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在线全文

# 神经内镜联合显微镜血肿清除术后中枢神经系统感染的风险因素与列线图模型构建*

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【摘要】 **目的** 分析神经内镜联合显微镜血肿清除术后患者中枢神经系统感染的危险因素，构建列线图模型并进行验证。**方法** 回顾性纳入2021年1月–2024年12月医院收治460例行神经内镜联合显微镜血肿清除术的患者，7∶3分配为建模集（$n$=322）和验证集（$n$=138），根据是否发生中枢神经系统感染将建模集分为感染组（$n$=68）和未感染组（$n$=254），通过logistic回归方程筛选中枢神经系统感染的独立预测因子，并据此建立列线图预测模型。**结果** 460例患者感染总发生率为20.65%（95/460），logistic回归分析结果显示，神经内镜联合显微镜血肿清除术后患者中枢神经系统感染的独立危险因素包括糖尿病史〔比值比（odds ratio, OR）=3.431，95%置信区间（confidence interval, CI）：1.300～9.057〕、格拉斯哥昏迷量表（GCS）评分（OR=0.574，95%CI：0.462～0.711）、脑脊液渗漏（OR=4.492，95%CI：1.430～14.116），以及手术时间（OR=1.011，95%CI：1.004～1.019）、引流管留置时间（OR=5.452，95%CI：2.423～12.268）和白蛋白（ALB）（OR=0.778，95%CI：0.720～0.840）（$P$<0.05）。基于上述危险因素构建列线图预测模型，在建模集和验证集中预测事件发生的曲线下面积（area under the curve, AUC）为0.928（95%CI：0.895～0.960）、0.918（95%CI：0.885～0.951），校准曲线与理想曲线拟合度良好（Hosmer-Lemeshow检验$P$>0.05），决策曲线分析具有显著净收益优势。**结论** 基于糖尿病史、GCS评分、脑脊液渗漏、手术时长、引流管留置时间及ALB水平构建的列线图预测模型，对神经内镜辅助显微镜下血肿清除术后并发中枢神经系统感染具有较高预测效能。

【关键词】 神经内镜 显微镜血肿清除术 中枢神经系统感染 列线图 危险因素

# Central Nervous System Infection After Neuroendoscopic and Microscopic Combined Hematoma Removal: Risk Factors and Construction of a Nomogram Prediction Model

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[**Abstract**] **Objective** To analyze the risk factors associated with central nervous system (CNS) infection in patients after neuroendoscopic hematoma removal combined with and microscopic hematoma removal, and to construct and validate a nomogram prediction model. **Methods** A total of 460 patients who underwent neuroendoscopic hematoma removal combined with microscopic hematoma removal at our hospital between January 2021 and December 2024 were retrospectively enrolled. The patients were assigned to a modeling cohort ($n$ = 322) and a validation cohort ($n$ = 138) in a 7∶3 ratio. Furthermore, the modeling cohort was divided into an infection group ($n$ = 68) and a non-infected group ($n$ = 254) according to whether CNS infection occurred. The independent predictors of central nervous system infection were identified by logistic regression analysis, and a nomogram prediction model was constructed accordingly. **Results** The overall incidence of CNS infection in the 460 patients was 20.65% (95/460). According to the logistic regression analysis, the independent risk factors for CNS infection in patients after neuroendoscopic and microscopic combined hematoma removal included a history of diabetes mellitus (odds ratio [OR] = 3.431, 95% CI: 1.300-9.057), the Glasgow Coma Scale (GCS) score (OR = 0.574, 95% CI: 0.462-0.711), cerebrospinal fluid leakage (OR = 4.492, 95% CI: 1.430-14.116), operation duration (OR = 1.011, 95% CI: 1.004-1.019), duration of drainage tube placement (OR = 5.452, 95% CI: 2.423-12.268) and albumin (ALB) level (OR = 0.778, 95% CI: 0.720-0.840) ($P$ < 0.05). Based on these risk factors, a nomogram prediction model was constructed, and the area under the receiver operating characteristic curve (AUC) of the predicted events in the modeling cohort and the validation cohort was 0.928 (95% CI: 0.895-0.960) and 0.918 (95% CI: 0.885-0.951), respectively. The calibration curve fitted well with the ideal curve (Hosmer-Lemeshow test, $P$ > 0.05), and the decision curve analysis demonstrated significant net benefit. **Conclusion** The nomogram model based on history of diabetes mellitus, GCS score, cerebrospinal fluid leakage, operation duration, duration of drainage tube placement, and

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ALB level demonstrates high predictive performance for CNS infection after neuroendoscopy-assisted microscopic hematoma removal.

