risk for hypertension in Shanghai, China.

Methods: A total of 3147 respondents from the 2013 Shanghai Chronic Disease and Risk Factor Surveillance were randomly divided into the derivation group and validation group. The coefficients obtained from multivariable logistic regression were used to assign a score to each variable category. The receiver operating characteristic (ROC) curve was used to find the optimal cut-off point and to evaluate the screening performance.

Results: Age, family history of hypertension, having diabetes, having dyslipidemia, body mass index, and having abdominal obesity contributed to the risk score. The area under the ROC curve was 0.817 (95% CI: 0.797–0.836). The optimal cut-off value of 20 had a sensitivity of 83.4%, and a specificity of 64.3%, demonstrating good performance.

Conclusion: We developed a simple and valid screening tool to identify individuals at risk for hypertension. Early detection could be beneficial for high-risk groups to better manage their conditions and delay the progression of hypertension and related complications.

Keywords: Eastern China, high-risk population, hypertension, risk scoring method, screening tool

Introduction

Hypertension has become a major public health problem around the world.[1] Hypertension and its complications accounted for more than 50% of the 17 million deaths caused by cardiovascular disease every year.[2] The population at risk for hypertension is a group with prevalent risk factors or characteristics and hence with a higher risk for hypertension than the general population.[3] The risk of developing hypertension in this group was doubled than those with normal blood pressure (BP).[4] Epidemiological studies have indicated that the prevalence of people at risk for hypertension was more than 40% in China.[5] A growing body of evidence has suggested that early identification and management of the people at risk for hypertension could be of great benefit to control the cardiovascular events, delay the onset of hypertension and reduce the disease and economic burden.[6,7] Therefore, development of a low-cost screening tool for population-based early identification of high-risk individuals is a critical public health strategy.

The blood pressure measured by trained general practitioners was commonly used to identify individuals at risk for hypertension in the community, according to the Guidelines for the Prevention and Treatment of Hypertension in the

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USA,[8] Europe,[9] and China.[10] Several studies also used BP to height ratios,[11] height-specific BP percentile charts,[12] or waist circumference (WC)[13] to identify the high-risk individuals. However, BP is dynamic and can only give information on a subject's current status, which may lead to misclassification of high-risk individuals with other risk factors. As the majority of adults have at least one risk factor for hypertension,[14] the application of the risk scoring method has advantages in identifying people at high risk for cardiovascular disease.[15] This method has been widely used in the screening of asymptomatic people with diabetes,[16,17] dementia,[18] and sleep-disordered breathing.[19] Several studies also used this method to predict the probability of incident hypertension.[20–22] However, they did not use this method to screen the people at risk for the purpose of hypertension prevention. To our knowledge, only one study used the method for the early identification of high-risk individuals in primary care settings, which was conducted in rural India.[23] Currently there were no such tools available for Chinese population.

Our study aimed to develop a simple and valid screening tool to prospectively identify people at risk for hypertension based on the risk scoring approach, and evaluate the performance of this tool in a cross-sectional setting. This screening tool could help general practitioners to identify high-risk individuals to potentially prevent them from developing hypertension.

Materials and Methods

Study Design and Data

Data for this study were from the survey of Shanghai Chronic Disease and Risk Factors Surveillance in 2013, where a sample of residents aged 15 years or above who had lived in Shanghai for more than 6 months was interviewed.[24] The survey was carried out by Shanghai Municipal Center for Disease Control and Prevention (CDC), with the supports of all 16 district-level CDCs from May to July 2013.

