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Iryna Bulakh[1], Robert Lucaciu[2], Nikola Duerr[3], Martin Scholz[2], Bogdana Suchorska[4]

■ OBJECTIVE: **Involvement of major cerebral arteries in skull-base tumors poses a significant surgical challenge and is associated with increased peri- and postoperative complication rates. The aim of the current study is to introduce a vascular encasement score (VES) to assess intraoperative risk and predict patient outcomes.**

■ METHODS: **Patients undergoing surgery for skull base tumors involving at least one major cerebral artery between April 2019 and March 2022 were included. Tumor-vessel contact was assessed on preoperative magnetic resonance imaging, evaluating both the longitudinal and circumferential encasement of arteries. Each parameter was graded from 1 to 5. The VES was calculated by multiplying the summed grades of both dimensions. Neurological outcomes were dichotomized into "good" and "poor" and correlated with VES.**

■ RESULTS: **Forty-eight patients were enrolled, most diagnosed with meningioma (79.17%). The mean resection rate was 77.23%, and the median VES was 32.5. Sixteen patients (33.3%) had poor outcomes. Higher VES scores were significantly associated with poor outcomes (P = 0.019). A receiver operating characteristic—derived threshold of 75 defined high-risk cases. Logistic regression confirmed that high VES (>75) predicted worse outcomes (P = 0.018). All patients with low VES had favorable outcomes and resection rates >90%. In contrast, 62.5% of patients with high VES had poor outcomes, influenced by a lower extent of resection (P < 0.001).**

■ CONCLUSIONS: **The magnetic resonance imaging—based VES provides a practical method to quantify vascular involvement in skull base tumors. It may support risk-adapted surgical planning and serve as a foundation for Artificial Intelligence—based tools enabling automated preoperative risk assessment.**

INTRODUCTION

Regardless of the continuing technical refinements in skull-base surgery, tumors with encasement of one or more main brain arteries continue to impose a challenge for the surgeon. Furthermore, vessel contact has been reported to be associated with a higher rate of peri- and postoperative complications. In order to avoid vessel injury and to prevent a postoperative deficit, often only a part of the tumor is removed.

A careful assessment of preoperative magnetic resonance imaging (MRI) regarding vessel/tumor conflict is crucial to avoid

Key words
- Internal carotid artery
- Meningioma
- Preoperative risk assessment
- Skull base
- Vascular encasement

Abbreviations and Acronyms
ACA: Anterior cerebral artery
AUC: Area under the curve
cm³: Cubic Centimeter
CTA: Computed tomography angiography
DSA: Digital subtraction angiography
GLM: Generalized linear model
ICA: Internal carotid artery
MCA: Middle cerebral artery
MPRAGE: Magnetization-prepared rapid gradient echo
MRA: Magnetic resonance angiography
MRI: Magnetic resonance imaging
PACS: Picture archiving and communication system
PCA: Posterior cerebral artery
ROC: Receiver operating characteristic
VES: Vascular encasement score

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potential intraoperative complications. However, so far, there is no objective means to predict a safest possible extent of resection, in particularly when the internal carotid artery is involved.

Our study aimed to objectify the extent of tumor-vessel contact using radiological measurements and the development of a vascular encasement score (VES), analyzing retrospectively the extent of resection and patient outcomes for each score value.

METHODS

Imaging Parameters

This retrospective study included patients suffering from skull base brain tumors with immediate contact with the main brain arteries, who underwent transcranial surgery and in whom tumor-to-vessel contact could be assessed in preoperative contrast-enhanced, thin-sliced T1-weighted Magnetization Prepared Rapid Gradient Echo (MPRAGE) sequences. We assessed tumor volume pre- and postoperatively using Brainlab Elements Software (Brainlab AG, München, Version 4.0, 2021, module cranial planning). Furthermore, both length and circumference of the artery involved in the tumor-vessel conflict were assessed. These measurements were made on preoperative MPRAGE MRI images using the Picture Archiving and Communication System (PACS)-Program (VISUS Health IT GmbH, Bochum, Germany; JiveX Diagnostic Advanced Client Version 5.2.2.1, 2022).

The study-specific segments of the arteries encased by tumors were defined as follows:

- Cavernous to terminal segment (C4-7) of the internal carotid artery
- Precommunicating segment (A1) of the anterior cerebral artery
- Sphenoidal segment (M1) of the middle cerebral artery
- Precommunicating segment (P1) of the posterior cerebral artery
- Basilar artery.

Arterial measurements were manually performed on enlarged, contrast-enhanced preoperative T1 MPRAGE MRI scans in the PACS system, allowing precise visualization of vascular structures. For each vessel segment (e.g., C4–C7 for the internal carotid artery [ICA], M1 for the middle cerebral artery [MCA]), multiple equidistant measurements of affected length (in mm) and circumference (in degrees) were taken. Each measurement was repeated in a second round, documented independently from the first, and the average was used for score calculation to ensure consistency and reproducibility (**Figure 1**, **Supplementary Figure 1**). This dual measurement approach allowed verification of the method's repeatability.

