·神经重症医学·

创伤性脑疝患者去骨瓣减压术后脑积水危险因素分析以及贝叶斯网络模型构建

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【摘要】 **目的** 筛查颅脑创伤后脑疝患者去骨瓣减压术后脑积水的危险因素，并基于危险因素构建贝叶斯网络模型。**方法** 纳入2020年3月至2022年1月在东南大学附属南京同仁医院行去骨瓣减压术的77例颅脑创伤后脑疝患者，根据术后是否并发脑积水分为脑积水组（25例）和无脑积水组（52例），单因素和多因素Logistic回归分析筛查颅脑创伤后脑疝患者去骨瓣减压术后脑积水的危险因素，并基于危险因素构建贝叶斯网络模型，绘制受试者工作特征（ROC）曲线和校准曲线并行Hosmer-Lemeshow拟合优度检验。**结果** 脑积水组患者入院时Glasgow昏迷量表（GCS）评分（$t = 2.178$，$P = 0.032$）、术后腰椎穿刺脑脊液置换术比例（$\chi^2 = 8.675$，$P = 0.003$）、术后血清β2微球蛋白水平（$t = 11.146$，$P = 0.000$）低于无脑积水组，术前合并蛛网膜下腔出血（$\chi^2 = 5.901$，$P = 0.015$）、双侧手术（$\chi^2 = 6.441$，$P = 0.011$）、术中未缝合硬脑膜（$\chi^2 = 9.759$，$P = 0.002$）、术后脑室积血（$\chi^2 = 8.938$，$P = 0.003$）、术后中线移位 > 10 mm（$\chi^2 = 7.589$，$P = 0.006$）、术后并发颅内感染（$\chi^2 = 4.519$，$P = 0.034$）比例以及术后昏迷时间（$t = 2.709$，$P = 0.008$）高于无脑积水组。Logistic回归分析显示，术前合并蛛网膜下腔出血（$OR = 1.885$，95%CI：1.432 ~ 2.240；$P = 0.012$）、术中未缝合硬脑膜（$OR = 1.468$，95%CI：1.215 ~ 1.930；$P = 0.006$）、术后昏迷时间长（$OR = 1.574$，95%CI：1.358 ~ 1.926；$P = 0.007$）、术后脑室积血（$OR = 1.550$，95%CI：1.254 ~ 1.768；$P = 0.010$）和术后血清β2微球蛋白水平升高（$OR = 1.622$，95%CI：1.165 ~ 1.840；$P = 0.004$）是颅脑创伤后脑疝患者去骨瓣减压术后脑积水的危险因素。基于上述5项危险因素构建贝叶斯网络模型，ROC曲线下面积为0.886（95%CI：0.823 ~ 0.925，$P = 0.000$），校准曲线显示预测概率与实际概率之间具有良好的一致性，Hosmer-Lemeshow拟合优度检验显示差异无统计学意义（$\chi^2 = 8.760$，$P = 0.232$），表示该模型具有良好的区分度、校准度和准确性。**结论** 术前合并蛛网膜下腔出血、术中未缝合硬脑膜、术后昏迷时间长、术后脑室积血、术后血清β2微球蛋白水平升高是颅脑创伤后脑疝患者去骨瓣减压术后脑积水的危险因素，基于上述5项危险因素构建的贝叶斯网络模型对术后并发脑积水风险具有重要预测价值。

【关键词】 脑损伤，创伤性；　脑膨出；　减压颅骨切除术；　脑积水；　手术后并发症；　危险因素；　Logistic模型；　贝叶斯定理

Risk factors analysis and Bayesian network model construction of hydrocephalus after decompressive craniectomy in patients with cerebral hernia after traumatic brain injury

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【**Abstract**】 **Objective** To screen the risk factors of hydrocephalus after decompressive craniectomy in patients with cerebral hernia after traumatic brain injury (TBI), and construct a Bayesian network model based on the risk factors. **Methods** A total of 77 patients with cerebral hernia after TBI who underwent decompressive craniotomy in Nanjing Tongren Hospital Affiliated to Southeast University from March 2020 to January 2022 were included. They were divided into hydrocephalus group (n = 25) and non -

