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Construction and validation of a risk prediction model for soldiers with frostbite in northeast China: a cross-sectional study

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Abstract

Background One of the challenges of physical training in extreme condition is frostbite, especially in Northeast China. In this study, we aimed to construct a risk prediction model for frostbite among soldiers in Northeast China, and verify its effect.

Methods 698 participants were selected via convenience sampling from Northeast China from December 2021 to January 2022 (winter). They were randomly divided into a training set ($N=479$) and a testing set ($N=202$) in a ratio of 7:3. All participants completed a researcher-made questionnaire on frostbite. The prediction model was constructed through the use of Logistic regression analysis, which was used to predict the independent risk factors for frostbite formation and screen significant indicators. The model's performance was assessed using the receiver operating characteristic (ROC) curve and decision curve analysis (DCA) to evaluate the prediction efficiency and goodness of fit.

Results The incidence of frostbite in the training set was 19.83% (95 people), all of which were first-degree frostbite. Among them, frostbite in multiple parts was the most common (58.95%), followed by singular body parts like hands (24.21%), ears (11.58%) and feet (5.26%). Single factor logistic regression analyses showed that ambient temperature, ambient wind speed, outdoor stationary time, stationary status, and history of frostbite are independent risk factors that affect the occurrence of frostbite. Furthermore, we constructed the frostbite risk prediction model for soldiers in the northeastern region of China. The area under the receiver operating characteristic curve (AUC) for the risk of frostbite in the training set and testing set was 0.816 (95% CI, 0.770 ~ 0.862) and 0.787 (95% CI, 0.713 ~ 0.860), respectively. The Hosmer-Lemeshow test of the model showed $\chi^2=11.328$ and $P=0.184$ (> 0.05). The DCA curve indicated that most of the clinical net benefits of the model are greater than 0, demonstrating good clinical usefulness.

Conclusion The constructed frostbite prediction model can effectively identify soldiers with a higher risk of frostbite. It provided theoretical support for commanders to take preventive measures to reduce the incidence of frostbite among soldiers and was of great clinical guiding significance.

Keywords Frostbite, China, Northeast region, Influencing factors, Prediction model

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Introduction

The Northeast China is a geographical region of China and is at the core of Northeast Asia. According to the National Statistical Bulletin for National Economic and Social Development of the People's Republic of China for 2020 [1], it corresponds specifically to three provinces, namely Liaoning, Jilin, and Heilongjiang. The Northeast China is the region with the highest latitude in China. It has climatic characteristics such as long cold period, extreme low temperature and heavy snowfall in winter, making it an area with high incidence of frostbite [2]. Frostbite, one of the diseases with high incidence in cold regions [3], can occur widely in outdoor workers such as soldiers [4] and field workers [5]. Frostbite can cause a series of damages on the skin and tissue. According to a retrospective survey by Frederick W et al. [6], nearly 29.00% of frostbite cases resulted in at least once amputation. The average economic cost and hospitalization time of readmission due to frostbite were 236,872 dollars and 34.7 days, respectively. In addition, even if there is no obvious tissue damage after healing from frostbite, patients may still suffer from sequelae such as vasoconstriction disorder, chronic pain, and cold sensitivity for a long time [7].

Due to the nature of their work, soldiers have always been a high-risk group for frostbite. According to records [8], more than 2,000 and 91,000 people in the U.S. military suffered from frostbite in World War I and World War II, respectively. In the Korean War, there were more than 7,300 non-combat casualties due to frostbite. In recent years, although much effort has been made on the prevention and prediction of frostbite worldwide, soldiers still have a high incidence of frostbite. According to the "Health Monitoring Reports" [9], frostbite is still the most common type of cold injury among active duty military service members in the United States between July 2018 and June 2021. Chinese scholars such as Zheng Wei and Han Song [10] found that the incidence of frostbite among soldiers in Northeast China ranged from 7.60 to 38.50%.

The prevention of frostbite is far more important than its treatment. The occurrence of frostbite can be affected by many factors. For example, early experimental studies by Ren Ke and Oliveira [11] revealed that ambient temperature, wind speed, outdoor exposure duration and personal protection level are all influencing factors of frostbite. In addition, the length of outdoor immobility, fatigue level, diabetes, Raynaud's disease, history of frostbite, length of enlistment, type of military service, etc. can also affect the occurrence of frostbite [12–14]. Currently, frostbite related studies are limited to small research scope without comprehensively covering all frostbite factors both individually and environmentally. There is a certain degree of uncertainty, and the risk of frostbite among soldiers in the Northeast China cannot be quantified. Therefore, the independent risk factors related to the occurrence of frostbite among them in Northeast China were obtained through logistics regression analysis, and a prediction model was established so as to screen out high-risk military service members who are about to suffer from frostbite, which could help provide targeted preventive measures and reduce non-combat attrition.

Materials and methods

This study was reported in accordance with the Transparent Reporting of Multivariable Prediction Models for Individual Prognosis or Diagnosis (TRIPOD) guideline [15].

