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Development of a simple prediction model for tracheostomy requirement after surgical resection of medulloblastoma in children

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Abstract

Objective Postoperative tracheostomy is a significant complication following medulloblastoma (MB) resection. This study aimed to develop a predictive model for postoperative tracheostomy requirement in children undergoing MB surgical resection. This model was derived as a side product of a larger research project analyzing surgical outcomes in pediatric MB patients.

Results Forty-five patients (26%) required tracheostomy postoperatively. Using multivariable logistic regression, five models were developed, and the final model was selected based on performance and simplicity. The simplified version included two predictors: preoperative brainstem invasion and postoperative brainstem contusion, each contributing equally to the score. The model demonstrated an AUC of 0.845. Predicted risks of requiring a tracheostomy were 5.8%, 57.7%, and 75% for scores of 0, 1, and 2, respectively. This tool provides clinicians with a quantitative approach to assess tracheostomy risk, improving decision-making and patient management.

Keywords Medulloblastoma, Tracheostomy, Risk forecasting model, Prediction modeling, Brainstem

Introduction

Brain tumors are among the most challenging issues in pediatric neurosurgery, with medulloblastoma being the most common malignant brain tumor [1, 2]. Treatment strategy for medulloblastoma is built upon surgical resection as the primary intervention. The surgery commonly involves a posterior fossa approach and may exposes the brainstem. One of the postoperative complications of surgical resection of medulloblastoma is the need for tracheostomy [3]. Tracheostomy can have significant negative implication for the quality of life of the children and their families and may contribute to prolonged hospitalization, increased care cost, morbidity, and mortality [4, 5].

Studies have shown that some factors may increase the likelihood of requiring a tracheostomy in children undergoing posterior fossa tumor surgery. These factors

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include younger age, larger tumor size, hydrocephalus, and postoperative neurologic deficit [6–8]. Medulloblastoma surgery involves a posterior fossa approach and exposes the brainstem, which places children at risk for respiratory complications such as airway obstruction that may necessitate tracheostomy. The link between brainstem injury and the need for a tracheostomy lies in the critical role of the brainstem in controlling essential autonomic and motor functions, particularly those related to respiration and airway protection.

During medulloblastoma resection, the posterior fossa approach often involves manipulation or exposure of the brainstem, which can lead to direct injury or disruption of its delicate structures. This injury may impair the cranial nerves and neural pathways responsible for swallowing, coughing, and maintaining airway patency, resulting in complications such as dysphagia, aspiration, and airway obstruction. Consequently, a tracheostomy may be required to provide a secure airway and facilitate long-term respiratory support in cases where normal airway and respiratory function cannot be maintained [9–11].

Several studies have highlighted the risk factors and the incidence of postoperative tracheostomy in children undergoing surgery for posterior fossa tumors. However, predicting which patients will require tracheostomy after medulloblastoma resection is still challenging [6, 7, 12, 13].

Development of a prediction model that accurately predicts tracheostomy requirement after surgical resection of medulloblastoma in children could help optimize patient care by identifying high-risk patients who could benefit from early interventions, enable appropriate resource allocation, and improve the outcome of these patients.

Herein, we aim to develop a model using clinical and radiological features that can predict the tracheostomy requirement in children undergoing medulloblastoma resection. The study will seek to identify the most critical predictors of this outcome and combine them into a simple predictive scoring model.

Materials and methods

Patient population

A retrospective analysis of clinical and radiologic factors extracted form medical records of all children who underwent primary medulloblastoma resection was carried out. The patients were surgically treated at Namazi Hospital, an academic tertiary referral center in Shiraz, south Iran, from April 2012 to September 2020. The study focused on individuals below 18 years of age, diagnosed with posterior fossa tumors with a histopathological confirmed medulloblastoma. We excluded the cases with incomplete medical records, ambiguous tumor histopathology, prior tumor resections, or age exceeding 18 years. Additionally, patients with anomalies in preoperative chest radiographs or those dependent on tracheostomy prior to surgery were excluded. The extracted data was previously presented in a previous publication [8].

