

· 临床研究 ·

胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素分析及风险预测模型建立

裴孝鹏, 杨勇, 孙宜保, 陈爽, 范富有, 代耀军, 李毅力

(郑州市骨科医院, 河南 郑州 450052)

摘要 **目的:**分析胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素,并建立风险预测模型。**方法:**以 2017 年 3 月至 2020 年 3 月,在郑州市骨科医院接受椎弓根螺钉内固定术或椎弓根螺钉内固定术联合仿生骨柱植骨术治疗的患者为研究对象,根据术后 2 年内是否并发脊柱后凸畸形分为 2 组。收集 2 组患者性别、年龄、体质量指数、是否合并内科疾病、骨折节段、骨折原因等一般资料,和是否合并椎间盘损伤、骨折爆裂程度、胸腰椎 AO 脊柱损伤评分(thoracolumbar AO Spine injury score, TLAOSIS)等损伤情况评价指标,以及手术入路、固定节段长短等手术情况。测量术前影像学参数,在术前 X 线侧位片上测量椎体楔形角、骨折节段 Cobb 角和椎体前缘高度(计算椎体前缘高度比值),在术前 X 线正位片上测量上位椎间盘角和下位椎间盘角。比较 2 组患者的一般资料、损伤情况评价指标、手术情况和影像学参数,进行单因素分析。根据单因素分析结果,采用 Logistic 回归分析胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素。依据危险因素分析结果建立胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险预测列线图模型,并对模型进行评价。**结果:**共纳入 176 例患者,并发畸形组 30 例,未并发畸形组 146 例。单因素分析结果显示,2 组患者合并椎间盘损伤情况、骨折爆裂程度、TLAOSIS,以及术前椎体前缘高度比值、骨折节段 Cobb 角、上位椎间盘角、下位椎间盘角的组间差异,均有统计学意义。Logistic 回归分析结果显示,合并椎间盘损伤、TLAOSIS > 8 分、完全爆裂骨折、术前椎体前缘高度比值 < 50%、术上位椎间盘角 ≤ 3.5° 是胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素[OR = 2.965, 95% CI(1.682, 4.534), P = 0.003; OR = 2.707, 95% CI(1.364, 4.216), P = 0.009; OR = 1.921, 95% CI(0.716, 3.357), P = 0.022; OR = 2.221, 95% CI(0.986, 3.627), P = 0.013; OR = 3.654, 95% CI(1.867, 4.853), P = 0.000]。列线图模型预测结果显示,上述 5 个因素对应的胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险预测值分别为 44.0 分、42.5 分、33.0 分、39.0 分、51.5 分,并发脊柱后凸畸形的概率为 0.10 ~ 0.56。受试者操作特征曲线分析结果显示,该模型预测胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的曲线下面积为 0.921(P = 0.000),灵敏度为 78.43%,特异度为 85.52%;模型验证 C-index 值为 0.823,校正曲线和标准曲线拟合度较好,模型校准度良好。决策曲线分析结果显示,根据该模型对胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险进行预测,可获得较好的净收益,阈值概率为 0.02 ~ 0.95。**结论:**合并椎间盘损伤、TLAOSIS > 8 分、完全爆裂骨折、术前椎体前缘高度比值 < 50%、术上位椎间盘角 ≤ 3.5° 均为胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素;基于这些因素构建的风险预测列线图模型,对于胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形具有一定的预测价值。

关键词 脊柱骨折;胸椎;腰椎;骨折固定术,内;手术后并发症;脊柱后凸;危险因素;风险;预测

Risk factors and a risk forecasting model for spinal kyphosis deformity after internal fixation in patients with thoracolumbar burst fractures

PEI Xiaopeng, YANG Yong, SUN Yibao, CHEN Shuang, FAN Fuyou, DAI Yaojun, LI Yili

Zhengzhou Orthopaedic Hospital, Zhengzhou 450052, Henan, China

ABSTRACT **Objective:** To analyze the risk factors for spinal kyphosis deformity after internal fixation in patients with thoracolumbar burst fractures(TLBF), and to build a risk prediction model. **Methods:** The TLBF patients who underwent internal fixation with pedicle screws or internal fixation with pedicle screws combined with bionic bone pillar bone grafting in Zhengzhou Orthopaedic Hospital from March 2017 to March 2020 were selected as the subjects, and they were divided into concurrent deformity group and non-concurrent deformity group according to whether spinal kyphosis deformity was found within 2 years after the surgery. The general information of the patients, including gender, age, body mass index, whether combined with morbus internus, fractured segment, cause of fracture; the injury evaluation

