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Prediction of Intraoperative Blood Loss during Surgery of Brain Meningiomas

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Abstract

Background The utilization of preoperative embolization is a well-established method for reducing intraoperative blood loss during surgery of meningiomas. However, the exact indications and contraindications for this technique remain controversial.

Objective The objective of this study is to determine the indications for preoperative embolization of brain meningiomas.

Materials and Methods A retrospective analysis of 46 patients who underwent surgical resection of intracranial meningioma from 2020 to the end of 2022 was conducted. Preoperative magnetic resonance imaging (MRI) and computed tomography (CT) data were studied to assess their relationship with the volume of intraoperative blood loss.

Results Invasive tumor growth and bone involvement (erosion, hyperostosis) were found to be the most significant factors influencing intraoperative blood loss ($p = 0.001$).

Conclusion This study clearly demonstrates an association between preoperative imaging data and intraoperative blood loss, which may be useful in predicting massive bleeding during surgery.

Keywords
- meningioma
- blood loss risk factors
- blood loss prognosis
- embolization
- bleeding

Introduction

Meningiomas are benign tumors of the brain that arise from arachnoid cap cells and are located in areas where arachnoid cells accumulate, such as along venous sinuses and the base of the skull. Due to their high vascularity by both extra and intracranial vessels, blood loss during meningiomas surgery can be significant, which requires intra- and postoperative blood transfusion. This may necessitate intra- and postoperative blood transfusion and increase the risk of surgical damage to the brain and neurovascular structures.[1] Preoperative embolization has been found to reduce intraoperative blood loss, minimize the need for blood transfusions, decrease the risk of brain damage and postoperative complications, and improve

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tumor removal.[2–4] However, this technique also carries certain risks such as hemorrhage into the tumor, cerebral ischemia, edema, and dislocation.[5–8] Therefore, it is important to identify the indications for preoperative embolization, which remain controversial and based primarily on the surgeon's experience.

The aim of this study is to determine the factors that affect intraoperative blood loss in order to establish the indications for preoperative embolization.

Materials and Methods

This study was approved by the Ethic committee of Republican Specialized Scientific-Practical Medical Center of Neurosurgery. Patient informed consent was obtained. This study involved a retrospective and comparative analysis of the surgical outcomes of 46 patients with cerebral meningiomas of various localizations who underwent surgery at our center from 2020 to the end of 2022. The patients' ages ranged from 19 to 72 years, with a mean age of 50 years, and included 34 women and 12 men (3:1 ratio). The general characteristics of the patients are presented in ►**Table 1**.

Table 1 General chtitle>

Features	Number
Gender, m/f (ratio)	34/12 (ratio 3:1)
Mean age	50 y
Localization	
Convexity	18 (39%)
Parasagittal/falx	19 (41%)
• Total occlusion of SSS	10 (22%)
• Partial occlusion of SSS	9 (19,5%)
Skull base	9 (19,5%)
• Medial	8 (17,4%)
• Lateral	1 (2%)
Vessels/sinus involvement: 27 (58.7%)	
ICA	3
BA	1
ACA	1
MCA	6
PCA	1
CS	4
SSS	17
Totality according Simpson grade	
I	14
II	29
III	3
Middle blood loss	594 ± 61

Abbreviation: ACA, anterior cerebral artery; BA, basilar artery; CS, cavernous sinus; ICA, internal carotid artery; MCA, middle cerebral artery; PCA, posterior cerebral artery; SSS, superior sagittal sinus.

To determine the hypervascularity of meningioma, which is the main cause of massive bleeding during surgery, we used the following criteria for evaluation: localization, volume, invasive growth, the presence of a dural tail, bone damage, calcification, and involvement of the large vessels.

Due to the complexity of embolization, intracerebral and posterior cranial fossa meningiomas were excluded from the study; recurrent meningiomas because of their destroyed vascular anatomy were also eliminated.

The patients were divided into three groups based on their localization: convexity meningiomas, parasagittal/falx meningiomas, and skull base meningiomas. Skull base meningiomas were divided into the medial and lateral groups based on their vascular supply. Medial tumors receive supply from both the external carotid artery (ECA) and the internal carotid artery (ICA), and lateral tumors mainly receive supply from the branches of the ECA. Parasagittal meningiomas were also divided into two groups based on occlusion of the superior sagittal sinus: complete and incomplete sinus occlusion.