Study design and population

This cross-sectional study used a convenience sampling method to recruit participants in Northeast China (including Heilongjiang Province, Jilin Province, Liaoning Province and the northeastern region of Inner Mongolia) from December 2021 to January 2022, and the ethics committee approved the trial at the General Hospital of Northern Theater Command. The inclusion criteria were as follows: (1) Age≥18 year-old; (2) Frostbite patients should have suffered frostbite within 7 days before the investigation (according to relevant literature and clinical practice, all clinical symptoms of frostbite generally appear within 7 days). The degree of frostbite injury is based on Wilderness Medical Society Clinical Practice Guidelines for the Prevention and Treatment of Frostbite: 2019 Update [3]; (3) No serious organic diseases; (4) Speak and write normally; (5) Voluntary participation. The exclusion criteria included: (1) Participants who dropped out midway; (2) People who were unable to complete the survey due to other force majeure factors.

Sample size calculation

Our study was a cross-sectional study, and the sample size was calculated based on logistic regression with a minimum of ten events for each dependent variable. Thirteen independent variables were included in the model, and the loss to follow-up rate was defined as 10% of the cases. In a previous study on the incidence of frostbite among 2,456 participants in Northeast China, about 30% of the military service members suffered from frostbite [16]. Therefore, the minimum sample size in the training set was calculated as:

$$N = \frac{13\times\ 10}{0.3\times\ (1+0.1)} = 477$$

Given the 7:3 ratio between the training and testing set [17], 202 cases were required for the testing set. The training set were used to develop the nomogram model, whereas the testing set were used to validate the resulting nomogram.

Measurements

Predictive variables were selected based on literature review, brainstorming and consultation with experts in related fields. Based on the pre-investigation, the Questionnaire on the Occurrence of Frostbite among soldiers in Northeast China was formulated, including 13 risk factors in 5 aspects: (1) sociodemographic factors: gender (male/female); survey region (Liaoning, Jilin, Heilongjiang, and northeastern Inner Mongolia); BMI value range (0 ~ 18.5, 18.5 ~ 24, ≥24). (2) Environmental factors (on the coldest day in the past 7 days): Outdoor exposure time (h) (total length of outdoor training); Ambient temperature (°C); ambient humidity (%); Ambient wind speed (m/s). The ambient temperature, ambient humidity and ambient wind speed was collected from the China Meteorological Data Service Centre. (3) Personal factors: antifreeze plaster (yes/no); hot water shower (yes/no); hot drinks and hot food (yes/no). (4) Training factors: nature of the task (outdoor patrol, physical training, business training, skills training, military training, standing guard, others); whether to be stationary (yes /no); task duration (h, on the coldest day in the past 7 days). (5) Symptoms and manifestations: occurrence of frostbite in the past 7 days (yes/no); frostbite locations (hands, feet, face, auricles, nose, others). The pilot data on 15 participants in this study found a Cronbach's alpha of 0.887 and the Scale-Content Validity Index of 0.89.

Data collection

Participants were recruited from the Northeast China after approval by the Ethics Committee of the General Hospital of Northern Theater in Shenyang, Liaoning Province, China (approval number: Y(2021)129). We provided unified questionnaire guidance and training for the designated research staff and all participants provided written informed consent before survey. In order to ensure the quality of questionnaire results, data were collected by two trained interviewers using standard face-to-face interviews. The participants who did not understand the items were given prompt interpretations. After completing the questionnaire, the investigators clarified and re-checked and analyzed the questionnaire in a timely manner to ensure the authenticity and completeness of the data.

Statistical analysis

Data were analyzed using SPSS 24.0 and R 4.2.1 software. Measurement data that were in line with normal distribution were expressed as mean ± standard deviation ($\bar{x} \pm s$), and independent sample *t* test was used for comparison between two groups. Measurement data that were not normally distributed were expressed as median and interquartile range M (P_{25}, P_{75}), and were compared by Mann-Whitney U test. Count data were expressed as frequency and percentage (n, %), and the χ^2 test, corrected χ^2 test, or Fisher 's χ^2 test were used to compare the groups. Logistic regression was used in multivariate analysis. In this model, the variables were selected based on the results of single factor analysis. The independent risk factors obtained based on the multivariate regression method were used to construct a nomogram model with the "rms" package of R software (version 4.2.1). AUC, calibration curve, and DCA were used to evaluate the predictive ability and performance of the risk model. When the area under ROC curve is between 0.5 and 0.7, the discriminant ability of the model is low; when the area under ROC curve is between 0.7 and 0.9, the discriminant ability is medium; when the area under ROC curve is between 0.9 and 1.0, the discriminant ability is high. Statistical tests used $P < 0.05$ as a significance level. as is shown in Fig. 1.