**[Key words]** Neuroendoscope　Microscopic hematoma removal　Central nervous system infection　Nomogram　Risk factor

脑出血占所有卒中类型的10%～15%, 发病后30 d内死亡率高达40%～50%, 是全球范围内导致残疾和死亡的主要病因之一[1]。在中国, 高血压性脑出血是急诊神经外科最常见的急危重症, 年发病率介于(60～80)/10万, 约占自发性脑出血的70%～80%[2]。神经内镜联合显微镜血肿清除术治疗脑出血不仅能够发挥神经内镜的微创性和精准性, 又能借助显微镜的立体视野和精细操作能力优化手术效果。随着神经内镜联合显微镜血肿清除术的广泛应用, 术后并发症的预防和管理也成为关注的焦点, 同时中枢神经系统感染的防控问题日益受到重视[3-4]。研究表明, 神经外科术后中枢神经系统感染的发生率约4.6%～25.4%, 而颅内血肿清除术后的感染风险显著高于其他术式[5]。感染不仅延长患者住院时间, 还导致患者3个月功能独立率下降37%, 直接医疗成本增加2.3倍[6]。但目前针对神经内镜联合显微镜血肿清除术后中枢神经系统感染的研究存在局限性, 多数研究仅关注单一危险因素, 缺乏多维度指标的综合分析, 此外, 传统logistic回归模型仅提供风险比, 临床医生难以直观评估个体化感染概率[7]。列线图模型通过可视化赋权将多变量转化为直观的评分-概率对应关系, 在肿瘤预后预测中已展现优异性能, 但其在神经内镜联合显微镜血肿清除术后感染风险评估中的应用仍有空白[8-9]。因此, 本研究旨在构建并验证神经内镜联合显微镜血肿清除术后中枢神经系统感染的列线图预测模型, 期望整合手术操作、患者基础状态及术后管理等多维度危险因素, 为临床提供可量化的个体感染风险分层工具, 为临床精准防控提供依据。

## 1　资料与方法

### 1.1　样本量计算

样本量计算公式: 变量数×(5～10)/发生率, 本研究纳入变量共21个, 根据马双媛等[10]的研究结果, 发生率取31%, 则本研究样本量至少为21×5/0.31, 即339例。考虑模型稳健性适当增加样本量后, 本次研究共纳入460例, 符合样本量需求。

### 1.2　研究对象

本研究经贵阳市第二人民医院伦理委员会审核批准。进行回顾性分析, 选择2021年1月–2024年12月在医院行神经内镜联合显微镜血肿清除术的460例患者纳入研究, 按照7∶3比例随机分配为建模集($n$=322)和验证集($n$=138), 建模集用于筛选变量及构建模型, 验证集用于验证建模集所得结果。

### 1.3　纳排标准

纳入标准: ①符合《中国脑出血诊治指南(2014)》[11]中脑出血诊断标准, 并经影像学检查确诊符合手术指征; ②均接受神经内镜联合显微镜血肿清除术; ③年龄>18岁; ④发病至入院时间间隔<24 h; ⑤临床资料完整。排除标准: ①合并其他恶性肿瘤; ②术前已出现中枢神经系统感染; ③神经系统或脑外伤疾病; ④凝血功能障碍。

### 1.4　研究方法

收集患者临床资料, 包括性别、年龄、体质量指数(body mass index, BMI)、糖尿病史、高血压史、冠心病史, 以及脑出血部位、术前格拉斯哥昏迷量表(Glasgow Coma Scale, GCS)评分[12]、脑出血分级量表(Intracerebral Hemorrhage Grading Scale, ICH-GS)评分[13]、美国麻醉师协会分级(American Society of Anesthesiologists, ASA)[14]、手术时机、气管切开情况、预防性使用抗生素、脑脊液渗漏、出血量、手术时间、术后使用呼吸机、住院时间、引流管留置时间等资料。实验室指标通过术后第二天, 采集患者清晨空腹静脉血5 mL, 抗凝后使用希森美康XN-2100型全自动血液分析仪测定血红蛋白(hemoglobin, Hb), 另取一份样本以3 000 r/min离心10 min后取上清液, 贝克曼AU5800型全自动生化分析仪测定血清白蛋白(albumin, ALB)水平。

