Development and validation of a prognostic nomogram for open elbow arthrolysis

THE SHANGHAI PREDICTION MODEL FOR ELBOW STIFFNESS SURGICAL OUTCOME

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Aims
The aim of this study was to develop and internally validate a prognostic nomogram to predict the probability of gaining a functional range of motion (ROM ≥ 120°) after open arthrolysis of the elbow in patients with post-traumatic stiffness of the elbow.

Methods
We developed the Shanghai Prediction Model for Elbow Stiffness Surgical Outcome (SPESSO) based on a dataset of 551 patients who underwent open arthrolysis of the elbow in four institutions. Demographic and clinical characteristics were collected from medical records. The least absolute shrinkage and selection operator regression model was used to optimize the selection of relevant features. Multivariable logistic regression analysis was used to build the SPESSO. Its prediction performance was evaluated using the concordance index (C-index) and a calibration graph. Internal validation was conducted using bootstrapping validation.

Results
BMI, the duration of stiffness, the preoperative ROM, the preoperative intensity of pain, and grade of post-traumatic osteoarthritis of the elbow were identified as predictors of outcome and incorporated to construct the nomogram. SPESSO displayed good discrimination with a C-index of 0.73 (95% confidence interval 0.64 to 0.81). A high C-index value of 0.70 could still be reached in the interval validation. The calibration graph showed good agreement between the nomogram prediction and the outcome.

Conclusion
The newly developed SPESSO is a valid and convenient model which can be used to predict the outcome of open arthrolysis of the elbow. It could assist clinicians in counselling patients regarding the choice and expectations of treatment.

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Introduction

The elbow is an unforgiving articulation with significant bony congruity and often develops stiffness after injury,[1] due to soft-tissue contracture[2] and heterotopic ossification (HO).[3] Post-traumatic stiffness of the elbow, manifested as limited flexion or extension, has an incidence as high as 56% after trauma involving the elbow.[4] Morrey et al[5] estimated that a reduction of 50° in range of motion (ROM; extension-flexion) could cause up to 80% loss of function of the upper limb. Post-traumatic stiffness of the elbow leads to disability and severe impairment of daily activities.

The goal of treatment of post-traumatic stiffness of the elbow is regaining a stable, painless elbow with a functional ROM. Generally, conservative treatment such as static progressive or dynamic splinting is the first choice, within six months after trauma.[6] After that, surgery should be considered if the patient is dissatisfied with the ROM and their limited function. Open arthrolysis is the most commonly reported form of surgical treatment and has been shown to be effective.[7-9] In order to improve the efficacy of the procedure, prognostic factors that might affect the functional outcome should initially be identified and addressed. Some authors have investigated variables associated with the clinical outcome of open elbow arthrolysis in isolation. Factors which have previously been studied include obesity,[10,11] diabetes mellitus,[12] and abnormal serum uric acid metabolism.[13] Nevertheless, as the outcome is

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clearly influenced by many factors, finding ways to integrate all the available information to arrive at a more accurate estimate of prognosis seems essential.

Nomograms are user-friendly and convenient prognostic tools which are currently widely used in disciplines such as oncology[14,15] and orthopaedics.[16-18] They graphically depict a statistical prediction of the overall probability of a clinical event or a specific outcome. Nomograms address the limitations of individual factors and incorporate many variables in order to improve the prediction of the outcome. However, to the best of our knowledge, a nomogram predicting the outcome of open arthrolysis of the elbow has not been reported. Thus, the aim of this study was to develop and validate a comprehensive and effective nomogram to improve the prediction of the outcome of open arthrolysis of the elbow in patients with post-traumatic stiffness, based on a relatively large sample size. The research questions were: what demographic and clinical features are independent prognostic factors for the outcome of open elbow arthrolysis?; and can we develop a nomogram to predict the probability of gaining a functional ROM (≥ 120°) after this procedure?

Methods

All patients who underwent open elbow arthrolysis in four municipal hospitals between April 2014 and December 2018 were included in this retrospective cohort study. The ethics committees of the four hospitals approved the study. Data were analyzed anonymously, and all patients approved the results of the study. All clinical investigations were conducted under the guidelines of the Declaration of Helsinki.[19]

The inclusion criterion was any post-traumatic stiffness of the elbow. Exclusion criteria were: trauma associated with burns or central nervous system injuries; stiffness associated with rotational dysfunction of the forearm caused by abnormalities of the distal radioulnar joint or interosseous membrane; patients who underwent other surgery to the elbow including a second arthrolysis during the follow-up period; and those who were unwilling to participate or lost to follow-up. A total of 626 patients underwent open elbow arthrolysis in the four hospitals during the study period. After applying the inclusion and exclusion criteria, 551 patients were eligible for inclusion (Figure 1).

