

## · 论著 · 重症烧伤 ·

## 本文亮点:

- (1) 通过分析 267 例严重烧伤患者的临床资料,筛选出治疗期间卧床时间>7 d、合并慢性阻塞性肺疾病、入院时简明烧伤严重指数评分高是患者并发肺动脉栓塞的独立危险因素。
- (2) 基于上述独立危险因素建立严重烧伤患者并发肺动脉栓塞风险预测模型,经评估该模型具有较好的预测价值,为防控严重烧伤患者并发肺动脉栓塞提供了依据。

## Highlights:

- (1) By analyzing the clinical data of 267 severe burn patients, the independent risk factors for pulmonary embolism in severe burn patients were screened out as bedtime during treatment beyond 7 days, combination of chronic obstructive pulmonary disease, and high abbreviated burn severity index score on admission.
- (2) Based on the aforementioned independent risk factors, a risk prediction model for pulmonary embolism in severe burn patients was established, which was evaluated to have good predictive value and provided a basis for prevention and control of pulmonary embolism in severe burn patients.



## 严重烧伤患者并发肺动脉栓塞风险预测模型的建立与验证

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**【摘要】** 目的 筛选严重烧伤患者并发肺动脉栓塞的危险因素,据此构建风险预测模型并进行验证。 方法 该研究为回顾性病例系列研究。收集 2021 年 3 月—2023 年 3 月武汉市第三医院烧伤科收治的符合入选标准的 267 例严重烧伤患者的临床资料,其中男 159 例、女 108 例,年龄 18~82 岁。根据是否并发肺动脉栓塞将患者分为肺动脉栓塞组(26 例)与非肺动脉栓塞组(241 例),收集并比较 2 组患者性别、年龄、体重指数、治疗期间卧床时间、烧伤原因、入院时白蛋白水平、合并慢性阻塞性肺疾病(COPD)情况、合并糖尿病情况、合并高血压情况、合并吸入性损伤情况和入院时简明烧伤严重指数(ABSI)评分。对组间比较差异有统计学意义的指标进行单因素和多因素 logistic 回归分析,筛选 267 例严重烧伤患者并发肺动脉栓塞的独立危险因素,并据此构建列线图预测模型。通过受试者操作特征(ROC)曲线评估预测模型的性能,采用校准曲线和临床决策曲线分析法对预测模型进行验证。 结果 肺动脉栓塞组患者中>60 岁、治疗期间卧床时间>7 d、合并 COPD、合并糖尿病患者比例( $\chi^2$  值分别为 7.75、29.15、29.86、5.94),入院时 ABSI 评分( $t=6.01$ )均明显高于非肺动脉栓塞组( $P<0.05$ )。2 组患者其余资料比较,差异均无统计学意义( $P>0.05$ )。单因素 logistic 回归分析显示,年龄、治疗期间卧床时间、合并 COPD、合并糖尿病、入院时 ABSI 评分均为严重烧伤患者并发肺动脉栓塞的

DOI:10.3760/cma.j.cn501225-20240122-00028

本文引用格式:姜胜攀,高小青,谭一清.严重烧伤患者并发肺动脉栓塞风险预测模型的建立与验证[J].中华烧伤与创面修复杂志,2024,40(12):1-8. DOI:10.3760/cma.j.cn501225-20240122-00028.

Jiang Shengpan,Gao Xiaoqing,Tan Yiqing.Establishment and validation of a risk prediction model for severe burn patients complicated with pulmonary embolism[J].Chin J Burns Wounds,2024,40(12):1-8.DOI:10.3760/cma.j.cn501225-20240122-00028.