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通讯作者:杨勇 E-mail:13603862327@126.com

information, including whether combined with intervertebral disc (IVD) injury, degree of fracture burst, and thoracolumbar AO Spine injury score (TLAOSIS); the surgical conditions, including surgical approach and length of fixed segments, was collected. In addition, the presurgical X-ray films were extracted for measuring the wedge angle of the vertebral body, the Cobb's angle of the fractured segment, and the anterior border height of the vertebral body (the anterior border height ratio was calculated) on the presurgical lateral X-ray films, as well as the upper and lower IVD angles on the presurgical anteroposterior X-ray films. After that, the general information, injury evaluation indicators, surgical conditions and radiological parameters were compared between the 2 groups, and a single factor analysis was performed, based on which the risk factors for spinal kyphosis deformity after internal fixation in TLBF patients were analyzed by logistic regression, and then, according to the findings, a risk prediction nomogram model for spinal kyphosis deformity after internal fixation in TLBF patients was constructed and evaluated. **Results:** One hundred and seventy-six TLBF patients were included in the final analysis, with 30 ones in the concurrent deformity group, and 146 ones in the non-concurrent deformity group. The single factor analysis showed that the differences were statistically significant between the 2 groups in combined with IVD injury, the degree of fracture burst, TLAOSIS, presurgical vertebral anterior border height ratio, the Cobb's angle of the fractured segment, the upper IVD angle, and the lower IVD angle. The logistic regression analysis revealed that combined with IVD injury, TLAOSIS > 8 points, complete burst fracture, presurgical vertebral anterior border height ratio < 50%, and presurgical upper IVD angle ≤ 3.5 degrees were the risk factors for spinal kyphosis deformity after internal fixation in TLBF patients ($OR = 2.965, 95\% CI(1.682, 4.534), P = 0.003$; $OR = 2.707, 95\% CI(1.364, 4.216), P = 0.009$; $OR = 1.921, 95\% CI(0.716, 3.357), P = 0.022$; $OR = 2.221, 95\% CI(0.986, 3.627), P = 0.013$; $OR = 3.654, 95\% CI(1.867, 4.853), P = 0.000$). The risk prediction nomogram model showcased that the values of the above five factors in predicting spinal kyphosis deformity after internal fixation in TLBF patients were 44.0, 42.5, 33.0, 39.0, and 51.5 points, respectively, with a probability of developing spinal kyphosis deformity ranged from 0.10 to 0.56. The receiver operating characteristics (ROC) curve analysis showed that the area under ROC curve (AUC) of the risk prediction nomogram model in predicting spinal kyphosis deformity after internal fixation in TLBF patients was 0.921 ($P = 0.000$), with a sensitivity of 78.43% and a specificity of 85.52%; besides, a good goodness-of-fit presented between the calibration curve and the standard curve, with a concordance index (C-index) of 0.823, suggesting the model had a good calibration. Furthermore, the decision curve analysis (DCA) indicated that a better net benefit was obtained using the nomogram model in predicting spinal kyphosis deformity after internal fixation in TLBF patients, with the threshold probability ranged from 0.02 to 0.95. **Conclusion:** Combined with IVD injury, TLAOSIS > 8 points, complete burst fracture, presurgical vertebral anterior border height ratio < 50%, and presurgical upper IVD angle ≤ 3.5 degrees are all the risk factors for spinal kyphosis deformity after internal fixation in TLBF patients. The risk prediction nomogram model constructed based on the above five risk factors has a certain applied value in predicting the risk for spinal kyphosis deformity after internal fixation in TLBF patients. **Keywords** spinal fractures; thoracic vertebrae; lumbar vertebrae; fracture fixation, internal; postoperative complications; kyphosis; risk factors; risk; forecasting