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hydrocephalus group (n = 52) according to whether hydrocephalus was complicated after surgery. The risk factors of hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI were analyzed by univariate and multivariate Logistic regression analyses. The Bayesian network model was constructed based on the risk factors, and the receiver operating characteristic (ROC) curve and calibration curve were drawn and Hosmer-Lemeshow goodness-of-fit test was conducted. **Results** In hydrocephalus group, the Glasgow Coma Scale (GCS) score at admission (t = 2.178, P = 0.032), the ratio of cerebrospinal fluid replacement after lumbar puncture (χ^2 = 8.675, P = 0.003), and the level of β2-microglobulin after operation (t = 11.146, P = 0.000) were lower than those in non-hydrocephalus group, while subarachnoid hemorrhage (χ^2 = 5.901, P = 0.015), bilateral operation (χ^2 = 6.441, P = 0.011), the ratio of dural unstitched during operation (χ^2 = 9.759, P = 0.002), postoperative intraventricular hemorrhage (χ^2 = 8.938, P = 0.003), postoperative midline displacement > 10 mm (χ^2 = 7.589, P = 0.006), and intracranial infection (χ^2 = 4.519, P = 0.034), as well as postoperative coma time (t = 2.709, P = 0.008) were higher than those in non-hydrocephalus group. Logistic regression analysis showed that subarachnoid hemorrhage (OR = 1.885, 95%CI: 1.432-2.240; P = 0.012), dural unstitched during operation (OR = 1.468, 95%CI: 1.215-1.930; P = 0.006), long postoperative coma time (OR = 1.574, 95%CI: 1.358-1.926; P = 0.007), postoperative intraventricular hemorrhage (OR = 1.550, 95%CI: 1.254-1.768; P = 0.010), the level of β2- microglobulin increased after operation (OR = 1.622, 95%CI: 1.165-1.840; P = 0.004) were risk factors for hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI. Based on these 5 factors, the Bayesian network model was constructed, and the area under ROC curve was 0.886 (95%CI: 0.823-0.925, P = 0.000). The calibration curve showed that there was a good consistency between the predicted probability and the actual probability, while the Hosmer-Lemeshow goodness-of-fit test showed no significant difference (χ^2 = 8.760, P = 0.232), which indicated that the model had good discrimination, calibration and accuracy. **Conclusions** Subarachnoid hemorrhage, dural unstitched during operation, long postoperative coma time, postoperative intra ventricular hemorrhage, and elevated β2-microglobulin level are the risk factors for hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI.

【Key words】 Brain injuries, traumatic; Encephalocele; Decompressive craniectomy; Hydrocephalus; Postoperative complications; Risk factors; Logistic models; Bayes theorem

Conflicts of interest: none declared

颅脑创伤(TBI)患者因外力因素出现颅骨骨折和脑损伤,脑损伤后机体分泌的阿片肽等物质可导致脑代谢异常,引起颅内高压,形成脑疝[1],导致呼吸抑制甚至死亡[2]。去骨瓣减压术是颅脑创伤的主要治疗方法,可以有效清除坏死脑组织和颅内血肿,增大颅内容积,减少脑组织受压并降低颅内压,避免术后脑水肿导致再次脑疝[3];然而,术后仍有5%~15%患者因脑脊液循环障碍出现脑积水,是术后1个月内最常见并发症[4],可引起步态异常、智力减退等,加重疾病负担,使患者预后不良[5]。贝叶斯网络通过图形方法描述各变量之间的相互关联以及整体变量对疾病风险的影响,从而更直观描述疾病与变量之间的复杂网络风险机制[6-7]。通过贝叶斯网络构建的老年高血压患者并发冠心病的风险预测模型具有较好的预测效能[8],但对于预测颅脑创伤后脑疝患者去骨瓣减压术后脑积水风险的贝叶斯网络模型鲜有报道。本研究回顾总结东南大学附属南京同仁医院近2年诊断与治疗的77例颅脑创伤后脑疝患者的临床资料,筛查去骨瓣减压术后脑积水危险因素并构建贝叶斯网络模型,以为颅脑创伤后脑疝患者脑积水的预防提供依据。

对象与方法

一、研究对象

1.纳入标准 (1)各种原因致颅脑创伤,且头部CT显示环池不清或受压,证实脑疝形成[9]。(2)创伤至入院时间≤6 h。(3)入院时Glasgow昏迷量表(GCS)评分[10]≤8分。(4)均行去骨瓣减压术。(5)年龄≥18岁。(6)预期生存期≥6个月。

2.排除标准 (1)术前存在脑积水。(2)既往曾行颅脑手术。(3)合并其他神经精神疾病。(4)合并恶性肿瘤或重要脏器功能障碍。(5)凝血功能障碍。(6)临床及随访资料不完整。