危险因素(比值比分别为 3.40、14.87、17.78、2.80、1.88, 95% 置信区间分别为 1.38~8.39、4.34~50.98、4.63~68.22、1.19~6.58、1.47~2.41,  $P<0.05$ )。多因素 logistic 回归分析显示, 治疗期间卧床时间 $>7$  d、合并 COPD、入院时 ABSI 评分高均为严重烧伤患者并发肺动脉栓塞的独立危险因素(比值比分别为 11.02、30.82、1.86, 95% 置信区间分别为 2.76~43.98、3.55~267.33、1.38~2.50,  $P<0.05$ )。根据前述 3 个独立危险因素构建严重烧伤患者并发肺动脉栓塞风险列线图预测模型。预测模型的 ROC 曲线显示, ROC 曲线下面积为 0.91(95% 置信区间为 0.82~0.99), 取最佳阈值 25% 时, 预测模型的敏感度为 84.6%、特异度为 93.4%; 校准曲线显示, 预测模型校准曲线在理想曲线附近, Cox 回归的一致性指数为 0.80(95% 置信区间为 0.74~0.87); 临床决策曲线显示, 该模型的阈值概率范围为 1%~98%, 其净收益率 $>0$ 。 **结论** 严重烧伤患者并发肺动脉栓塞的独立危险因素包括治疗期间卧床时间 $>7$  d、合并 COPD、入院时 ABSI 评分高, 据此构建的列线图预测模型对严重烧伤患者并发肺动脉栓塞具有较佳的预测价值。

**【关键词】** 烧伤; 危险因素; 列线图; 肺动脉栓塞

**基金项目:** 湖北省卫生健康委 2019~2020 年度项目(WJ2019F004); 2019 年湖北省知识创新专项(自然科学基金)项目(2019CFC917); 武汉市卫生与计划生育委员会科研项目(WX16D13)

### Establishment and validation of a risk prediction model for pulmonary embolism in severe burn patients

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**【Abstract】 Objective** To screen the risk factors risk factors for pulmonary embolism in severe burn patients, based on which, a risk prediction model was established and validated. **Methods** This study was a retrospective case series study. The clinical data of 267 severe burn patients who met the inclusion criteria and were admitted to the Department of Burns of Wuhan Third Hospital from March 2021 to March 2023 were collected, including 159 males and 108 females, aged 18–82 years. The patients were divided into pulmonary embolism group (26 cases) and non-pulmonary embolism group (241 cases) according to whether they were complicated with pulmonary embolism. The following data of patients in the 2 groups were collected and compared, including gender, age, body mass index, bedtime during treatment, cause of burn, albumin level on admission, combination of chronic obstructive pulmonary disease (COPD), combination of diabetes mellitus, combination of hypertension, combination of inhalation injury, and the abbreviated burn severity index (ABSI) on admission. The indicators with statistically significant differences between the two groups were conducted with univariate and multivariate logistic regression analyses to identify the independent risk factors for pulmonary embolism in 267 severe burn patients. Based on these findings, a nomogram prediction model was constructed. The performance of the prediction model was evaluated by the receiver operating characteristic (ROC) curve, while its validation was conducted through calibration curve and clinical decision curve analysis. **Results** The proportions of beyond 60 years old, bedtime during treatment beyond 7 days, combination of COPD, and combination of diabetes (with  $\chi^2$  values of 7.75, 29.15, 29.86, and 5.94, respectively), and ABSI score on admission ( $t=6.01$ ) of patients in pulmonary embolism group were higher than those of non-pulmonary embolism group ( $P<0.05$ ). There were no statistically significant differences in the other indicators between the two groups of patients ( $P>0.05$ ). The univariate logistic regression analysis showed that, age, bedtime during treatment, combination of COPD, combination of diabetes, and ABSI score on admission were the risk factors for pulmonary embolism in severe burn patients (with odds ratios of 3.40, 14.87, 17.78, 2.80, and 1.88, respectively, 95% confidence intervals of 1.38–8.39, 4.34–50.98, 4.63–68.22, 1.19–6.58, and 1.47–2.41, respectively,  $P<0.05$ ). The multivariate logistic regression analysis showed that, bedtime during treatment beyond 7 days, combination of COPD, and high ABSI score on admission were the independent risk factors for pulmonary embolism in severe burn patients (with odds ratios of 11.02, 30.82, and 1.86, respectively, 95% confidence intervals of 2.76–43.98, 3.55–267.33, and 1.38–2.50, respectively,  $P<0.05$ ). Based on the three aforementioned independent risk factors, a nomogram prediction model for the risk of pulmonary embolism in severe burn patients was constructed. The ROC curve of prediction model showed that,

the area under the ROC curve was 0.91 (with 95% confidence interval of 0.82–0.99). When the optimal cut-off value of 25% was taken, the sensitivity and specificity of prediction model was 84.6% and 93.4%, respectively. The calibration curve showed that, the calibration curve of prediction model was around the ideal curve, with a consistency index of 0.80 in Cox regression (with 95% confidence interval of 0.74–0.87). The clinical decision curve showed that the threshold probability value of the prediction model was in the range of 1% to 98%, with net return rate over 0. **Conclusions** The independent risk factors for pulmonary embolism in severe burn patients include bedtime during treatment beyond 7 days, combination of COPD, and high ABSI score on admission. The nomogram prediction model constructed based on this has a good ability to predict pulmonary embolism in severe burn patients.