### 1.5　诊断方法

依据《中国神经外科重症患者感染诊治专家共识(2017)》[15]中关于中枢神经系统感染的定义, 符合以下任一条件即确诊: ①腰穿或脑室外引流获得的脑脊液培养结果为阳性; ②脑脊液培养结果为阴性, 但出现以下情况: 患者意识及精神状态改变, 出现全身感染性症状, 脑膜刺激征阳性, 颅内压增高, 血常规检查白细胞计数>$10\times10^9\,L^{-1}$或中性粒细胞百分比>80%, 脑脊液检查白细胞计数升高(>$100\times10^6\,L^{-1}$), 葡萄糖水平降低(<2.6 mmol/L), 蛋白定量升高(>0.45 g/L)。

### 1.6　统计学方法

采用SPSS 26.0进行数据统计分析。符合正态分布的定量数据以$\bar{x}\pm s$表示, 组间比较采用独立样本$t$检验; 计数资料以例数(%)表示, 组间差异通过$\chi^2$检验分析。通过logistic多因素向后逐步回归法分析中枢神经系统感染的

相关因素，据此建立列线图预测模型。模型效能验证采用双队列设计：在建模集与验证集中分别使用受试者工作特征(receiver operator characteristic curve, ROC)曲线下面积(area under the curve, AUC)评估模型的区分能力，采用校准曲线配合Hosmer-Lemeshow检验评价预测概率与实际观测值的一致性，运用临床决策曲线(decision curve analysis, DCA)量化模型的临床净获益值。检验水准$\alpha$=0.05。

## 2 结果

### 2.1 两组患者临床资料比较

见表1。纳入460例患者，共95例患者住院期间发生

**表 1 两组患者临床资料比较**

**Table 1 Comparison of clinical data between two the groups of patients**

| Indicator | Modeling cohort ($n$ = 322) | Validation cohort ($n$ = 138) | $\chi^2/t$ | $P$ |
|---|---|---|---|---|
| Sex/case (%) | | | 0.166 | 0.684 |
| Male | 156 (48.45) | 64 (46.38) | | |
| Female | 166 (51.55) | 74 (53.62) | | |
| Age/yr., $\bar{x} \pm s$ | 57.49 ± 11.52 | 57.84 ± 11.14 | 0.302 | 0.763 |
| BMI/(kg/m$^2$), $\bar{x} \pm s$ | 22.22 ± 2.26 | 22.58 ± 2.74 | 1.466 | 0.143 |
| History of diabetes/case (%) | | | 2.605 | 0.107 |
| Yes | 52 (16.15) | 31 (22.46) | | |
| No | 270 (83.85) | 107 (77.54) | | |
| History of hypertension/case (%) | | | 2.394 | 0.122 |
| Yes | 102 (31.68) | 54 (39.13) | | |
| No | 220 (68.32) | 84 (60.87) | | |
| History of coronary heart disease/case (%) | | | 0.192 | 0.661 |
| Yes | 44 (13.66) | 21 (15.22) | | |
| No | 278 (86.34) | 117 (84.78) | | |
| Cerebral hemorrhage site/case (%) | | | 7.117 | 0.068 |
| Basal nucleus region | 143 (44.41) | 79 (57.25) | | |
| Thalamencephalon | 86 (26.71) | 32 (23.19) | | |
| Brain stem | 42 (13.04) | 11 (7.97) | | |
| Cerebellum | 51 (15.84) | 16 (11.59) | | |
| GCS score/points, $\bar{x} \pm s$ | 9.24 ± 2.41 | 9.51 ± 2.08 | 1.146 | 0.253 |
| ICH-GS score/points, $\bar{x} \pm s$ | 9.63 ± 1.44 | 9.52 ± 1.37 | 0.762 | 0.447 |
| ASA grading/case (%) | | | 0.577 | 0.447 |
| Ⅰ and Ⅱ | 179 (55.59) | 82 (59.42) | | |
| Ⅲ and Ⅳ | 143 (44.41) | 56 (40.58) | | |
| Timing of operation/case (%) | | | 0.071 | 0.791 |
| Emergency treatment | 173 (53.73) | 76 (55.07) | | |
| Elective opration | 149 (46.27) | 62 (44.93) | | |
| Tracheotomy/case (%) | | | 0.800 | 0.371 |
| Yes | 257 (79.81) | 105 (76.09) | | |
| No | 65 (20.19) | 33 (23.91) | | |
| Prophylactic use of antibiotics/case (%) | | | 1.697 | 0.193 |
| Yes | 126 (39.13) | 63 (45.65) | | |
| No | 196 (60.87) | 75 (54.35) | | |
| Cerebrospinal fluid leakage/case (%) | | | 3.223 | 0.073 |
| Yes | 42 (13.04) | 27 (19.57) | | |
| No | 280 (0.87) | 111 (0.8) | | |
| Intracerebral hemorrhage volume/mL, $\bar{x} \pm s$ | 32.54 ± 3.78 | 33.06 ± 3.45 | 1.387 | 0.166 |
| Operation time/min, $\bar{x} \pm s$ | 236.57 ± 54.28 | 241.36 ± 53.42 | 0.871 | 0.384 |
| Use of ventilator after operation/case (%) | | | 0.867 | 0.352 |
| Yes | 58 (18.01) | 30 (21.74) | | |
| No | 264 (81.99) | 108 (78.26) | | |
| Drainage tube indwelling time/case (%) | | | 0.159 | 0.690 |
| < 3 d | 199 (61.80) | 88 (63.77) | | |
| ⩾ 3 d | 123 (38.20) | 50 (36.23) | | |
| Length of stay/d, $\bar{x} \pm s$ | 11.19 ± 2.32 | 11.22 ± 2.63 | 0.122 | 0.903 |
| Hb/(g/L), $\bar{x} \pm s$ | 99.14 ± 11.37 | 98.52 ± 10.96 | 0.542 | 0.588 |
| ALB/(g/L), $\bar{x} \pm s$ | 38.65 ± 5.36 | 38.27 ± 5.17 | 0.704 | 0.482 |