The stratified multistage random sampling method was used in the survey. First, sixteen districts were divided into two groups: urban and sub-urban. Sixty townships or communities were randomly selected in each group. Second, within each sampled township or community, four villages or neighborhood blocks were selected by probability proportional to size sampling. The sampled villages or neighborhood blocks were divided into several lanes according to their geographical location, where each lane consisted of about 50 households. Third, two lanes were randomly selected from each sampled village or neighborhood block. Fourth, 27 households were randomly selected from each sampled lane and one person was picked up to participate in the survey from the selected household through the Kish Grid sampling method. Finally, a total of 25,657 respondents participated in the survey. All the participants were interviewed face-to-face by trained interviewers, using a structured questionnaire. Questionnaires included demographic information, socioeconomic status, clinical conditions (eg disease history of diabetes and dyslipidemia, family history of hypertension), physical examination information (eg height, weight, waist circumference, BP), health-related behaviors (eg diets, drinking alcohol, smoking). Hypertension was defined as: (i) having an average systolic BP of 140 mmHg or higher or (ii) having an average diastolic BP of 90 mmHg or higher, or (iii) the respondent was currently taking antihypertensive medications (either Western or traditional Chinese medications) to manage hypertension condition.[25] BP was measured by the trained general practitioners, following the standard procedure recommended by the Chinese Guidelines for the Prevention and Treatment of Hypertension. After resting quietly in a seated position for 5 minutes, 3 consecutive BP readings were obtained by the automated validated Omron electronic sphygmomanometer (OMRON Corporation, Kyoto, Japan).

The sample in this study included respondents from one urban and one sub-urban district, with a total of 3495 respondents. After excluding 348 individuals with incomplete information, our final sample consisted of 3147 respondents who had provided complete data for all variables. Comparing the age distributions (Myer's index=7.77, less than 60) of the 3147 respondents against those of all residents in Shanghai in 2013 suggested that the sample was representative of the population in Shanghai for age and population structure.[26,27] The study respondents were then randomly divided into two groups of similar size, one for developing the screening algorithm (1573 cases) and the other for validating (1574 cases). The flowchart of sample selection was shown in Figure 1.

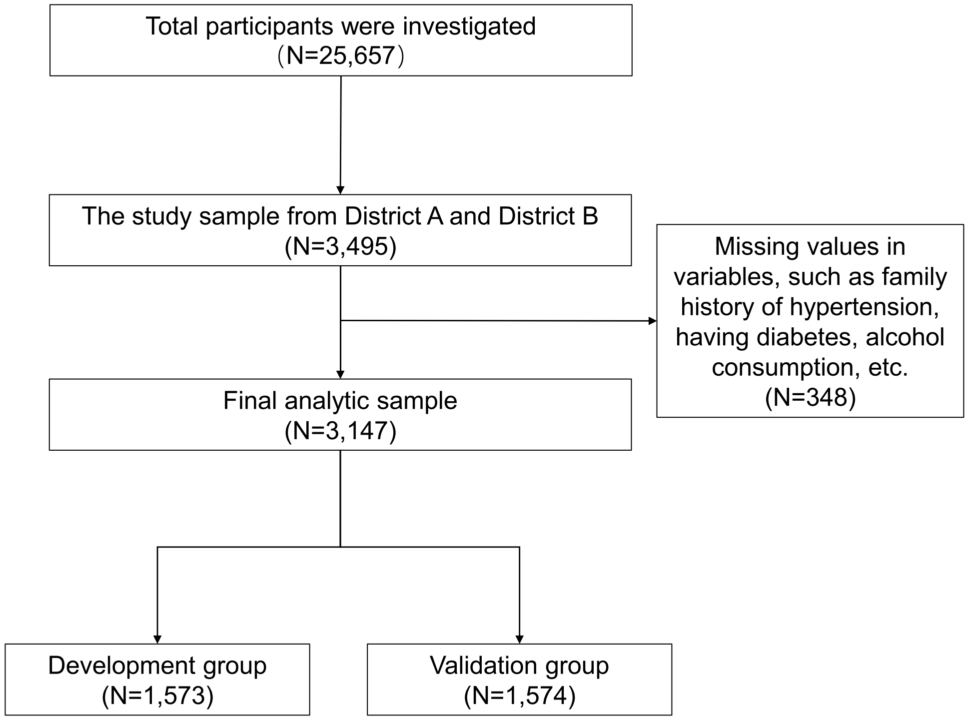

Figure 1 Flowchart of sample selection from the survey of Shanghai Chronic Disease and Risk Factors Surveillance in 2013.