Our indications and detailed surgical techniques for the open elbow arthrolysis have been extensively reported.[9,20–22] The lateral (along the lateral column) and medial-posterior (posterior to the medial epicondyle) incisions are used, unless the patient has a previous posterior incision.

The strategies for arthrolysis are basically similar for post-traumatic elbow stiffness. The factors which affect the ROM of the elbow can be divided into tethers and blocks.[22] Posterior tethers such as a thickened posterior capsule and contracted triceps, or anterior blocks such as those due to HO, loose bodies in the radial fossa, and osteophytes around the coronoid process can cause loss of flexion. Similarly, anterior tethers such as a thickened anterior capsule, contracture or HO affecting the anterior band of the medial collateral ligament, or posterior blocks such as HO or loose bodies in the olecranon fossa, or olecranon osteophytes, may cause loss of extension. We generally use a combined medial-lateral approach, with the medial aspect addressing posterior tethers and blocks, and the lateral aspect managing anterior tethers and blocks. For tethers, release and excision of scarred or ossified soft-tissue is performed; for blocks, HO, osteophytes, or loose bodies are removed (Figure 2).

The ulnar nerve is identified at the medial border of the triceps in the medial approach, and is routinely released as far as its passage under the flexor carpi ulnaris distally. Careful attention is paid to the preservation of its vascular pedicles.[23,24]

We routinely remove any implants if preoperative radiographs show sound union of a fracture. In order to avoid iatrogenic fractures, the principle of “release first, removal next” is followed, meaning that the implants should be removed after complete release.

The relevant information was obtained from the medical records. We collected preoperative demographic and clinical characteristics which could possibly be associated with the outcome of surgery. A total of 16 items were identified after discussion and pilot-tested by an expert committee led by the senior author (CF). Demographic data comprised age, sex, BMI, and smoking and drinking habits. Clinical characteristics comprised dominance and the affected side, the duration of stiffness, the type of initial injury classified as simple/complex fracture or dislocation, the initial treatment (conservative/operative), number of previous arthrolysis procedures, ROM of the elbow, stability, pain intensity, ulnar neuropathy, post-traumatic osteoarthritis (OA) of the elbow, and HO around the elbow. BMI was classified according to the Chinese BMI criteria of the Working Group on Obesity in China.[25] ROM was measured using a goniometer, as previously described,[21] with three landmarks (lateral epicondyle, tip of the acromion, and middle portion of wrist).[26] The intensity of pain was evaluated using a visual analogue scale (VAS, 0 = no pain, 10 = very severe pain).[27] Ulnar neuropathy was evaluated according to the classification of Dellon.[28] Post-traumatic OA was graded according to the Broberg and Morrey rating system.[29] HO was classified as described by Hastings and Graham,[30] divided into three groups as not clinically significant (none and Hastings I), Hastings II, and Hastings III. The postoperative ROM at the last follow-up (> two years) was collected. We divided the medium-term ROM into two groups: < and ≥ 120°, based on the functional ROM requirement reported by Sardelli et al.[31]

The 551 patients comprised 358 males (64.9%) and 193 females (35.0%), with a mean age of 34.4 years (5 to 70) and a median duration of stiffness of 14 months (IQR 2 to 360). A total of 446 patients (80.9%) underwent surgery after the initial injury. The mean preoperative ROM of the elbow was 41° (0° to 115°), with mean flexion and extension of 81° (20° to 140°) and 40° (-5° to 100°), respectively. A total of 310 patients (56.2%) had stiffness in their dominant arm, and 389 (70.6%) had severe to extremely severe limitation of movement (ROM ≤ 60°) according to the Mansat classification of stiffness of the elbow.[32] The detailed information is shown in Table I.