Tumor volume was assessed pre- and postoperatively on thin-slice contrast-enhanced T1 MRI using Brainlab Elements (**Figure 2**). Tumor borders were manually segmented, and the extent of resection was calculated as:

$$\text{Extent of resection} = \frac{(\text{Preoperative tumor volume} - \text{postoperative tumor volume})}{\text{Preoperative tumor volume}} \times 100\%$$

Tumor volumetry was performed twice to assess measurement reliability. As with arterial measurements, the average was used for statistical analysis. Standard deviations were calculated to evaluate consistency.

Development of the VES

To quantify both longitudinal and circumferential vessel involvement, we developed the VES based on MRI-derived measurements of arterial length and circumference. Each artery was scored individually; summed values were multiplied to yield the final score. The manual approach ensured precision in the absence of automated tools.

The circumference (C), assessed in degrees from 0 to 360, reflecting a circumferential envelopment of the corresponding vessel was classified in 5 grades: 0 for no contact with the artery, Grade 1 for a circular encasement of 0° to 72°, Grade 2 for >72° to 144°, Grade 3 for >144° to 216°, Grade 4 for >216° to 288°, and Grade 5 for >288° to 360°. Due to the anatomically varying lengths of the cerebral arteries, the measured segment length (L) in mm was expressed as a percentage of the total length of the relevant vascular segment and depending on the corresponding length of involvement similarly converted into a scoring system from 0 to 5 grades: 0 for no contact, Grade 1 for tumor invasion of 0 to 20% of the length, Grade 2 for >20% to 40%, Grade 3 for >40% to 60%, Grade 4 for >60% to 80%, and Grade 5 for >80% to 100%.

The VES was then calculated by multiplying the sum of the points for the circumferential vessel encasement (C) with the sum of the points for the longitudinal encasement (L):

VES = $(C1+C2+.Cn) \times (L1+L2+.Ln)$ (**Supplementary Figure 1**).

Subsequently, the receiver operating characteristic (ROC) analysis was selected as it offers a robust and intuitive approach for evaluating the predictive performance of the VES in distinguishing between dichotomous outcomes ("good" vs. "poor"). The primary objective of using ROC analysis was to determine the optimal threshold for high-grade VES and to assess its utility as a reliable predictor of clinical outcomes in both a statistical and clinical context.

Neurological Outcome

Pre- and postoperative neurological status was retrospectively assessed at discharge and up to 6 months. Outcomes were classified into 4 categories ("worse," "unchanged-poor," "unchanged-good," "improved") and then dichotomized into "poor" (0: worse/unchanged-poor) and "good" (1: unchanged-good/improved) to simplify analysis and reduce variance. Neurological status was collected prior to any imaging measurements. VES and volumetry were assessed separately, and correlation analyses were performed only after completion of both datasets to ensure blinding.

Statistical Analyses

After descriptive analysis of the cohort and imaging measurements, the validity and prognostic value of the VES were evaluated using RStudio Version 2024.04.2 + 764 (RStudio, PBC, Boston, Massachusetts, USA, 2024). Standard deviations were calculated to assess measurement consistency. Subsequently, regression analyses examined the association of VES and resection extent with outcome, including an interaction analysis to assess their combined effect. A Chi-square test further explored the relationship between categorized VES, resection extent, and outcome.

RESULTS

Descriptive Analysis

Study Cohort. During a period of 36 months (01.04.2019–31.03.2022), 947 tumors have been treated at the Department of Neurosurgery, Sana Hospital, Duisburg. In 137 cases (14.5%), preoperative MRI revealed a tumor–vessel conflict. This study included 48 patients (29 female, 19 male; age 15–89 years, mean 62.85) with skull base tumors contacting proximal sections of the major cerebral arteries, all treated via transcranial microsurgical approaches. In 93.75% of cases, a pterional approach was used due to internal carotid artery (ICA) proximity; subfrontal or retrosigmoid approaches were used in 3 cases.

Meningiomas were the most common histology (38/48, 79.17%), predominantly sphenoid wing meningiomas (**Supplementary Table 1**), followed by neurinomas, craniopharyngiomas, and other rare entities (**Table 1**).