胸腰椎爆裂骨折是由暴力导致的严重脊柱损伤,可并发一系列并发症,甚至威胁患者生命^[1]。椎弓根螺钉内固定术或椎弓根螺钉内固定术联合仿生骨柱植骨术可恢复脊柱的结构,维持脊柱稳定,是临床治疗胸腰椎爆裂骨折常用的手术方法。但胸腰椎爆裂性骨折患者骨小梁支架结构损伤严重,内固定术后易并发脊柱后凸畸形^[2-4],严重影响患者生活质量。目前的相关临床研究多集中于探讨胸腰椎骨折患者内固定术后并发脊柱后凸畸形的影响因素^[5-7],尚缺乏可准确进行风险预测的方法。列线图模型根据影响因素对患者进行个体化预测,操作简便,可直观呈现风险发生的概率,具有个性化、精确化的特点^[8-9]。为早期识别术后并发脊柱后凸畸形的高危患者,给临床早期采取措施预防胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形提供依据,我们对胸腰椎爆裂骨

折患者术后并发脊柱后凸畸形的危险因素进行分析,建立风险预测模型,并对模型进行评价,现报告如下。

1 临床资料

1.1 一般资料

选取 2017 年 3 月至 2020 年 3 月,在郑州市骨科医院接受椎弓根螺钉内固定术或椎弓根螺钉内固定术联合仿生骨柱植骨术治疗的胸腰椎爆裂骨折患者为研究对象。本研究方案经郑州市骨科医院医学伦理委员会审查通过,伦理批件号:(2024)医院伦理审批第 24 号。

1.2 纳入标准

①胸腰椎爆裂骨折^[10],且椎弓根完整;②年龄 18 ~ 60 岁;③胸腰椎 AO 脊柱损伤评分(thoracolumbar AO Spine injury score, TLAOSIS)^[11] > 5 分;④手术为同一组医生完成;⑤术后随访时间 ≥ 2 年;⑥临床资料完整。

1.3 排除标准

①强直性脊柱炎、脊柱肿瘤等导致的病理性骨折者;②陈旧性骨折者;③合并严重的骨质疏松(骨密度 T 值 < -2.5)者;④合并严重的脊柱退行性疾病者;⑤非初次手术者;⑥骨折节段 ≥ 2 节段者。

2 方法

2.1 分组方法

以术后伤椎上位椎体上终板和伤椎下位椎体下终板之间的 Cobb 角评价脊柱矫正度。术后并发脊柱后凸畸形判定标准^[12]:脊柱矫正度丢失, Cobb 角增加 10° 以上(较术前改善不小于 10°)。术后 2 年内,并发脊柱后凸畸形者归为并发畸形组,未并发脊柱后凸畸形者归为未并发畸形组。

2.2 数据收集方法

收集 2 组患者性别、年龄、体质量指数、是否合并内科疾病(糖尿病、高血压、冠心病、脑血管疾病)、骨折节段、骨折原因等一般资料和是否合并椎间盘损伤、骨折爆裂程度、TLAOSIS 等损伤情况评价指标,以及手术入路、固定节段长短(以伤椎为中心,固定节段包含伤椎及其上下各 1 个正常节段为短节段固定,固定节段包含伤椎及其上下各 2 个正常节段为长节段固定)等手术情况。测量术前影像学参数,在术前 X 线侧位片上测量椎体楔形角(伤椎上终板和下终板之间的 Cobb 角)、骨折节段 Cobb 角和椎体前缘高度(计算椎体前缘高度比值),在术前 X 线正位片上测量上位椎间盘角(伤椎上终板与上位椎体下终板之间的 Cobb 角)和下位椎间盘角(伤椎下终板与下位椎体上终板之间的 Cobb 角)。

2.3 数据统计方法

采用 SPSS20.0 统计软件处理数据。采用 χ^2 检

验比较 2 组患者的一般资料、损伤情况评价指标、手术情况和影像学参数,进行单因素分析。根据单因素分析结果,采用 Logistic 回归分析胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素。依据危险因素分析结果建立风险预测列线图模型,采用受试者操作特征(receiver operating characteristics, ROC)曲线评价模型区分度,采用 Bootstrap 法对模型进行内部验证,采用决策曲线分析(decision curve analysis, DCA)评估模型的临床净获益。检验水准 $\alpha = 0.05$ 。