二、研究方法

1.临床资料采集 (1)社会人口学资料:性别、年龄、既往史(高血压、糖尿病、吸烟、饮酒)。(2)疾病相关资料:入院时GCS评分、创伤性质(开放性或闭合性)、创伤部位(额叶、颞叶、顶叶、枕叶)、创伤类型(硬膜外血肿、硬膜下血肿、多发血肿、脑挫裂伤)[11]、合并蛛网膜下腔出血。(3)实验室指标:术后

血清β2微球蛋白（β2-MG）水平。（4）治疗相关资料：手术侧别、手术时间、术中硬脑膜缝合，以及术后昏迷时间、脑室积血、颅内压、中线移位、腰椎穿刺脑脊液置换术、并发颅内感染。

2. 脑积水诊断标准　所有患者均于术后12 h内参照《颅脑创伤后脑积水诊治中国专家共识》[12]诊断标准：临床表现为持续昏迷，意识好转后再次昏迷，或疾病后期出现痴呆、尿失禁和步态不稳等症状；影像学检查可见脑沟、大脑纵裂消失且颞角宽度 > 2 mm，或者额角最大宽度与同水平颅骨内板内径比值 > 0.50且额角宽度 > 2 mm。

3. 统计分析方法　采用SPSS 22.0统计软件进行数据处理与分析。计数资料以相对数构成比（%）或率（%）表示，采用 χ^2 检验或Mann-Whitney U 检验。正态性检验采用Shapiro-Wilk检验，呈正态分布的计量资料以均数 ± 标准差（$\bar{x} \pm s$）表示，采用两独立样本的 t 检验。颅脑创伤后脑疝患者去骨瓣减压术后脑积水影响因素的筛查采用单因素和多因素逐步法Logistic回归分析（$\alpha_{入} = 0.05$，$\alpha_{出} = 0.10$）。采用R 3.5.2版本软件将筛选出的危险因素构建贝叶斯网络模型，采用Netica 5.18版本软件进行贝叶斯网络模型推理，绘制该模型的受试者工作特征（ROC）曲线评价模型区分度（曲线下面积 ≥ 90%为区分度好、70% ~ 89%为区分度较好、50% ~ 69%为区分度一般，< 50%为区分度较差）；绘制校准曲线评价模型准确性（预测模型与实际概率之间具有良好的一致性提示校准度良好）；Hosmer-Lemeshow拟合优度检验行内部验证（$P > 0.05$提示稳定性良好）。以 $P \leqslant 0.05$ 为差异具有统计学意义。

结　　果

根据上述纳入与排除标准，选择2020年3月至2022年1月在我院神经外科住院治疗的颅脑创伤后脑疝患者共77例，男性37例，女性40例；年龄18 ~ 70岁，平均（43.87 ± 10.36）岁；既往合并高血压占44.16%（34/77）、糖尿病占35.06%（27/77），吸烟占23.38%（18/77）、饮酒占24.68%（19/77）。入院时GCS评分3 ~ 8分，平均（6.01 ± 1.08）分；开放性颅脑创伤29例（37.66%），闭合性颅脑创伤48例（62.34%）；创伤部位分别位于额叶20例（25.97%），颞叶19例（24.68%），顶叶22例（28.57%），枕叶16例（20.78%）；创伤类型为硬膜外血肿7例（9.09%），硬膜下血肿19例（24.68%），多发血肿35例（45.45%），脑挫裂伤16例（20.78%）；其中37例（48.05%）合并蛛网膜下腔出血。单侧手术52例（67.53%），双侧手术25例（32.47%）；手术时间3 ~ 6 h，平均（4.11 ± 1.20）h；术中缝合硬脑膜47例（61.04%），未缝合硬脑膜30例（38.96%）；术后昏迷时间为25 ~ 40 h，平均为（31.63 ± 9.25）h；术后有28例（36.36%）出现脑室积血；术后颅内压10 ~ 14 mm Hg（1 mm Hg = 0.133 kPa），平均（11.74 ± 4.06）mm Hg；中线移位 > 10 mm者35例（45.45%），≤ 10 mm者42例（54.55%）；有46例（59.74%）行腰椎穿刺脑脊液置换术；术后30例（38.96%）患者并发颅内感染。术后血清β2微球蛋白2.20 ~ 4.00 mmol/L，平均（3.04 ± 0.48）mmol/L。根据术后是否并发脑积水分为脑积水组（25例）和无脑积水组（52例），脑积水组患者入院时GCS评分（$P = 0.032$）、术后行腰椎穿刺脑脊液置换术比例（$P = 0.003$）、术后血清β2微球蛋白水平（$P = 0.000$）低于无脑积水组，合并蛛网膜下腔出血（$P = 0.015$）、双侧手术（$P = 0.011$）、术中未缝合硬脑膜（$P = 0.002$）、术后脑室积血（$P = 0.003$）、术后中线移位 > 10 mm（$P = 0.006$）、术后并发颅内感染（$P = 0.034$）比例以及术后昏迷时间（$P = 0.008$）高于无脑积水组，其余指标组间差异无统计学意义（均 $P > 0.05$，表1）。