Developing the Screening Tool

Risk factors associated with hypertension were selected to be evaluated, both from literature and clinical knowledge. To keep the screening tool simple and easy to use, we excluded information that can only be assessed in laboratory tests or other clinical measurements, as well as interaction terms in the model. The variables included in the model were age (<60 years; ≥60 years), sex, educational levels (junior high school or below; high school or above), marital status (single; married), smoking (never; previous smoker; smoking but not every day; smoking every day), average frequency of drinking alcohol (never; <1 day a month; 1–3 days a month; 1–4 days a week; ≥5 days a week), average frequency of consumption of meat/vegetables/fresh fruits in a week (< once per day; ≥ once per day), salt intake (low (< 6g per day); moderate (6–9g per day); high (≥ 9g per day)), sleep quality (defined by the average frequency of being unable to sleep or hard to sleep well in a week, and categorized into three groups: good (never); medium (1–3 days per week); poor (≥ 3 days per week)), body mass index (BMI,<24kg/m^2; ≥24kg/m^2), abdominal obesity (Yes/No, waist circumference ≥90 cm in males or ≥85 cm in females), family history of hypertension (Yes/No), having diabetes (Yes/No), and having dyslipidemia (Yes/No).

Each selected variable was separately tested for their association with the status of hypertension using Pearson's Chi-square test. Variables significant in the tests were included in the multivariable logistic model using stepwise backward elimination, with the status of hypertension as the dependent variable. The screening tool was then established, including all variables that were kept in the final model. For each variable, the risk score was derived by multiplying the regression coefficients by 10 and rounding to the nearest integer. The reference category of each variable was given a score of 0. A sum score was calculated for each participant by adding the score of each variable.

Validating the Screening Tool

The screening tool was tested for sensitivity and specificity in the validation group, independent of the group in which the score was derived. The receiver operating characteristic (ROC) curve was used to obtain the optimal cut-off value for the risk score. The performance of the screening tool was evaluated according to the area under the curve (AUC) in the ROC curve, sensitivity, specificity, the positive predictive value, and the negative predictive value with 95% Confidence

Intervals (CIs). In general, an AUC of more than 0.8 indicates excellent discrimination.[28] Furthermore, the trend of the risk score categories and the prevalence of hypertension were calculated using the Trend Chi-square test.

Statistical Analysis

All analyses were performed using SPSS 22.0 (SPSS Inc., Chicago, IL, USA). Descriptive analyses were performed to show the characteristics of the participants. Univariate and multivariable logistic regression analyses were performed to identify independent factors in the risk model. P values were two-sided, and $P<0.05$ was considered as statistically significant.

Results

Characteristics

The general characteristics of the study population are presented in Table 1. The derivation group consisted of 1573 individuals, and 503 (32.0%) of whom had hypertension. The validation group consisted of 1574 individuals, and 494 (31.4%) of whom had hypertension. There were no differences between these two groups regarding the socio-demographic characteristics and clinical conditions, including age, sex, education, marital status, family history of hypertension, etc.

Development of the Screening Tool

The results of the separate Chi-square tests were presented in Supplementary Table 1. After stepwise backward elimination of the non-significant variables, the final model included variables of age, family history of hypertension, having diabetes, having dyslipidemia, BMI, and abdominal obesity (Table 2). The model showed a good fit (Hosmer-Lemeshow test $P>0.05$). The score for each variable is shown in the last column in Table 2. The sum score was calculated as the sum of the individual scores and may vary from 0 to 48.

Validation of the Screening Tool

The performance of the screening tool in the validation group is shown in the ROC curves (Figure 2) and in Table 3. The area under the ROC curve was 0.817 (95% CI: 0.797–0.836), which indicated that the tool identified the people at risk for hypertension very well. The cut-off value was chosen to maximize the sensitivity and specificity, aiming to minimize the number of false positives and false negatives. The risk score value of 20 was selected as the optimal cut-off value, with a sensitivity of 83.4%, a specificity of 64.3%, a positive predictive value of 51.6%, and a negative predictive value of 89.4%.