The study protocol was reviewed and approved by the Ethics Committee of Shiraz University of Medical Sciences (Approval No. IR.SUMS.MED.REC.1402.268). Written informed consent for participation and publication was obtained from all participants or their legal guardian on admission. All methods were performed in accordance with the relevant guidelines and regulation and the Declaration of Helsinki.

Study variables and outcome

The study variables included demographic, clinical, pathologic, and outcome parameters, namely age, sex, presence of hydrocephalus, Ventriculoperitoneal (VP) shunt insertion, brainstem compression and invasion by the tumor (as determined by preoperative imaging), lateral localization of MB tumors in the cerebellopontine Angle (CPA), cystic component presence in the tumor, calcification in the tumor, cervical invasion, the extent of tumor resection, and postoperative brainstem contusion (determined by postoperative imaging). The primary outcome was tracheostomy requirement in the post-operative period.

Statistical analysis

Interval data were reported as mean ± standard deviation. Categorical variables were presented as frequencies and percentages. Independent t-test and chi-square test or their non-parametric equivalent tests were used for univariate analysis to identify potential risk factors of tracheostomy requirement. Moreover, a multivariable logistic regression analysis was carried out to identify the variables independently associated with the outcome.

The variables with a significant association with the outcome were selected through a systematic approach for model development. We employed forward stepwise selection and backward stepwise elimination techniques to refine the model. Forward stepwise selection involved iteratively adding variables to the model based on their statistical significance and contribution to improving model fit, while backward stepwise elimination systematically removed variables that did not meet the pre-specified significance threshold. Both methods were guided by the Wald statistic, which evaluates the strength of association between each predictor and the outcome, and the likelihood ratio test, which assesses the improvement in model performance with the inclusion or exclusion of variables. This combined approach ensured that the final model included only the most relevant predictors, enhancing its interpretability and predictive accuracy.

To develop the clinical predictive risk scores, a strategy similar to that employed by Ho et al. [14] was followed. Each variable was assigned an integer score based on its relative contribution to the logistic regression model, determined by the regression coefficient. Area under the ROC Curve (AUC) and Akaike Information Criterion (AIC) were used to evaluate the performance of models. The data were analyzed using SPSS version 27.0 (IBM Corp., Armonk, NY) and Stata version 14.0 (StataCorp LLC, Lakeway Drive College Station, TX). A p-value below 0.05 was considered significant. This study was conducted and written in accordance with the TRIPOD Statement [15].

Results

173 patients were included in this study, 68 females and 105 males. Tracheostomy tube insertion was carried out for 45 patients (26%). Brainstem compression (80%) followed by subtotal resection (62%), were the most common indications for the insertion of the tracheostomy tube. Uni- and multivariable analysis of the features and their association with tracheostomy requirement is summarized in Table 1.

Four models were developed using stepwise forward selection and backward elimination based on Wald and likelihood ratio. Forward selection based on Wald and likelihood ratio resulted in the inclusion of the same variables. The variable included in each model and the performance of the models is presented in Table 2. ROC curve of the three models is plotted on Fig. 1.

Model 1 which was developed using stepwise Wald backward elimination comprised brainstem infiltration, calcification, and post-operative brainstem contusion. AIC and the AUC of the model were 122.574 and 0.869 (95% Confidence Interval; CI = 0.804–0.934), respectively. AUC of the model in internal validation was 0.7824. Model 2 comprised brainstem infiltration, brainstem compression, calcification, and post-operative brainstem

Table 1 Univariate and multivariable analysis of the factors predicting tracheostomy in children undergoing surgical tumor resection. OR; odds ratio, SD; Standard Deviation