Results

Participants characteristics

In total, 698 participants were recruited in our study. Of these, 12 participants gave up the study, and 5 participants refused to participate. Ultimately, 681 participants were included in this study, and they were randomly divided into the training set ($N=479$) and the testing set ($N=202$) at a ratio of 7:3. Table 1 showed that except for the differences in environmental humidity and task duration, the other variables between the two groups were not statistically significant, proving that they were relatively balanced and successfully randomized.

Univariate analysis of frostbite risk

A total of 479 subjects were included in training set, 95 participants (95/479, 19.83%) developed frostbite in the past 7 days. Among them, frostbite in multiple parts was the most common, with a total of 56 people (58.95%), followed by frostbite on the hands in 23 people (24.21%), ears in 11 people (11.58%) and feet in 5 people (5.26%). Single factor analysis showed that survey region, history of frostbite, the nature of the task, antifreeze plaster, hot water shower, intake of hot drinks and foods, stationary status, the duration of outdoor exposure, ambient temperature, and ambient wind speed were correlated with the occurrence of frostbite ($P<0.05$, Table 2).

Prediction model construction

Multivariate logistic regression was used to establish the prediction model. Ten of the original thirteen variables were included in the risk prediction model. Up to 5 independent risk indicators were screened out, namely

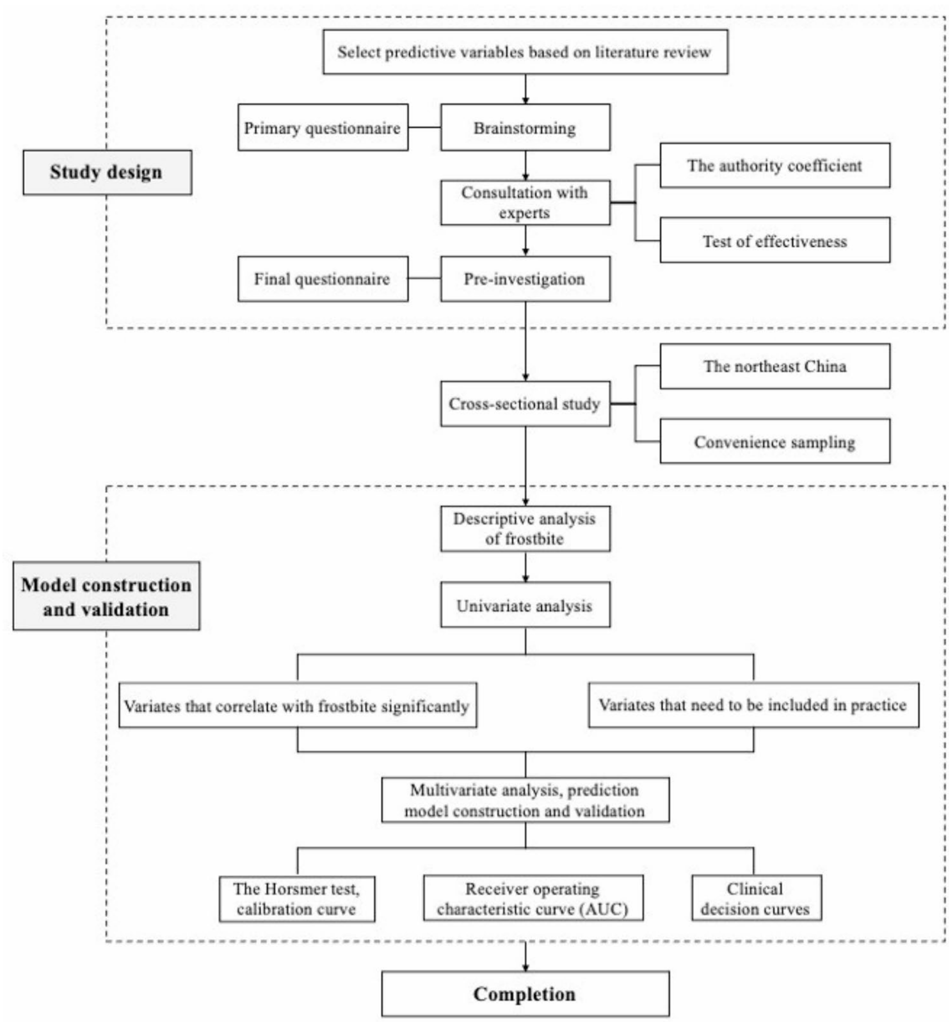

Fig. 1 Flowchart of the research process

history of frostbite, stationary status, the duration of outdoor exposure, ambient temperature, and ambient wind speed. The detailed results are shown in Tables 3 and 4.

$$\begin{aligned}\text{Logit (occurrance of frostbite)} &= -6.085 - 0.094 \times \text{ambient temperature } (^\circ\text{C}) \\ &+ 0.553 \times \text{ambient wind speed } \left(\frac{\text{m}}{\text{s}}\right) \\ &+ 0.429 \times \text{duration of outdoor exposure (h)} \\ &+ 0.649 \times \text{stationary status (yes)} \\ &+ 1.234 \times \text{history of frostbite (yes)}\end{aligned}$$

The prediction model was visualized with the help of the "rms" package in R software (Fig. 2).