In Table 4, individuals in the validation group were classified into three risk score categories. The prevalence of hypertension rose with higher risk score categories ($p<0.001$), which was markedly elevated in the two highest categories. Compared to those with risk score between 0–20, the Odds Ratio (OR) of being hypertensive was 4.08 (95% CI: 3.04–5.47) for the group with risk score between 21–30 and 11.52 (95% CI: 8.41–15.79) for the group with risk score between 31–48.

Discussion

We have developed a simple and valid screening tool to identify the people at increased risk for hypertension in Shanghai, with good discrimination and calibration. Age, family history of hypertension, having diabetes, having dyslipidemia, BMI, and abdominal obesity contributed to the risk score. It was derived from a randomly selected, population-based sample covering both young and old. The tool focused on factors that are easy to measure without invasive methods, known to be associated with being hypertensive, and draw attention to modifiable risk factors of hypertension.[29,30]

Our study has a sensitivity of 83.4% and specificity of 64.3%, which showed higher sensitivity (83.4% VS 78.6%) than the risk score developed in India.[23] Furthermore, the AUC exceeded those for the published risk factor questionnaire,[23,29] which indicated that our screening tool had good discriminative ability. Although the positive predictive value and specificity may seem low, the negative predictive value was quite high given that this was

Table 1 Characteristics of the Study Population

Variables	Derivation Group (N=1573)	Validation Group (N=1574)	P value
Age (n,%)			0.462
<60 years	706(44.9)	727(46.2)	
≥60 years	867(55.1)	847(53.8)	
Sex (n,%)			0.734
Male	682(43.4)	673(42.8)	
Female	891(56.6)	901(57.2)	
Educational level (n,%)			0.605
Junior high school or below	740(47.0)	726(46.1)	
High school or above	833(53.0)	848(53.9)	
Marital status (n,%)			0.171
Single	253(16.1)	282(17.9)	
Married	1320(83.9)	1292(82.1)	
Family history of hypertension (n,%)			0.761
No	746(47.4)	755(48.0)	
Yes	827(52.6)	819(52.0)	
BMI (n,%)			0.509
<24Kg/m^2	810(51.5)	792(50.3)	
≥24 Kg/m^2	763(48.5)	782(49.7)	
Abdominal obesity (n,%)			0.717
No	1039(66.1)	1030(65.4)	
Yes	534(33.9)	544(34.6)	
Having hypertension (n,%)			0.721
No	1070(68.0)	1080(68.6)	
Yes	503(32.0)	494(31.4)	
Having diabetes (n,%)			0.735
No	1385(88.0)	1392(88.4)	
Yes	188(12.0)	182(11.6)	

Note: P-values resulted from comparing the derivation group and the validation group from Chi-square tests.
Abbreviation: BMI, body mass index.

a screening tool and not a confirmatory tool. Therefore, this tool could be used as a simple and convenient tool to help the primary health care workers identify high-risk individuals who might develop hypertension. For example, individuals with a low-risk score are less likely to develop hypertension so that they do not need to be tightly followed up for further management. Moreover, the screening tool could be used to stratify the high-risk individuals into different subsets according to their risk score (eg the sum score more than 30), in order to adopt different interventions precisely.[31] This could make the preventive interventions and health education more focused on the target population. Additionally, the

Table 2 Results of the Multivariable Logistic Model of the Risk Factors of Hypertension, and the Corresponding Score for Each Variable

Variables	β Coefficient	P value	OR (95% CI)	Score
Age (≥60 years)				
No	0		1	0
Yes	1.172	<0.001	3.23(2.30–4.54)	12
Family history of hypertension				
No	0		1	0
Yes	1.100	<0.001	3.00(2.32–3.89)	11
Having diabetes				
No	0		1	0
Yes	0.621	0.001	1.86(1.30–2.67)	6
Having dyslipidemia				
No	0		1	0
Yes	0.694	<0.001	2.00(1.45–2.77)	7
BMI≥24Kg/m^2				
No	0		1	0
Yes	0.775	<0.001	2.17(1.62–2.91)	8
Abdominal obesity				
No	0		1	0
Yes	0.433	0.004	1.54(1.15–2.07)	4