**【Key words】** Burns; Risk factors; Nomograms; Pulmonary embolism

**Fund program:** Project of Hubei Provincial Health Commission from 2019 to 2020 (WJ2019F004); Hubei Province Knowledge Innovation Project (Natural Science and Technology Fund) in 2019 (2019CFC917); Scientific Research Program of Wuhan Health and Family Planning Commission (WX16D13)

烧伤是一种突发的身体创伤,通常由高温、化学物质、电击或其他因素引起<sup>[1]</sup>。烧伤对皮肤和深层组织造成损害,导致皮肤发红、水疱形成、疼痛、瘢痕形成和感染等并发症<sup>[2-5]</sup>。其中,肺动脉栓塞是一种严重的并发症,其发生机制是来自静脉系统的血栓堵塞肺动脉,导致肺循环障碍和低氧血症<sup>[6-8]</sup>。如果不及时诊断和治疗,肺动脉栓塞可引起呼吸功能不全、心力衰竭和死亡等严重后果<sup>[9]</sup>。相关文献研究显示,肺动脉栓塞在严重烧伤患者中时有发生<sup>[10-11]</sup>,与此同时,肺动脉栓塞在临床上的表现可能因人而异,且发病隐匿,无特异性表现,这也增加了该疾病在早期被误诊或漏诊的风险<sup>[12-14]</sup>。早期识别严重烧伤患者并发肺动脉栓塞的危险因素并对其进行预防和干预具有重要意义。因此,本研究旨在探讨严重烧伤患者并发肺动脉栓塞的危险因素,据此构建列线图预测模型并进行验证,以期严重烧伤患者并发肺动脉栓塞的早期防治提供参考依据。

## 1 对象与方法

本回顾性病例系列研究收集匿名患者临床资料,分析过程中不泄露患者身份及相关疾病信息,获武汉市第三医院(以下简称本院)伦理委员会豁免,符合《赫尔辛基宣言》的基本原则。

### 1.1 入选标准

纳入标准:(1)患者已确诊为严重烧伤,烧伤总面积 $\geq 30\%$ TBSA;(2)年龄 $\geq 18$ 岁;(3)患者已接受对症治疗;(4)临床资料完整。排除标准:(1)伤后3 d内自动出院或死亡;(2)合并其他严重疾病,如心、肝、肾等器官损伤;(3)合并血栓性基础疾病;(4)有既往房颤史。

### 1.2 临床资料与分组统计

收集2021年3月—2023年3月本院烧伤科收治的符合入选标准的267例严重烧伤患者的临床资料,其中男159例、女108例,年龄18~82(37 $\pm$ 15)岁,其中 $>60$ 岁者126例、 $\leq 60$ 岁者141例。对患者均行预防性抗凝治疗以及采用间歇性充气装置预防深静脉血栓。根据是否并发肺动脉栓塞将患者分为肺动脉栓塞组(26例)和非肺动脉栓塞组(241例),收集并比较2组患者性别、年龄、体重指数、治疗期间卧床时间、烧伤原因、入院时白蛋白水平、合并慢性阻塞性肺疾病(chronic obstructive pulmonary disease, COPD)情况、合并糖尿病情况、合并高血压情况、合并吸入性损伤情况和入院时简明烧伤严重指数(abbreviated burn severity index, ABSI)评分。

