

心脏骤停存活者心肺复苏并发症的影响因素

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摘要 目的 基于临床资料及胸外按压相关参数构建心肺复苏并发症风险LASSO-logistic回归模型, 为预防心肺复苏并发症提供参考。**方法** 选取2020年4月至2023年5月石家庄循环化工园区医院收治的100例心脏骤停存活患者, 根据并发症情况分为并发症组和无并发症组, 比较2组临床资料、胸外按压相关参数, 用LASSO回归初筛心肺复苏并发症的影响因素, 用logistic回归分析心肺复苏并发症的影响因素, 绘制Nomogram预测心肺复苏并发症的风险。**结果** LASSO回归初筛显示, 体重指数、胸廓前后径、施救者文化程度、施救者性别的系数被压缩, 当 $\lambda=1.786$ 时, 影响因素最少, 模型性能优良, 此时筛选出施救者身份、施救者心肺复苏培训、应用气垫床、应用减压垫、按压深度、按压时长、严格控制液体量7个预测变量, 达到最佳影响因素的选择; logistic回归分析显示, 施救者为护士、施救者接受过心肺复苏培训、应用气垫床、应用减压垫、严格控制液体量是心肺复苏并发症的相关保护因素, 按压深度、按压时长是心肺复苏并发症的相关危险因素 ($P < 0.05$); 绘制心肺复苏并发症风险logistic预测模型的列线图显示, 其C指数为0.932, 具有良好的区分度, 且校正曲线与理想曲线拟合良好, 所构建预测模型与实际观测结果有较好的一致性。**结论** 胸骨骨折、肺挫伤、肋骨骨折等心肺复苏并发症的发生风险与施救者身份、施救者心肺复苏培训、应用气垫床、应用减压垫、按压深度、按压时长、严格控制液体量情况密切相关。

关键词 胸外按压; 心肺复苏; 并发症; 风险预测模型

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Influencing factors of cardiopulmonary resuscitation complications in cardiac arrest survivors

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Abstract Objective To construct a LASSO-logistic regression model for the risk of complications of cardiopulmonary resuscitation (CPR) based on clinical data and relevant parameters of external chest compression and to provide a reference for the prevention of complications of cardiopulmonary resuscitation. **Methods** One hundred cardiac arrest survivor patients admitted to Shijiazhuang Circular Chemical Industrial Park Hospital from April 2020 to May 2023 were selected and divided into complication and non-complication groups according to complications. The clinical data, chest compression-related parameters of the 2 groups were compared, and LASSO regression was used to initially screen the influencing factors of CPR complications. Logistic regression was used to analyze the influencing factors of CPR complications, and Nomogram was drawn to predict the risk of CPR complications. **Results** LASSO regression screening showed that the coefficients of body mass index, thoracic anteroposterior diameter, rescuer education level, and rescuer gender were compressed. When λ was 1.786, the number of influencing factors was minimized, and the model performance was excellent. At this time, seven predictive variables including rescuer identity, rescuer CPR training, application of air mattress, application of decompression pad, compression depth, compression duration, and strict control of fluid volume were selected to achieve the best selection of influencing factors. Logistic regression analysis showed that rescuer being a nurse, rescuer having received CPR training, application of air mattress bed, application of decompression pad, and strict control of fluid volume were related protective factors for CPR complications, while compression depth and compression duration were related risk factors for CPR complications ($P < 0.05$). The nomogram diagram of the logistic prediction model for CPR complication risk showed that its C-index was 0.932, indicating good discrimination, and the calibration curve fitted well with the ideal curve. The constructed prediction model had good consistency with the actual observed results. **Conclusion** CPR complications included sternal fractures, lung contusions, and rib fractures. The risk closely relates to the rescuer, the rescuer's CPR training, the application of air mattress bed, the application of decompression pad, the depth of compression, the duration of compression, and the strict con-

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trol of fluid volume.