Univariate Analysis				**Multivariable analysis**				
Mb patients who underwent surgery	**No tracheostomy (*n* = 128)**	**Tracheostomy (*n* = 45)**	**p-value**	**Wald**	**Adjusted OR**	**95% confidence interval for adjusted OR**		**p-value**
						Lower	**Upper**	
Mean age, years (SD)	6.52 (4.024)	5.36 (4.739)	0.11	0.060	2.574	0.428	15.487	0.276
Range	1–17	1–17						
Sex			0.81	0.502	0.033	0.009	0.116	0.683
Female (68)	51	17						
Male (105)	77	28						
Cystic degeneration			0.08	0.519	0.937	0.834	1.053	0.176
Present (55)	36	19						
Not present (118)	92	26						
Calcification			0.16	0.690	0.540	0.194	1.503	0.052
Present (27)	17	10						
Not present (146)	111	35						
Brainstem compression			< 0.001	0.561	0.228	0.071	0.733	0.130
Present (84)	53	36						
Not present (89)	75	9						
Brainstem infiltration			< 0.001	0.595	0.293	0.017	5.132	0.013
Present (44)	20	24						
Not present (129)	108	21						
Cervical invasion			0.07	0.532	1.228	0.459	3.284	0.869
Present (2)	0	2						
Not present (171)	128	43						
CP angle			0.36	0.916	0.428	0.143	1.284	0.302
Present (14)	9	5						
Not present (159)	119	40						
Extent of resection			< 0.001	0.523	0.496	0.179	1.371	0.238
Subtotal (66)	38	28						
Total resection (107)	90	17						
Post operation brainstem contusion			< 0.001	0.644	3.828	0.989	14.814	< 0.001
Present (32)	8	24						
Not present (140)	119	21						

Table 2 An outline of the variables included in each model and the performance of each one as measured by AUC and AIC. CI; confidence interval, OR; odds ratio, AIC; Akaike Information Criterion, AUC; Area under the receiver operator curve

Model	Variable Selection	Variable	Coefficient	Wald	OR	95% CI for OR		p-value	-2 log likelihood	AIC	AUC (95% CI)	Validation AUC
						Lower	Upper					
Model 1	Wald backward elimination	Brainstem infiltration	-2.313	22.252	0.099	0.038	0.259	0.000	128.574	122.574	0.869 (0.804–0.934)	0.7824
		Calcification	1.217	3.297	3.375	0.908	12.549	0.069				
		Post-operative brainstem contusion	-3.505	32.567	0.030	0.009	0.100	0.000				
Model 2	Likelihood ratio backward elimination	Brainstem infiltration	-1.788	11.104	0.167	0.058	0.479	0.001	120.498	112.498	0.892 (0.838–0.946)	0.7674
		Brainstem compression	−0.911	2.784	0.402	0.138	1.173	0.095				
		Calcification	1.255	3.475	3.507	0.937	13.121	0.062				
		Post-operative brainstem contusion	-3.334	29.310	0.036	0.011	0.119	0.000				
Model 3	Wald and likelihood ratio forward selection	Brainstem infiltration	-2.144	20.188	0.117	0.046	0.299	0.000	132.247	128.247	0.862 (0.794–0.930)	0.7922
		Post-operative brainstem contusion	-3.067	33.114	0.047	0.016	0.132	0.000				