### 1.3 肺动脉栓塞诊断

根据中华医学会呼吸病学分会肺栓塞与肺血管病学组等制订的《肺血栓栓塞症诊治与预防指南》<sup>[15]</sup>,相关临床症状(以呼吸困难最为常见,其他症状包括气促、胸痛、晕厥、烦躁不安、咯血、咳嗽、心悸等)或检查结果(D-二聚体 $\geq 5.0$  mg/L)怀疑存在肺动脉栓塞风险,此时患者需要行CT肺动脉造影来确诊,直接征象为肺动脉内充盈缺损,部分或完全包围在不透光的血流之间(轨道征),或呈完全充盈缺损,远端血管不显影。

### 1.4 统计学处理

采用SPSS 22.0和R 4.2.2统计软件进行数据分析。计数资料数据用频数(百分比)表示,组间比较行 $\chi^2$ 检验。符合正态分布的计量资料数据用 $\bar{x} \pm s$ 表示,组间比较行独立样本 $t$ 检验;不符合正态分布的计量资料数据用 $M(Q_1, Q_3)$ 表示,组间比较行

Mann-Whitney *U* 检验。 $P < 0.05$  为差异有统计学意义。

对组间比较差异有统计学意义的指标进行单因素和多因素 logistic 回归分析,筛选 267 例严重烧伤患者并发肺动脉栓塞的独立危险因素。根据独立危险因素建立肺动脉栓塞风险预测模型并绘制列线图。通过受试者操作特征(receiver operator characteristic, ROC)曲线评估预测模型的性能,采用校准曲线评估预测模型符合度,采用临床决策曲线分析法对预测模型进行验证。

## 2 结果

### 2.1 临床资料比较

肺动脉栓塞组患者中>60 岁、治疗期间卧床时间>7 d、合并 COPD、合并糖尿病患者比例,入院时 ABSI 评分均明显高于非肺动脉栓塞组( $P < 0.05$ )。见表 1。

### 2.2 严重烧伤患者并发肺动脉栓塞的单因素和多

### 因素 logistic 回归分析

将 2.1 中组间比较差异有统计学意义的年龄、治疗期间卧床时间、合并 COPD、合并糖尿病、入院时 ABSI 评分作为自变量,并进行赋值:年龄>60 岁=1、≤60 岁=0,治疗期间卧床时间>7 d=1、≤7 d=0,合并 COPD 和合并糖尿病均为是=1、否=0,入院时 ABSI 评分以原始值代入,将是否并发肺动脉栓塞(是=1、否=0)作为因变量,进行单因素 logistic 回归分析。结果显示,年龄、治疗期间卧床时间、合并 COPD、合并糖尿病、入院时 ABSI 评分均为严重烧伤患者并发肺动脉栓塞的危险因素( $P < 0.05$ )。将单因素分析结果里有统计学意义的自变量纳入多因素 logistic 回归分析。结果显示,治疗期间卧床时间>7 d、合并 COPD、入院时 ABSI 评分高均为严重烧伤患者并发肺动脉栓塞的独立危险因素( $P < 0.05$ )。见表 2。

### 2.3 严重烧伤患者并发肺动脉栓塞风险的列线图预测模型的构建

表 1 2 组严重烧伤患者临床资料比较

Table 1 Comparison of clinical data between two groups of severe burn patients

组别	例数	性别(例)		年龄(例)		体重指数(例)		治疗期间卧床时间(例)		入院时白蛋白水平(例)		合并 COPD(例)	
		男	女	>60 岁	≤60 岁	≥24 kg/m <sup>2</sup>	<24 kg/m <sup>2</sup>	>7 d	≤7 d	>35 g/L	≤35 g/L	是	否
肺动脉栓塞组	26	13	13	19	7	14	12	23	3	16	10	6	20
非肺动脉栓塞组	241	146	95	107	134	170	71	82	159	176	65	4	237
统计量值		$\chi^2=1.09$		$\chi^2=7.75$		$\chi^2=3.05$		$\chi^2=29.15$		$\chi^2=1.53$		$\chi^2=29.86$	
<i>P</i> 值		0.296		0.005		0.081		<0.001		0.216		<0.001	

组别	例数	合并糖尿病(例)		合并高血压(例)		烧伤原因(例)				合并吸入性损伤(例)		入院时 ABSI 评分(分, $\bar{x} \pm s$ )
		是	否	是	否	热液	火焰	电烧伤	化学	是	否	
肺动脉栓塞组	26	10	16	10	16	20	3	2	1	2	24	12.8±2.1
非肺动脉栓塞组	241	44	197	89	152	215	20	2	4	8	233	10.1±2.2
统计量值		$\chi^2=5.94$		$\chi^2=0.02$		$\chi^2=4.42$				$\chi^2=1.25$		$t=6.01$
<i>P</i> 值		0.015		0.878		0.220				0.265		<0.001