Tumor volume was calculated using the Coniglobus formula (cm^3) based on magnetic resonance imaging (MRI) and computed tomography (CT) findings. The classification of meningiomas located near different areas within the skull was restructured based on the brain's ability to compensate. For those meningiomas situated near the convexity or parasagittal region, the sizes were categorized as follows: small-sized tumors were defined as being less than 40 cm^3, medium-sized tumors ranged from 40 to 62.5 cm^3, and large-sized tumors were identified as 62.5 cm^3 or larger. In contrast, meningiomas located at the skull base were classified differently, with small tumors being less than 13.5 cm^3, medium tumors between 13.5 and 32 cm^3, and large tumors being 32 cm^3 or larger. The distribution data of meningiomas by size according to their location are indicated in ►**Table 2**. Invasive growth was determined using MRI and CT data based on the absence of a border between the brain and the tumor (absence of arachnoid space) and tuberous contours of the tumor. The presence of a dural tail, perifocal edema, local bone lesion (hyperostosis, erosion), calcifications, and involvement of large vessels in the process were also determined by using preoperative imaging features.

Blood loss data were taken from the anesthesia card. Intraoperative blood loss in our hospital is typically calculated using the following methods:

- *Analyzing the suction drain*: This method involves measuring the total volume collected in the suction drain; the amount of irrigation fluid (saline) used during the operation is subtracted from the total volume in the suction drain.
- *Surgical sponges and wipes* used during the operation are weighed before and after use. The difference in weight is used to estimate blood loss. The method was based on the principle that 1 g of weight gain in the sponges and wipes is approximately equivalent to 1 mL of blood.

IBM SPSS Statistics 23.0 was used to perform the statistical analysis. The Kruskal–Wallis and the Mann–Whitney *U* tests were used to compare the blood loss among the risk

Table 2 Distribution of patients depending on the localization and volume of meningiomas

Localization	Small volume (%)	Medium volume (%)	Large volume (%)
• Convexity	4 (22%)	7 (39%)	7 (39%)
• Parasagittal/falx		10 (53%)	9 (47%)
• Skull base		4 (44%)	5 (56%)

factors. Using binary logistic regression, a statistical model for predicting intraoperative blood loss was created.

Results

The findings of this study regarding blood loss and its related risk factors are presented in ►**Table 3**. The mean blood loss was 594 ± 61. Analysis of blood loss based on localization revealed that parasagittal localization resulted in the highest volume of blood loss. However, there was no significant difference in blood loss among different localizations ($p = 0.654$). Tumors with a larger volume led to twice and three times as much blood loss compared to tumors with medium and small volumes, respectively ($p < 0.01$), which is attributed to the greater blood supply and number of supply vessels. In addition, invasive tumor growth and peritumoral edema were significant factors contributing to profuse blood loss ($p < 0.01$), indicating a high degree of angiogenesis activity. The presence of a dural tail expanded the area of the matrix and significantly increased blood loss ($p = 0.02$). Among various factors, bone lesion (erosion, hyperostosis) was found to be the most significant factor influencing the amount of blood loss ($p = 0.001$). There was no statistically significant difference in the volume of blood loss associated