GCS: Glasgow Coma Scale; ICH-GS: Intracerebral Hemorrhage Grading Scale; ASA: American Society of Anesthesiologists; Hb: hemoglobin; ALB: serum albumin.

中枢神经系统感染, 发生率为20.65%(95/460)。根据感染发生情况将建模集患者分为感染组($n$=68)和非感染组($n$=254), 验证集分为感染组($n$=27)和非感染组($n$=111)。对建模集和验证集患者的临床资料进行比较, 两组资料差异无统计学意义, 可进行后续研究。

### 2.2　建模集两组患者临床资料比较

分析建模集中感染组和非感染组患者临床资料分布情况, 和非感染组相比, 感染组有糖尿病史、脑脊液渗漏以及引流管留置时间≥3 d的患者占比更高, GCS评分及ALB水平更低($P$<0.05), 其余资料则未见明显差异($P$>0.05)。见表2。

**表 2　建模集两组患者临床资料比较**

**Table 2　Comparison of clinical data between two subgroups of patients in the modeling cohort**

| Indicator | Infection subgroup ($n$ = 68) | Non-infected subgroup ($n$ = 254) | $\chi^2/t$ | $P$ |
|---|---|---|---|---|
| Sex/case (%) | | | 0.282 | 0.595 |
| Male | 31 (45.59) | 125 (49.21) | | |
| Female | 37 (54.41) | 129 (50.79) | | |
| Age/yr., $\bar{x} \pm s$ | 57.23 ± 11.34 | 58.07 ± 11.26 | 0.546 | 0.586 |
| BMI/(kg/m$^2$), $\bar{x} \pm s$ | 22.57 ± 2.14 | 22.43 ± 2.09 | 0.488 | 0.626 |
| History of diabetes/case (%) | | | 11.198 | 0.001 |
| Yes | 20 (29.41) | 32 (12.60) | | |
| No | 48 (70.59) | 222 (87.40) | | |
| History of hypertension/case (%) | | | 1.713 | 0.191 |
| Yes | 26 (38.24) | 76 (29.92) | | |
| No | 42 (61.76) | 178 (70.08) | | |
| History of coronary heart disease/case (%) | | | 0.461 | 0.497 |
| Yes | 11 (16.18) | 33 (12.99) | | |
| No | 57 (83.82) | 221 (87.01) | | |
| Cerebral hemorrhage site/case (%) | | | 2.559 | 0.465 |
| Basal nucleus region | 30 (44.12) | 113 (44.49) | | |
| Thalamencephalon | 20 (29.41) | 66 (25.98) | | |
| Brain stem | 11 (16.18) | 31 (12.20) | | |
| Cerebellum | 7 (10.29) | 44 (17.32) | | |
| GCS score/points, $\bar{x} \pm s$ | 8.35 ± 2.04 | 10.24 ± 2.13 | 6.556 | < 0.001 |
| ICH-GS score/points, $\bar{x} \pm s$ | 9.23 ± 1.37 | 9.46 ± 1.41 | 1.202 | 0.230 |
| ASA grading/case (%) | | | 0.773 | 0.379 |
| Ⅰ and Ⅱ | 41 (60.29) | 138 (54.33) | | |
| Ⅲ and Ⅳ | 27 (39.71) | 116 (45.67) | | |
| Timing of operation/case (%) | | | 3.202 | 0.074 |
| Emergency treatment | 30 (44.12) | 143 (56.30) | | |
| Elective surgery | 38 (55.88) | 111 (43.70) | | |
| Tracheotomy/case (%) | | | 0.061 | 0.805 |
| Yes | 55 (80.88) | 202 (79.53) | | |
| No | 13 (19.12) | 52 (20.47) | | |
| Prophylactic use of antibiotics/case (%) | | | 0.203 | 0.653 |
| Yes | 25 (36.76) | 101 (39.76) | | |
| No | 43 (63.24) | 153 (60.24) | | |
| Cerebrospinal fluid leakage/case (%) | | | 6.177 | 0.013 |
| Yes | 15 (22.06) | 27 (10.63) | | |
| No | 53 (77.94) | 227 (89.37) | | |
| Intracerebral hemorrhage volume/mL, $\bar{x} \pm s$ | 32.54 ± 3.12 | 32.46 ± 3.31 | 0.179 | 0.858 |
| Operation time/min, $\bar{x} \pm s$ | 254.36 ± 61.35 | 227.63 ± 51.38 | 3.651 | < 0.001 |
| Ventilator use after operation/case (%) | | | 0.071 | 0.790 |
| Yes | 13 (19.12) | 45 (17.72) | | |
| No | 55 (80.88) | 209 (82.28) | | |
| Drainage tube indwelling time/case (%) | | | 31.667 | < 0.001 |
| < 3 d | 22 (32.35) | 177 (69.69) | | |
| ≥3 d | 46 (67.65) | 77 (30.31) | | |
| Length of stay/d, $\bar{x} \pm s$ | 11.28 ± 2.74 | 11.06 ± 2.41 | 0.649 | 0.517 |
| Hb/(g/L), $\bar{x} \pm s$ | 98.52 ± 11.52 | 99.63 ± 11.27 | 0.718 | 0.473 |
| ALB/(g/L), $\bar{x} \pm s$ | 36.24 ± 5.21 | 44.28 ± 6.53 | 9.382 | < 0.001 |