3 结果

3.1 分组结果

共纳入 176 例患者,并发畸形组 30 例,未并发畸形组 146 例。

3.2 单因素分析结果

2 组患者合并椎间盘损伤情况、骨折爆裂程度、TLAOSIS,以及术前椎体前缘高度比值、骨折节段 Cobb 角、上位椎间盘角、下位椎间盘角的组间差异,均有统计学意义;2 组患者性别、年龄、体质量指数、合并内科疾病情况、骨折节段、骨折原因、手术方式、固定节段长短及术前椎体楔形角的组间差异,均无统计学意义。见表 1 至表 3。

3.3 多因素分析结果

将单因素分析中组间差异有统计学意义的因素作为自变量,将术后是否并发脊柱后凸畸形作为因变量,进行多因素 Logistic 回归分析。结果显示,合并椎间盘损伤、TLAOSIS > 8 分、完全爆裂骨折、术前椎体前缘高度比值 < 50%、术前上位椎间盘角 ≤ 3.5° 是胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素(表 4)。

表 1 2 组胸腰椎爆裂骨折患者一般资料

单位:例

组别	样本量	年龄		性别		合并内科疾病				
		≤50 岁	>50 岁	男	女	是	否			
并发畸形组	30	16	14	21	9	19	11			
未并发畸形组	146	98	48	104	42	46	100			
χ^2 值		2.074		0.018		10.823				
P 值		0.150		0.892		0.001				

组别	体质量指数		骨折节段				骨折原因 ¹⁾			
	<24 kg · m ²	≥24 kg · m ²	T ₁₁	T ₁₂	L ₁	L ₂	①	②	③	④
并发畸形组	13	17	5	9	10	6	10	6	9	5
未并发畸形组	89	57	20	52	48	26	39	21	49	37
χ^2 值		3.173	0.448				1.784			
P 值		0.075	0.930				0.618			

注:1)中①为高处坠落,②为重物砸伤,③为交通事故,④为其他暴力外伤。

表 2 2 组胸腰椎爆裂骨折患者损伤及手术情况

单位:例

组别	样本量	骨折爆裂程度		TLAOSIS ¹⁾	
		不完全爆裂	完全爆裂	≤8 分	>8 分
并发畸形组	30	14	16	17	13
未并发畸形组	146	99	47	119	27
χ^2 值		4.840		8.744	
P 值		0.028		0.003	

组别	合并椎间盘损伤		手术方式 ²⁾		固定节段长短	
	是	否	①	②	短节段	长节段
并发畸形组	19	11	25	5	7	23
未并发畸形组	48	98	137	9	16	130
χ^2 值	9.791		3.749		3.354	
P 值	0.002		0.053		0.067	

注:1)为胸腰椎 AO 脊柱损伤评分;2)中①为椎弓根螺钉内固定术联合仿生骨柱植骨术,②为椎弓根螺钉内固定术。

表 3 2 组胸腰椎爆裂骨折患者术前影像学参数

单位:例

组别	样本量	术前椎体楔形角		术前椎体前缘高度比值	
		≤18°	>18°	<50%	≥50%
并发畸形组	30	16	14	22	8
未并发畸形组	146	55	91	68	78
χ^2 值		2.537		7.131	
P 值		0.111		0.008	

组别	术前上位椎间盘角		术前下位椎间盘角		术前骨折节段 Cobb 角	
	≤3.5°	>3.5°	≤5°	>5°	≤21°	>21°
并发畸形组	20	10	21	9	11	19
未并发畸形组	45	101	61	85	94	52
χ^2 值	13.728		7.964		7.944	
P 值	0.000		0.005		0.005	

表 4 胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形危险因素的分析结果

自变量	β 值	S. E.	Wald 值	P 值	OR 值	95% CI	
						下限	上限
合并椎间盘损伤	1.087	0.365	8.869	0.003	2.965	1.682	4.534
胸腰椎 AO 脊柱损伤评分 >8 分	0.996	0.368	7.325	0.009	2.707	1.364	4.216
完全爆裂骨折	0.653	0.278	5.517	0.022	1.921	0.716	3.357
术前椎体前缘高度比值 <50%	0.798	0.318	6.297	0.013	2.221	0.986	3.627
上位椎间盘角 ≤3.5°	1.296	0.378	11.755	0.000	3.654	1.867	4.853