单因素Logistic回归分析显示，合并蛛网膜下腔出血（$P = 0.010$）、术中未缝合硬脑膜（$P = 0.002$）、术中昏迷时间（$P = 0.008$）、术后脑室积血（$P = 0.003$）、术后血清β2微球蛋白（$P = 0.000$）是颅脑创伤后脑疝患者去骨瓣减压术后并发脑积水的影响因素（表2，3）；将上述差异有统计学意义的因素纳入多因素Logistic回归方程，结果显示，合并蛛网膜下腔出血（$OR = 1.885$，95%CI：1.432 ~ 2.240；$P = 0.012$）、术中未缝合硬脑膜（$OR = 1.468$，95%CI：1.215 ~ 1.930；$P = 0.006$）、术后昏迷时间长（$OR = 1.574$，95%CI：1.358 ~ 1.926；$P = 0.007$）、术后脑室积血（$OR = 1.550$，95%CI：1.254 ~ 1.768；$P = 0.010$）、术后血清β2微球蛋白水平升高（$OR = 1.622$，95%CI：1.165 ~ 1.840；$P = 0.004$）是颅脑创伤后脑疝患者去骨瓣减压术后并发脑积水的危险因素（表4）。

将Logistic回归分析筛查出的合并蛛网膜下腔出血、术中未缝合硬脑膜、术后昏迷时间（按照中位数进行分层）、术后脑室积血、术后血清β2微球蛋白（按照中位数进行分层）共5项危险因素作为预测因素，以脑积水为结局，构建颅脑创伤后脑疝患者去

表1 脑积水组与无脑积水组患者临床资料的比较

Table 1. Comparison of clinical data between hydrocephalus group and non-hydrocephalus group

观察指标	无脑积水组(n=52)	脑积水组(n=25)	统计量值	*P*值
性别[例(%)]			0.243	0.622
男性	26(50.00)	11(44.00)		
女性	26(50.00)	14(56.00)		
年龄($\bar{x} \pm s$,岁)	42.85 ± 10.55	43.16 ± 10.48	0.121	0.904
高血压[例(%)]	24(46.15)	10(40.00)	0.259	0.611
糖尿病[例(%)]	18(34.62)	9(36.00)	0.014	0.905
吸烟[例(%)]	12(23.08)	6(24.00)	0.008	0.929
饮酒[例(%)]	10(19.23)	9(36.00)	2.554	0.110
入院时GCS($\bar{x} \pm s$,评分)	6.42 ± 2.17	5.35 ± 1.65	2.178	0.032
合并蛛网膜下腔出血[例(%)]	20(38.46)	17(68.00)	5.901	0.015
创伤部位[例(%)]			0.575	0.902
额叶	13(25.00)	7(28.00)		
颞叶	14(26.92)	5(20.00)		
顶叶	15(28.85)	7(28.00)		
枕叶	10(19.23)	6(24.00)		
创伤类型[例(%)]			-0.122	0.903
硬膜外血肿	5(9.62)	2(8.00)		
硬膜下血肿	13(25.00)	6(24.00)		
多发血肿	23(44.23)	12(48.00)		
脑挫裂伤	11(21.15)	5(20.00)		
创伤性质[例(%)]			0.044	0.835
开放性	20(38.46)	9(36.00)		
闭合性	32(61.54)	16(64.00)		
手术侧别[例(%)]			6.441	0.011
单侧	40(76.92)	12(48.00)		
双侧	12(23.08)	13(52.00)		
手术时间($\bar{x} \pm s$,h)	4.21 ± 1.31	4.02 ± 1.24	0.606	0.546
术中缝合硬脑膜[例(%)]			9.759	0.002
未缝合	14(26.92)	16(64.00)		
缝合	38(73.08)	9(36.00)		
术后昏迷时间($\bar{x} \pm s$,h)	28.76 ± 8.24	34.50 ± 9.62	2.709	0.008
术后脑室积血[例(%)]	13(25.00)	15(60.00)	8.938	0.003
术后颅内压($\bar{x} \pm s$,mm Hg)	11.26 ± 3.86	12.21 ± 4.32	0.973	0.334
术后中线偏移[例(%)]			7.589	0.006
> 10 mm	18(34.62)	17(68.00)		
≤ 10 mm	34(65.38)	8(32.00)		
术后腰椎穿刺脑脊液置换术[例(%)]	37(71.15)	9(36.00)	8.675	0.003
术后并发颅内感染[例(%)]	16(30.77)	14(56.00)	4.519	0.034
术后β2微球蛋白($\bar{x} \pm s$,mmol/L)	3.66 ± 0.52	2.42 ± 0.28	11.146	0.000