Encasement of the Brain Arteries in the Study Cohort and Their Frequencies. The ICA was the most frequently affected vessel, involved in 39 of 48 cases (81.25%), with bilateral involvement in

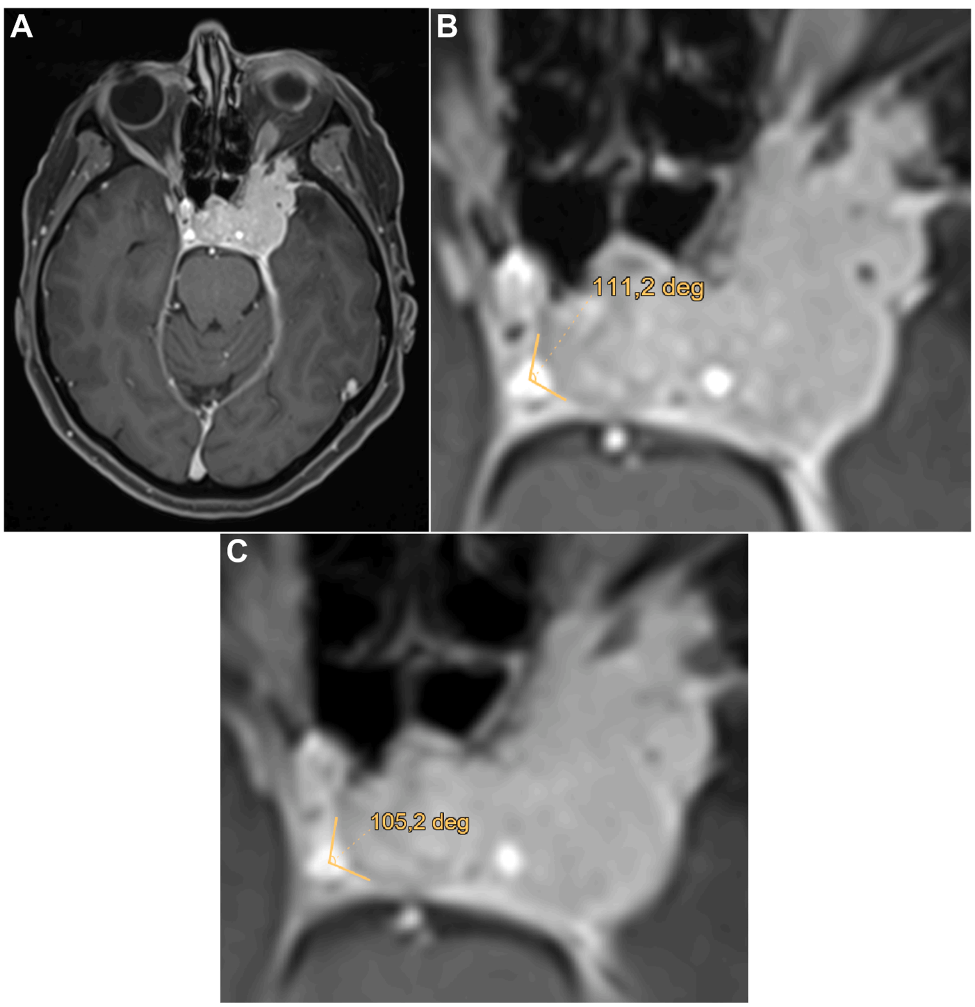

Figure 1. Measurement of the circumferential encasement of the internal carotid artery in a patient with a sphenoid wing meningioma (meningothelial meningioma WHO Grade I): Axial contrast-enhanced T1-weighted MRI showing the left ICA is encased by the tumor to 360°(**A**), the right to 111.2° (**B**), in a repeat measurement, 105.2° (**C**).

18. In 14 cases, the ICA was 100% encased, and in 19 cases, surrounded 360°; both conditions co-occurred in 11 patients.

The anterior cerebral artery (ACA) was affected in 14 cases, bilaterally in 9; 4 showed 100% encasement, one with 360° encasement. The middle cerebral artery (MCA) was involved in 14 cases, never bilaterally; 360° encasement occurred in two, 100% in one.

Overall, more than one artery was involved in 27 of the 48 patients (56.25%), most commonly both ICAs (n = 9) or both ICAs plus both ACAs (n = 6) (Supplementary Tables 2–4).

Neurological Deficits in the Study Cohort. Most patients (41.67%, n = 20) presented with visual acuity and/or field defects (18.75%, n = 9) due to optic nerve involvement. Clinical symptoms are summarized in Table 2. A total of 16 out of 48 patients (33.3%) experienced a poor neurological outcome.

Distribution of the VES in the Study Population. In the study cohort, the VES varied from 2 to 525. The mean VES was 72.65, while the median was 32.5. The interquartile range, which encompasses the middle 50% of the VES values, ranged from 7.5 to 92.25, corresponding to the 25th and 75th percentiles (Figure 3).

