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Original Article

Predictive modeling of frailty status in elderly abdominal surgery patients by preoperative quadriceps ultrasound testing

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Abstract: Objective: To develop a predictive model based on preoperative quadriceps ultrasound measurements to determine frailty status in elderly patients undergoing abdominal surgery. Methods: The clinical data of 148 elderly patients who underwent abdominal surgery from July 2018 to June 2022 were retrospectively analyzed. The patients were assessed for frailty using the Fried Frailty Phenotype Assessment Scale after operation and divided into a no-frailty group (n=89) and a frailty group (n=59). The differences in the patient's clinical data, perioperative indexes, and imaging indexes were compared. The risk factors affecting the frailty status of elderly patients undergoing abdominal surgery were analyzed by logistic regression. The efficacy of the prediction model was evaluated by receiver operating characteristic (ROC) curve, with model validity confirmed through calibration curves and decision curve analysis (DCA). Results: The proportion of patients with age ≥80 and BMI ≥23 kg/m^2 in the frailty group was significantly higher than that in the no-frailty group (both P<0.01). The operation duration and postoperative hospital stay in the frail group were significantly longer the non-frail group, and the complication rate within postoperative 7 days was significantly higher than that in the non-frail group (all P<0.05). The cross-sectional area of rectus femoris muscle, vastus medialis muscle thickness, vastus intermedius muscle thickness, rectus femoris muscle thickness, and lateral femoris muscle thickness were significantly less in the frail group than those of the no-frail group (all P<0.001). Multifactorial logistic regression analysis showed that BMI, surgical duration, vastus medialis muscle thickness, vastus intermedius muscle thickness, rectus femoris muscle thickness, and lateral femoral muscle thickness were independent risk factors affecting frailty status in elderly patients undergoing abdominal surgery (all P<0.05). The predictive model demonstrated high accuracy with an AUC of 0.926. Conclusion: BMI and thickness of all quadriceps muscle components were significant factors affecting the frailty status of elderly patients undergoing abdominal surgery. In addition, the developed model, with excellent accuracy, offers a potential tool for preoperative risk assessment in this patient population.

Keywords: Quadriceps, frailty, elderly, abdominal surgery, risk modeling

Introduction

The aging population in China is escalating into a significant challenge, primarily due to the frailty and deteriorating health outcomes of the elderly, posing a serious challenge to China's healthcare [1]. Over the past two decades, the number of elderly patients undergoing surgery has grown faster than the rate of population aging [2]. This may be related to advances in anesthesia surgical techniques, growing evidence of the safety and efficacy of geriatric surgery, and improvements in postoperative morbidity and mortality rates [3]. Despite the advances in medicine and improvements in healthcare for geriatric surgical patients, older patients remain at a higher risk of experiencing adverse postoperative outcomes than their younger counterparts [4]. Therefore, a thorough assessment of physiologic status of elderly patients is imperative to accurately evaluating their surgical risk and postoperative outcomes. Frailty, a condition prevalent among the elderly, arises with aging and hinders the body's resilience to stressors [5]. It is characterized by age-related reductions in physiological reserves

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and declines in multiple organ system function, which contribute to adverse health outcomes such as increased falls, disability, hospitalization, and mortality [6].

The quadriceps muscle, a pivotal component of the lower extremities, plays a crucial role in knee extension and maintaining body balance, essential for everyday activities such as walking and running [7]. The quadriceps may atrophy and lose strength due to aging, lifestyle change, and disease. This atrophy is strongly associated with frailty, leading to reduced mobility, increased risk of falls and fractures, and impacting quality of life and self-care [8]. Current methods for assessing muscle strength include handgrip strength testing, walking speed testing, and bioelectrical impedance analysis (BIA). While handgrip strength tests are straightforward, they do not provide insights into specific muscle groups. Walking speed tests reflect lower limb function but rely heavily on the patient's overall mobility. BIA assesses muscle mass, but its accuracy can be affected by the patient's hydration status and the precision of the equipment used [9]. Ultrasound testing, as a non-invasive, rapid, and cost-effective alternative, is suitable for assessing the size, structure, and function of the quadriceps muscle and evaluating the health and surgical risk of older adults [9]. In perioperative management, understanding the health status of the quadriceps muscle is crucial for the predicting the postoperative recovery trajectory of elderly patients undergoing abdominal surgery [10]. Maintaining or improving quadriceps function can significantly mitigate postoperative complications, accelerate the recovery process, and shorten the length of hospitalization. Targeted quadriceps training and rehabilitation programs, especially for surgical patients, can help build muscle strength and improve walking and balance, reducing the risk of weakness and complications [11].