Two-independent-sample *t* test for comparison of age, GCS at admission, operation time, postoperative coma time, postoperative intracranial pressure and postoperative β2-microglobulin, Mann-Whitney *U* test for comparison of trauma type, and χ^2 test for comparison of others,年龄、入院时GCS评分、手术时间、术后昏迷时间、术后颅内压、术后β2微球蛋白的比较采用两独立样本的*t*检验,创伤类型的比较行Mann-Whitney *U*检验,其余指标的比较行χ^2检验。GCS,Glasgow Coma Scale,Glasgow昏迷量表

骨瓣减压术后脑积水的贝叶斯网络模型,该模型包含6个节点,9条有向边,采用最大似然估计法(MLE)获得各节点条件概率,结果显示,术中未缝合硬脑膜、术后昏迷时间、术后脑室积血与术后并发脑积水存在直接联系(即箭头直接指向),而合并蛛网膜下腔出血、术后血清β2微球蛋白水平升高与术后并发脑积水存在间接联系(箭头非直接指向,图1);采用Netica软件进行贝叶斯网络模型风险预测推理,结果显示,合并蛛网膜下腔出血和术后发生脑室积血预测术后并发脑积水的概率均为100%,故选择这两项指标,即当合并蛛网膜下腔出血和术后发生脑室积血时,颅脑创伤后脑疝患者去骨瓣减压术后脑积水发生率为68.32%(图2)。进一步绘制ROC曲线,贝叶斯网络模型曲线下面积为0.886(95%CI: 0.823 ~ 0.925, P = 0.000),灵敏度为87.80%、特异度为89.42%,提示该模型的预测效能较好(图3);绘制校准曲线显示,经贝叶斯网络模型获得的预测概率与实际概率之间具有良好的一致性,表明该模型的校准度良好;经Hosmer-Lemeshow拟合优度检验显示差异无统计学意义(χ^2 = 8.760, P = 0.232),该模型的一致性指数为0.886,提示其准确度较高(图4)。

讨 论

颅脑创伤因其高病残率和高病死率成为全球范围内的严重公共卫生问题[13],特别是重型颅脑创伤(sTBI)病死率高达60%[14]。脑疝是颅脑创伤的严重并发症,主要由颅内压急剧升高所致,部分患者可出现脑组织移位,造成神经、血管受压并产生相应症状群,病残率和病死率极高[15]。脑疝患者脑组织受压导致的脑脊液循环障碍可进一步加重脑疝[16],最佳救治时间为发病后30分钟内,随时间进展,不可逆性脑损伤加重[17]。去骨瓣减压术是颅脑创伤的重要治疗方法,可快速、有效缓解颅内高压,

表2 颅脑创伤后脑疝患者去骨瓣减压术后并发脑积水相关影响因素的变量赋值表

Table 2. Variable assignment of related influencing factors of hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI

变量	赋值				变量	赋值			
	0	1	2	3		0	1	2	3
脑积水	否	是			创伤类型	硬膜外血肿	硬膜下血肿	多发血肿	脑挫裂伤
性别	女性	男性			合并蛛网膜下腔出血	否	是		
高血压	否	是			手术侧别	单侧	双侧		
糖尿病	否	是			术中缝合硬脑膜	缝合	未缝合		
吸烟	否	是			术后脑室积血	否	是		
饮酒	否	是			术后中线偏移(mm)	≤10	> 10		
创伤性质	开放性	闭合性			术后腰椎穿刺脑脊液置换术	否	是		
创伤部位	额叶	颞叶	顶叶	枕叶	术后并发颅内感染	否	是		