Prediction model verification

The accuracy of the frostbite risk prediction model was estimated by internal validation in the training set and testing sets. The ROC curve was used to evaluate the accuracy of the model, and the AUC was calculated for both the training and testing sets. The AUC was 0.816 (95% CI, 0.770 ~ 0.862) in the training set (Fig. 3a) and 0.787 (95%CI, 0.713 ~ 0.860) in the testing set (Fig. 3b), illustrating that the model had high discrimination. When the danger threshold is 0.152 in the training set, the specificity and sensitivity are 0.656 and 0.905, respectively. In the testing set, when the risk threshold is 0.244, the specificity and sensitivity of the model are 0.764 and 0.704, respectively, indicating that the model has great prediction performance. Hosmer ‐ Lemeshow test was used to evaluate the goodness of fit of training set (χ^2=11.328, P=0.184>0.05, Fig. 4a). The calibration curve almost coincides with the reference line in the training set and in the testing set, demonstrating good consistency between the model ' s actually observed probability and the predicted probability (Fig. 4b). Using 'rmda' package in R, we developed clinical decision curves to judge the clinical effectiveness of the model.

Table 1 Participants characteristics (*N* = 681)

Variables	Training set (*N* = 479)	Testing set (*N* = 202)	Z/χ^2	*P* value*
Gender, *N* **(%)**				
Male	479(80.17)	202(19.83)	-	-
Survey region, ***N*****(%)**			2.056	0.559*
Liaoning	89(18.58)	38(18.81)		
Jilin	93(19.42)	38(18.81)		
Northeastern Inner Mongolia	49(10.23)	14(6.93)		
Heilongjiang	248(51.77)	112(55.45)		
BMI (kg/m^2), ***N*****(%)**			1.699	0.428*
<18.5	6(1.25)	1(0.49)		
18.5 ~ 24	341(71.19)	152(75.25)		
≥24	132(27.56)	49(24.26)		
History of frostbite, ***N*****(%)**			0.220	0.639*
No	282(58.87)	115(56.93)		
Yes	197(41.13)	87(43.07)		
Nature of task, ***N*****(%)**			10.055	0.122*
Outdoor patrol	17(3.55)	5(2.48)		
Skills training	30(6.26)	27(13.36)		
Military training	111(23.17)	48(23.76)		
Physical training	140(29.23)	53(26.24)		
Business training	44(9.19)	17(8.42)		
Standing guard	111(23.17)	42(20.79)		
Others	26(5.43)	10(4.95)		
Use of antifreeze plaster, ***N*****(%)**			0.859	0.354*
No	399(83.30)	174(86.14)		
Yes	80(16.70)	28(13.86)		
Hot water shower, ***N*****(%)**			1.001	0.317*
No	236(49.27)	108(53.47)		
Yes	243(50.73)	94(46.53)		
Intake of hot drinks and foods, ***N*****(%)**			0.274	0.601*
No	203(42.38)	90(44.55)		
Yes	276(57.62)	112(55.45)		
Stationary status, ***N*****(%)**			1.484	0.223*
No	285(59.50)	110(54.46)		
Yes	194(40.50)	92(45.54)		
Duration of outdoor exposure (h)	2(1.00, 2.00)	2(1.00, 3.00)	-2.511	0.012**
Ambient temperature (°C)	-14.65(-20.49, -4.47)	-20.50(-24.80, -14.15)	-1.186	0.236**
Ambient humidity (%)	62.50(49.63, 72.94)	63.33(53.50, 70.33)	-3.566	0.000**
Ambient wind speed (m/s)	2.22(0.51, 2.98)	3.05(1.80, 3.60)	-1.028	0.304**

* Chi-square test, ** non-parametric test

Most of the clinical net benefits of the prediction model are greater than 0, indicating good clinical usefulness (Fig. 5a and b).

Discussion

In this study, we found that the incidence rate of frostbite among soldiers in Northeast China was 19.83% (95/479), all of which were first-degree frostbite. Among the 95 participants who suffered frostbite, 56 suffered from combined frostbite in multiple body parts (58.95%). Hands, feet, and auricles were high-risk areas for frostbite, accounting for 24.21%, 11.58%, and 5.26% of the total, respectively. Standing on guard duty (44.62%), military training (43.08%), and physical training (24.62%) were the workplace with a higher incidence of frostbite. Our findings were consistent with other domestic and foreign research results. The US military once analyzed the frostbite situation of Marines and found that 60% of the soldiers suffered from frostbite on the feet and 30% on the hands [18]. Through a retrospective survey, Norheim AJ et al. [19] found that between January 2010 and December 2014, 397 out of 460 people in the Norwegian Armed Forces suffered from frostbite, and 96% of the injuries were on the hands and feet. Collectively,

Table 2 Single factor analysis of frostbite in training set (*N* = 479)