In this study, ultrasound testing of the quadriceps muscle was performed within one week after surgery to assess muscle strength in elderly patients undergoing abdominal surgery. Compared to traditional assessment methods, ultrasonography is a non-invasive, rapid and reliable technique that provides a more accurate assessment by visualizing the structure and quality of the muscle. In addition, this technique not only improves accuracy, but also aids physicians in predicting the patient's postoperative recovery, providing an important basis for preoperative risk assessment and postoperative care planning.

Methods and materials

Patient inclusion

In this retrospective study, elderly patients admitted for abdominal surgery from July 2018 to June 2022 were included. The study was conducted with the approval from the Medical Ethics Committee of The Second People's Hospital of Lanzhou City.

Sample size calculation

Studies revealed that the prevalence of frailty in patients ranged from 32.5% to 43.8% [12, 13], with an average prevalence of 38.15%, which was taken for the calculation. The sample size was calculated according to $n = \frac{Z_{\alpha/2}^2 \times p \times (1 - p)}{E^2}$ where p is the prevalence rate, $Z_{\alpha/2}$ corresponds to a 95% confidence level (usually 1.96), e is the acceptable error margin (usually 0.05). This calculation yielded a required sample size of 362 individuals, adjusted according to the actual clinical scenario.

Inclusion criteria: (1) Age ≥70, with the ability for everyday verbal communication; (2) Patients underwent a complete Fried frailty phenotype assessment within one week after the operation; (3) No serious underlying diseases; (4) Hospitalization length ≥7 d; (5) Complete clinical data.

Exclusion criteria: (1) History of hemiplegia or Parkinson's disease; (2) Presence of malignant tumors; (3) Use of medications, such as antidepressants that known to cause muscle weakness; (4) History of sarcopenia and other diseases affecting muscles; (5) History of impaired consciousness or mental illness.

Fried frailty phenotype measurement scale [14]

The scale consists of five dimensions, namely, unintentional weight loss, self-reported exhaustion, reduced grip strength, slow walking speed, and reduced physical activity, with a score of 1 for each entry.