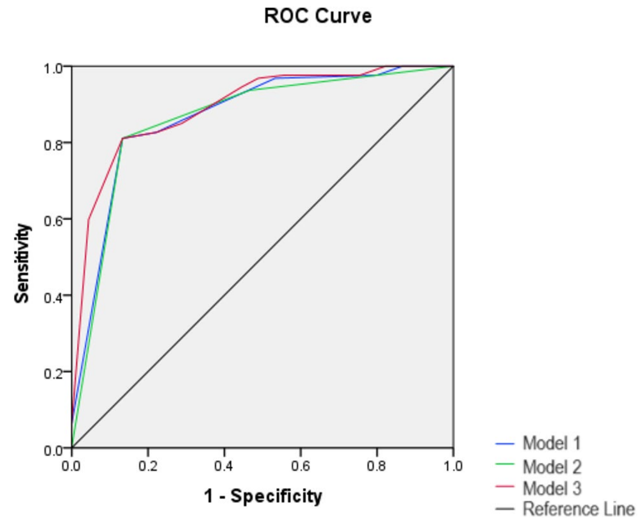

Fig. 1 A plot of ROC curves of the models

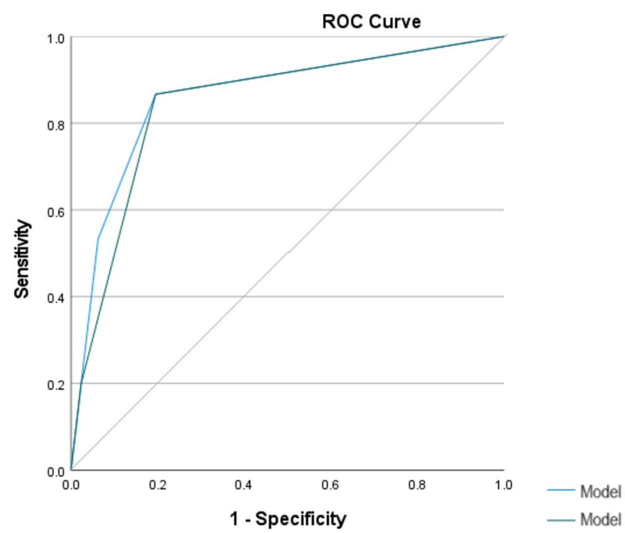

Fig. 2 ROC curve of the simplified models. Model a comprised brainstem infiltration with a score of 2 and post-operative brainstem contusion with a score of 3 and Model b, the further simplified model, which comprised the same variables with equal contribution from each one

contusion. AIC and the AUC of Model 2 were 112.498 and 0.892 (95% CI = 0.838–0.946), respectively. AUC of the model in internal validation was 0.7674. Despite incorporating only 2 variables, Model 3 was superior in terms of performance with AIC and AUC of 128.247 and 0.862 (95% CI = 0.794–0.930), respectively. The AUC of the model on internal validation was 0.7922.

To simplify, the score assigned to the variables were rounded to 2 and 3 for brainstem infiltration and post-operative brainstem contusion, respectively. Figure 2 shows the ROC curve of the model after assigning an integer score to each variable. A further simplified model was also plotted in Fig. 2, with assigning equal contribution (score of 1) to each variable. Table 3 outlines the

Table 3 Comparison of Model a which comprised brainstem infiltration with a score of 2 and post-operative brainstem contusion with a score of 3 and model b, the further simplified model, which comprised the same variables with equal contribution from each one

	AUC	Standard Error	95% confidence interval		p-value
			Lower	*Upper*	
Model a	0.8607	0.0320	0.7979	0.9234	0.0602
Model b	0.8451	0.037	0.7830	0.9071	

comparison of the two simplified models. Delong test results showed that the difference between the models was not significant, favoring the simpler one.

The final simplified model can have three possible score for each case (Table 4). A patient who has a score of zero, having neither of the features, had a 5.8% chance of requiring post-operative tracheostomy. Scores of one and two each indicated a 57.7% and 75%% risk of requiring tracheostomy, respectively. The sensitivity and specificity of the model with a cut-off of one were measured at 86.7% and 80.5%, respectively.

Discussion

Medulloblastoma is a type of malignant brain tumor that primarily affects children [4]. It usually originates in the cerebellum and can cause symptoms such as headaches, vomiting, and balance problems. Treatment for medulloblastoma typically involves surgical resection followed by radiation and chemotherapy [5]. While these treatments have improved survival rates, they can also result in significant complications [5]. Surgical complications can include Posterior fossa syndrome, cranial nerve palsies, and hemiparesis. In addition, there may be pitfalls in the timing and delivery of treatment, such as the risk of radiation-induced secondary malignancies [16–18].

Early tracheostomy may be beneficial in some cases to minimize the need for invasive mechanical ventilation and reduce the risk of complications. On the other hand, delayed tracheostomy may be necessary in cases where the underlying cause of respiratory distress is not apparent or where other treatments option can be tried [19–22]. Posterior fossa tumors, including medulloblastoma, can cause respiratory compromise due to the compression of the brainstem and associated breathing centers [3]. Tracheostomy may be necessary to manage this respiratory distress and ensure adequate oxygenation.