Variables	Non-frostbite (*N* = 384)	Frostbite (*N* = 95)	Z/χ²	*P* value*
Gender, *N*(%)				
Male	384(80.17)	95(19.83)	-	-
Survey region, *N*(%)			16.637	0.001*
Liaoning	84(94.38)	5(5.62)		
Jilin	77(82.80)	16(17.20)		
Northeastern Inner Mongolia	36(73.47)	13(26.53)		
Heilongjiang	187(75.40)	61(24.60)		
BMI (kg/m²), *N*(%)			1.521	0.468*
<18.5	6(1.00)	0(0)		
18.5 ~ 24	272(79.77)	69(20.23)		
≥24	106(80.30)	26(19.70)		
History of frostbite, *N*(%)			23.754	<0.001*
No	247(87.59)	35(12.41)		
Yes	137(69.54)	60(30.46)		
Nature of task, *N*(%)			28.260	<0.001*
Outdoor patrol	11(64.71)	6(35.29)		
Skills training	23(76.67)	7(23.33)		
Military training	83(74.77)	28(25.23)		
Physical training	124(88.57)	16(11.43)		
Business training	44(100.00)	0(0)		
Standing guard	82(73.87)	29(26.13)		
Others	17(65.38)	9(34.62)		
Use of antifreeze plaster, *N*(%)			4.450	0.035*
No	313(78.45)	86(21.55)		
Yes	71(88.75)	9(11.25)		
Hot water shower, *N*(%)			6.583	0.010*
No	154(75.86)	49(24.14)		
Yes	230(83.33)	46(16.67)		
Intake of hot drinks and foods, *N*(%)			4.107	0.043*
No	154(75.86)	49(24.14)		
Yes	230(83.33)	46(16.67)		
Stationary status, *N*(%)			18.679	<0.001*
No	247(86.67)	38(13.33)		
Yes	137(70.62)	57(29.38)		
Duration of outdoor exposure (h)	2(1.00, 2.00)	2(1.00, 3.00)	-2.372	0.018**
Ambient temperature (°C)	-14.65(-20.49, -4.47)	-20.50(-24.80, -14.15)	-5.345	<0.001**
Ambient humidity (%)	62.50(49.63, 72.94)	63.33(53.50, 70.33)	-0.264	0.792**
Ambient wind speed (m/s)	2.22(0.51, 2.98)	3.05(1.80, 3.60)	-3.642	<0.001**

* Chi-square test, ** non-parametric test. Each variable (ambient temperature, ambient wind speed, history of frostbite etc.) is assigned a score based on their significance and by summing up each score, the total score would provide readers a corresponding probability to the frostbite. The significance of variables is determined by the effect estimates and is influenced by co-variables

Table 3 The way to evaluate the value of the variables

Variables	Assignment
Ambient temperature	Continuity variable
Ambient wind speed	Continuity variable
Duration of outdoor exposure	Continuity variable
Stationary status	No = 0, Yes = 1
History of frostbite	No = 0, Yes = 1

frostbite among soldiers mostly occurs in the field and during outdoor training. The hands, feet, and auricles are located at the distal end of the body and have relatively less blood supply, resulting in poor blood circulation. Meanwhile, these body parts are also hard or easy to neglect in daily protection against cold. During daily duties, participants sometimes need to complete a series of delicate operations without adequate cold-proof equipment and remain stationary for a long time. The above reasons lead to insufficient heat supply and rapid heat dissipation, resulting in a high incidence of frostbite.

Table 4 Multivariate logistic regression analysis of risk factors for frostbite among participants in Northeast China

Variables	β	Standard error	Wald	*P* value	OR	95%CI
Constant	-6.085	0.646	88.674	<0.001	-	-
Ambient temperature	-0.094	0.016	32.477	<0.001	0.911	0.882 ~ 0.940
Ambient wind speed	0.553	0.108	26.352	<0.001	1.738	1.407 ~ 2.146
Duration of outdoor exposure	0.429	0.133	10.369	<0.001	1.536	1.183 ~ 1.995
Stationary status (yes)	0.649	0.264	6.060	0.014	1.913	1.141 ~ 3.206
History of frostbite (yes)	1.234	0.267	21.423	<0.001	3.436	2.037 ~ 5.795

According to the results of multivariate analysis, five variables were used as predictors of frostbite to construct the risk prediction model for soldiers in northeast China. The expression of the prediction model is:

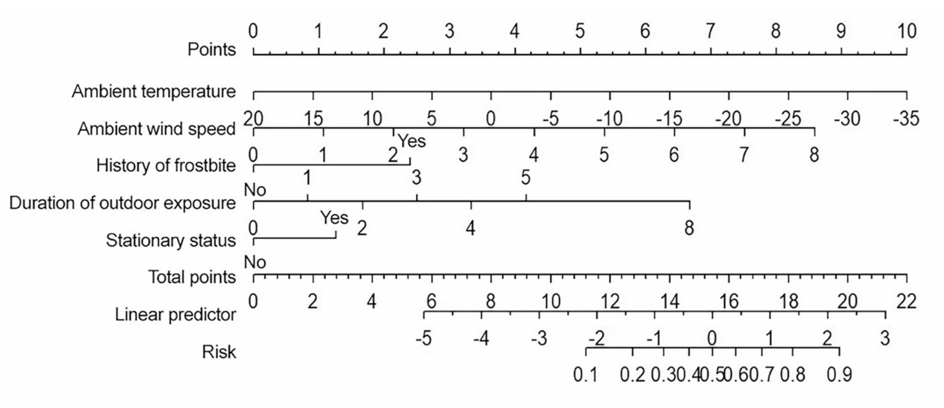

Fig. 2 Nomogram for predicting frostbite among soldiers in Northeast China

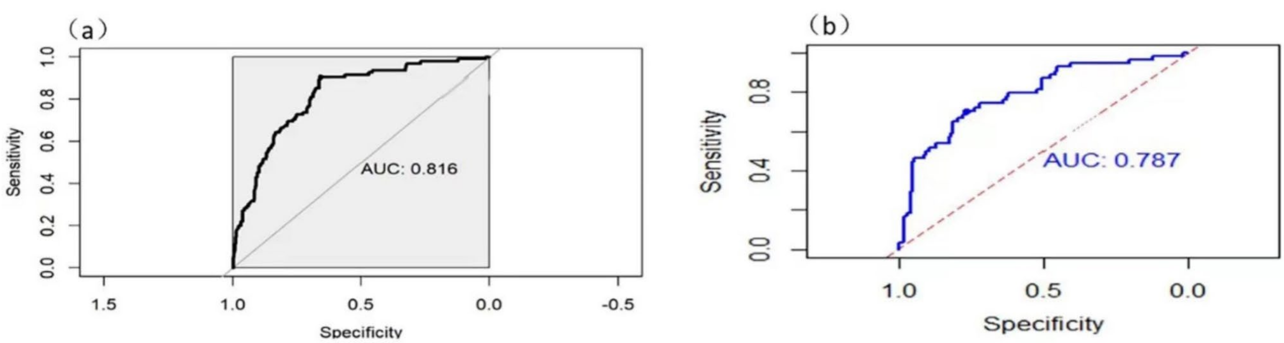

Fig. 3 Comparison of the area under the receiver operating characteristic curve in soldier frostbite risk prediction model between the training set **(a)** and the testing set **(b)**

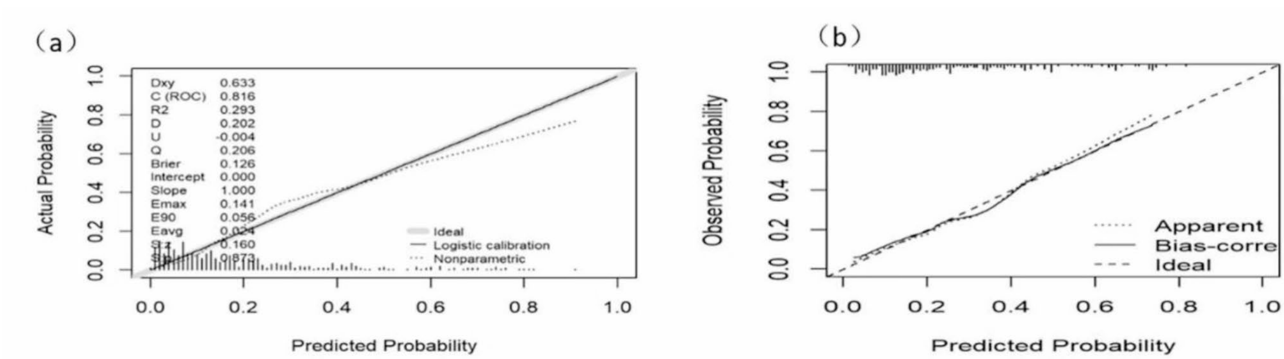

Fig. 4 Comparison of calibration curves between the training set **(a)** and the testing set **(b)**

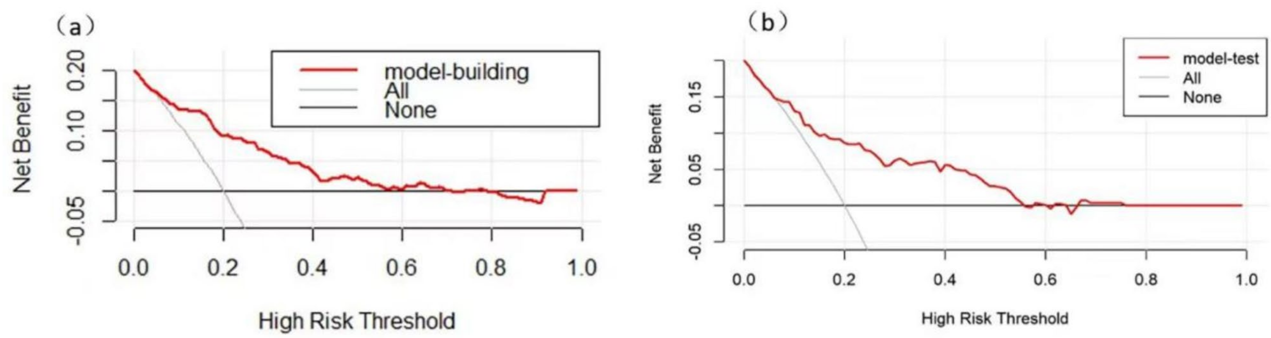

Fig. 5 Comparison of decision curve analyzes between the training set **(a)** and the testing set **(b)**