注:COPD为慢性阻塞性肺疾病,ABSI为简明烧伤严重指数

表 2 267 例严重烧伤患者并发肺动脉栓塞的单因素和多因素 logistic 回归分析结果

Table 2 Results of univariate and multivariate logistic regression analysis of 267 severe burn patients complicated with pulmonary embolism

自变量	单因素					多因素				
	回归系数	标准误	比值比	95% 置信区间	<i>P</i> 值	回归系数	标准误	比值比	95% 置信区间	<i>P</i> 值
年龄(岁)	1.22	0.46	3.40	1.38~8.39	<i>P</i> 值	0.94	0.61	2.56	0.78~8.45	0.123
治疗期间卧床时间(>7 d)	2.70	0.63	14.87	4.34~50.98	0.008	2.40	0.71	11.02	2.76~43.98	0.001
合并 COPD	2.88	0.69	17.78	4.63~68.22	<0.001	3.43	1.10	30.82	3.55~267.33	0.002
合并糖尿病	1.03	0.44	2.80	1.19~6.58	<0.001	0.68	0.63	1.97	0.58~6.69	0.279
入院时 ABSI 评分(10.7~14.9 分)	0.63	0.13	1.88	1.47~2.41	<0.001	0.62	0.15	1.86	1.38~2.50	<0.001

注:COPD为慢性阻塞性肺疾病,ABSI为简明烧伤严重指数

依据上述多因素 logistic 回归分析筛选出的 3 个独立危险因素构建的严重烧伤患者并发肺动脉栓塞风险的列线图预测模型见图 1。

### 2.4 严重烧伤患者并发肺动脉栓塞风险预测模型的评估与验证

ROC 曲线显示,预测模型的 ROC 曲线下面积为 0.91(95% 置信区间为 0.82~0.99),对严重烧伤患者并发肺动脉栓塞具有较好预测价值。当取最佳阈值 25% 时,列线图预测模型的敏感度为 84.6%、特异度为 93.4%,见图 2。校准曲线显示,预测模型校准曲线在理想曲线附近,Cox 回归的一致性指数为 0.80(95% 置信区间为 0.74~0.87),该模型有较高校准度,见图 3。临床决策曲线显示,该模型的阈值概率范围为 1%~98%,其净收益率 > 0,提示该模型预测能力较好见图 4。

### 3 讨论

本研究纳入的 267 例严重烧伤患者中并发肺动脉栓塞者 26 例,发病率约 10%,高于既往类似研究的报道。分析原因可能为本研究纳入的是严重烧伤患者,这些患者由于烧伤的严重性,往往伴随大面积的组织损伤和血流动力学改变<sup>[16-17]</sup>。这种血流动力学改变可能增加静脉血栓及肺动脉栓塞的风险<sup>[18-19]</sup>。此外,严重烧伤通常需要复杂的手术治疗和长期的住院治疗<sup>[20-21]</sup>,在这些治疗和恢复过程中患者可能长时间卧床,活动量减少,增加了静脉血栓形成的可能性。本研究中多因素 logistic 回归分析结果显示,治疗期间卧床时间 >7 d、合并 COPD、入院时 ABSI 评分高为严重烧伤患者并发肺动脉栓塞的独立危险因素。长时间的卧床可能导致静脉血流减慢,当血液在静脉系统中流动速度减慢时,血液中的血小板和凝血因子有机会在血管壁