All abbreviations are explained in the footnote to Table 1.

### 2.3 建模集患者中枢神经系统感染的影响因素

以建模队列患者是否发生中枢神经系统感染为因变量(发生=1, 未发生=0), 以糖尿病史(是=1, 否=0)、GCS评分(原始值)、脑脊液渗漏(是=1, 否=0)、手术时间(原始值)、引流管留置时间(≥3 d=1, <3 d=0)、ALB(原始值)为自变量, 进行logistic回归分析, 结果显示, 糖尿病史〔比值比(odds ratio, OR)=3.431, 95%置信区间(confidence interval, CI): 1.300 ~ 9.057)、GCS评分(OR=0.574, 95%CI: 0.462 ~ 0.711)、脑脊液渗漏(OR=4.492, 95%CI: 1.430 ~ 14.116)、手术时间(OR=1.011, 95%CI: 1.004 ~ 1.019)、引流管留置时间(OR=5.452, 95%CI: 2.423 ~ 12.268)、ALB(OR=0.778, 95%CI: 0.720 ~ 0.840)是患者中枢神经系统感染的独立危险因素($P$<0.05), 见表3。

### 2.4 构建预测患者中枢神经系统感染发生风险的列线图

基于糖尿病史、GCS评分、脑脊液渗漏、手术时长、引流管留置时间及ALB水平6项独立危险因子, 开发列线图风险分层工具。通过变量赋值加权生成累积风险评分, 依据总分阈值界定高危人群: 当个体综合评分>136分(对应风险概率≥30%)时, 判定为中枢神经系统感染高风险对象, 见图1。

### 2.5 评价列线图预测效能

ROC分析显示建模集与验证集的AUC分别为0.928(95%CI: 0.895 ~ 0.960)和0.918(95%CI: 0.885 ~ 0.951), 提示该模型区分度较高(图2); 校准曲线与理想线高度重合, Hosmer-Lemeshow检验统计量在建模集($\chi^2$=10.925, $P$=0.754)和验证集($\chi^2$=4.529, $P$=0.806)均无统计学意义($P$>0.05), 证实预测概率与实际值一致性较高(图3)。

### 2.6 列线图临床应用价值

通过DCA曲线分析神经内镜联合显微镜血肿清除术后患者中枢神经系统感染预测模型的临床适用性, 结果可见(图4), DCA决策曲线在0.1 ~ 0.9阈值区间始终高于参考线, 表明应用该模型可使临床干预获得正向净收益。