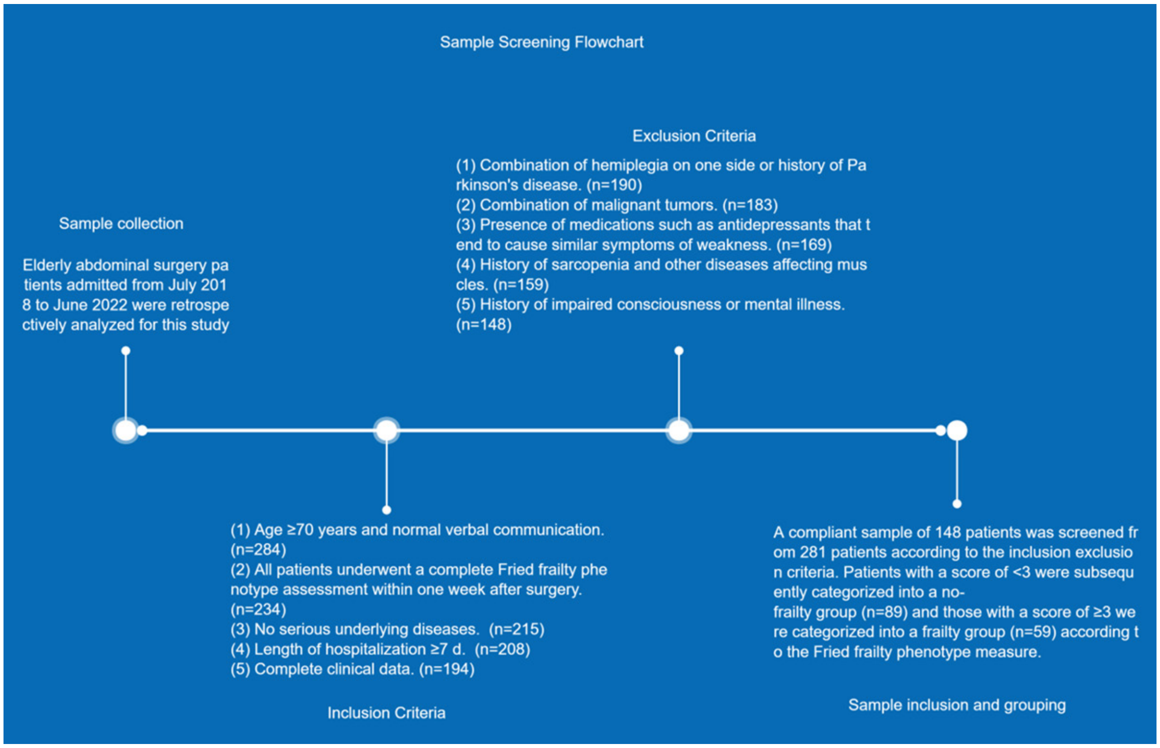


Figure 1. Sample screening flowchart.

Unintentional weight loss: patients' self-reported weight loss of more than 4.5 kg in the last year, verified through medical records. Self-reported exhaustion: it is assessed using specific questions from the Center for Epidemiologic Studies Depression Inventory, such as feelings of overwhelming difficulty in initiating activities or making progress. A response of "often" or "most of the time" indicates exhaustion. Weakness of grip strength: grip strength was measured using a grip strength meter, with the average of three consecutive measurements with the non-dominant hand. Thresholds vary by gender and BMI: 20.5 kg, 21.5 kg, and 23.0 kg for BMI ≤24 kg/m^2, 24 kg/m^2~26 kg/m^2, and >26 kg/m^2 in males, respectively, and 11.5 kg and 13 kg for BMI ≤23 kg/m^2 and >23 kg/m^2 in females, respectively. Walking speed: the examinees were tested for standing up from the armchair, walking 3 m, turning around, walking back, and siting down again, with a critical threshold of 10 s. Reduced physical activity: low-intensity activities accounted for ≤20% of all activities within 2 weeks. A total score of <3 indicates no frailty, and a score ≥3 indicates frail state, and patients were divided into a no-frailty group and a frail group based on their scores.

Sample inclusion and grouping

According to the inclusion/exclusion criteria, a total of 148 patients were selected from an initial pool of 281. Subsequently, patients with a score of <3 were categorized into a no-frailty group (n=89), and patients with a score of ≥3 were categorized into a frailty group (n=59) according to the Fried Frailty Phenotype assessment score. The sample screening flow chart is shown in **Figure 1**.

Clinical data collection

Patients' clinical data, including age, gender, BMI (body mass index), history of hypertension, diabetes mellitus, coronary heart disease, cerebrovascular disease, and type of surgery, were collected through electronic medical records. Perioperative indicators included operation duration, intraoperative bleeding, postoperative Fried Frailty Phenotype score, and complication rate within postoperative 7 days. Imaging indices included preoperative muscle cross-sectional area of rectus femoris, vastus medialis muscle thickness, vastus intermedius muscle thickness, rectus femoris muscle thickness, and lateral femoral muscle thickness.

Table 1. Clinical information

Variant	Frailty group (n=59)	No frailty group (n=89)	χ^2-value	*P*-value
Age (years)				
≥80	35	31	8.613	0.003
<80	24	58		
Gender				
Male	24	45	1.246	0.264
Female	35	45		
BMI (kg/m^2)				
≥23	21	13	8.831	0.003
<23	38	76		
History of hypertension				
Yes	35	45	1.246	0.264
No	24	45		
History of diabetes				
Yes	25	40	0.095	0.758
No	34	49		
History of coronary heart disease				
Yes	22	38	0.431	0.512
No	37	51		
History of cerebrovascular disease				
Yes	15	31	1.466	0.226
No	44	58		
Type of surgery				
Liver and gallbladder	30	43	0.091	0.763
Gastrointestinal	29	46		

Outcome measurement

1. The differences in patients' clinical data, perioperative indices, and imaging indices were compared between the two groups. 2. The risk factors affecting the frailty status of elderly patients undergoing abdominal surgery was screened by logistic regression. 3. The efficacy of the prediction model was evaluated by receiver operation characteristic (ROC) curve and verified by decision curve analysis (DCA).