3.4 风险预测列线图模型构建及验证结果

将是否合并椎间盘损伤、TLAOSIS、骨折爆裂程度、术前椎体前缘高度比值、术前上位椎间盘角作为预测指标,构建胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险预测列线图模型。模型预测结果显示,合并椎间盘损伤、TLAOSIS >8 分、完全爆裂骨折、术前椎体前缘高度比值 <50%、术前上位椎间盘角 ≤3.5°对应的胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险预测值分别为 44.0 分、42.5 分、33.0 分、39.0 分、51.5 分,并发脊柱后凸畸

形的概率为 0.10 ~ 0.56。见图 1。ROC 曲线分析结果显示,该模型预测胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的曲线下面积为 0.921 ($P = 0.000$),灵敏度为 78.43%,特异度为 85.52%,模型具有较好的预测效能;模型验证 C-index 值为 0.823,校正曲线和标准曲线拟合度较好,模型校准度良好。见图 2。DCA 曲线显示,根据模型对胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险进行预测,可获得较好的净收益,阈值概率 0.02 ~ 0.95(图 3)。

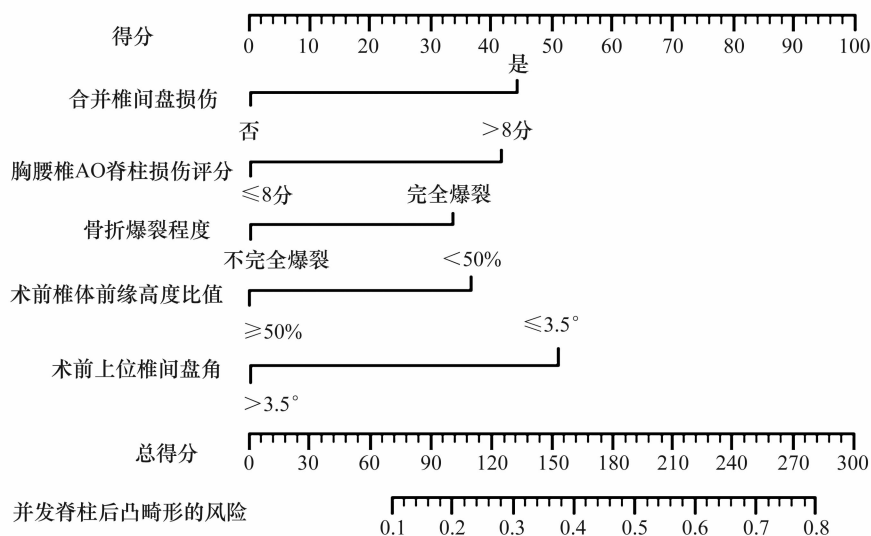


图1 胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险预测列线图

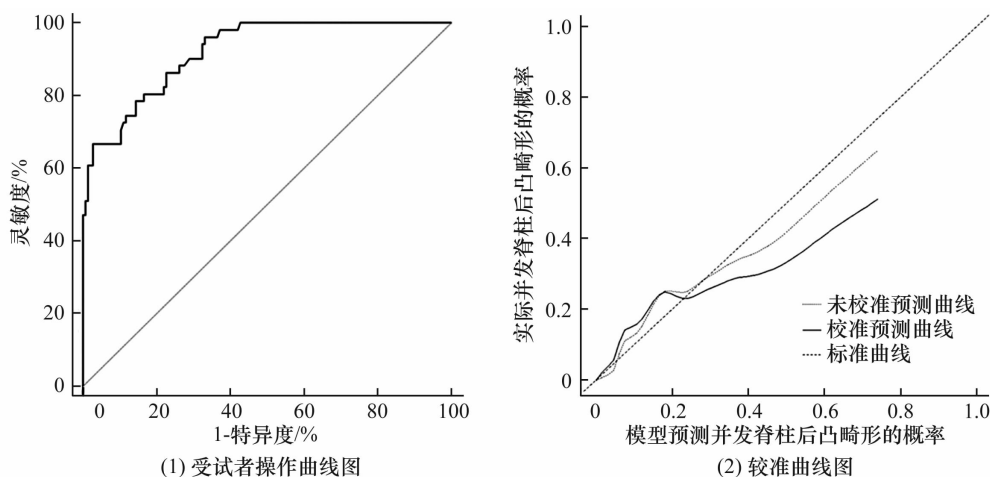


图2 胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形风险预测列线图模型的评价图

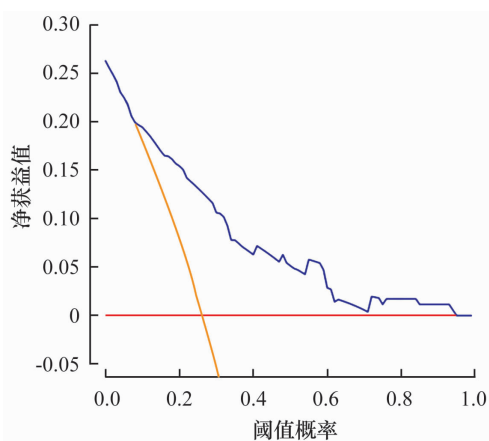


图3 胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形风险预测列线图模型的决策曲线分析图

4 讨论

胸腰椎爆裂骨折极易造成脊髓损伤及脊柱不稳,是脊柱损伤致残的重要原因之一^[13]。虽然采用内固定手术可对损伤的椎体进行固定和支撑,但胸腰椎爆

裂骨折患者术后仍易并发一系列并发症,其中脊柱后凸畸形是发生率高、预测困难、对患者预后影响较大的并发症之一^[14-15]。因此,探讨胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素,并依此建立方便临床应用的风险预测模型,对筛选术后并发脊柱后凸畸形的高风险患者和预防脊柱后凸畸形发生具有重要意义。