**表 3 建模集患者中枢神经系统感染的影响因素( $n$=322 )**

**Table 3 Influencing factors of central nervous system infection in patients in the modeling cohort ($n$ = 322)**

| Factor | $\beta$ | SE | $Z$ | $P$ | OR (95% CI) |
|---|---|---|---|---|---|
| History of diabetes mellitus | 1.233 | 0.495 | 2.489 | 0.013 | 3.431 (1.300-9.057) |
| GCS score | −0.556 | 0.110 | −5.057 | < 0.001 | 0.574 (0.462-0.711) |
| Cerebrospinal fluid leakage | 1.502 | 0.584 | 2.572 | 0.010 | 4.492 (1.430-14.116) |
| Operation time | 0.011 | 0.004 | 3.104 | 0.002 | 1.011 (1.004-1.019) |
| Drainage tube indwelling time | 1.696 | 0.414 | 4.098 | < 0.001 | 5.452 (2.423-12.268) |
| ALB | −0.251 | 0.039 | −6.432 | < 0.001 | 0.778 (0.720-0.840) |

$\beta$: partial regression coefficient; SE: standard error; OR: odds ratio; the other abbreviations are explained in the footnote to Table 1.

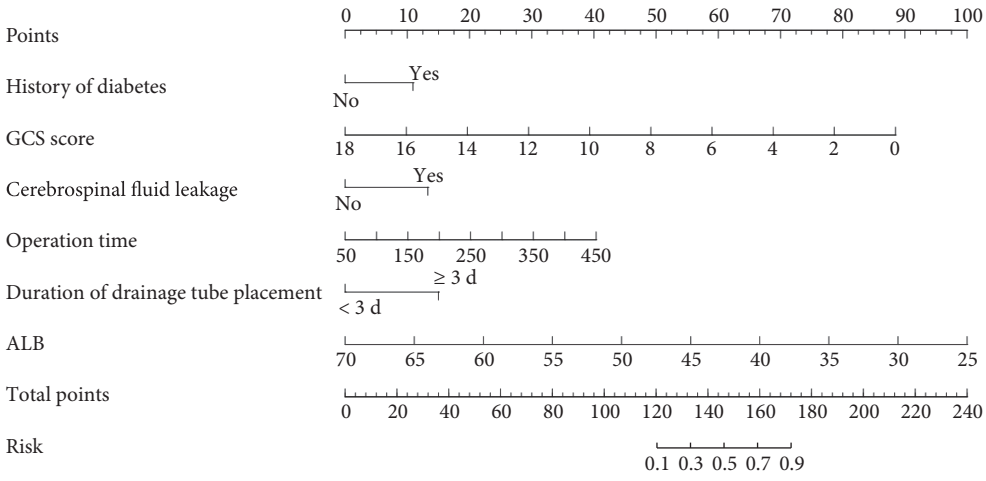


**图 1 预测患者中枢神经系统感染的列线图**

**Fig 1 Nomogram for predicting central nervous system infection in patients**

The abbreviaions are explained in the footnote to Table 1.

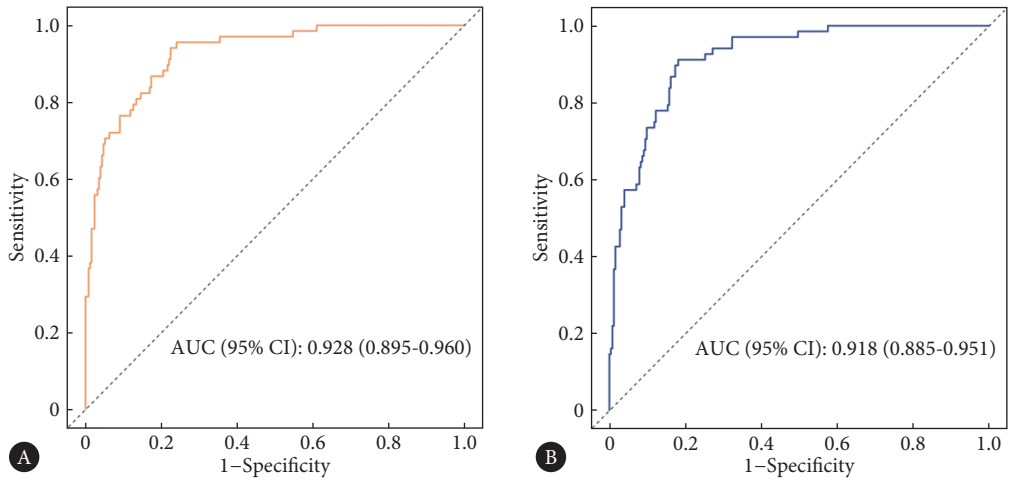


**图 2　预测患者中枢神经系统感染列线图模型的ROC曲线**

**Fig 2　ROC curve of nomogram model for predicting central nervous system infection in patients**

A, Modeling cohort, $n$ = 322; B, validation cohort, $n$ = 138.

