Development and Validation of a Nomogram to Predict Hemiplegic Shoulder Pain in Patients With Stroke: A Retrospective Cohort Study

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Abstract  Objective: The development and validation of a nomogram for the individualized prediction of hemiplegic shoulder pain (HSP) during the inpatient rehabilitation of patients with stroke.
Design: Retrospective cohort study.
Setting: The rehabilitation department at a tertiary hospital.
Participants: A total of 376 patients (N=376) with stroke admitted to inpatient rehabilitation from January 2018 to April 2021 were included in this study.
Interventions: Not applicable.
Main Outcome Measures: The outcome measure was shoulder pain on the patients’ hemiplegic side occurring at rest or with movement during hospitalization.
Results: Among the 376 patients with stroke, 113 (30.05%) developed HSP. Five independent predictors were included in the nomogram: subluxation, Brunnstrom stage, hand edema, spasticity, and sensory disturbance. The nomogram was a good predictor, with a C-index of 0.85 (95% confidence interval, 0.81-0.89) and corrected C-index of 0.84. The Homer-Lemeshow test ($\chi^2=13.854, P=.086$) and calibration plot suggested good calibration ability of the nomogram. The optimal cutoff value for the predicted probability of HSP was 0.30 (sensitivity, 0.73; specificity, 0.83). Moreover, the decision curve analysis revealed that the nomogram would add net clinical benefits if the threshold possibility of HSP risk was from 5%-88%.
Conclusions: Our nomogram could accurately predict HSP, which may help clinicians accurately quantify the HSP risk in individuals and implement early interventions.

KEYWORDS
Hemiplegia; Nomograms; Rehabilitation; Risk factors; Shoulder Pain; Stroke

List of abbreviations: CI, confidence interval; DCA, decision curve analysis; HSP, hemiplegic shoulder pain; OR, odds ratio.
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Hemiplegic shoulder pain (HSP) is a common disabling complication that often occurs between 2 and 3 months post stroke. Previous studies have reported incidences of HSP ranging from 9%-73%. HSP in patients with stroke may result in negative effects, such as interference with the rehabilitation process, decreased quality of life, poor functional recovery of the upper limbs, and prolonged hospital stay. The complex and multifactorial nature of HSP frequently complicates treatment. Therefore, early and accurate identification of patients at a high risk of HSP is essential. HSP is associated with several factors. Many clinical features have been reported as predictors, including shoulder subluxation, spasticity, sensory disturbance, stroke type, and restricted range of motion. A recent systematic review revealed that decreased motor activity of the upper extremities, diabetes, and shoulder pain history were significant predictors of HSP. Nonetheless, the precise mechanism of HSP remains unclear, and its predictors emerge from various sources, posing a major challenge in the identification of high-risk groups for HSP. Previous studies have developed multivariate models to identify independent predictors of HSP and consequently screen potentially high-risk populations. However, obtaining individualized HSP risk probabilities is difficult using these models because they generally lack comprehensive evaluations of their performance parameters, such as discrimination, calibration, and clinical usefulness. The clinical use of these models is limited. Therefore, a simple and practical predictive model that integrates HSP-associated predictors is required.

A nomogram is a graphical display tool of a multivariable model used to visualize the relative contributions of each predictor to the outcome event. A complex mathematical model can be converted into a continuous scoring system for the quantification of the individualized risk probability of specific diseases or events. It has more advantages than traditional scoring systems, such as user-friendly graphical interfaces, increased accuracy, and easily comprehensible features. In recent years, nomograms have been used in patients with stroke at the convalescence stage, including the risk evaluation of complications and the prognosis prediction after stroke. Wang et al developed a nomogram for predicting dysphagia recovery in patients with stroke used to assist the decision making of enteral nutrition to achieve individualized swallowing rehabilitation. Zhang et al also created a nomogram for the quantification of risks of unfavorable outcomes in patients with stroke undergoing mechanical thrombectomies, allowing clinicians to accurately assess the unfavorable outcome risks using easily accessible clinical parameters. Therefore, this study aimed to develop and internally validate a nomogram for the prediction of HSP in patients with stroke during inpatient rehabilitation. This nomogram is expected to help clinicians accurately predict the risks of HSP and implement early interventions.