Table 3 Influence of the risk factors on the volume of blood loss

Risk factors	Amount (%)	Blood loss (mL)	Reliability
Localization			
• Convexity	18 (39%)	530.5 ± 86.6	$p = 0.654$
• Parasagittal/falx	19 (41%)	636.8 ± 106.3	
• Skull base	9 (20%)	633.3 ± 141.4	
Volume			
• Small	4 (9%)	300 ± 70.7	$p < 0.01$
• Medium	21 (45,5%)	407.1 ± 53.5	
• Large	21 (45,5%)	838.1 ± 99.1	
Invasive tumor growth			
• Yes	31 (67%)	746.7 ± 76	$p < 0.01$
• No	15 (33%)	280 ± 26.2	
Peritumoral edema			
• Yes	37 (80%)	677 ± 69.3	$p < 0.01$
• No	9 (20%)	255.5 ± 24.2	
Dural tail			
• Yes	22 (48%)	700 ± 91	$p = 0.02$
• No	24 (52%)	498 ± 79	
Calcification			
• Yes	3 (7%)	266.6 ± 120.2	$p = 0.07$
• No	43 (93%)	617.4 ± 63.5	
Bone damage (erosion, hyperostosis)			
• Yes	15 (33%)	893.3 ± 126.3	$p = 0.001$
• No	31 (67%)	450 ± 50.6	
Vessels/sinuses involvement			
• Yes	27 (69%)	607.4 ± 79	$p = 0.51$
• No	19 (31%)	576.3 ± 98.7	

with tumor vessels ($p = 0.51$) or the presence of calcifications ($p = 0.07$). These findings are presented in ►**Table 3**.

The study utilized binary logistic regression to determine the significance of various factors in predicting intraoperative blood loss during brain meningioma surgery. As a result, invasive growth and bone lesion were identified as the most significant risk factors for predicting intraoperative blood loss. Other significant factors, such as volume, edema, and dural tail, were designated as the secondary factors. A statistical model was created that included these factors, and a mathematical model of the probability (odds ratio) of intraoperative blood loss was constructed.

Based on our research, we developed a risk assessment scale for massive intraoperative blood loss during brain meningiomas surgery. At the same time, the main factors were assessed with the maximum scores, and the secondary factors were evaluated with the minimum in descending order of reliability. If one major factor and one or two minor factors are present, the risk is medium; if two major factors or one major and all minor factors are present, the risk is high; if there are no major factors, the risk is low. The assigned scores were as follows:

- Bone lesion ($p < 0.001$): 5 points.
- Invasive growth ($p < 0.01$): 5 points.
- Peritumoral edema ($p < 0.01$): 2 points.
- Tumor volume ($p < 0.01$): 2 points.
- Dural tail ($p < 0.02$): 1 point.

The maximum score on the scale was 15 points, with a score of less than 5 indicating low risk of bleeding, 6 to 9 indicating medium risk, and $\geq$10 indicating high risk. These findings are presented in ►**Table 4**.

According to the results of our scale, all the patients were divided into three groups depending on the risk of massive blood loss (►**Table 4**). The mean volume of blood loss was 850 ± 93.3 mL ($p < 0.05$) in the high-risk group, 690 ± 135 in the medium-risk group, which was three and two times more than that in the low-risk group (300 ± 26 mL; $p < 0.05$). Based on this, we recommend preoperative embolization for meningiomas with high and medium risk of massive intraoperative blood loss.

►**Table 5** provides a summary of the average blood loss associated with different histological types of meningiomas, based on a sample of 46 patients. The information in the table indicates that the highest average blood loss is associated with anaplastic meningiomas, while the lowest is with fibrous meningiomas. This information could be relevant for presurgical planning and patient counseling. The overall average blood loss across all patients and histologies is 595 mL.

Discussion

Meningiomas are highly vascularized brain tumors, and the surgery to remove them often results in significant bleeding, and its volume, according to the literature, can range from 200 to 2,200 mL.[1,9] Intraoperative bleeding can lead to impaired visibility for the surgeon, increased risk of brain damage, and the need for blood transfusions. Preoperative embolization is a technique that can significantly reduce intraoperative blood loss, but it is not without risks such as hemorrhage into the tumor, cerebral ischemia due to embolization of nontarget vessels, and edema.[5–8,10–12] Additionally, it is expensive, which necessitates establishing specific indications for its use.