Keywords external chest compression; cardiopulmonary resuscitation; complication; risk prediction model

心脏位于胸腔中部偏左下方,其正常跳动是维持生命体征的必要条件,心脏骤停时若未能及时获救,可导致严重后果^[1]。胸外按压是一种基础且重要的心肺复苏手段,能挽救生命、提高存活率,但可能造成肋骨和(或)胸骨骨折、心肌挫伤、肝脾破裂等并发症,影响胸外按压复苏的顺利实施,且会导致旁观者产生畏惧心理,影响施救意愿,使患者错过黄金救治时间而危及生命,因此,了解心肺复苏并发症并掌握其发生原因及影响因素意义重大^[2-3]。本研究基于临床资料及胸外按压相关参数分析心肺复苏并发症的影响因素,构建其发生风险的LASSO-logistic回归模型,旨在为减少心肺复苏并发症提供理论参考。

1 材料与方法

1.1 研究对象

选取2020年4月至2023年5月石家庄循环化工园区医院收治的100例心脏骤停患者。纳入标准:年龄 ≥ 18 岁;心脏骤停^[4];行胸外心脏按压等复苏方式存活者。排除标准:胸廓严重畸形;来院时已恢复自主循环;妊娠期;心脏骤停前有胸骨或肋骨骨折、胸部皮肤挫伤等相关损伤;家属拒绝抢救;复苏前伴心脏受伤、肺部损伤、胸壁开放性损伤。记录患者在心肺复苏过程中是否发生胸骨骨折、肺挫伤、肋骨骨折、胸部皮肤挫伤、急性压力性损伤、气胸等并发症,发生其中一种即纳入并发症组,否则纳入无并发症组。并发症由主治医师结合患者的症状、查体、影像学检查等进行判定。本研究获得石家庄循环化工园区医院伦理委员会批准,所有患者知情同意。

1.2 方法

以量表形式收集临床资料,包括年龄、性别、体重指数、胸围、胸廓前后径、内科疾病、心肺复苏诱因、施救者身份、施救者文化程度、施救者性别、施救者心肺复苏培训、应用气垫床、应用减压垫情况;采用Laerdal Q CPR 软件记录按压深度、按压频率、按压时长;心肺复苏后2 min采血行血气分析,记录动脉血氧分压、动脉血二氧化碳分压、血乳酸、pH值;心肺复苏期间,将采用超声监测血流动力学并进行

限制性液体复苏^[5]定义为严格控制液体量,否则为未严格控制液体量。

1.3 统计学分析

采用SPSS 24.0软件与R-Studio软件进行统计学分析。计数资料用率(%)表示,行 χ^2 检验比较。计量资料用 $\bar{x} \pm s$ 表示,行 t 检验比较。等级资料采用Ridit检验比较。采用LASSO回归初筛心肺复苏并发症的影响因素,采用logistic回归分析心肺复苏并发症的影响因素,绘制列线图预测心肺复苏并发症的风险,采用预测风险能力指数(concordance index, C-index)评价预测模型的区分度,采用受试者操作特征(receiver operator characteristic, ROC)曲线评价所构建模型的预测能力,采用bootstrap法绘制校准曲线评价预测模型的校准度。 $P < 0.05$ 为差异有统计学意义。

2 结果

2.1 2组临床资料及胸外按压相关参数比较

100例心脏骤停患者中,共22例发生并发症,其中包括胸骨骨折8例、肺挫伤2例、肋骨骨折6例、胸部皮肤挫伤2例、急性压力性损伤3例、气胸1例。并发症组体重指数、胸廓前后径、施救者身份、施救者文化程度、施救者性别、施救者心肺复苏培训、应用气垫床、应用减压垫、按压深度、按压时长、严格控制液体量方面与无并发症组比较,差异有统计学意义($P < 0.05$)。见表1。

2.2 心肺复苏并发症影响因素的LASSO回归初筛

以是否发生并发症(未发生=0,发生=1)为因变量,以体质量指数(原值代入)、胸廓前后径(原值代入)、施救者身份(旁观者=1,旁观者+护士=2,护士=3)、施救者文化程度(初中及以下=1,高中=2,大专及以上=3)、施救者性别(男=1,女=2)、施救者是否接受过心肺复苏培训(否=0,是=1)、应用气垫床(否=0,是=1)、应用减压垫(否=0,是=1)、按压深度(原值代入)、按压时长(原值代入)、严格控制液体量(否=0,是=1)11个变量为自变量,对心肺复苏并发症影响因素进行初筛。结果显示,随着惩罚系数 λ 变化,体重指数、胸廓前后径、施救者文化程度、施救