Methods

Study design and participants

This retrospective cohort study was conducted in compliance with the Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis. The medical records of 376 patients with stroke admitted to the rehabilitation department of our hospital from January 2018 to April 2021 were reviewed. The inclusion criteria were as follows: (1) first occurrence of stroke confirmed by magnetic resonance imaging examination or brain computed tomography scan and 1-sided paralysis; (2) older than 18 years; (3) stable medical condition for at least 48 hours post stroke; and (4) regular rehabilitation therapy on the upper limbs before the occurrence of HSP. The exclusion criteria were as follows: (1) previous brain injury or other neurologic disorders, such as brain tumors, Parkinson disease, or Alzheimer disease; (2) history of shoulder pain on the affected side before rehabilitation treatment; (3) other pathologies compatible with the clinical characteristics of HSP, such as inflammatory arthritis, musculature dystrophy, or peripheral neuropathy; (4) severe cognitive impairment; (5) severe organic disease or psychiatric impairment; and (6) missing data.

Data collection and variable definition

A self-designed Excel sheet was used to record detailed clinical characteristics. The typical predictors for HSP including age, sex, disease course on admission, length of stay, stroke type (ischemic or hemorrhagic), affected side (left or right), hypertension, diabetes mellitus, arm strength (manual muscle testing), Brunnstrom stage, subluxation, spasticity, sensory disturbance, and hand edema were collected at admission. Hypertension was diagnosed based on the 2010 Chinese guidelines to manage hypertension. Diabetes mellitus was diagnosed using the 1999 World Health Organization’s Diabetes Mellitus diagnosis and classification criteria. The upper limb motor function was assessed using the Brunnstrom stage (upper limb score). Shoulder subluxation of the affected side was assessed by palpating the space between the acromion and humeral head while the hemiplegic arm hung freely. Subluxation was defined as present when the gap between the acromion and humerus exceeded half a finger. Spasticity was measured at the shoulder flexor muscles and defined as a score on the Modified Ashworth Scale ≥1. Sensory disturbance was defined as an abnormal superficial sensation or proprioceptive sensation at the affected side and diagnosed when the sensation was reported as increased or decreased. The superficial sensation was assessed by evaluating factors such as light touch, cold perception, and sensation of sharpness of the affected side, using the contralateral side as a reference. Proprioception was assessed using joint position sense at the thumb of both hands. The presence of hand edema was assessed by palpating the space between the acromion and humeral head while the hemiplegic arm hung freely.
determined by visual inspection. Shoulder pain on the hemiplegic side occurring at rest or with movement during hospitalization was the measured outcome. The clinical data were extracted into an Excel spreadsheet by an independent researcher uninvolved in the patients' treatments. Subsequently, patients' identifying information was removed and saved in a new data sheet, thereby blinding the data. Two researchers independently reviewed the new data set, coded all the relevant variables, and crosschecked the data. This study was approved by the ethics hospital’s committee (ethics no.: KL901296, date: May 12, 2021), which authorized the collection of clinical data. The requirement for informed consent was waived by the ethics committee because of the retrospective nature of the study.

**Sample size**

We calculated the sample size using the method previously proposed by Peduzzi et al., using events per variable of 10 as the optimal value. At least 90 patients with HSP events were required for the evaluation of 9 candidate predictors. An HSP prevalence at 35% required a minimum sample size of 257.

**Statistical analysis**

The statistical analyses was performed using SPSS 22.0 and R 4.0.5. The data are presented as the median (interquartile range) for nonnormally distributed continuous variables, the mean and standard deviation for normally distributed continuous variables and as frequencies (percentages) for categorical variables. Mann-Whitney U tests or independent t tests were used to analyze the continuous variables, and Fisher exact tests or χ² tests were used to analyze the categorical variables between groups. To determine the independent HSP predictors, the variables obtained from the univariate analysis (P<.05) were subsequently subjected to multivariable logistic regression analysis. The resulting variables from the multivariate analysis with P<.1 were applied in the construction of the nomogram using the R software with the “rms” package. To reduce the overfitting bias, an internal validation procedure was performed using 1000 bootstrap resamples. Furthermore, a web application facilitating the use of nomograms was developed using the “DynNom” package in the R software. Statistical significance was set at P<.05 (2-sided).