表3 颅脑创伤后脑疝患者去骨瓣减压术后并发脑积水的单因素Logistic回归分析

Table 3. Univariate Logistic regression analysis of related influencing factors of hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI

变量	*b*	*SE*	Wald χ^2	*P*值	*OR*值	*OR* 95%CI	变量	*b*	*SE*	Wald χ^2	*P*值	*OR*值	*OR* 95%CI
性别	0.376	0.288	2.611	0.120	1.456	1.286 ~ 2.466	脑挫裂伤	0.750	0.554	2.708	0.220	2.130	1.745 ~ 2.436
年龄	0.919	0.745	2.467	0.204	2.507	2.055 ~ 3.382	合并蛛网膜下腔出血	0.434	0.272	3.191	0.010	1.544	1.156 ~ 1.785
高血压	0.972	0.660	2.945	0.176	2.643	2.121 ~ 3.878	双侧手术	0.360	0.288	2.500	0.052	1.433	1.235 ~ 2.072
糖尿病	0.720	0.552	2.609	0.152	2.054	1.582 ~ 2.795	手术时间	0.940	0.655	2.870	0.541	2.560	2.265 ~ 2.782
吸烟	1.274	0.854	2.984	0.220	3.576	2.372 ~ 4.563	术中未缝合硬脑膜	0.508	0.320	3.175	0.009	1.662	1.256 ~ 1.940
饮酒	0.810	0.780	2.077	0.211	2.247	1.696 ~ 2.687	术后昏迷时间	0.574	0.346	3.318	0.012	1.776	1.416 ~ 2.254
入院时GCS评分	0.623	0.496	2.512	0.060	1.865	1.432 ~ 1.996	术后脑室积血	0.486	0.320	3.038	0.026	1.625	1.404 ~ 1.960
创伤性质	1.145	0.762	3.005	0.423	3.142	2.562 ~ 3.433	术后颅内压	0.622	0.387	5.168	0.340	1.862	1.585 ~ 2.143
创伤位于颞叶	1.233	0.875	2.818	0.566	3.432	2.857 ~ 3.766	术后中线偏移	0.610	0.450	2.711	0.243	1.840	1.642 ~ 2.016
创伤位于顶叶	0.932	0.672	2.774	0.192	2.540	1.863 ~ 2.880	术后腰椎穿刺脑脊液置换术	0.581	0.432	2.690	0.120	1.787	1.542 ~ 2.250
创伤位于枕叶	0.521	0.435	2.395	0.090	1.684	1.320 ~ 2.252	术后并发颅内感染	0.514	0.337	3.050	0.165	1.672	1.308 ~ 1.877
硬膜下血肿	1.049	0.764	2.746	0.302	2.855	2.473 ~ 3.164	术后β2微球蛋白	0.377	0.156	4.833	0.005	1.458	1.167 ~ 1.732
多发血肿	0.534	0.386	2.767	0.255	1.722	1.336 ~ 2.087							

GCS, Glasgow Coma Scale, Glasgow昏迷量表

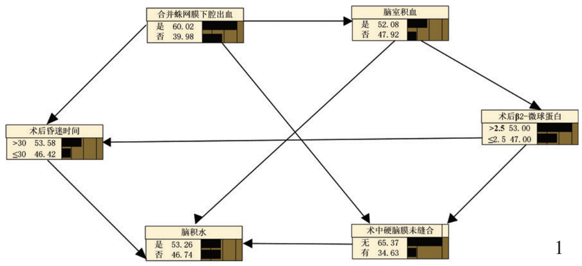
表4 颅脑创伤后脑疝患者去骨瓣减压术后并发脑积水的多因素逐步法Logistic回归分析

Table 4. Multivariate stepwise Logistic regression analysis of related influencing factors of hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI

变量	*b*	*SE*	Wald χ^2	*P*值	*OR*值	*OR* 95%CI	变量	*b*	*SE*	Wald χ^2	*P*值	*OR*值	*OR* 95%CI
合并蛛网膜下腔出血	0.634	0.462	2.745	0.012	1.885	1.432 ~ 2.240	术后脑室积血	0.438	0.226	3.876	0.010	1.550	1.254 ~ 1.768
术中未缝合硬脑膜	0.384	0.146	5.260	0.006	1.468	1.215 ~ 1.930	术后β2微球蛋白	0.484	0.215	4.502	0.004	1.622	1.165 ~ 1.840
术后昏迷时间	0.454	0.270	3.363	0.007	1.574	1.358 ~ 1.926	常数项	2.432	0.525	8.154	0.000		