In a previous study conducted by Goethe et al., involving 197 patients, 6.1% required tracheostomy placement, at a mean of 69.1 days postoperatively. Patients needing tracheostomy were notably younger, more likely to experience postoperative dysphagia, and had a diagnosis of ependymoma or astrocytoma. Factors associated with eventual tracheostomy included delayed extubation, prolonged postoperative intubation, higher reintubation rates within 48 h, and longer hospital and ICU stays. Despite the challenges, 25% of those requiring tracheostomy were decannulated by first year after the index surgery [6].

In another investigation conducted by Totapally et al. on 461 children undergoing surgical resection for cerebellar tumors, a small percentage of patients required mechanical ventilation (7.8%), and a further minority underwent tracheostomy (1.5%) following the excision of cerebellar tumors. The study characterizes these patients as a high-risk cohort in the United States, emphasizing the need for intensive airway management, hydrocephalus treatment, and long-term nursing support [7].

Tracheostomy, despite being a life-saving intervention in managing respiratory compromise, poses significant challenges and complications. The impact on language development, infection risks, caregiver stress, and financial burdens necessitate a careful weighing of benefits and risks in approaching tracheostomy [19–22].

In this study, we aimed to develop a simple and easy-to-apply clinical prediction model predicting tracheotomy requirement in medulloblastoma patients. The models developed here utilized variables such as brainstem infiltration, calcification, and post-operative brainstem contusion. Our model, which includes only two variables, demonstrated remarkable performance in predicting the outcome of interest, achieving an AUC of 0.862. Its simplicity makes it more feasible for incorporation into clinical practice.

Table 4 An outline of the final selected simplified model

Factor	Description	Clinical Significance	Assigned Score	Multivariable Odds Ratio (95% CI)	*p*-value
Brainstem Infiltration	Direct tumor involvement within the brainstem causing disruption of critical autonomic functions as determined by preoperative imaging.	Associated with respiratory compromise and need for airway management.	1	0.117 (0.046–0.299)	< 0.001
Post-Operative Brainstem Contusion	Brainstem injury following surgery, indicated by imaging findings.	Reflects surgical complications leading to impaired neural control of respiration.	1	0.047 (0.016–0.132)	< 0.001

Limitations

Despite our efforts, several limitations should be considered when interpreting this study. First, this study was based on retrospective data collected from a single center, so the generalizability and external validity of the developed model needs to be addressed in future studies in diverse populations as much as possible. Moreover, future studies showed investigate whether the implementation of the model developed in the present study will translate into an improvement in the outcomes including earlier identification and intervention, shorter assisted ventilation period, or functional outcome and mortality.

Conclusion

Tracheostomy is a burdensome complication of management of medulloblastoma, one of the most common pediatric malignancies. Postoperative ventilator dependency is an important complication in postoperative recovery of patients undergoing medulloblastoma resection. Early prediction of tracheostomy requirement can be utilized to develop a well-organized and effective postoperative care for medulloblastoma patients.

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Author contributions
SZ: Conceptualization, Data Curation, Methodology, Formal analysis, Project administration, Writing – original draft, Writing - review & editing. ZT: Investigation, Data Curation. AA: Investigation, Data Curation, Writing – original draft. OY: Investigation, Writing – original draft. MSM: Conceptualization, Methodology. RT: Conceptualization, Methodology, Investigation, Supervision.

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Data availability
All of the data generated or used has been presented in this manuscript.

Declarations

Ethics approval and consent to participate
The study protocol was reviewed and approved by the Ethics Committee of Shiraz University of Medical Sciences (Approval No. IR.SUMS.MED.REC.1402.268). Written informed consent for participation was obtained from all participants or their legal guardian on admission. All methods were performed in accordance with the relevant guidelines and regulation and the Declaration of Helsinki.

Consent for publication
Written informed consent for publication of this study was obtained from the parents or legal guardians of all participants, given that all participants in this study were minors under the age of 18.

Competing interests
The authors declare no competing interests.

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