Statistical analysis

SPSS 26.0 software was used to process and analyze the data in this study. Mean ± SD was used to represent the measurement data, and a t-test was used to compare two independent samples. Counted data were expressed as a rate (%) and analyzed using a chi-square test. The independent risk factors affecting the frailty was further analyzed using logistic regression analysis. In addition, to assess the accuracy of the predictive model, a calibration curve was established in this study, which can help to understand the agreement between the predicted values of the model and the actual observed values. Finally, to assess the value of the predictive model in clinical decision-making, a DCA was used to determine the value of the model's clinical application by calculating and comparing the net benefit at different thresholds. Differences were considered statistically significant at *P*-value <0.05.

Results

Comparison of clinical data between the two groups

The clinical data of the two groups of patients were compared, and there were no significant differences between the frailty and no-frailty groups regarding gender, history of hypertension, diabetes, coronary heart disease, cerebrovascular disease, and type of surgery (all P>0.05, **Table 1**). However, the percentage of patients in the frailty group with age ≥80 and

Table 2. Perioperative data

Cluster	Surgical time (min)	Intraoperative bleeding (mL)	Length of postoperative hospitalization (d)
Frailty group (n=59)	175.22±19.15	131.95±51.11	9.00 [8.00, 10.00]
No frailty group (n=89)	159.43±14.34	142.28±40.51	10.00 [8.00, 12.00]
χ^2/t value	5.409	-1.305	-2.391
P-value	<0.001	0.195	0.015

Table 3. 7 d complication rate

Cluster	Lower extremity venous thrombosis	Chills, high fever	Inflammatory exudation from the incision	Delirium	Complication rate within 7 d
Frailty group (n=59)	4	2	3	6	15 (25.42%)
No frailty group (n=89)	1	3	1	2	7 (7.87%)
χ^2/t value					8.643
P-value					0.003

Table 4. Imaging data

Group	Rectus femoris muscle cross-sectional area (cm^2)	Vastus medialis muscle thickness (cm)	Vastus intermedius muscle thickness (cm)	Rectus femoris muscle thickness (cm)	Lateral femoral muscle thickness (cm)
Frailty group (n=59)	3.43±0.29	3.24±0.39	1.02±0.12	1.00±0.10	1.56±0.25
No frailty group (n=89)	3.73±0.37	3.48±0.46	1.17±0.14	1.16±0.16	1.71±0.28
t-value	5.535	3.439	7.176	7.293	3.306
P-value	<0.001	<0.001	<0.001	<0.001	0.001

BMI ≥23 kg/m^2 was significantly higher than that of patients in the no-frailty group (both P<0.01, **Table 1**).

Comparison of perioperative data between the two groups

The perioperative data of the two groups of patients were compared. The results showed no significant difference in intraoperative bleeding between the two groups (P>0.05). The operation duration and postoperative hospital stay were significantly longer, and the complication rate within postoperative 7 days was significantly higher in the frailty group than those in the no-frailty group (all P<0.05, **Tables 2**, **3**).

Comparison of imaging data between the two groups

The imaging data showed that cross-sectional area of rectus femoris muscle, vastus medialis muscle thickness, vastus intermedius muscle thickness, rectus femoris muscle thickness, and lateral femoral muscle thickness were all significantly less than those in the no-frailty group (all P<0.001, **Table 4**).