改善脑脊液循环[18]。去骨瓣减压术主要通过剪开硬脑膜以释放颅内压，但是由于骨窗相对较小，无法充分显露颅底、额极等部位，无法完全止血和清除颅内血肿，使颅内减压不充分，导致脑积水、慢性脑膨出等并发症，使患者预后不良[19]。

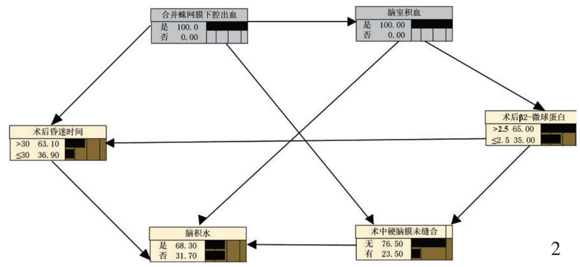
既往研究显示，颅脑创伤后脑疝患者去骨瓣减压术后脑积水的病理生理学机制主要包括：(1)脑血管受压变形，使脑表面和脑深部毛细血管密度降低，引起脑低灌注，导致脑脊液与蛛网膜颗粒交换减少[20]。(2)脑组织一氧化氮和谷氨酸分泌增加，引起谷氨酸代谢紊乱，脑代谢平衡破坏[21]。(3)脑组织含水量增加且侧脑室脑脊液循环障碍，易诱发脑积水[22]。(4)去骨瓣减压术中骨瓣面积减少，生理结构受损，导致脑实质与外界直接接触，脑室内压高于



1

图1　颅脑创伤后脑疝患者去骨瓣减压术后并发脑积水的贝叶斯网络模型结构图

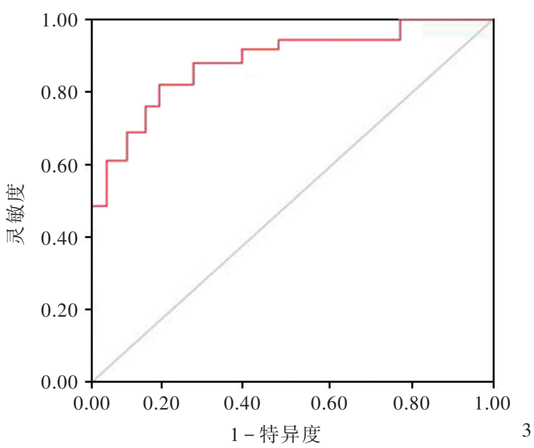
Figure 1　The structure of Bayesian network model for hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI.



2

图2　合并蛛网膜下腔出血和术后发生脑室积血时，颅脑创伤后脑疝患者去骨瓣减压术后并发脑积水的贝叶斯网络模型推理图

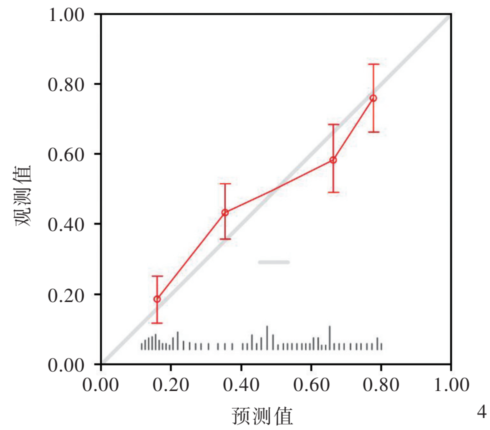
Figure 2　Inference diagram of Bayesian network model for hydrocephalus after decompressive craniectomy in patients with cerebral hernia after TBI with subarachnoid hemorrhage and postoperative intraventricular hemorrhage.



3

图3　ROC曲线显示，贝叶斯网络模型的曲线下面积为0.886（95%CI：0.823～0.925，P = 0.000），提示该模型的预测效能较好

Figure 3　The ROC curve of the Bayesian network model showed the area under the curve was 0.886 (95%CI: 0.823-0.925, P = 0.000), suggesting that the prediction efficiency of the model was good.



4

图4　校准曲线显示，贝叶斯网络模型预测曲线与理想曲线的趋势较为一致，提示该模型的校准度较好

Figure 4　The calibration curve of the Bayesian network model showed the trend of the model curve was consistent with the ideal curve, suggesting that the accuracy of the model was good.