Statistical analysis. Demographic and clinical characteristics were coded as categorical data, for making the nomogram succinct and facilitating its use.[33] The assignments for the variables are shown in Supplementary Table i. All analyses

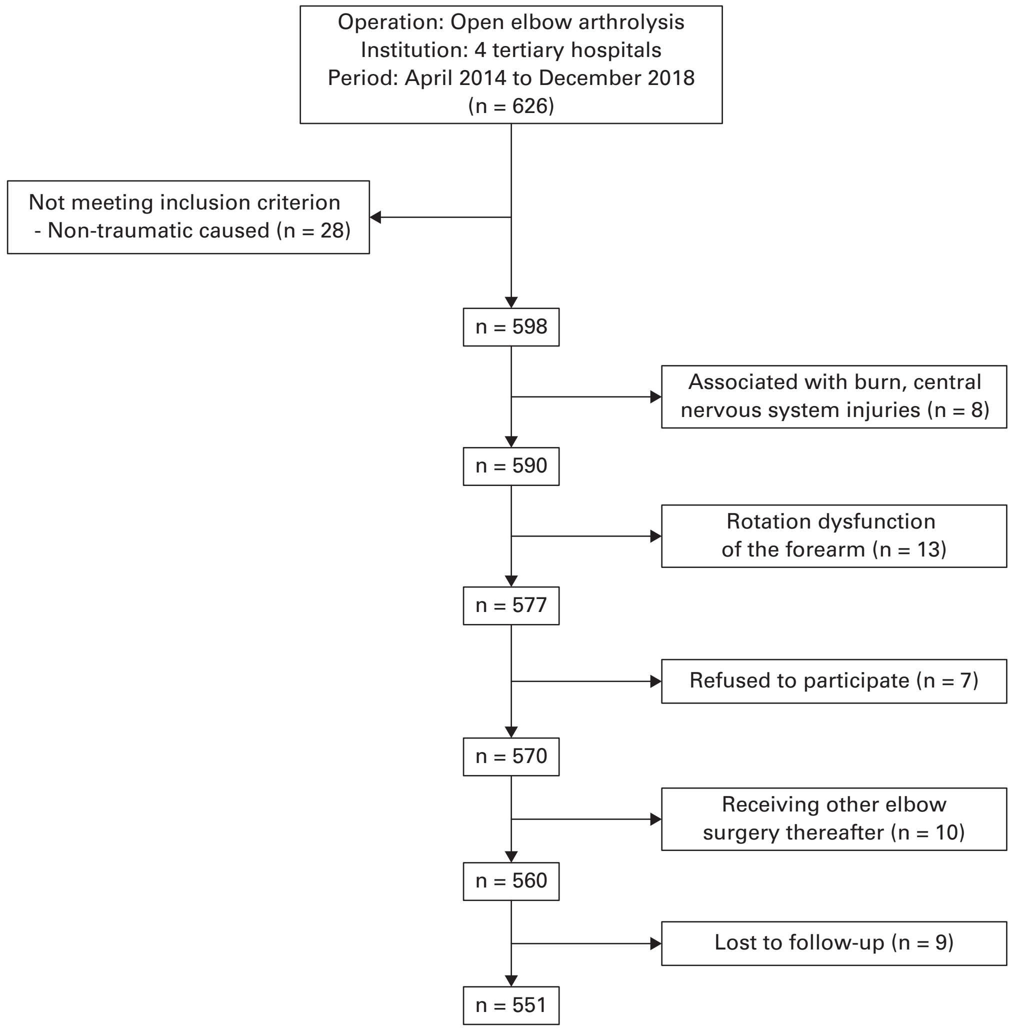


Fig. 1

Flow diagram for patient selection and enrolment.

were performed using R software (v. 4.0.2; R Foundation for Statistical Computing, Austria). Significance was set at $\alpha = 0.05$ (two-tailed).

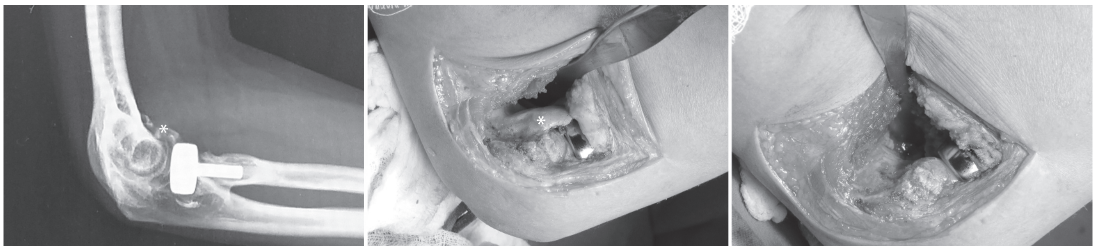
The least absolute shrinkage and selection operator (LASSO) method, which is suitable for reducing high-dimensional data,[34] was used to select the optimal predictive features for gaining a functional ROM (≥ 120°). Features with non-zero coefficients in the LASSO regression model were selected.[35] Then, multivariable logistic regression analysis was used to build a prediction model for the probability of gaining a functional ROM by incorporating the selected features. A nomogram graphically representing the prediction model was developed.[36] Regardless of statistical significance, the variable with the highest effect, which is the regression coefficient (absolute value) in the model, was assigned 100 points on the scale, and the remaining variables were assigned a smaller number of points proportional to their effect size.[37]