Tumor Volumetry. Median preoperative tumor volume was 16.85 cm^3 (range: 1.13–122.2 cm^3), the mean was 26.37 cm^3 with a mean standard deviation of 1.72 cm^3. The interquartile range (25th–75th percentile) spanned from 5.3 to 36.75 cm^3. Postoperatively, tumor volumes ranged from 0 to 53.2 cm^3, with a mean of 5.27 cm^3 and a standard deviation of 0.364 cm^3. The median was 0.965 cm^3, with an interquartile range from 0 to 4.585 cm^3 (Figure 4). The mean resection rate was 77.23%, with a range from 1% to 100%. In the cohort, the median resection percentage was 94.15%, with an interquartile range from 56.75 to 100%. In 20 patients (41.67% of the cohort), the tumor was completely resected.

Validation of Measurement Methodology and Precision Analysis. The analysis of standard deviations showed that the majority of length and circumference measurements displayed very low variability, with a median of 0.424 mm and 1.98°, mean of 0.613 mm and 1.987°. The minimum and maximum values of the standard deviation for length measurements were 0 and 2.758 mm (mean 0,613 mm) and for circumferential measurements 0 and 6.859° (mean 1987°).

The standard deviations in preoperative volumetry showed moderate variability with mean of 1.72 cm^3 and a median of 0.495 cm^3, indicating generally consistent measurements. The

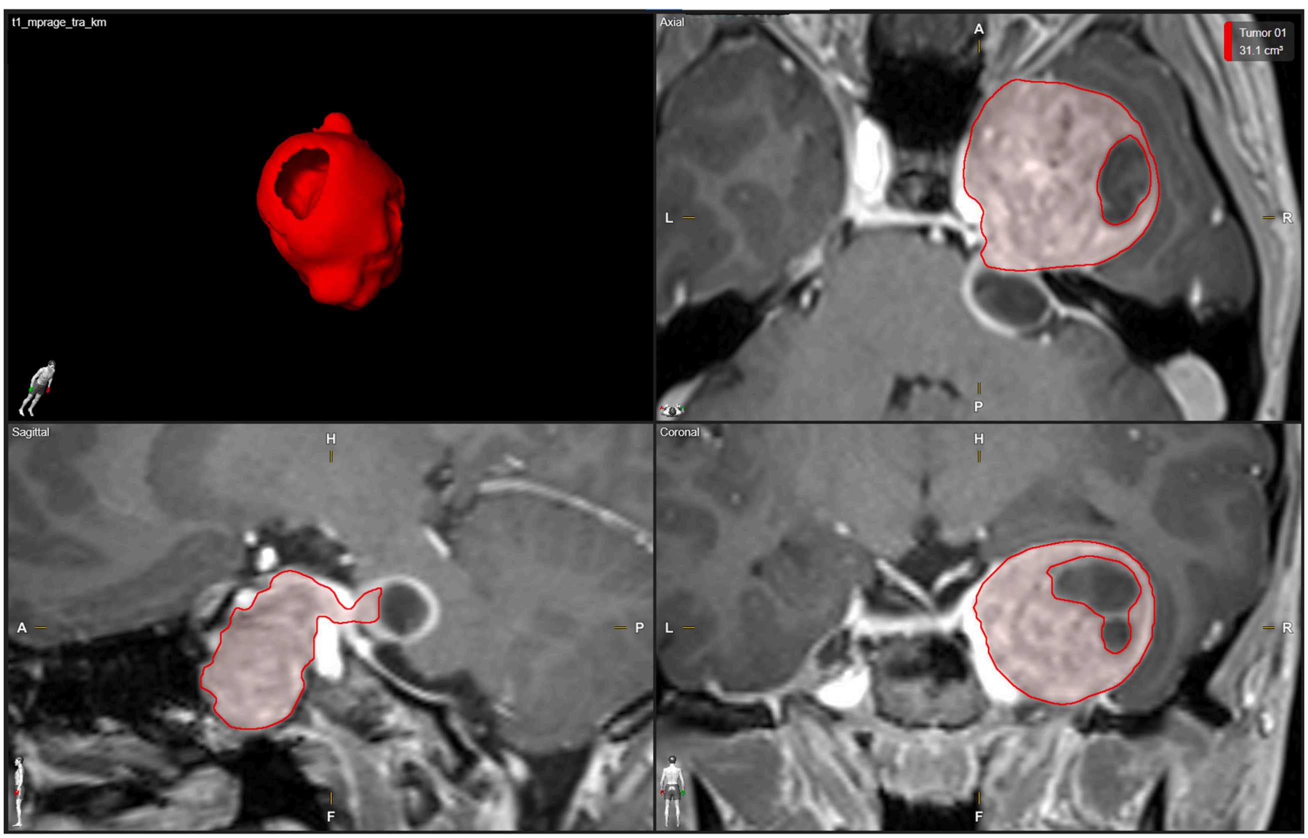

Figure 2. Conducting tumor volumetry in Brainlab. Patient with a cystic trigeminal neurinoma, volume 31,1 cm^3, in contact with the left internal carotid artery.

Table 1. Frequency of Tumor Types in the Patient Cohort.