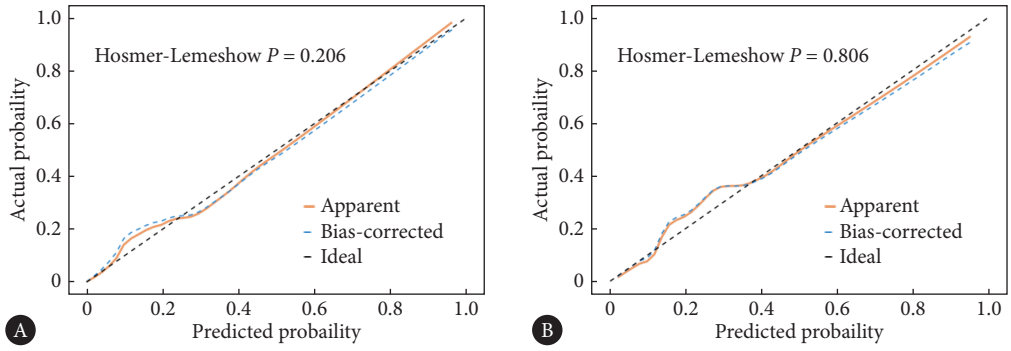


**图 3　预测患者中枢神经系统感染列线图模型的校准曲线**

**Fig 3　Calibration curve of nomogram model for predicting central nervous system infection in patients**

A, Modeling cohort, $n$ = 322; B, validation cohort, $n$ = 138.

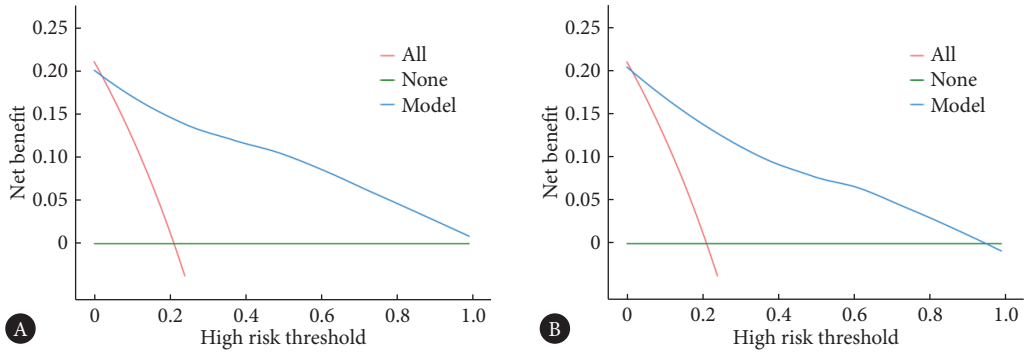


**图 4　预测患者中枢神经系统感染列线图模型的DCA曲线**

**Fig 4　DCA curve of nomogram model for predicting central nervous system infection in patients**

A, Modeling cohort, $n$ = 322; B, validation cohort, $n$ = 138.

## 3　讨论

随着医疗技术的不断发展，神经内镜联合显微镜血肿清除术已成为治疗脑出血的重要手段，其微创性和精准性在临床中得到了广泛认可，并取得了显著的疗效。然而，术后中枢神经系统感染仍然难以完全避免，对患者的手术效果和预后造成严重影响[16]。研究报道[17]，神经外科术后中枢神经系统感染的发生率约为4.6%～25.4%，而颅内血肿清除术后的感染风险尤为突出。本研究中，中枢神经系统感染的发生率为20.65%，与现有文献报道的数据基本一致[18]，说明颅内血肿清除术后的感染问题具有较高的普遍性和临床复杂性。