Harrell's concordance index (C-index), which is an approximation of the area under the curve (AUC) for a receiver operating characteristic (ROC) curve, was measured to quantify the discriminatory performance of the nomogram. A C-index of 0.5 is equal to chance discrimination and a C-index of 1.0 represents a perfect discrimination. Specifically, a C-index of 0.7 indicates that the nomogram can discriminate between a patient with and without the outcome of interest 70% of the time. The nomogram was subjected to bootstrapping validation (1,000 bootstrapping resamples)[38] to calculate a relatively corrected C-index. A calibration curve was plotted to assess the calibration of the nomogram. The calibration graph is used to determine how closely the actual probabilities correspond to the predicted probabilities calculated with the nomogram. An ideal calibration curve perfectly fits the 45° reference line. The better the model, the closer the predicted probability is to the actual probability, and the closer the curve is to the 45° line.

Results

For the demographic and clinical characteristics, 16 features were reduced to five potential predictive features based on the cohort of 551 patients, which had non-zero coefficients in the LASSO regression model (Supplementary Figure aa and

a



b

Fig. 2

The management of tethers and blocks in open elbow arthrolysis. a) Posterior tether release: contracted triceps pie-crusting technique. Multiple stab incisions are made in the triceps tendon in the medial-to-lateral and distal-to-proximal directions. b) Removal of an anterior block: radiograph shows anterior heterotopic ossification (HO). An irregularly shaped HO (*) originating from the distal humerus can be seen anteriorly. All figures are used with permission of the owner. All rights reserved (Sun et al. *Bone Jt Open*. 2020;1(8):576 to 584).

ab). These predictive features for gaining a functional ROM (≥ 120°) comprised BMI, duration of stiffness, preoperative ROM, preoperative VAS for pain, and grade of post-traumatic OA of the elbow. The logistic regression analysis results for these features as explanatory variables are shown in Table II. The model incorporating them was developed and presented as the nomogram (Figure 3a). Preoperative ROM has the highest effect and is converted into 100 points. A patient with preoperative ROM of ≥ 90° is assigned 100 points, whereas a patient with ROM< 30° gets zero points. A patient with no sign of OA would be given 77.7 points, which is equal to the ratio of β_{OA} / β_{ROM} multiplied by 100.[37]

The use of the nomogram has been previously described in detail.[39,40] In brief, points are accrued for each of the five explanatory factors. These are determined by drawing a vertical line from the corresponding scale to the “points” row at the top of the nomogram. The total points are then translated into a probability of gaining a functional ROM after open elbow arthrolysis by drawing a vertical line from the “total points” row to the corresponding “probability of functional ROM” scale.

A worked example of how to use the nomogram with a patient is as follows: in one who presents with a BMI of 23 kg/m^2, duration of stiffness of 18 months, baseline ROM of 40°, mild pain, and no sign of OA, the nomogram scores are 28.5 + 7.5 + 41 + 45 + 78 = 200 points and the probability of functional ROM is 0.81. This patient, therefore, has an 81% probability of gaining a functional ROM after the procedure (Figure 3b).

The C-index for the nomogram was 0.73 (95% confidence interval 0.64 to 0.81) for the cohort and was confirmed to be 0.70 through bootstrapping validation, which suggested the model’s good discrimination. The calibration curve of the nomogram showed good agreement in this cohort (Figure 4). This performance showed a good prediction capability of the nomogram.