Tumor	Patients, n (%)
Meningeoma	38 (79.17)*
Neurinoma	3 (6.25)
Epidermoid cyst	3 (6.25)
Craniopharyngeoma	2 (4.17)
Pituitary adenoma	2 (6.25)*
Hemangiopericytoma	1 (2.08)

*In one case, two tumors that had grown together were resected in a single session; histopathologically, one was identified as a WHO Grade I meningioma, and the other as a null cell adenoma of the adenohypophysis.

minimum and maximum standard deviation was 0 and 7.071 cm^3. Lower variability was noted in postoperative volumetry; the mean was 0.364 cm^3 and the median was 0.042 cm^3. This is due in part to the fact that many postoperative measurements were identical, particularly in cases of complete resections where the postoperative volume was 0 cm^3. The minimum and maximum standard deviation in postoperative volumetry were 0 and 4.243 cm^3.

Analytical Statistics

Regression Analyses for the Prognostic Significance of the VES. In exploring the prognostic relevance of the VES, logistic regression analysis (generalized linear model [GLM]; Supplementary Figure 2) first assessed the association of the score and the extent of resection with the dichotomized patient outcome: "poor outcome" (0, including "worse" and "unchanged-poor") and "good outcome" (1, including "unchanged-good" and "improved").

The log-odds for VES (−0.019) indicate that each unit increase in VES decreases the log-odds of a good outcome by 0.019, demonstrating a statistically significant association ($P = 0.019$) between higher VES and poorer outcomes (Supplementary Table 5). The extent of resection also indicates a significant association ($P = 0.0006$), with log-odds of 0.083 per percentage increase, suggesting higher resection extents improve the likelihood of a good outcome. The negative intercept (−3.929) implies negative log-odds for a good outcome if both VES and resection extent are zero, with statistical significance ($P = 0.016$).

Analysis of the Categorized VES for Prognostic Significance. After regression analysis indicated that higher VES is associated with poorer outcomes, the question arose as to what score value should be defined as "high"-grade?

The ROC analysis was performed to evaluate the predictive performance of the VES in distinguishing between 'good' and 'poor' outcomes and to identify the optimal threshold for clinical application. The analysis resulted in an AUC of 0.778, indicating good discriminative ability. An optimal threshold of 75, identified via the Youden index, achieved a sensitivity of 81.25% and a specificity of 62.50%, providing a good balance for clinical use (Supplementary Figure 3).

Subsequent logistic regression analysis (GLM) was performed to examine the influence of the categorized VES (based on the ROC-derived threshold of 75) and the extent of resection on the outcome.

A high VES significantly reduced the log-odds for a good outcome by 3.166 units ($P = 0.018$, Supplementary Table 6), indicating a strong negative association. In contrast, each additional percent of resection extent increased the log-odds for a good outcome by 0.028 units ($P = 0.001$). Figure 5 demonstrates that lower VES values were associated with higher rates of complete resection and good neurological outcomes.

Impact of the Interaction Between VES and Extent of Resection on Outcome. To examine whether the VES in combination with the extent of resection could influence the outcome, and whether modifying the outcome by adjusting the extent of resection was possible, an interaction analysis using logistic regression (GLM) was conducted.

However, the results did not show any significant interaction between VES and resection extent ($P = 0.673$) regarding outcomes (Supplementary Table 7).

A Chi-Square test was performed to further analyze the relationship between vascular involvement (categorized VES, based on the ROC-derived threshold of 75) and the extent of resection, which was categorized as high for resections >90%, in the patient cohort.

The Chi-square analysis showed significant results with a P-value of <0.001, suggesting a statistically significant association between the combined categories of VES and resection extent and the outcome. In the Low VES category, a high extent of resection was clearly associated with a higher frequency of good outcomes (19 good outcomes at 'Low/High' and no poor outcomes), while a lesser extent of resection was less associated with symptom improvement (6 cases with poor and 7 cases with good outcomes). High VES values, in combination with any resection extent, more frequently led to poor outcomes (10 out of 16 cases with the poor outcome, Figure 6).

DISCUSSION

Prognostic Relevance of Vascular Encasement

Accurate pre-operative evaluation of the extent of skull base tumors and their relationship to brain arteries plays a crucial role in tumor resection planning.

Our study includes complex cases, even involving multiple brain arteries, which were variously involved in the tumor masses, complicating the tumor resection in terms of the risk for intraoperative vessel injuries. This study aims to objectify the encasement of brain arteries by tumor masses and thus develop a prognostic score to assess patient outcomes.