者性别的系数被压缩,见图1A。绘制均方误差随 $\log\lambda$ 的变化图显示, $\lambda=1.786$ 时,影响因素最少,模型性能优良,此时筛选出施救者身份、施救者心肺复苏培

训、应用气垫床、应用减压垫、按压深度、按压时长、严格控制液体量7个预测变量达到最佳影响因素的选择,见图1B。

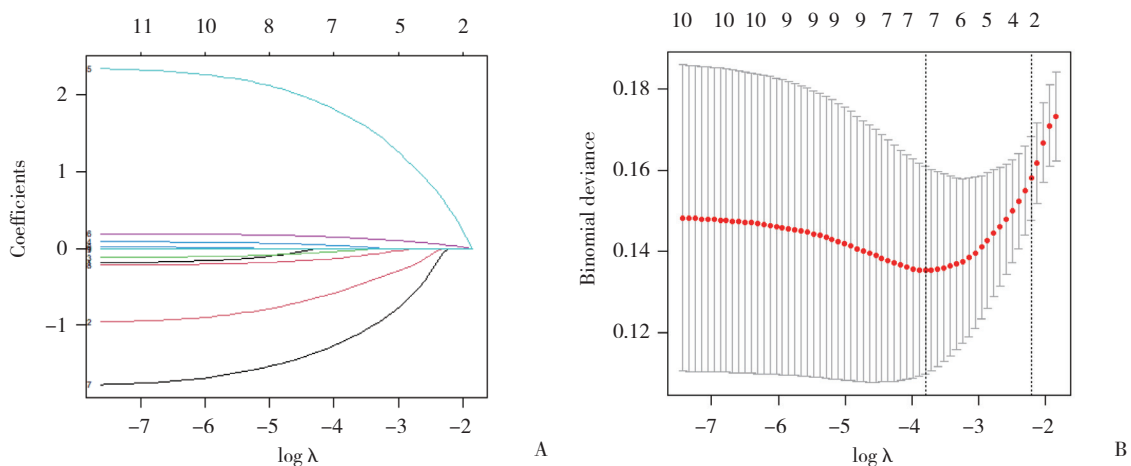
表1 2组临床资料及胸外按压相关参数比较

Tab.1 Comparison of of clinical data and parameters related to external chest compressions of two groups

Item	Complication group (n = 22)	Non-complication group (n = 78)	t/ χ^2 /U	P
Age (year)	41.59 ± 9.83	40.37 ± 10.51	0.487	0.627
Sex [n (%)]			0.233	0.629
Male	12 (54.55)	38 (48.72)		
Female	10 (45.45)	40 (51.28)		
Body mass index (kg/m ²)	23.45 ± 0.57	23.96 ± 0.62	3.466	0.001
Chest circumference (cm)	85.68 ± 8.35	87.09 ± 9.28	0.643	0.522
Chest anterior posterior diameter (cm)	24.79 ± 1.68	23.96 ± 1.50	2.232	0.028
Internal diseases [n (%)]				
Hyperlipidemia	2 (9.09)	4 (5.13)	0.034	0.855
Diabetes	4 (18.18)	18 (23.08)	0.039	0.843
Heart disease	9 (40.91)	35 (44.87)	0.109	0.741
Hypertension	15 (68.18)	48 (61.54)	0.325	0.569
Causes of cardiopulmonary resuscitation [n (%)]			1.702	0.945
Explosive myocarditis	1 (4.55)	3 (3.85)		
Acute myocardial infarction	6 (27.27)	20 (25.64)		
Pulmonary embolism	3 (13.64)	10 (12.82)		
Septic shock	2 (9.09)	13 (16.67)		
Hyperthyroidism heart disease	2 (9.09)	11 (14.10)		
Acute aortic dissection	4 (18.18)	12 (15.38)		
Acute trauma	4 (18.18)	9 (11.54)		
Rescuer identity [n (%)]			6.547	0.038
Bystander	8 (36.36)	10 (12.82)		
Nurse	9 (40.91)	47 (60.26)		
Bystander+nurse	5 (22.73)	21 (26.92)		
Educational level of the rescuer [n (%)]			2.304	0.021
Junior high school and below	3 (13.64)	2 (2.56)		
High school	14 (63.64)	37 (47.44)		
College degree or above	5 (22.73)	39 (50.00)		
Sex of rescuer [n (%)]			5.325	0.021
Male	13 (59.09)	25 (32.05)		
Female	9 (40.91)	53 (67.95)		
Rescuers' cardiopulmonary resuscitation training [n (%)]			6.868	0.009
No	8 (36.36)	8 (10.26)		
Yes	14 (63.64)	70 (89.74)		
Application of air mattress bed [n (%)]			5.424	0.020
No	21 (95.45)	56 (71.79)		
Yes	1 (4.55)	22 (28.21)		
Application of decompression pad [n (%)]			6.294	0.012
No	21 (95.45)	54 (69.23)		
Yes	1 (4.55)	24 (30.77)		