本研究结果发现,有糖尿病史是患者术后中枢神经系统感染的危险因素($P$<0.05),原因分析为:糖尿病患者体内的高血糖状态会导致中性粒细胞和巨噬细胞的功能下降,削弱机体对抗感染的能力;其次,糖尿病造成的微血管病变会影响局部组织的血液供应,进一步降低组织修复能力和抗感染能力,增加术后感染风险[19]。多项研究已证实糖尿病是术后感染的重要危险因素,程利等[20]研究表明,在神经外科手术中,糖尿病患者的感染率是非糖尿病患者的3倍以上;CHENG等[21]指出,糖尿病患者的高血糖状态会导致伤口愈合延迟,增加术后感染可能性。本研究结果发现,GCS评分较低是患者术后中枢神经系统感染的危险因素($P$<0.05),原因分析为:GCS评分直接反映患者的意识状态与脑损伤严重程度,低分患者因颅内压升高、脑血流自动调节功能受损,易继发全身炎症反应综合征和免疫抑制状态,导致血脑屏障通透性增加,病原体更易侵入中枢神经系统[22]。此外,GCS评分低的患者常需延长手术时间以彻底清除血肿,进一步增加呼吸道病原体逆行感染风险[23]。值得注意的是,神经内镜联合显微镜手术虽通过微创入路减少脑组织牵拉,但对深部血肿的精细操作可能因患者意识障碍导致术中体位限制或脑肿胀而复杂化,进而间接延长手术时间,形成感染风险的恶性循环。相关研究指出[24],进行神经外科手术的患者GCS评分每降低1分,术后感染风险将增加约15%,并在ZHAO等[25]的报道中发现,低GCS评分患者由于免疫功能低下和屏障功能受损,更容易发生中枢神经系统感染等术后并发症。本研究结果发现,脑脊液渗漏是患者术后中枢神经系统感染的危险因素($P$<0.05),原因分析为:脑脊液渗漏是指脑脊液通过硬脑膜或其他结构的缺损流出,而脑脊液渗漏会破坏正常的颅内解剖屏障,使外界病原体更容易侵入中枢神经系统[26]。神经内镜联合显微镜血肿清除术需要打开颅腔并操作脑组织,手术创伤可能导致硬脑膜或蛛网膜破裂,增加脑脊液渗漏发生概率,渗漏后病原体可通过渗漏通道进入颅内,进而提高中枢神经系统感染风险[27]。一项针对内窥镜鼻内颅底手术的分析显示[28],脑脊液渗漏是术后脑膜炎的危险因素,与本研究结论相似。

本研究结果发现,较长的手术时长是患者术后中枢神经系统感染的危险因素($P$<0.05),原因分析为:神经内镜联合手术需在内镜通道建立后切换至显微镜操作,器械转换和术野反复调整可能破坏无菌屏障,延长开放性操作时间,增加空气或器械表面病原体的定植风险,以及病原体侵入颅内的机会[29]。相关研究也表明[30],手术时间超过3 h的患者,其中枢神经系统感染的发生率显著高于手术时间较短的患者。本研究结果发现,引流管留置时间≥3 d是患者术后中枢神经系统感染的危险因素($P$<0.05),原因分析为:引流管表面易被金黄色葡萄球菌、鲍曼不动杆菌等细菌黏附并形成生物膜,而生物膜成熟后会释放游离病原体,通过管腔或管周间隙逆行侵入颅内。此外,长时间留置还可能破坏局部组织的完整性,削弱脑脊液屏障功能,从而为病原体提供入侵途径[31]。本研究结果发现,低ALB水平是术后患者中枢神经系统感染的危险因素($P$<0.05),原因分析为:ALB水平反映机体营养状态,低ALB水平可能导致中性粒细胞数量减少或功能障碍,同时影响巨噬细胞的吞噬能力和抗原呈递功能,进而削弱机体免疫力,导致免疫调节失衡,使机体更易受到感染[32]。NIE等[33]的多因素logistic 回归分析结果中,术后ALB水平(OR: 0.84)是神经外科术后颅内感染的风险因子。本研究基于上述危险因素构建的列线图模型体现了较高的区分能力,建模集和验证集的AUC分别达到0.928和0.918,校准曲线与理想曲线高度一致($P$>0.05),同时模型临床收益较高。本研究结果将多维度指标转化为易于理解的量化工具,可帮助临床医生快速识别高危患者,临床可通过缩短引流管留置时间或术前纠正低蛋白血症等措施降低术后感染风险。

综上所述,糖尿病史、GCS评分、脑脊液渗漏、手术时长、引流管留置时间及ALB水平是神经内镜联合显微镜血肿清除术后患者中枢神经系统感染的危险因素,基于上述危险因素构建的列线图模型通过整合多维度指标,为临床提供了可量化的感染风险分层工具,有助于早期识别高危患者并针对性干预。但本次研究数据来源于单一医疗中心,可能存在选择偏倚,未来应纳入多中心前瞻性研究进一步确认其外推性能,并通过随机对照试验验证干预措施的实际效益。

* * *

**作者贡献声明** 梁郸负责论文构思、数据审编、正式分析、调查研究、初稿写作和审读与编辑写作,周焜负责经费获取、研究方法、研究项目管理、提供资源和软件,舒波负责监督指导、验证和可视化。所有作者已经同意将文章提交本刊,且对将要发表的版本进行最终定稿,并同意对工作的所有方面负责。

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**利益冲突** 所有作者均声明不存在利益冲突

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