Notes: P-values resulted from multivariable logistic regression analyses using stepwise backward elimination in the derivation group. The risk score was calculated by multiplying the regression coefficients by 10 and rounding to the nearest integer.
Abbreviations: OR, odds ratio; CI, confidence interval; BMI, body mass index.

variables included in the screening tool are mostly modifiable risk factors, and some factors may become apparent over time.[32] Therefore, the screening should be an ongoing process.[33]

Defining a suitable cut-off point is a trade-off. The ROC curve has been recommended for finding the optimal threshold in screening and diagnostic tests, ie, the point maximizing the sum of sensitivity and specificity.[34] However, the trade-off between sensitivity and specificity must be weighed against many conditions, including: the prevalence of the disease, the workload of the general practitioners, whether the test is a part of a screening strategy or a single screening test, how often the test should be offered, the effectiveness of subsequent treatment,[35] etc. The general practitioners were engaged in the prevention and management of most of the hypertensive patients. If a lower threshold was used, more individuals would be classified as high-risk for hypertension, which would become a challenging workload for the general practitioners. According to the choice of the cut-off point in this study, up to 45% of the population would be classified as high-risk individuals, which was similar to the current prevalence of prehypertension (41.3%) in China.[5] This would not cause any substantial increase in workload for the general practitioners since it is already part of their work to manage the individuals at risk for hypertension.[25] However, the cut-off point could be evaluated dynamically according to the workload and prevalence of hypertension in the future, and be adjusted when needed.

A screening tool regarding phenotypical characteristics could never be perfect.[36] In our study, approximately 20% of individuals with hypertension had a low score. The reason for this may be (i) they had other risk factors that were not

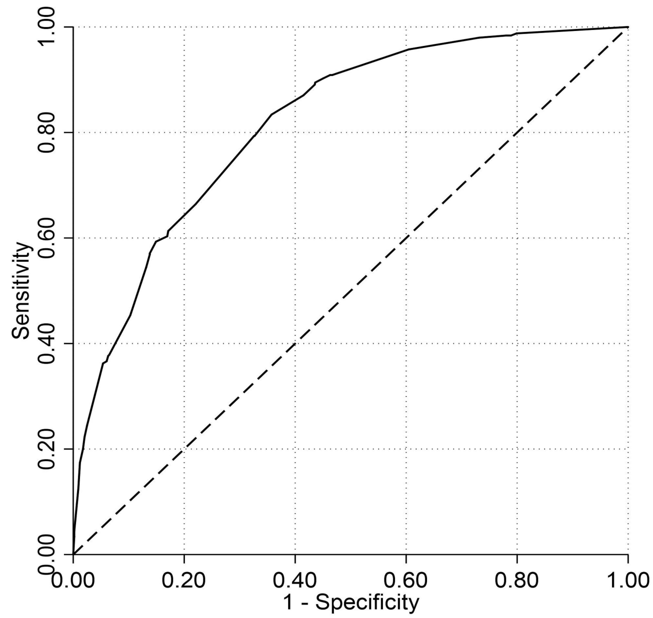

Figure 2 Receiver operating characteristic (ROC) curve for identifying the people at risk for hypertension in the validation group: the area under the curve (AUC) = 0.817 (95% CI:0.797–0.836).

included in our screening tool, and very likely to be that information that required laboratory work, for example, genetic factors, biomarker factors, and so on; (ii) these individuals changed their lifestyle after diagnosis of hypertension and therefore had low scores.[37] Unfortunately, due to the limit of the cross-sectional setting of our study, we are not able to distinguish the true reason. On the other hand, approximately 33% of the non-hypertensive individuals had a high score. However, it does not necessarily mean that these individuals were misclassified. The main reason is that these individuals appeared to be non-hypertensive at the time of the survey, but they may develop hypertension later. These two problems should be further investigated in a prospective setting.