(续表)

Item	Complication group (n = 22)	Non-complication group (n = 78)	t/χ ² /U	P
Compression depth (cm)	5.92 ± 0.54	5.43 ± 0.49	4.050	<0.001
Compression frequency (times/min)	112.49 ± 6.68	110.95 ± 7.33	0.887	0.378
Compression duration (min)	23.69 ± 7.11	18.43 ± 5.25	3.823	<0.001
Blood gas analysis after resuscitation				
Arterial partial pressure of oxygen (mmHg)	55.86 ± 9.22	57.00 ± 8.48	0.546	0.586
Partial arterial carbon dioxide pressure (mmHg)	32.20 ± 4.81	31.79 ± 4.95	0.345	0.731
Blood lactate (mmol/L)	6.94 ± 1.25	7.03 ± 1.16	0.316	0.753
pH value	7.33 ± 0.15	7.34 ± 0.13	0.308	0.759
Strictly control the amount of liquid [n (%)]			5.176	0.023
No	7 (31.82)	8 (10.26)		
Yes	15 (68.18)	70 (89.74)		



A, LASSO regression screening process diagram; B, selection diagram of optimal parameter λ.

图1 心肺复苏并发症影响因素的LASSO回归初筛过程和最佳参数λ的选择

Fig.1 LASSO regression screening process diagram and selection diagram of optimal parameter λ for influencing factors of cardiopulmonary resuscitation complications

2.3 心肺复苏并发症影响因素的logistic回归分析

各自变量、因变量及其赋值参考LASSO回归,运用逐步后退法进行logistic回归分析显示,施救者为护士、施救者接受过心肺复苏培训、应用气垫床、

应用减压垫、严格控制液体量是心肺复苏并发症相关保护因素,按压深度、按压时长是心肺复苏并发症的相关危险因素(P<0.05)。见表2。

2.4 心肺复苏并发症风险的列线图

表2 心肺复苏并发症影响因素的logistic回归分析

Tab.2 Logistic regression analysis of factors influencing complications of cardiopulmonary resuscitation

Influence factor	β	SE	Wald χ ²	OR	95%CI	P
The rescuer is a nurse	-1.266	0.321	15.545	0.282	0.104-0.765	<0.001
The rescuer has received training on cardiopulmonary resuscitation	-0.514	0.136	14.286	0.598	0.368-0.972	<0.001
Application of air mattress bed	-0.752	0.259	8.440	0.471	0.257-0.864	<0.001
Application of decompression pad	-1.140	0.394	8.373	0.320	0.136-0.752	<0.001
Compression depth	1.158	0.355	10.649	3.185	1.049-9.671	<0.001
Compression duration	1.505	0.401	14.085	4.504	1.625-12.483	<0.001
Strictly control the amount of liquid	-0.672	0.213	9.963	0.511	0.288-0.905	<0.001

列线图显示,该预测模型C指数为0.932,具有良好的区分度,见图2。ROC曲线显示,其曲线下面积为0.932,灵敏度为92.31%,特异度为90.91%,见图3。