Discussion

As Charalambous and Morrey[41] noted, “Dealing with posttraumatic elbow stiffness is a challenging task for the orthopaedic surgeon”. Open arthrolysis is commonly used in the treatment of this condition. In 1944, Wilson[42] first reported treatment by capsular excision for stiffness of the elbow following a supracondylar fracture of the humerus, with good effect. In the following 70 years, significant improvements have occurred in open elbow arthrolysis.[7,43,44] An individualized prediction of the outcome of surgery may help the counselling and perioperative management to optimize the care of these patients. Although there are previous data about the influential factors, using them in combination in a practical way is impossible without a nomogram. Our study is the first to introduce a predictive nomogram which may be used in the treatment of this condition, and in the area of research into joint stiffness generally.

In this study, approximately 36% of the patients with post-traumatic stiffness of the elbow did not gain a functional ROM of ≥ 120° after open arthrolysis. In the analysis of risk factors, BMI, the duration of stiffness, preoperative ROM, preoperative VAS for pain, and the grade of post-traumatic OA were associated with the ROM of the elbow at follow-up. Specifically, higher BMI, later arthrolysis, poorer baseline ROM, more severe pain, and more severe OA may be the key factors that hinder functional recovery. We built a nomogram for outcome prediction which was relatively accurate and demonstrated good discrimination and power of calibration.

Table I. Demographic and clinical characteristics of the patients.

Functional ROM of ≥ 120°	Yes (n = 355)	No (n = 196)	Total (n = 551)
Demographic characteristics, n (%)			
Age, yrs			
< 18	26 (7.3)	15 (7.7)	41 (7.4)
18 to 54	315 (88.7)	168 (85.7)	483 (87.7)
≥ 55	14 (3.9)	13 (6.6)	27 (4.9)
Sex			
Male	225 (63.4)	133 (67.9)	358 (65.0)
Female	130 (36.6)	63 (32.1)	193 (35.0)
BMI, kg/m²*			
Underweight, < 18.5	46 (13.0)	17 (8.7)	63 (11.4)
Normal, 18.5 to 23.9	193 (54.4)	93 (47.4)	286 (51.9)
Overweight, 24 to 27.9	99 (27.9)	73 (37.2)	172 (31.2)
Obese, ≥ 28	17 (4.8)	13 (6.6)	30 (5.4)
Tobacco use			
No	246 (69.3)	127 (64.8)	373 (67.7)
Yes	109 (30.7)	69 (35.2)	178 (32.3)
Alcohol use			
No	239 (67.3)	124 (63.3)	363 (65.9)
Yes	116 (32.7)	72 (36.7)	188 (34.1)
Clinical characteristics, n (%)			
Dominant limb			
No	154 (43.4)	87 (44.4)	241 (43.7)
Yes	201 (56.6)	109 (55.6)	310 (56.3)
Initial injury			
Simple fracture/dislocation	250 (70.4)	134 (68.4)	384 (69.7)
Complex fracture/dislocation	105 (29.6)	62 (31.6)	167 (30.3)
Initial treatment			
Conservative	70 (19.7)	35 (17.9)	105 (19.1)
Operative	285 (80.3)	161 (82.1)	446 (80.9)
Duration of stiffness, mths			
6 to 10	84 (23.7)	37 (18.9)	121 (22.0)
11 to 20	195 (54.9)	104 (53.1)	299 (54.3)
> 20	76 (21.4)	55 (28.1)	131 (23.8)
Previous arthrolysis procedures, n			
0	303 (85.4)	168 (85.7)	471 (85.5)
1	44 (12.4)	23 (11.7)	67 (12.2)
≥ 2	8 (2.3)	5 (2.6)	13 (2.4)
Preoperative ROM, °†			
< 30	85 (23.9)	92 (46.9)	177 (32.1)
30 to 59	146 (41.1)	66 (33.7)	212 (38.5)
60 to 89	107 (30.1)	35 (17.9)	142 (25.8)
≥ 90	17 (4.8)	3 (1.5)	20 (3.6)
Clinically significant HO‡			
No (None and I)	80 (22.5)	41 (20.9)	121 (22.0)
II	254 (71.5)	125 (63.8)	379 (68.8)
III	21 (5.9)	30 (15.3)	51 (9.3)
Pain intensity§			
None	218 (61.4)	107 (54.6)	325 (59.0)
Mild	107 (30.1)	57 (29.1)	164 (29.8)
Moderate and severe	30 (8.5)	32 (16.3)	62 (11.3)
Instability			
Stable	327 (92.1)	180 (91.8)	507 (92.0)
Moderate	24 (6.8)	13 (6.6)	37 (6.7)
Severe	4 (1.1)	3 (1.5)	7 (1.3)
Ulnar neuropathy¶			
None	253 (71.3)	147 (75.0)	400 (72.6)
I	68 (19.2)	30 (15.3)	98 (17.8)