Therefore, the author constructed a predictive model based on logistic regression and analyzed the risk factors for the occurrence of frostbite among soldiers in Northeast China, so as to take measures to maximumly avoid the occurrence of frostbite.

Ambient temperature and wind speed

We found that the incidence of frostbite is inversely proportional to the ambient temperature (β = -0.094) and directly proportional to the ambient wind speed (β=0.553), which is consistent with previous research [14, 19]. Fallahi et al. [20] constructed a three-dimensional thermal model of human fingers for frostbite and found that when the ambient wind speed was 6.8 m/s, the fingertip reached the skin freezing point in 9.7 min. When the ambient wind speed was 9 m/s and 10 m /s, the model reached the skin freezing point within 6.4 min and 5.8 min, respectively. Additionally, under the same ambient wind speed, the body had no risk of frostbite at 0 °C. When the temperature gradually dropped to -10 °C, -20 °C, and −25 °C, the body's tolerance time to the cold environment gradually decreased from 28 min to 13.5 min and 10 min. The results indicated that the higher ambient wind speed and lower ambient temperature can accelerate heat loss and increase the possibility of frostbite. Our results showed that for every 1 °C increase in ambient temperature, the probability of frostbite was reduced by 0.911 times (OR=0.911, 95% CI, 0.882 ~ 0.949); For every increase in ambient wind speed of 1 m/s, the odds of frostbite increased by 1.738 times (OR=1.738, 95% CI, 1.407 ~ 2.146). The imbalance of heat production and heat dissipation in local tissues of the body is the main cause of frostbite [21]. In a low-temperature environment, the main heat dissipation methods of the body are radiation and evaporation, which can be affected by the temperature difference between the object and the airflow. Generally speaking, the greater the difference between the ambient temperature and the body temperature, the more heat the body loses through radiation. The stronger the ambient wind speed, the faster the air flows, and the more heat the body loses through evaporation. Radiation and evaporation interact and affect together to accelerate the body's heat loss, thereby significantly increasing the risk of frostbite. Therefore, when arranging duties and tasks in winter, the commanding officers should promptly strengthen the assessment of ambient temperature and wind speed in order to adjust the mission plan and effectively avoid the occurrence of frostbite.

Duration of outdoor exposure

This study found that outdoor exposure time was an independent risk factor that affected the occurrence of frostbite in soldiers ($P<0.001$). For every 1 h of outdoor exposure time during the execution of tasks, the risk of frostbite increases by 1.536 times (OR=1.536, 95% CI, 1.183 ~ 1.995). By comparing the frostbite group and the non-frostbite group in the US military, Kowtoniuk RA et al. [14] found that shortening the outdoor exposure time is one of the effective measures to prevent frostbite. Also, the length of outdoor exposure is significantly related to the severity of frostbite. Chinese scholar Baolong [22] retrospectively analyzed 157 frostbite patients treated during snowstorms in the northeastern plateau region of China from January 2015 to February 2017 and found that when the lag time in a low-temperature environment was ≤24 h, most of the patients had first-degree or shallow second-degree frostbite. When the lag time was 24 ~ 48 h, they could develop deep second-degree frostbite, and when the lag time was >48 h, deep second-degree or third-degree frostbite appeared. The longer the exposure time outdoors, the more heat the body loses through radiation, evaporation, etc., and the risk of frostbite and the degree of damage greatly increase. Therefore, the task duration should be reasonably arranged in winter based on the characteristics of the task and actual conditions to minimize outdoor exposure time.

Stationary status

Research showed that participants who remained stationary during training or on duty are 1.913 times more likely to suffer from frostbite than those who do not (OR=1.913, 95%CI, 1.141 ~ 3.206). Chinese scholar Han

Dezhi et al. [23] found that 45.27% of the frostbite of soldiers occurred during guard patrols. The body's heat mainly comes from basal metabolic rate, physical activity, thermogenesis caused by cold environments, and heat generated by food metabolism [24]. The body's exercise thermogenesis mainly includes the effects of exercise activities and non-exercise daily activities, both of which have obvious effects on the body's heat production. The heat generated by skeletal muscles during walking is 3 times more than that at rest, and it can increase 10–20 times during strenuous exercise [25]. At the same time, appropriate exercise can effectively expand peripheral blood vessels, increase the body's blood flow velocity, maintain peripheral blood circulation, and maintain the perfusion of local tissues of the body. Therefore, when executing missions in winter, soldiers should organically combine stationary tasks with other dynamic training, and arrange the type and intensity of training reasonably.