Raper et al, in their research, identified key criteria for preoperative embolization of meningiomas. Convexity meningiomas with extensive, hypervascular blood supply are ideal for embolization, whereas embolizing tuberculum or olfactory groove meningiomas is less advisable due to potential risks to the ocular blood supply. Raper et al also recommend considering this procedure for tumors with a diameter greater than 3 to 4 cm mainly fed by the ECA, those with complex, deep vascular networks, and tumors in critical brain areas, but not for heavily calcified tumors. They underline the importance of safety over complete tumor devascularization in embolization practices, aligning with our approach of carefully evaluating the advantages of lowering intraoperative blood loss against the specific risks embolization poses in the cases with unique surgical complexities.[11]

The main determinants of intraoperative blood loss are the following: tumor volume, localization, presence of a dural tail, invasive growth, bone lesion (erosion, hyperostosis), involvement of arteries/sinuses in the tumor, and presence of tumor calcifications.[13–15] Tumor volume ($p = 0.01$), invasive growth ($p = 0.01$), perifocal edema ($p = 0.01$), dural tail ($p = 0.02$), and bone lesion ($p = 0.001$) are all important factors in our study. However, binary logistic regression revealed that only invasive growth and bone lesion were significant predictors of intraoperative blood loss.

Other studies have also examined factors that affect intraoperative blood loss in meningioma surgery. Volume ($p = 0.003$) and tumor localization ($p = 0.024$) were important factors in Lü's study[13] that affected intraoperative blood loss. The author also notes that the relationship between the tumor and the arteries or sinuses was a significant predictor of intraoperative blood transfusion ($p = 0.019$). In the Tabibkhooei et al study,[14] there were substantial influences on intraoperative bleeding from tumor volume ($p = 0.003$), tumor relationship with venous sinuses ($p = 0.06$), and

Table 4 Distribution of patients depending on the risk of massive blood loss during meningiomas surgery

Risk of massive intraoperative blood loss	Number (%)	Mean volume of blood loss (mL)	Mean volume of hemotransfusion
High risk	20 (43%)	850 ± 93.3	318 ± 60
Medium risk	10 (22%)	690 ± 135	200 ± 89
Low risk	16 (35%)	300 ± 26	–

Table 5 The average blood loss associated with different histological types of meningiomas

Histology	No. of patients	Average blood loss based on histology (mL)
Anaplastic meningioma	3	1,233
Atypical meningioma	1	500
Angioblastic meningioma	1	1,000
Meningothelial meningioma	15	587
Metaplastic meningioma	1	600
Transitional meningioma	14	511
Psammomatous meningioma	1	700
Fibrous meningioma	10	490
Total	46	595

time of surgery ($p = 0.001$). The 19 patients in our analysis had parasagittal meningiomas that had invaded the sagittal sinus to varied degrees, but this relationship did not appear to be a significant factor affecting blood loss following tumor removal. This is because in our cases, partial invasion of the tumor into the sinus caused the subtotal removal (according to Simpson III), leaving a small portion on the sinus wall, and complete occlusion caused the sinus to be ligated from both sides and the tumor to be removed completely (according to Simpson I–II). Despite this, tumors of this localization showed the highest blood loss, which is most likely because hyperostosis occurs there frequently. While some studies have suggested that the time of surgery is a significant factor in intraoperative bleeding,[15–18] we believe that it is independent of blood loss volume and is more dependent on tumor localization and the surgeon's experience.

Hyperostosis, or excessive bone growth, is a common occurrence in meningiomas, and our study found that it was a significant factor in intraoperative blood loss. There are several theories explaining this phenomenon, including tumor invasion into bone,[19–22] previous bone trauma,[21,23] stimulation of osteoblasts in the bone by factors secreted by tumor cells,[19,21,22,24] and bone irritation by a tumor without invasion of the tumor itself.[19,25] However, the cause of hyperostosis in meningiomas is still unknown. Although we did not perform a separate morphological analysis of the affected bone, the information presented above enables us to come to the conclusion that bone lesion is the cause of the invasive tumor growth in the surrounding tissues and that bone damage significantly affects intraoperative blood loss ($p = 0.001$). Also, the authors of several studies on meningiomas with hyperostosis and bone erosion highlight the enhanced vascularization and significant blood loss that occurred after surgery.[26–28]

Conclusion

Preoperative embolization can significantly reduce intraoperative blood loss during meningioma's surgery, but it is not without risks, which highlights the importance of establishing specific indications for its use. Our study suggests that a new scale for predicting massive intraoperative blood loss can be used as a noninvasive radiological marker to determine the indications for preoperative embolization in patients with meningiomas.

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Conflict of Interest
None declared.

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