Determination of the optimal cut-off value

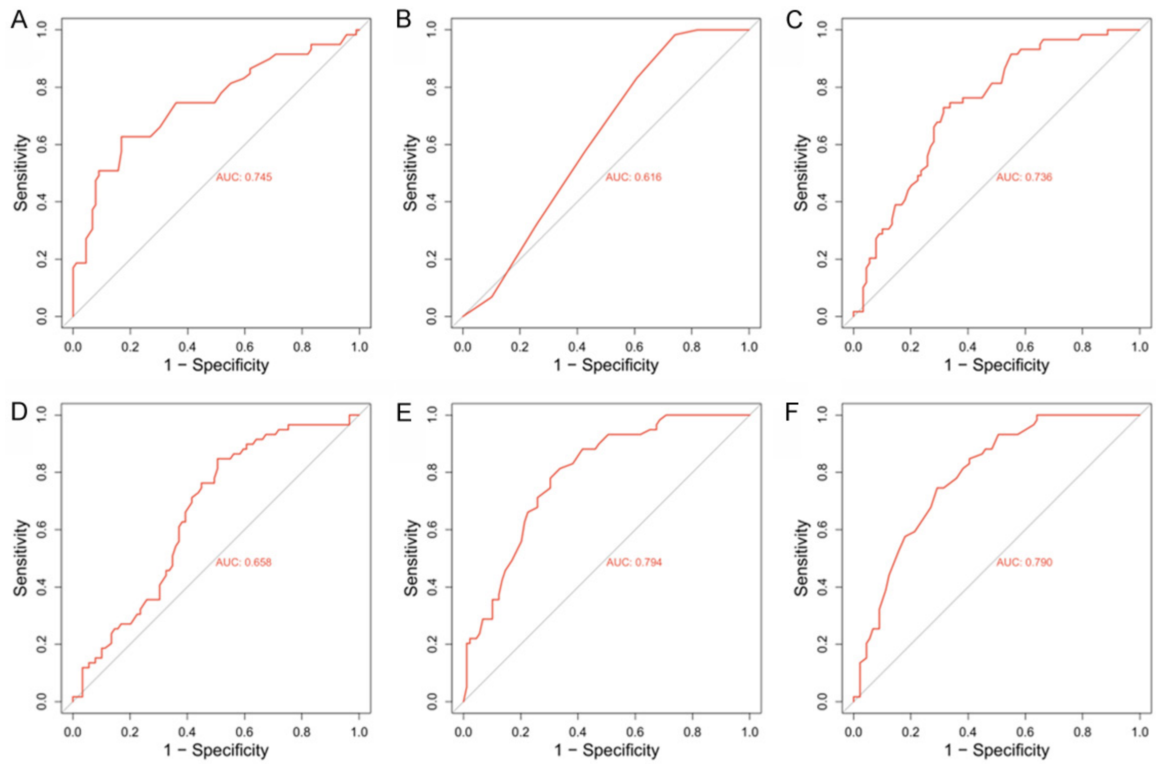
Since logistic regression requires dichotomous data, we used the cut-off value of the ROC curve to categorize the measures. The results showed that the cut-off values for operation time, postoperative hospitalization time, cross-sectional area of rectus femoris muscle, vastus medialis muscle thickness, vastus intermedius muscle thickness, rectus femoris muscle thickness and lateral femoral muscle thickness were 169.5 min, 11.5 d, 3.65 cm^2, 3.565 cm, 1.125 cm, 1.055 cm, and 1.595 cm, respectively (**Table 5**; **Figure 2**).

Logistic regression analysis of risk factors affecting frailty status in elderly patients undergoing abdominal surgery

We subjected meaningful data to multifactor logistic regression analysis based on previous data statistics. First, we categorized the mea-

Table 5. ROC values

Variant	AUC	95% CI	Specificity%	Sensitivity%	Youden index	Cut off
Surgical time (min)	0.745	0.660-0.745	83.15%	62.71%	45.86%	169.5
Length of postoperative hospitalization (d)	0.616	0.529-0.616	25.84%	98.31%	24.15%	11.5
Rectus femoris muscle cross-sectional area (cm^2)	0.736	0.657-0.736	68.54%	72.88%	41.42%	3.56
Vastus medialis muscle thickness (cm)	0.658	0.571-0.658	49.44%	84.75%	34.18%	3.565
Vastus intermedius muscle thickness (cm)	0.794	0.723-0.794	66.29%	81.36%	47.65%	1.125
Rectus femoris muscle thickness (cm)	0.790	0.718-0.790	70.79%	74.58%	45.36%	1.055
Lateral femoral muscle thickness (cm)	0.668	0.579-0.668	69.66%	62.71%	32.37%	1.595



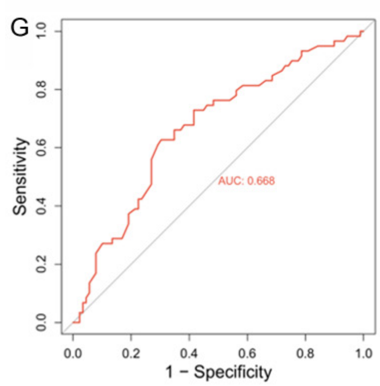


Figure 2. ROC curves for measures. A. Surgical time ROC curve in predicting patient frailty status. B. Length of postoperative hospitalization ROC curve in predicting patient frailty status. C. ROC curve of Rectus femoris muscle cross-sectional area in predicting the patient's frailty status. D. Vastus medialis muscle thickness in the ROC curve for predicting patient frailty status. E. Vastus intermedius muscle thickness in the ROC curve predicting the patient's frailty state. F. Rectus femoris muscle thickness ROC curve in predicting patient frailty status. G. Lateral femoral muscle thickness ROC curve in predicting patient frailty status. Note: AUC, area under the curve.