Currently, there is no objective measure for evaluating arterial involvement in tumor masses. The development of a preoperative score for patients with vascular encasement has been explored in several studies. McCracken et al. offer a score based on the circular encasement of major brain arteries, which assesses the extent of vascular encasement by sphenoid wing meningiomas, demonstrating a positive correlation between vascular involvement and infarct volume.[1] For predicting the extent of tumor

Table 2. Summary of Preoperative Symptoms

Symptom	Patients, n
Visual acuity defects	20 (41.67%)
Cranial nerve palsy	14 (29.17%)
Headaches	12 (25%)
Visual field defects	9 (18.75%)
Walk and stand insecurity	9 (18.75%)
Memory disorders	4 (8.3%)
Motor deficits (upper and lower extremities)	3 (6.25%)
Dizziness	3 (6.25%)
Vigilance disorder	2 (4.17%)
Seizure	2 (4.17%)
Aphasia	1 (2.08%)

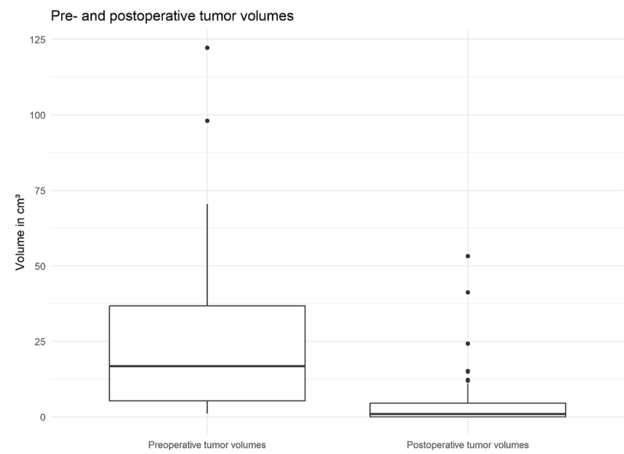

Figure 4. Boxplot of pre- and postoperative tumor volumes.

resection, Wang et al. developed a score based on preoperative 3D multimodality fusion imaging.[2] Although vascular involvement is included in the score calculation, precise measurements of vessel length or circumference are not performed; instead, points are awarded for the presence of the following findings: involvement of a brain artery, complete vessel encasement, involvement of multiple arteries, and stenosis. The results show a positive correlation between the score and the extent of resection according to Simpson, and a negative correlation with the neurological outcome.

VES and Surgical Planning: From Manual Application to AI Integration

We introduce the VES, derived from MRI-based measurements of longitudinal and circumferential vessel encasement, each graded from 1 to 5. Multiplying the summed scores provides a detailed representation of tumor-vessel interaction (Supplementary Figure 1). The scaling method reflects the increasing vascular involvement and the associated complications risk. This method supports preoperative planning and risk assessment, especially in cases with multiple arterial involvements. Low measurement variability confirms the reliability of the scoring approach.

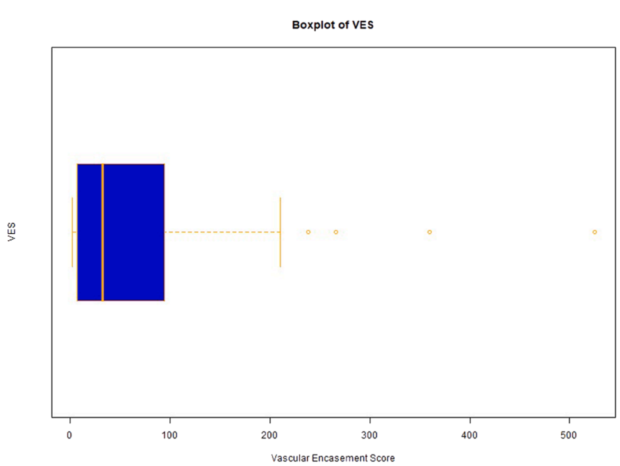

Figure 3. Boxplot of the distribution of VES in the study cohort.

However, all measurements were performed by the same examiner, and inter-rater reliability was not assessed, which represents a methodological limitation that should be addressed in future studies.

Logistic regression confirmed that higher VES scores are significantly associated with poor outcomes. The significant intercept suggests that, without preoperative assessment of vascular involvement, the likelihood of a favorable outcome is low. These findings underline the clinical relevance of VES for preoperative risk evaluation.

The categorization of the score into low (≤75) and high (>75), based on the ROC analysis, facilitated a differential examination of the impact of varying degrees of vascular involvement. Subsequent regression analysis confirmed a significant association of high-grade VES with poor outcomes.

Despite its multidimensional calculation, the VES is based on simple geometric parameters—length and circumference of vessel involvement—which can be reliably measured on preoperative MRI using standard PACS tools. Once these values are obtained, the score can be quickly calculated using a straightforward formula. This allows for manual application in daily surgical planning, especially in complex skull base cases.

The manual measurements used in this study to quantify arterial involvement represent a foundation for the development of AI-based tools capable of automating the scoring process. Future implementation of such systems into PACS environments could enable real-time, automated risk assessment and support individualized surgical planning, particularly in complex cases with multiple arterial encasements.