校正曲线与理想曲线拟合良好,所构建的logistic预测模型与实际观测结果有较好的一致性,见图4。

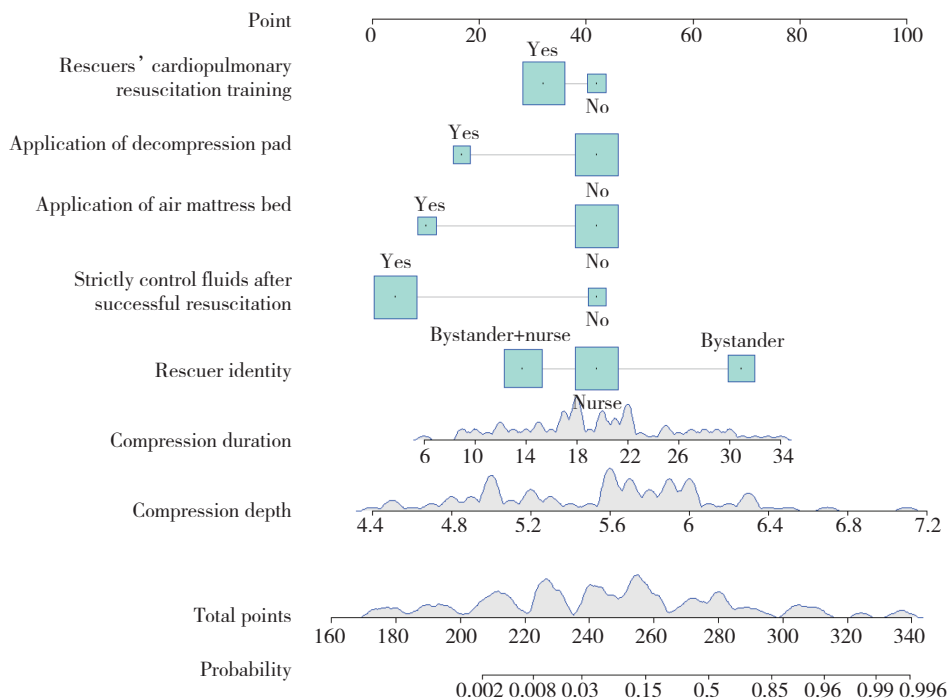


图2 心肺复苏并发症风险logistic预测模型的列线图

Fig.2 Nomogram for logistic prediction model of cardiopulmonary resuscitation complication risk