或血管内皮上聚集,形成血栓<sup>[22-24]</sup>。这些血栓一旦形成,就可能随着血液流动到达肺动脉,由于肺动脉的管腔较小,血栓有可能堵塞肺动脉,阻止正常的血流,导致肺动脉栓塞<sup>[25-26]</sup>。COPD、肺部恶性肿瘤是常见的慢性呼吸系统疾病,随着病情的进展,COPD 患者由于活动减少、肺部感染风险高、长期吸烟和静脉淤滞而容易发生静脉血栓<sup>[27-30]</sup>。同时 COPD、肺部恶性肿瘤患者经历长期慢性缺氧及二氧化碳增加<sup>[31-32]</sup>,这种缺氧状态会刺激骨髓中的红细胞生成,导致血液中的红细胞数量增加。缺氧还会刺激血红蛋白的合成,使血液中的血红蛋白增加。这些变化会使血液的黏度增加,因为红细胞和血红蛋白都是血液中的重要成分,它们的变化可以影响血液的流动性<sup>[33-36]</sup>。另外,COPD 患者往往存在炎症反应,这种炎症反应也可能导致血液黏度增加<sup>[37-39]</sup>。COPD 患者的这些变化都可能增加其并发肺动脉栓塞的风险<sup>[40-43]</sup>。

大面积烧伤和深度烧伤,特别是深度烧伤,可能导致皮肤的血管损伤,这些损伤可能导致血管壁形状变得不规则,增加了血栓形成的风险,血管损伤会导致内皮细胞受损,激活血小板和凝血系统,从而形成血栓<sup>[44-45]</sup>。另外,烧伤患者的血液循环也会受到影响,导致血液黏度增加,血流减慢,这也增加了血栓形成的风险<sup>[46]</sup>。在严重烧伤患者中,如果存在大面积烧伤或深度烧伤的情况,需要特别关注预防血栓形成的措施,如适当的抬高患肢、保持适当的体位、应用抗凝药物等<sup>[47-51]</sup>。同时,还需要早期进行创面处理、抗感染治疗、营养支持等综合治疗,并密切监测患者的生命体征和血液生物化学、影像学指标,及时治疗肺动脉栓塞等并发症<sup>[52]</sup>。入院时 ABSI 评分常用于评估烧伤严重程度,如果入院时 ABSI 评分高,表明烧伤严重程度高,烧伤严重

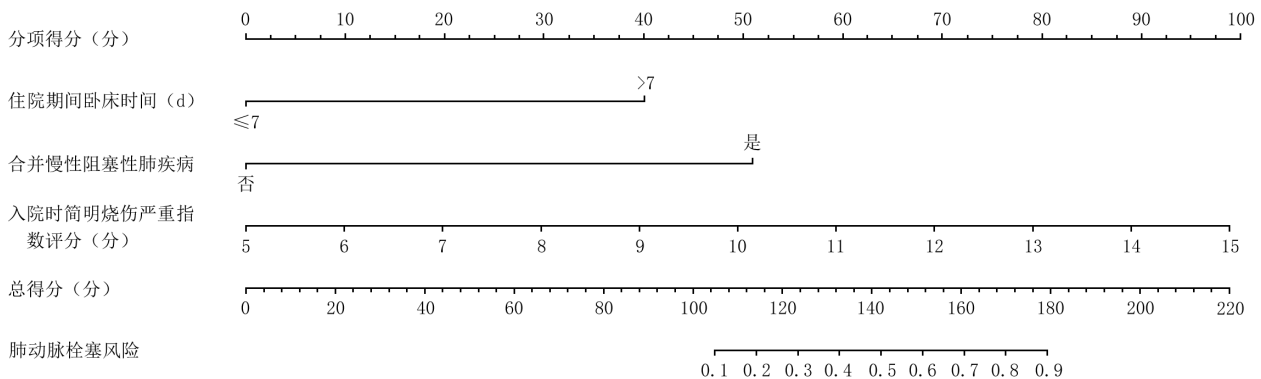


图 1 267 例严重烧伤患者并发肺动脉栓塞风险的列线图预测模型

Figure 1 A nomogram prediction model for the risk of pulmonary embolism in 267 severe burn patients