The C-index was calculated to evaluate the discriminatory power of the nomogram and ranged from 0.5-1. Higher C-indices indicate models with high discrimination abilities. Therefore, a value of 0.5 represented no discrimination, 0.7-0.8 represented acceptable discrimination, 0.8-0.9 represented excellent discrimination, and >0.9 represented outstanding discrimination. A calibration curve and the Hosmer-Lemeshow test were performed to evaluate the nomogram’s calibration ability. The calibration curve reflects the consistency between the predicted and actual

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**Fig 1** Enrollment flow chart of the patients.
outcomes. A well-calibrated nomogram matches the observed and predicted risks. A Hosmer-Lemeshow test with $P>0.05$ was used to indicate the goodness of fit of the nomogram model. The Youden index (Youden index=sensitivity +specificity−1) was used to determine the optimum cutoff value of the predicted probability of HSP and to identify the corresponding sensitivity and specificity.23

Decision curve analysis (DCA) was performed to identify the clinical utility of the nomogram by measuring the net benefits at distinct probability thresholds. DCA plotted the net benefit of the nomogram model and compared it with 2 default strategies: “treat all” or “treat none.” The “treat-all” strategy is grounded on the supposition that all the patients will be treated, irrespective of their estimated risks. In contrast, the “treat-none” strategy is grounded on the supposition that no patients will be treated because all of them have low risks.23 When the net benefit curve of a nomogram is higher than that of the “treat all” or “treat none” within a range of the reasonable risk thresholds, the nomogram model is considered clinically useful.

## Results

### Patient characteristics

This study included 376 patients with stroke, of whom 113 (30.05%) presented with HSP. The enrollment flow chart is summarized in fig 1. The characteristics of the non-HSP and HSP groups are also depicted in table 1. In total, 240 men and 136 women were enrolled in this study. The age of the participants ranged from 27-90 years, with a median age of 67 years. Approximately 46.81% and 53.19% of patients had left and right hemiplegia, respectively, and 69.95% and 30.05% had ischemic and hemorrhagic strokes, respectively.

### Univariate and multivariate HSP risk factors

Univariate analysis was performed to compare the candidate predictors between non-HSP and HSP groups. The results showed that 9 variables were statistically significant ($P<0.05$): age, type of stroke, diabetes mellitus, arm strength, spasticity, Brunnstrom stage, sensory disturbance, subluxation, and hand edema (see table 1). These predictors were subsequently subjected to multivariate logistic regression analysis, which showed that subluxation (odds ratio [OR], 0.432; 95% CI, 0.334-1.261), diabetes mellitus (OR, 0.423; 95% CI, 0.202-0.649), and hand edema (OR, 2.169; 95% CI, 1.072-4.428) were independent predictors of HSP.

## Table 1  Patient characteristics and univariate analysis for predictors of HSP

| Characteristic                  | Non-HSP (n=263) | HSP (n=113) | P   | Statistical Magnitude |
|--------------------------------|-----------------|-------------|-----|-----------------------|
| Age (y), median (IQR)          | 68 (57-74)      | 64 (54-74)  | .030*|                      |
| Sex, female, n (%)             | 94 (35.74)      | 42 (37.17)  | .792|                      |
| Disease course on admission (d), median (IQR) | 19 (13-41) | 22 (14-44.5) | .260|                      |
| Length of stay (d), median (IQR) | 51 (10,162)     | 59 (7-177)  | .570|                      |
| Stroke type, n (%)             | 203 (77.19)     | 60 (53.10)  | <.001*|                      |
| Ischemic                      | 60 (22.81)      | 19 (7.98)   | .001*|                      |
| Hemorrhagic                    | 117 (44.49)     | 59 (22.81)  | .169|                      |
| Hypertension, n (%)            | 193 (73.38)     | 82 (72.57)  | .870|                      |
| Diabetes mellitus, n (%)       | 102 (38.78)     | 22 (19.47)  | <.001*|                      |
| Arm strength, median (IQR)     | 3 (2-4)         | 2 (1-2)     | <.001*|                      |
| Spasticity, n (%)              | 79 (30.0)       | 55 (44.2)   | .001*|                      |
| Brunnstrom stage, median (IQR) | 4 (2-5)         | 2 (2-3)     | <.001*|                      |
| Sensory disturbance, n (%)     | 105 (39.92)     | 78 (69.03)  | <.001*|                      |
| Subluxation, n (%)             | 21 (7.98)       | 67 (59.29)  | <.001*|                      |
| Hand edema, n (%)              | 16 (6.08)       | 18 (15.93)  | 0.002*|                      |