surement data and assigned values (**Table 6**). The results after analysis showed that BMI (P=0.035, OR=3.891, 95% CI: 1.101-13.747), Surgical time (P=0.012, OR=3.807, 95% CI: 1.346-10.769), Vastus medialis muscle thickness (P=0.005, OR=0.223, 95% CI: 0.079-0.63), Vastus intermedius muscle thickness (P<0.001, OR=0.134, 95% CI: 0.043-0.422), Rectus femoris muscle thickness (P<0.001, OR=0.104, 95% CI: 0.033-0.325), and Lateral

Table 6. Assignment table

Variant	An expression of value (math.)
Age	≥80 years =1, <80 years =0
BMI	≥23 kg/m^2 =1, <23 kg/m^2 =0
Complications	Present =1, absent =0
Surgical time	≥169.5 min =1, <169.5 min =0
Postoperative hospitalization time	≥105 d =1, <105 d =0
Rectus femoris muscle cross-sectional area	≥11.5 cm^2 =1, <11.5 cm^2 =0
Vastus medialis muscle thickness	≥3.56 cm =1, <3.56 cm =0
Vastus intermedius muscle thickness	≥3.565 cm =1, <3.565 cm =0
Rectus femoris muscle thickness	≥1.125 cm =1, <1.125 cm =0
Lateral femoral muscle thickness	≥1.055 cm =1, <1.055 cm =0
weak state	Weakness group =1, no weakness group =0

Note: BMI, Body Mass Index.

Table 7. Multifactor logistic regression analysis

Variant	β	SE	Chi-square value	*P*-value	OR value	95% CI	
						Lower limit	Limit
Age	0.643	0.654	0.966	0.326	1.901	0.528	6.848
BMI	1.359	0.644	4.452	0.035	3.891	1.101	13.747
Complications	0.188	1.141	0.027	0.869	1.207	0.129	11.291
Surgical time	1.337	0.53	6.351	0.012	3.807	1.346	10.769
Postoperative hospitalization time	-0.179	0.641	0.078	0.780	0.836	0.238	2.938
Rectus femoris muscle cross-sectional area	-1.633	1.153	2.006	0.157	0.195	0.02	1.872
Vastus medialis muscle thickness	-1.499	0.529	8.035	0.005	0.223	0.079	0.63
Vastus intermedius muscle thickness	-2.009	0.586	11.776	0.001	0.134	0.043	0.422
Rectus femoris muscle thickness	-2.26	0.58	15.168	<0.001	0.104	0.033	0.325
Lateral femoral muscle thickness	-1.884	0.538	12.278	<0.001	0.152	0.053	0.436

Note: BMI, Body mass index.

femoral muscle thickness (P<0.001, OR= 0.152, 95% CI: 0.053-0.436) were independent risk factors affecting the elderly abdominal surgery patients' independent risk factors for frailty status (P<0.05, **Table 7**).

Risk model construction and internal validation

Based on the beta coefficient of the logistic regression model, we constructed a frailty prediction model based on the screened risk factors: BMI*1.359 + vastus medialis muscle thickness*-1.499 + vastus intermedius muscle thickness*-2.009 + rectus femoris muscle thickness*-2.26 + lateral femoral muscle thickness*-1.884 + 1.963. The risk score of patients in the frailty group was significantly higher than that of patients in the no-frailty group (P<0.001, **Figure 3A**). ROC curve analysis revealed that the risk score had an AUC of 0.926 in predicting frailty in elderly patients (**Figure 3B**). The bootstrap self-sampling method was used for internal validation, and after repeating the self-sampling 200 times, the calibration curve was obtained (**Figure 3C**). The calibration curve was close to the diagonal line. The C-index was 0.926 (0.885-0.967), and the Akaike Information Criterion (AIC) was 113.174, suggesting that the predicted risk was close to the actual risk and that the model's predictive ability was good (**Figure 3C**). In addition, DCA analysis found that the predictive model performed best with an average net return of 0.426, between 2%-98% (**Figure 3D**).