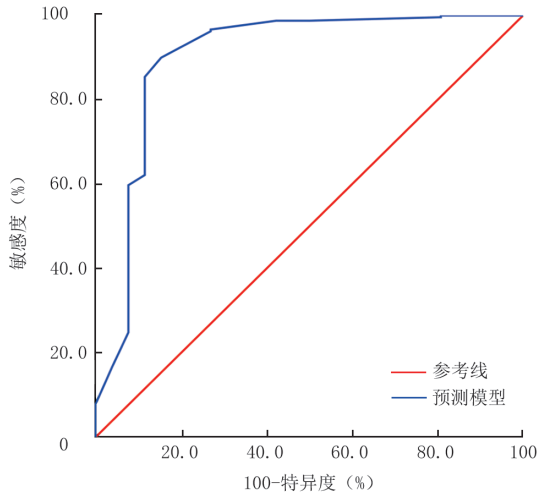


图2 267例严重烧伤患者并发肺动脉栓塞风险预测模型评估的受试者操作特征曲线

Figure 2 The receiver operating characteristic curve in the evaluation of prediction model for the risk of pulmonary embolism in 267 severe burn patients

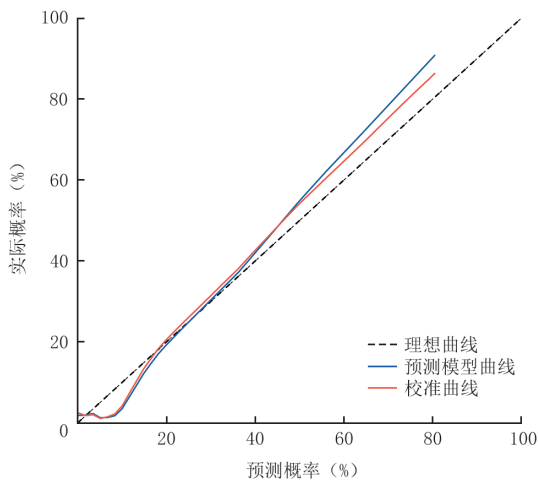


图3 267例严重烧伤患者并发肺动脉栓塞风险预测模型评估的校准曲线

Figure 3 The calibration curve in the evaluation of prediction model for the risk of pulmonary embolism in 267 severe burn patients

程度与血栓形成风险之间可能存在相关性,具体机制可能涉及身体的应激反应、炎症反应和血液的黏度变化等<sup>[53-58]</sup>。本研究团队通过ROC曲线分析得出本列线图预测模型对严重烧伤患者并发肺动脉栓塞具有较好预测价值。当取最佳阈值为25%时,列线图预测模型的敏感度和特异度较高。这表明该模型在预测严重烧伤患者并发肺动脉栓塞方面具有较高的准确性。校准曲线显示,预测模型校准曲线在理想曲线附近,这进一步表明该模型的预测能力较好。临床决策曲线显示在该模型下,对严重烧伤患者进行肺动脉栓塞风险评估是有益的,即使

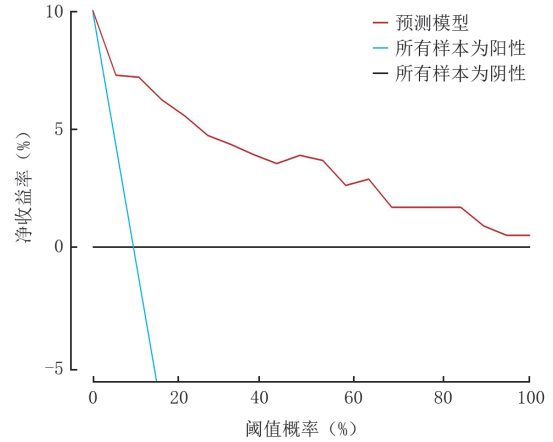


图4 267例严重烧伤患者并发肺动脉栓塞风险预测模型评估的临床决策曲线

Figure 4 The clinical decision curve in the evaluation of prediction model for the risk of pulmonary embolism in 267 severe burn patients

阈值概率较低也能获得较高的净收益率。

综上所述,治疗期间卧床时间>7 d、合并COPD、入院时ABSI评分高是严重烧伤患者并发肺动脉栓塞的独立危险因素,据此构建的预测模型具有一定预测价值。但鉴于本研究仅为单中心回顾性研究,样本量较小,缺少外部验证,且因并发肺动脉栓塞非特异性的症状和诊断条件的限制,存在肺动脉栓塞漏诊的可能性。因此,在进行风险评估和干预时,医师应综合考量患者具体情况,结合预测模型和其他临床信息,确保患者得到及时有效的治疗。

利益冲突 所有作者均声明不存在利益冲突

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(收稿日期: 2024-01-22)