Abbreviation: IQR, interquartile range  
* $P<.05.$

## Table 2  Multivariate logistic regression analysis for predictors of HSP

| Variables/Intercept | $\beta$ | P Value | OR   | 95% CI |
|---------------------|---------|---------|------|--------|
| Age                 | −0.005  | .659    | 0.995| 0.971-1.019 |
| Stroke type         | 0.423   | .202    | 1.527| 0.797-2.926  |
| Diabetes mellitus   | −0.432  | .202    | 0.649| 0.334-1.261  |
| Arm strength        | 0.221   | .307    | 1.247| 0.817-1.905  |
| Spasticity          | 0.725   | .013*   | 2.065| 1.163-3.668  |
| Brunnstrom stage    | −0.398  | .046*   | 0.671| 0.454-0.992  |
| Sensory disturbance | 0.684   | .021*   | 1.982| 1.109-3.543  |
| Subluxation         | 2.316   | <.001*  | 10.137| 5.289-19.428|
| Hand edema          | 0.840   | .074*   | 2.316| 0.922-5.818  |
| Intercept           | −1.233  | .229    | 0.291|        |

Abbreviation: $\beta$, regression coefficient.  
* $P<.1.$
Nomogram development and validation

Internal validation was performed using the bootstrap technique with 1000 resamples. The nomogram demonstrated excellent discrimination ability for assessing HSP risk, with an unadjusted C-index of 0.85 (95% CI, 0.81-0.89) and a bootstrap-corrected C-index of 0.84. The Hosmer-Lemeshow test also indicated a good fit of the prediction nomogram ($\chi^2=13.854, P=0.086$). The calibration plot suggested good calibration ability of the nomogram (fig 3), demonstrating good agreement between the forecasted probabilities and actual observations. The optimal cutoff
value was 0.30, and the corresponding sensitivity and specificity were 0.73 and 0.83, respectively.

Clinical utility

Figure 4 presents the DCA curve used to assess the clinical utility of the nomogram, demonstrating a threshold probability range of 5%-88%. This result revealed that the threshold probability range in the application of this nomogram might be more beneficial than the “treat-all” or “treat-none” strategy. For example, based on a 50% HSP probability, the nomogram added a net benefit of 11.9% compared with the “treat-all” or “treat-none” strategy.

Discussion

In this study, a nomogram was developed and internally validated for the risk prediction of HSP development by combining the following independent predictors: subluxation, Brunnstrom stage, hand edema, spasticity, and sensory disturbance. These 5 predictors are readily available through routine clinical practice. The nomogram exhibited promising performance in terms of discrimination, calibration, and clinical utility. With this nomogram, the HSP risk in patients with stroke can be accurately quantified, consequently assisting clinicians in the implementation of individualized treatments.