Continued

Table I. Continued

Functional ROM of ≥ 120°	Yes (n = 355)	No (n = 196)	Total (n = 551)
II	21 (5.9)	12 (6.1)	33 (6.0)
III	13 (3.7)	7 (3.6)	20 (3.6)
OA of the elbow**			
None	189 (53.2)	65 (33.2)	254 (46.1)
I	105 (29.6)	64 (32.7)	169 (30.7)
II	44 (12.4)	33 (16.8)	77 (14.0)
III	17 (4.8)	34 (17.3)	51 (9.3)

*Classified according to the Chinese BMI criteria of the Working Group on Obesity in China.[25]
†Classified according to Mansat classification,[32] by ROM: > 90°, mild; 60° to 90°, moderate; 30° to 60°, severe; < 30°, extremely severe.
‡Classified according to Hastings and Graham classification:[30] I, no functional limitation; IIA, limited flexo-extension; IIB, limited prono-supination; IIC, IIA combined with IIB; III, ankylosis.
§Classified according to VAS for pain: none (0); mild (1 to 3); moderate (4 to 6); severe (7 to 10).
¶Classified according to the Dellon classification,[28] including sensory (paresthaesia, vibratory perception, and two-point discrimination) and motor symptoms (muscle weakness and atrophy).
**Classified according to Broberg and Morrey classification[29] (grade 0, normal joint; grade 1, slight joint-space narrowing with minimum osteophyte formation; grade 2, moderate joint-space narrowing with moderate osteophyte formation; and grade 3, severe degenerative change with gross destruction of the joint).
HO, heterotopic ossification; OA, osteoarthritis; ROM, range of motion; VAS, visual analogue scale.

Table II. Multivariate logistic regression analysis incorporating predictive features for functional range of motion after open elbow arthrolysis in patients with post-traumatic stiffness of the elbow.

Variable	β	Odds ratio (95% CI)	p-value
Intercept	1.282	3.606 (1.684 to 8.048)	0.001
BMI			
Underweight	Reference	Reference	Reference
Normal	-0.314	0.731 (0.369 to 1.396)	0.354
Overweight	-0.638	0.528 (0.260 to 1.040)	0.070
Obese	-0.916	0.400 (0.147 to 1.086)	0.071
Duration of stiffness, mths			
6 to 10	Reference	Reference	Reference
11 to 20	-0.356	0.701 (0.424 to 1.141)	0.158
> 20	-0.509	0.601 (0.339 to 1.057)	0.079
Preoperative ROM, °			
< 30	Reference	Reference	Reference
30 to 59	0.862	2.369 (1.531 to 3.689)	< 0.001
60 to 89	1.104	3.015 (1.824 to 5.062)	< 0.001
≥ 90	2.097	8.144 (2.295 to 40.288)	0.003
Pain intensity			
None	Reference	Reference	Reference
Mild	-0.051	0.950 (0.618 to 1.468)	0.817
Moderate and severe	-0.993	0.370 (0.201 to 0.678)	0.001
OA of the elbow			
None	Reference	Reference	Reference
Grade 1	-0.621	0.537 (0.344 to 0.836)	0.006
Grade 2	-0.728	0.483 (0.274 to 0.853)	0.012
Grade 3	-1.630	0.196 (0.098 to 0.381)	< 0.001

CI, confidence interval; OA, osteoarthritis; ROM, range of motion.

In previous studies, abnormal BMI has been confirmed as a risk factor for poor postoperative functional outcomes after open elbow arthrolysis,[10,45] and recurrent HO among children and teenagers.[11] Increased soft-tissue around the elbow and abnormal whole-body metabolism may be mechanisms. An earlier release could yield better functional outcomes, which previous authors have reported. A systematic review of 27 studies including 836 patients showed that those undergoing surgery earlier achieved a higher mean gain in ROM with fewer complications.[46] After long-standing dysfunction of the elbow, stiffness is likely to be aggravated by secondary OA, including fibrosis of the capsule and ligaments, degeneration of the articular cartilage and muscular atrophy.[47] Poorer preoperative ROM and more intense pain reflect increased severity and complexity in this condition. Post-traumatic OA is also a common sequela of trauma involving the elbow, and is often accompanied by stiffness.[48] The destruction of articular cartilage, and formation of ostephytes and loose bodies, leads to limited ROM of the elbow.[49]