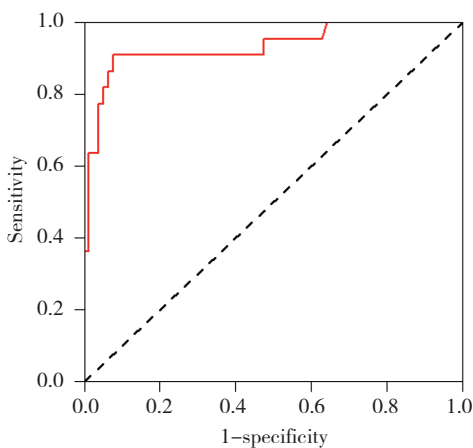


图3 logistic预测模型的ROC曲线

Fig.3 ROC curve of logistic prediction model

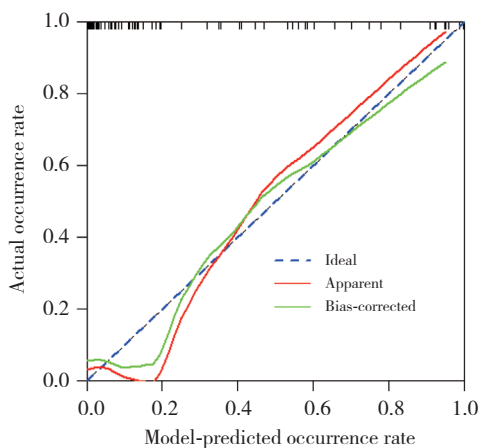


图4 列线图的校准曲线

Fig.4 Calibration curve of nomogram

3 讨论

每年我国约有54.4万人发生心脏骤停,与心肺复苏相关的并发症也逐渐引起临床上的重视^[5-6]。心肺复苏并发症不仅会给患者带来额外的伤害,还

会影响救治的顺利进行^[7]。因此,分析心肺复苏并发症的影响因素及预测模型十分必要。

本研究共纳入100例心肺复苏患者,因发生并发症的患者数量较少,为避免造成统计学的偏倚,本研究运用LASSO回归对差异有统计学意义的因

素进行初筛,并经logistic回归分析验证,施救者为护士、施救者接受过心肺复苏培训、应用气垫床、应用减压垫、严格控制液体量是心肺复苏并发症的保护因素。当施救者为护士时,因其多接受过心肺复苏培训,能根据心肺复苏要求和标准准确定位和施救,故心肺复苏并发症少见^[8-9]。气垫床是一种具有快速放气和充气功能的床垫,垫上标有“CPR”字样的黄色字条,在实施胸外按压时可打开气体阀门,放出胸部气垫内的气体,保证胸外按压的效果,由于在按压时除胸部以外的气垫其他部位仍保持充气状态,有利于减少急性压力性损伤、肺挫伤等并发症的发生。研究^[10]显示,胸外按压时气垫床的工作会显著影响按压质量,对气垫床胸部位置放气后,气垫床的弹性能提高心肺复苏安全性。心脏骤停患者在呼吸循环复苏过程中,因机体缺氧、局部组织受到压力及摩擦力作用,加之患者可能存在大小便失禁,易引起压力性损伤、胸部皮肤挫伤,因此在保证标准正确的心肺复苏的前提下,应及时清理可能压迫皮肤的物品以及采用减压垫等,以预防皮肤损伤的发生^[11-12]。减压垫是一种透明绝缘塑料垫片,正中连接有起固定作用的胸外按压装置固定架,其上下挡板能指导与限制按压深度,为操作者进行合适深度的胸外按压提供参考,从而有利于减少并发症的发生。

本研究结果显示,发生心肺复苏并发症患者的平均按压深度大于未发生并发症的患者,平均按压深度是心肺复苏并发症的相关危险因素。胸外按压相关参数是影响患者呼吸和脉搏恢复的主要因素^[13-14]。有研究^[15]指出,胸外按压深度应为4~5 cm;也有研究^[16-17]指出,胸外按压深度应为5 cm,且不应超过6 cm,胸外按压越深,发生的并发症越多,与本研究结果一致。另有研究^[18]表明,有利于患者最大生存率的胸外按压深度为4~5 cm,峰值为4.6 cm。不同人种间的体型存在差别,以上推荐按压深度均为基于欧美国家的研究,我国成年人体型普遍较欧美人群小,建议根据指南推荐的按压深度进行心肺复苏,在推荐范围内根据患者的体型稍作调整。心肺复苏按压时,肺脏可能受到机械性损伤^[19]。有文献^[20]显示,复苏后5 h患者肺部影像学检查可见明显的渗出和挫伤。若在抢救患者的危急状态下,快速输入肾上腺素等液体,可增大血容量,升高中心静

脉压,加大心脏负荷,加之肺脏缺血再灌注损伤,易诱发肺水肿,加重肺部损伤^[21]。因此,在心肺复苏初期应注意液体量,心脏复跳后尽快置管监测中心静脉压,以指导和控制液体输入量,避免加重肺脏负荷,影响患者病情转归。在以上研究的基础上,本研究绘制了预测心肺复苏并发症风险的logistic预测模型列线图,其C指数为0.932,具有良好的区分度,且所构建的logistic预测模型与实际观测结果一致性良好,可作为心肺复苏并发症风险的一种预测方法。

综上所述,本研究结果显示,胸骨骨折、肺挫伤、肋骨骨折等心肺复苏并发症的发生风险与施救者身份、施救者心肺复苏培训、应用气垫床、应用减压垫、按压深度、按压时长、严格控制液体量的情况密切相关,以上发现可为心肺复苏过程中优化操作、减少并发症的发生提供一定的参考。

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