It is important to identify and manage the high-risk groups for hypertension as early and effectively as possible so as to delay the progression to hypertension.[38] After the early detection, appropriate community-based interventions could be provided to encourage them to adopt healthy lifestyles,[39] which will likely improve modifiable risk factors. For instance, our study indicated that BMI was a strong influencing factor for developing hypertension, which was similar to the results of other studies.[40,41] For those high-risk groups with high BMI, knowledge regarding healthy diet, such as "DASH (Dietary Approaches to Stop Hypertension) diet", could be promoted to them to form correct

Table 3 Performance of the Screening Tool Through the Comparison of the Cut-off Value in Identifying the People at Risk for Hypertension in the Validation Group

Cut-off Value	Sensitivity (95% CI)	Specficity (95% CI)	PPV (95% CI)	NPV (95% CI)
≥17	89.5(86.4–92.0)	56.4(53.4–59.4)	48.4(46.6–50.3)	92.1(90.0–93.8)
≥18	89.1(86.0–91.7)	56.5(53.5–59.5)	48.4(46.5–50.2)	91.9(89.7–93.6)
≥19	87.0(83.8–89.9)	58.5(55.5–61.5)	49.0(47.0–50.9)	90.8(88.7–92.6)
≥20	83.4(79.8–86.6)	64.3(61.3–67.1)	51.6(49.4–53.9)	89.4(87.4–91.2)
≥22	79.4(75.5–82.8)	67.3(64.4–70.1)	52.6(50.2–55.0)	87.7(85.6–89.5)
≥23	79.4(75.5–82.8)	67.4(64.5–70.2)	52.7(50.3–55.1)	87.7(85.7–89.5)
≥24	66.4(62.0–70.6)	78.0(75.4–80.4)	58.0(54.8–61.0)	83.5(81.7–85.2)

Abbreviations: CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

Table 4 Association Between the Risk Scores and the Prevalence of Hypertension in the Validation Group

Risk Score	The Number of Total Respondents (N=1574)	The Number of Respondents with Hypertension (N=494)	Prevalence (%)	OR (95% CI)	P value
0–20	829	102	12.3	1	
21–30	410	168	41.0	4.08(3.04–5.47)	<0.001
31–48	335	224	66.9	11.52(8.41–15.79)	<0.001

Note: Odds ratio adjusted for age and gender.
Abbreviations: OR, odds ratio; CI, confidence interval.

beliefs on low fat and low sodium diet, and eventually change to a light diet and reduce energy intake.[42] Furthermore, these high-risk subjects should be encouraged to be engaged in more physical exercises to control their BMIs.[43]

Our study has several limitations. First, we did not analyze all the possible factors that may contribute to the incidence of hypertension due to data availability. Second, we could not predict the short- or long-term risk of hypertension, as reported in other studies,[44] because the dataset was derived from a cross-sectional study. Third, selection bias may exist because of missing information in the key variables. Fortunately, the characteristics of those with and without missing values were not significantly different in the dataset. Finally, since the survey was conducted in Shanghai, it was mainly applicable to the developed regions in Eastern China. It should be relevant to evaluate the generalizability before the screening tool could be used in other parts of China.

Conclusions

In summary, our study has developed a simple and valid screening tool with good sensitivity and medium specificity, to identify individuals at risk for hypertension for the general practitioners in Shanghai. It is a practical way to early detect and manage those at high risk, to delay the progression of hypertension and related complications, which would be beneficial to the individual, the family, and the whole society. Such strategies should be adopted into the nationwide program for hypertension prevention and be launched thoroughly across the country, which could help to delay the onset of hypertension and reduce its prevalence in China.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author, Chengyue Li, upon reasonable request by emailing lichengyue@fudan.edu.cn.

Ethics Approval and Consent to Participate

This study was approved by the Ethical Review Committee at Shanghai Municipal CDC, Shanghai, China, and the approval number was IRB#2013-1. And all participants gave consent in written format.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests in this work.

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