It is also noteworthy that the type of the original injury, the initial treatment and the number of previous operations have no influence on the final outcome in the LASSO regression. This is consistent with our experience and previous research, as the

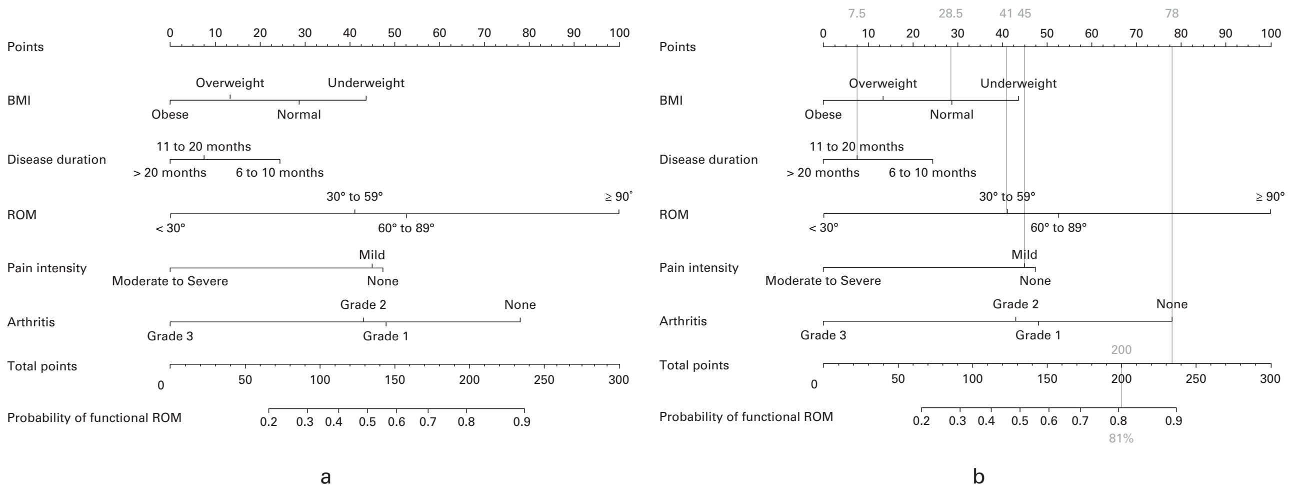


Fig. 3

The developed prognostic nomogram: Shanghai Prediction Model for Elbow Stiffness Surgical Outcome (SPESSO). a) SPESSO was developed incorporating BMI, duration of stiffness, preoperative range of motion (ROM), preoperative pain intensity, and grade of osteoarthritis (OA) of the elbow. b) This example shows the probability of gaining a functional ROM (≥ 120°) after open elbow arthrolysis in a patient with post-traumatic stiffness of the elbow presenting with a BMI of 23 kg/m^2, duration of stiffness of 18 months, baseline ROM of 40°, mild pain, and no sign of OA of the elbow.

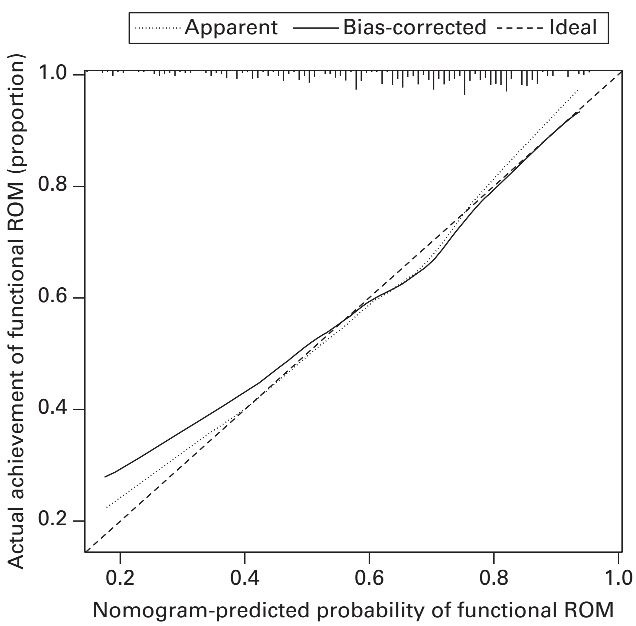


Fig. 4

Calibration curve of the nomogram prediction in the cohort. The diagonal dotted line represents a perfect prediction by an ideal model. The solid line represents the performance of this nomogram, of which a closer fit to the diagonal dotted line represents a better prediction. The calibration curve of the nomogram showed a good fit. ROM, range of motion.