外界大气压，脑室向外扩张，无法恢复生理结构，进展为脑积水[23-24]。(5)去骨瓣减压术后颅内压脉搏波振幅随脑水肿的消退和脑组织顺应性的增加而逐渐减小，无法正常驱动脑脊液流动，导致脑积水[25]。本研究结果显示，合并蛛网膜下腔出血、术中未缝合硬脑膜、术后昏迷时间长、术后脑室积血、术后血清β2微球蛋白水平升高是颅脑创伤后脑疝患者去骨瓣减压术后脑积水的危险因素。术后昏迷时间延长可能与入院时脑损伤较重有关，此类患者脑脊液吸收和循环障碍严重，易引起脑积水[26]。颅脑创伤后脑疝患者还可因合并蛛网膜下腔出血引起术后继发性脑积水，脑脊液残留红细胞碎片或纤维蛋白产物通过脑脊液循环堵塞蛛网膜下腔，使蛛网膜颗粒粘连，导致蛛网膜下腔狭窄或闭塞，引起脑脊液吸收和循环障碍，导致脑脊液积聚[11]，诱发脑积水[27]。目前多项研究认为，脑室积血是导致急性脑积水的主要危险因素[28-29]。去骨瓣减压术后发生脑室积血，一方面脑室周围脑组织顺应性降低，使脑室扩张；另一方面颅内血肿压迫脑室壁，凝血块溶解还可造成脑脊液吸收和循环困难，进而引发脑积水[30]。脑池位于大脑与外侧蛛网膜之间，其内含有脑脊液并被蛛网膜分隔为大小不等的腔隙，这些具有隔离作用的蛛网膜在颅脑创伤后抑制脑脊液循环[31]。生理状态下，侧脑室脉络丛分泌的脑脊液经室间孔进入第三脑室，并与第三脑室脉络丛分泌的脑脊液汇合，经中脑导水管进入第四脑室，再与第四脑室脉络丛分泌的脑脊液共同经侧孔、正中孔流入小脑延髓池，经蛛网膜下腔流向大脑背面，通过蛛网膜颗粒渗透至上矢状窦，最终回流入血液，当脑脊液循环障碍时即引发脑积水[32]。β2微球蛋白

是一种反映肾小球滤过功能的小分子蛋白[33]，Signorelli等[34]研究发现，颅脑创伤患者血清β2微球蛋白水平越高、脑积水风险越高，究其原因可能为创伤灶及其周围脑组织水肿坏死，神经细胞代谢障碍，β2微球蛋白自坏死的神经细胞表面释放，游离于脑脊液，加重脑损伤，导致脑脊液循环障碍[35]。此外，颅脑创伤后脑疝患者还可出现以促炎因子和抗炎因子生成以及受损神经细胞内中性粒细胞聚集为特征的急性炎症反应，增强中性粒细胞合成和分泌β2微球蛋白作用，引起脑积水[36]。颅脑创伤后脑疝患者颅内血肿位于硬脑膜下或脑室内时，多合并蛛网膜下腔出血，术中需打开硬脑膜，硬脑膜完整性对保持颅内压梯度和减少蛛网膜下腔出血具有重要意义[37]。目前认为，去骨瓣减压术后应行硬脑膜减张缝合，但临床实践中因术中脑膨出等原因导致难以缝合硬脑膜，增加脑积水风险[38]。在本研究中，基于上述5项危险因素构建贝叶斯网络模型，并经ROC曲线、校准曲线和Hosmer-Lemeshow拟合优度检验证实该模型区分度、校准度和稳定性均较好，提示该模型对颅脑创伤后脑疝患者去骨瓣减压术后脑积水风险具有重要预测价值。

综上所述，术前合并蛛网膜下腔出血、术中未缝合硬脑膜、术后昏迷时间长、术后脑室积血、术后血清β2微球蛋白水平升高是颅脑创伤后脑疝患者去骨瓣减压术后脑积水的危险因素，提示临床应重视上述因素以提高患者预后。然而，本研究存在一定的局限性：单中心研究，样本量较小，未分析手术方式及术中出血量对术后并发脑积水的影响，术后降低颅内压的方法仅采用脑脊液置换术，可能存在选择偏倚。未来尚待开展多中心研究，扩大样本量，且对手术方式及术中出血量进行分析，进一步验证本研究结论。

利益冲突　无

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