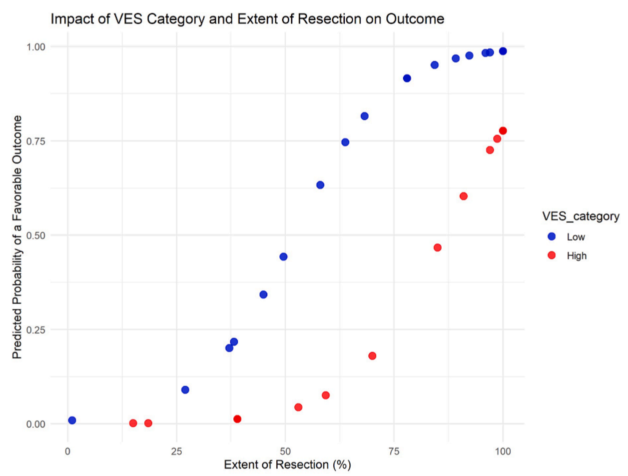

Figure 5. Scatter plot of the impact of categorized VES and extent of resection on outcome.

Interaction Between VES and Extent of Resection

In cases with low VES, extensive resection was consistently associated with good outcomes (all patients in the cohort with low VES experienced good outcomes with a high extent of resection), likely due to reduced vascular risk. Conversely, limited resection in low-VES cases was linked to poorer outcomes in nearly half of the patients. Overall, low VES indicates a low-risk scenario that enables more aggressive surgery with favorable results.

High VES values were associated with poorer outcomes (10 of 16 cases), highlighting the prognostic importance of vascular encasement. In such cases, the severity of involvement may outweigh the impact of resection extent. This is supported by the interaction analysis, which showed no significant combined effect of VES and resection extent on an outcome ($P = 0.67$).

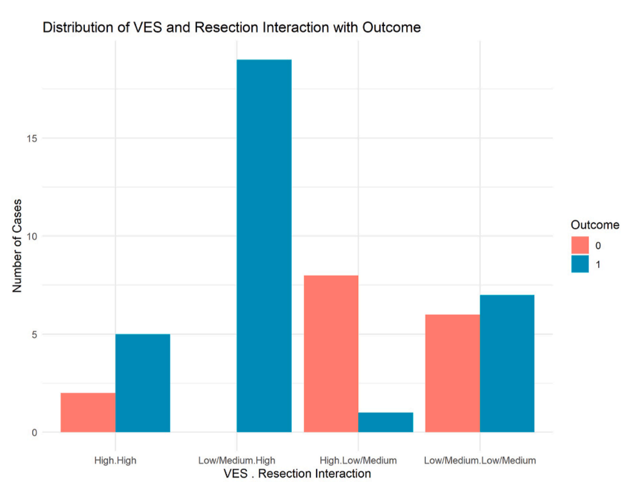

Figure 6. Grouped bar chart of the distribution of VES and extent of resection combinations with outcome (based on Chi-square test).

Our findings indicate that in cases with high vascular encasement (high VES), postoperative outcomes were predominantly poor, regardless of the extent of resection. This suggests that in such high-risk cases, the severity of vascular involvement itself may be a key determinant of outcome, potentially outweighing the benefit of more extensive tumor removal. This is supported by our interaction analysis, which showed no significant effect of resection extent on outcome in high-VES patients. In contrast, Champagne et al. reported no significant difference in outcome between chordoma cases with and without vertebrobasilar artery encasement, despite lower rates of gross total resection in the encasement group.[3] Nevertheless, both studies converge in advocating individualized, risk-adapted surgical strategies in the presence of major vascular involvement.

Outcome differences suggest that surgical goals vary by VES grade: in low-grade cases, symptom improvement is prioritized, while in high-grade cases, avoiding deterioration takes precedence. This is reflected in our data: most low-grade VES patients (26/32) had good outcomes, whereas high-grade patients (10/16) often showed no improvement or new deficits, either preserving their neurological state with preoperative pareses or developing new deficits.

Postoperative neurological status was assessed clinically, without systematic radiological confirmation of vascular injury. Therefore, while poor outcomes may result from actual vascular complications, they may also reflect the indirect influence of vascular encasement on surgical decision-making—particularly in high VES cases, where aggressive resection is avoided to prevent vessel injury. Although the VES does not establish a direct causal link to neurological deterioration, it serves as a clinically plausible indicator of surgical complexity and associated outcome risk.