pathological characteristics and strategies for arthrolysis are basically similar for the management of post-traumatic stiffness of the elbow.[21,22]

Our findings have several clinical implications. First, the efficacy of surgery could be improved by addressing risk factors preoperatively, such as losing weight and shortening the time between the initial injury and arthrolysis. Secondly, while baseline ROM accounts for the greatest amount of variation in the model and the duration of stiffness the least, patients with post-traumatic stiffness of the elbow should be encouraged to carry out active rehabilitation exercises, such as stretching, as the first-line of treatment to improve the ROM before the decision about surgery is made. A systematic review by Veltman et al,[50] which included eight studies with a total of 232 patients, showed that stretching could increase the ROM of the elbow by a mean of 36°. Thirdly, patients with poorly predicted outcomes should be appropriately counselled preoperatively. More attention should be paid to perioperative management, postoperative rehabilitation, and other measures, to maximize the efficacy of surgery. Lastly, open arthrolysis of the elbow could adequately address tethering and blocking factors,[21] but could not solve the articular cartilage injury. The predicted possibility of gaining a functional outcome is low for patients with severe post-traumatic OA of the elbow, and reconstruction with an interposition arthroplasty or total elbow arthroplasty should be considered. In general, with an estimate of the individual prognosis, clinicians and patients can make appropriate adjustments by monitoring the condition and medical interventions to achieve the best possible functional outcome.

These findings could expand to include the outcome of arthroscopic arthrolysis, because the pathological characteristics of stiff elbows and the principles of arthrolysis are the same as for an open procedure. As the five identified predictors (BMI, duration, ROM, pain, and OA) for the outcome of surgery are not elbow-specific, the nomogram may also be used for other stiff joints. These could be verified by the external validation of this prediction model in corresponding groups of patients. Furthermore, the model for the development of stiffness after trauma to the elbow merits further study, which could help with early warning and reducing the occurrence of this intractable complication.

This was a multicentre study involving four tertiary teaching hospitals from China. We followed consistent indications for surgery, and carefully defined inclusion and exclusion criteria. It is, thus, easy to idenify which patients our findings best apply to. However, we acknowledge several limitations. First, there may be some reporting bias, as the information about smoking and drinking was obtained by patients reporting orally. Secondly, analysis of the risk factors did not include all potential factors that affect the functional outcome, such as patients' comorbidities. However, we believe that the 16 features which were selected were enough to develop the nomogram. Lastly, although the robustness of the nomogram was examined extensively with internal validation using bootstrap testing, external validation could not be conducted, and the generalizability for other regions and countries would be uncertain. It needs to be externally evaluated in large international series of patients with post-traumatic stiffness of the elbow.

In conclusion, higher BMI, later arthrolysis, poorer baseline ROM, more severe pain, and more severe OA of the elbow are individual factors that hinder functional recovery after open elbow arthrolysis. The newly developed SPESSO is a convenient and effective prognostic model for the outcome in patients with post-traumatic stiffness of the elbow. It helps clinicians assess the probability of gaining a functional ROM after open arthrolysis, and to use medical interventions to enhance the efficacy of surgery by assessing individual risk factors in advance and personalizing treatment.

Take home message

- We developed and validated a nomogram (the Shanghai Prediction Model for Elbow Stiffness Surgical Outcome (SPESSO)) that would predict the probability of gaining a functional range of motion (ROM) in post-traumatic elbow stiffness patients undergoing open elbow arthrolysis.
- BMI, disease duration, preoperative ROM, preoperative pain intensity, and grade of post-traumatic elbow arthritis are independent predictors for open elbow arthrolysis outcome.
- SPESSO could assist clinicians in counselling patients regarding treatment expectations and taking medical interventions to optimize care for post-traumatic elbow stiffness patients.

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Supplementary material

Value assignments to candidate variables and the least absolute shrinkage and selection operator regression model.

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