The results of the current study showed that the HSP incidence was 30.05%, consistent with a recent systematic review that reported an incidence ranging from 22%-47%. The 5 variables included in the nomogram reportedly correlate with HSP in previous studies. Poor upper limb motor function was generally considered an independent predictor for HSP. Our results showed that the Brunnstrom stage, a variable used to reflect the recovery stage of movement functions in patients with hemiparesis, was significantly associated with HSP, a finding consistent with the results of a previous study by Pong et al. Because of the lack of major protective mechanism of the shoulder girdle muscles, patients with severe motor impairment of the arm had increased susceptibility to periarticular soft tissue and nerve injuries, especially during inappropriate stretching or passive arm exercises. Thus, overstretching of the hemiplegic upper extremity should be avoided to prevent HSP development, particularly in patients with severe paralysis. Moreover, shoulder subluxation significantly increased the risk of HSP, with an OR of 10.630 (95% CI, 5.581-20.246). The regression coefficient of subluxation was the highest in the multivariate analysis, indicating a strong relationship between subluxation and HSP. A high incidence of shoulder subluxation has been reported in patients with stroke and shoulder pain. Subluxation may not result in shoulder pain at the early stages but can cause pain if it persists into chronic and spastic phases. Long-standing shoulder subluxation could lead to soft tissue overstretching and repeated microtrauma of joint structures, especially in the supraspinatus and biceps muscles, which are the major causes of shoulder pain post stroke. Therefore, prevention and treatment of shoulder subluxation should be sufficiently considered. The relationship between spasticity and HSP remains controversial. Some studies have reported a significant role of spasticity in HSP development, whereas others have revealed contrasting results. In this study, a positive relationship was found between the spasticity and HSP. Increased muscle tone around the shoulder has been generally reported to cause acromion impingement, humeral head displacement, and traction on muscle attachment points, thereby leading to HSP development. Additionally, the treatments aiming to decrease spasticity of the shoulder girdle muscles have been proven effective in improving HSP. In this study, 48.7% of patients presented with sensory disturbances of the upper limb, a finding consistent with that of a previous observational study. Sensory disturbances, including superficial sensation and proprioception, have been reportedly associated with HSP.
Isaksson et al.⁶ argued that light touch loss further increases the vulnerability of hemiplegic shoulders to soft tissue injury. Niessen et al.¹⁵ found that proprioceptive deficits can result in shoulder instability, an indirect cause of HSP. However, a few studies did not reach similar conclusions.⁶,⁹ The conflicting results emerging from these studies may be attributed to the different measurement methods applied and the vague definitions of sensory disturbance.⁹ Although hand edema is a common problem in patients with stroke, with an incidence rate reportedly ranging from 30%-40%,³⁶,³⁷ studies on the association between hand edema and HSP are limited. To our knowledge, only 1 study has reported the moderate association of hand edema with HSP.²⁴ Patients with stroke with shoulder pain and upper limb swelling are frequently diagnosed with shoulder-hand syndrome, a common cause of HSP.³⁸,³⁹ The present study demonstrated hand edema as an independent predictor for HSP, suggesting that edema plays a role in HSP development. However, hand edema, especially in the initial stages, is often overlooked. Thus, these findings have clinical implications. Early recognition and intervention for hand edema by clinicians is essential to prevent HSP development.

In the current study, the proposed nomogram showed good discrimination with unadjusted and corrected C-indices of 0.85 and 0.84, respectively. The Hosmer-Lemeshow test results and calibration plot supported good consistency between the forecasted and actual probabilities, indicating a good degree of calibration of the nomogram. However, in addition to discrimination and calibration, clinical utility is an important indicator for assessing the prediction models. DCA is a helpful decision-making tool frequently used to measure clinical utility by calculating the net benefits of predictive models. The net benefit is determined by obtaining the sum of all true positives and subtracting the sum of all false positives while considering the odds of the chosen risk probability threshold.⁴⁰ The model with higher net benefit for specified probabilities is deemed as having higher clinical utility. In our study, when the predicted probability range was 5%-88%, the application of this nomogram could increase the benefits as opposed to the “treat-none” or “treat-all” strategy. Thus, the nomogram developed in this study has good clinical utility.

Our study provides further evidence of the key role of several clinical variables thought to increase the risk of HSP. This may be helpful for a better understanding of HSP pathogenesis. The identified HSP predictors are noninvasive and readily available at hospital admission. Additionally, the nomogram is a simple and practical tool for clinicians to rapidly predict the risk of developing HSP, resulting in the implementation of early and individualized interventions. Further studies from other medical centers are required to verify the scope of clinical applications of the nomogram model.

Study limitations

This study has several limitations. First, the retrospective design, which may lead to potential biases, may have weakened the implications of the statistical analyses. Second, the external validation of the nomogram was not conducted in this study, and further studies are required to validate the performance of the nomogram externally using a multicenter cohort. Finally, some risk factors, such as depression, hemineglect, and the shoulder’s range of motion, were not included in the analysis. These factors act as potential predictors of HSP and may affect the results of the nomogram.

Conclusions

We developed a simple and practical nomogram for forecasting the risk of HSP in patients with stroke during inpatient rehabilitation. This nomogram used 5 easily ascertainable clinical characteristics: subluxation, Brunnstrom stage, hand edema, spasticity, and sensory disturbance. It exhibited satisfactory prediction performance and good clinical utility, potentially assisting clinicians in accurately predicting the patient’s risks of HSP and the implementation of early interventions. Further external validation of this nomogram is required in future studies.

Suppliers

a. SPSS 22.0; IBM, Armonk, NY.

b. R 4.0.5; R Foundation, Vienna, Austria.

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