Additional Considerations and Limitations

Another crucial factor to consider is tumor consistency, which significantly influences the feasibility and extent of surgical resection, particularly in cases with substantial vascular involvement. Ishikawa et al. states that even if the ICA is extensively involved in the tumor center, but the tumor has a soft consistency so that it can be aspirated, in this case, a resection with ICA dissection is possible.[4] Balasa et al. also describe a patient with a very soft sinus cavernous meningioma that was aspirated, achieving complete tumor resection.[5] Variations in outcomes with different resection extents in cases of high-grade VES suggest that high vascular involvement requires a personalized treatment approach, considering additional factors such as intraoperative tumor consistency. In our retrospective study, tumor consistency was documented in only a few cases, thus it could not be used as an additional variable in the regression analyses for prognostic assessment.

In some studies, both MRI and angiography were performed for preoperative diagnosis.[4,6-8] However, the extent of vascular invasion is not always accurately identifiable using these imaging techniques alone.[6,9] While MRI and angiography provide essential information about the position of the brain arteries, also relative to the tumor,[7-11] but findings such as stenosis, effacement, or stretching of the artery do not always indicate invasion of the arterial wall.[9] The study by Champagne et al. found no correlation between the degree of vascular encasement or stretching of the artery in digital subtraction angiography (DSA) and intraoperative difficulties.[6] Sahu et al. reported no significant correlation between vessel injuries and over-180-degree vessel encasement on MRI, but they emphasized that complete circumferential encasement is a significant risk factor for vascular injuries.[12] However, Kattner et al. recommend conducting both examinations—MRI and angiography—as part of preoperative planning for better identification of the tumor's location relative to the vessel. Thus, these two methods are considered complementary to each other.[9]

The small sample size (48 patients) limits statistical power and generalizability. All measurements were MRI-based, with digital subtraction angiography (DSA) performed in only one case. While MRI ile MRI is sufficient for assessing vascular encasement and was available for all patients in this retrospective cohort, future studies may benefit from integrating vascular imaging modalities such as computed tomography angiography (CTA) or *magnetic resonance angiogram* (MRA) in selected cases where MRI suggests significant vessel involvement, in order to enhance diagnostic accuracy and support preoperative risk stratification.

The VES was categorized into low and high grades; larger prospective studies could refine grading and its impact on resection strategies. As a retrospective study, arterial wall invasion could not be histologically confirmed, as in Shaffrey's study,[8] limiting insights into tumor-vessel interaction. Tumor consistency was documented in only a few operative reports and therefore could not be included as an additional variable in the present analysis. However, future prospective studies should consider systematically assessing tumor consistency, as it may significantly influence resectability and clinical outcomes. Future research with histological validation and en-bloc samples is needed to enhance score accuracy. While our study cohort included a variety of skull base tumor types, the majority were meningiomas. Other entities—such as neurinomas, epidermoid cysts, craniopharyngiomas, and pituitary adenomas—were included based on their common localization at the skull base and their shared potential for relevant arterial encasement. All tumors were extra-axial, and in all cases, resection was performed with curative intent, underlining the comparability of the surgical goal across the cohort. Ultimately, our findings offer a foundation for considering vascular encasement as a generalizable surgical risk marker, but this concept requires further validation in larger, histology-stratified, and ideally prospective studies.

As part of the manuscript preparation process, the authors used ChatGPT (OpenAI) exclusively to refine the language and improve readability. The tool was not involved in data analysis, interpretation, or content generation. All scientific content was developed by the authors and thoroughly reviewed to ensure accuracy and responsibility for the final manuscript.

CONCLUSIONS

Involvement of the major brain arteries in tumor masses complicates but does not preclude tumor resection. An objective preoperative measure is necessary for assessing intraoperative risks and deciding the extent of resection. Our study introduces a VES based on radiological measurements to determine whether a situation is safe (low VES) and associated with a favorable outcome in cases of extensive resection, or if it constitutes a high-risk scenario (high-grade VES), which correlates with poorer outcomes. In such high-risk cases, with the goal to prevent new deficits, an individualized procedure is required, taking into account vascular involvement, patient- and tumor-specific factors, and probably the surgeon's expertise. Thus, the resection of tumors that extensively encase cerebral arteries requires a highly personalized therapeutic strategy. The score should be considered in preoperative tumor resection planning. Large prospective studies are needed to confirm our findings and demonstrate the benefits of resection extent based on the calculated VES. Such studies should also incorporate additional factors, including vascular imaging modalities (CTA, MRA, or DSA) for improved preoperative assessment, as well as intraoperative parameters such as tumor consistency and histology, to enhance the clinical utility of the score. Ideally, the calculation of VES and its measurements should be automated, potentially through artificial intelligence, to save time on manual measurements and calculations.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Iryna Bulakh: Data curation, Formal analysis, Validation, Writing – original draft. **Robert Lucaciu:** Project administration, Resources, Software, Supervision. **Nikola Duerr:** Methodology, Supervision, Visualization. **Martin Scholz:** Conceptualization, Methodology, Project administration, Supervision, Writing – review & editing. **Bogdana Suchorska:** Conceptualization, Methodology, Project administration, Writing – review & editing.

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