Imaging documents

From the imaging file of the two patients, we can observe a clear contrast. The thigh mus-

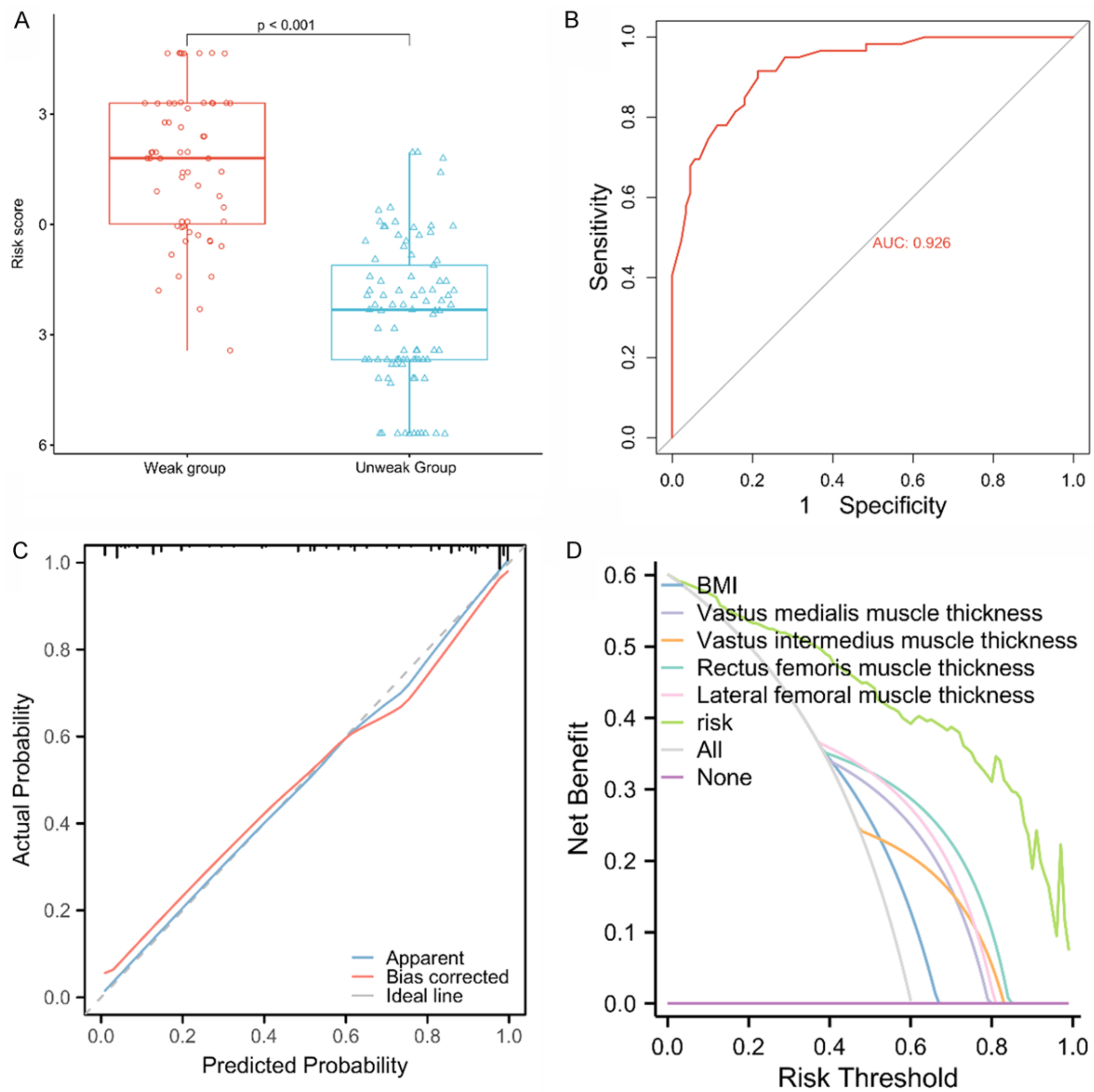


Figure 3. Energy efficiency of risk models in predicting patient frailty status with model internal validation. A. Risk scores in patients in the frailty group versus those in the no-frailty group. B. ROC curves for risk scores in predicting frail elderly patients. C. Calibration curve analysis to predict the efficacy of the frailty model in old age. D. DCA analysis to predict the efficacy of the frailty model in old age. Note: ROC, subject job characteristic curve; DCA, decision curve score.

cles of the patient with frailty (**Figure 4A**) appear weaker, indicating muscle atrophy or reduced muscle mass, which is often associated with physical weakness. In contrast, the thigh muscles of non-frailty patients (**Figure 4B**) are thicker and more pronounced, indicating healthy muscle development. This difference in muscle thickness not only reveals significant differences in physical health status, but also highlights the importance of muscle health in assessing a patient's overall health.