椎间盘损伤会加速椎间盘本身的退变,且由于纤维环破损,髓核组织会嵌入骨折椎体,诱导椎体终板塌陷,加重损伤^[16]。嵌入椎体的髓核组织还会导致椎体复位、愈合困难,影响脊柱的功能,增加术后并发脊柱后凸畸形的概率。TLAOSIS 越高表明脊柱骨折损伤越重,手术难度越大,术后脊柱的稳定性越难维持^[17-18]。根据骨折爆裂程度,胸腰椎爆裂性骨折可分为不完全爆裂骨折(骨折 AO 分型 A3 型)和完全爆裂骨折(骨折 AO 分型 A4 型)^[19]。骨折爆裂越严重,脊柱的稳定性越差^[20-21]。椎体前缘高度比值越小表

示骨折节段椎体压缩越严重,内固定手术虽然对椎体前缘高度进行恢复,但术后椎体内仍存在较大的骨松质缺损区,会诱导椎间盘从终板中央进入椎体^[22-23];且椎体压缩越严重,术后椎体前缘高度越容易丢失。上位椎间盘角变小,表示椎间高度变小,是脊柱失稳的指标之一。张青元等^[24]研究发现,上位椎间盘角变小是胸腰椎单椎体骨折患者术后并发脊柱后凸畸形的重要影响因素之一。

列线图模型作为简单实用的图形化工具已常被临床用来预测某事件的发生概率^[25-26]。本研究构建的胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险预测列线图模型,具有较好的区分度和校准度,符合列线图预测模型的基本条件;且该模型的净获益值较高,表明模型的预测效能较好。通过风险预测列线图模型对胸腰椎爆裂骨折患者进行术后并发脊柱后凸畸形的风险预测,可得到每个预测指标对应的分值,各项指标分值之和被记录为总分,与总分相对应的预测概率即为患者术后并发脊柱后凸畸形的概率。尽早对胸腰椎爆裂骨折患者进行内固定术后并发脊柱后凸畸形的风险预测,有利于对患者进行风险分层和针对危险因素为患者提供个体化的干预措施。术前对患者损伤情况进行准确的评估,术后早期对患者采取支具保护、功能锻炼等干预措施维持胸腰椎的稳定性,有利于降低胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的风险。

本研究结果表明,合并椎间盘损伤、TLAOSIS > 8 分、完全爆裂骨折、术前椎体前缘高度比值 < 50%、术前上位椎间盘角 ≤ 3.5° 均为胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形的危险因素;基于这些因素构建的风险预测列线图模型,对于胸腰椎爆裂骨折患者内固定术后并发脊柱后凸畸形具有一定的预测价值。

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