History of frostbite

Among 95 participants who suffered frostbite in this study, 44 (9.19%) suffered frostbite of varying degrees in the past, and the location of frostbite this time was consistent with the previous one. Further analysis found that under the same environmental conditions, the risk of another frostbite for people with a history of frostbite was 3.436 times that of those who had never experienced frostbite (OR = 3.436, 95%CI, 2.037 ~ 5.795). As early as 1974, Sumner DS et al. [26] conducted a retrospective survey in the US military and found that the probability of frostbite for soldiers with a history of frostbite was 1.68 times that of those who had not experienced frostbite. Cappaert et al. [27] also proposed that the probability of reoccurrence of frostbite among people who have a history of frostbite is 2–4 times higher than average. The mechanism by which a history of frostbite affects the occurrence is currently unclear. Some studies believed that the tissues frostbitten before were more sensitive to cold or had undergone tissue remodeling [14]. This suggested that commanding officers need to identify subordinates who have suffered frostbite in the past in advance and take personalized protective measures to reduce the harm of cold environments to people who were susceptible to frostbite. Further large-sample, multi-center research is needed to explore the pathophysiological mechanism of its occurrence and provide a theoretical basis for better prevention of frostbite.

Ambient humidity

The analysis found that environmental humidity is not a risk factor for frostbite among participants (Z = -0.264, $P = 0.792 > 0.1$), which was inconsistent with previous research reports [28, 29]. Previous studies have suggested [21] that ambient humidity can affect the temperature of the body by affecting the specific heat dissipation capacity of the air and the materials in contact with the body. The greater the specific heat capacity, the stronger the heat dissipation capacity. Among common substances, water has the largest specific heat capacity. Therefore, the thermal conductivity of humid air in a low-temperature environment is much greater than that of dry air. Thus, the greater the humidity of the air, the faster the body's heat dissipates, increasing the probability of frostbite. In this study, however, it was concluded that although the ambient humidity of the frostbite group was slightly higher than that of the non-frostbite group, the difference between the two groups was not statistically significant. The possible reasons are that the humidity data in this study were collected from the average environmental humidity at a certain time published by the China Meteorological Network, which was not real-time data and might affect the final analysis. In addition, Northeast China has a typical temperate monsoon climate, characterized by warm and rainy summers and cold and dry winters. The annual average temperature is 5 ~ 10°C, and the annual precipitation decreases from east to west, ranging from 400 ~ 1000 mm. 70% of the precipitation is concentrated in summer, leading to a dry climate in winter in Northeast China [30].

Limitations

The limitations of this study were as follows: (1) Affected by the gender ratio of participants and the confidentiality agreement, this study was unable to explore the impact of gender and clothing on the incidence of frostbite among military service members. (2) The participants enrolled in this study were those who suffered from frostbite within 7 days before the investigation, and there may be recall bias. (3) In addition, the ambient temperature, wind speed, and humidity were derived from the average values published by the China Meteorological Network. The figures are not real-time data at the specific time point and may have some impact on the final results. (4) Due to limited funds and manpower, the sample size of this study was relatively small, and all data were collected from Northeast China. Future research could focus on the risk factors of frostbite in other regions of China (such as northwest, south, etc.), through prospective studies to verify the effectiveness of the model and further optimize the prediction model.

Conclusion

To sum up, this study investigated the risk factors of frostbite among soldiers in Northeast China, namely, history of frostbite, stationary status, the duration of outdoor exposure, ambient temperature, and ambient wind speed. We used the nomogram to construct and validate a model to predict the risk of frostbite. It has been verified that the model can effectively distinguish soldiers with a high risk of frostbite. The model could provide a reference for troop commanders to formulate rational combat and training plans in winter, take targeted preventive care measures, and reduce the incidence of frostbite.

Abbreviations

BMI	Body mass index
SPSS	Statistical package for the social sciences
SD	Standard Deviation
DBP; OR	odds ratio
CI	Confidential interval
AUC	Area under the curve
LR	Logistic regression
AUROC	Area under the receiver operating characteristic curve
ROC curve	Receiver operating characteristic curve

Supplementary Information

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Supplementary Material 1

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Not applicable.

Author contributions
All authors made substantial contributions to editing and revising of the manuscript. Xueyu Li and Sitong Wang were responsible for the study design. Xueyu Li, Sitong Wang, Yuli Fang and Qin Shu drafted the manuscript. Ruihang Ma and Di Wu were responsible for the statistical analysis, Xueyu Li revised the article. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethical approval
Approved by the Institutional Research Ethics Committee of General Hospital of Northern Theater, Shenyang, Liaoning province, P.R. China. Project Number: Y(2021)129. Before the formal investigation, informed consent had been obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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