Discussion

The growing concern over aging and frailty among the elderly has garnered significant academic interest [15], recognizing frailty as a critical state marked by the organism's diminished resilience against health stressors diseases, such as health events and organ function decline [16]. This state renders the elderly susceptible to a range of adverse outcomes, from disease progression to organ failure [17]. Re-

Figure 4. Quadriceps thickness in frail and non-frail patients. A. Quadriceps thickness in a frail patient. B. Quadriceps thickness in a non-frail patient.

search by Xu et al. [18] has established that frailty is an independent risk factor for postoperative complications, prolonged hospital stay, and mortality in elderly patients, potentially increasing morbidity and mortality by 15-50% and significantly amplifying healthcare resource utilization and costs. Consequently, early screening for frailty in the elderly is crucial for enhancing their quality of life and disease prognosis. Our study found that approximately 39.8% of the 148 elderly patients examined were in a state of frailty, with the most common symptom being reduced physical activity, closely followed by a decline in walking speed.

In clinical practice, two-dimensional ultrasound is a valuable tool for assessing muscle mass, offering key indicators such as muscle thickness and cross-sectional area [19]. Muscle thickness is a direct indicator of muscle content, while the cross-sectional area is closely associated with muscle strength [20]. Recent studies have shown that the accuracy of ultrasound in measuring quadriceps muscle is comparable to CT scans and aligns well with dual-energy X-ray [21]. Quadriceps atrophy leads to reduced lower limb muscle tone, decreasing each muscle's circumference, significantly impacting knee joint stability and consequently limiting mobility, walking speed, and physical activity levels [22]. Ultrasonographic detection revealed notable reductions in the cross-sectional area of rectus femoris muscle and thickness of the quadriceps muscles in patients of the frailty group. It has been discovered that the cross-sectional area of rectus femoris muscle is a crucial marker for assessing lower limb muscle damage and knee extensor weakness, providing an accurate gauge of muscle atrophy [23]. In terms of prognosis, this research also confirmed that patients in the frail group experienced longer postoperative hospital stays and a higher incidence of complications. Therefore, early identification of muscle weakness is crucial in elderly patients undergoing abdominal surgery. Detection of weakness necessitates heightened attention to the physiological status of elderly patients, and prompt clinical interventions are essential to improve surgical outcomes and enhance quality of life.

This study has several limitations that must be acknowledged. First, it is a single-center retrospective study with a relatively small sample size of only 148 cases, which limits the representativeness of our findings. Second, there is a need for external validation of our model. Since our sample was exclusively from our center, the broader applicability of the results remains uncertain. Additionally, as a retrospective study, we cannot guarantee the completeness of the collected case characteristics and clinical data. Despite these challenges, our study successfully demonstrates that ultrasound assessment of the quadriceps, combined with clinical data, can effectively predict frailty in elderly patients undergoing abdominal surgery. Moving forward, we aim to address these limitations by adopting a prospective study design, expanding our sample size, and including samples from multiple centers to enhance the clinical representativeness of our results. We also plan to conduct external validation of the model to ensure its applicability to a broader population. Lastly, efforts will be made to optimize the collection of case information, ensuring the acquisition of more comprehensive and accurate data.

In summary, this study has identified that both BMI and the thickness of each component of the quadriceps muscle are significant factors influencing the frailty status of elderly patients undergoing abdominal surgery, as determined through logistic regression analysis. Furthermore, the model constructed in this study has demonstrated excellent predictive accuracy, offering a valuable tool for preoperative risk assessment in this patient population.

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Preoperative bedside ultrasound can evaluate the frailty status of elderly patients and predict postoperative outcomes (No. 2022-5-138).

Disclosure of conflict of interest

None.

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