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Review Article

Concurrent meningioma and intracranial aneurysm: Insights from an updated systematic review and a case report

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ABSTRACT

Background: The concurrent presentation of meningioma and intracranial aneurysm (IA) poses diagnostic and therapeutic challenges, with no standardized management protocol available. This study aims to address this through an updated systematic review, delineating optimal strategies for managing this dual pathology.

Methods: A systematic review was conducted across PubMed, Web of Science, and Embase databases. Articles were screened independently by two reviewers. Treatment strategies and patient outcomes were comprehensively analyzed to formulate a treatment framework based on several characteristics. In addition, one concurrent meningioma and IA case from our institution was presented.

Results: A total of 69 articles comprising 115 patients were included in the study. The cohort exhibited a female predominance (80%) with a mean age of 56 (±13) years. Meningiomas were primarily localized to the frontotemporal and sellar regions, while aneurysms favored the anterior circulation – notably, 16.5% of cases presented with ruptured aneurysms. Management strategies varied based on the spatial relationship between lesions and aneurysm rupture status. In unruptured cases, 34% underwent a single craniotomy for simultaneous resection of both pathologies, while endovascular intervention was favored when the IA originated from an artery feeding the meningioma (73%). Remarkably, postoperative aneurysm rupture occurred in 33% of cases managed solely through tumor resection (range 0–30 days postop).

Conclusion: This study proposes a comprehensive treatment algorithm to guide neurosurgeons in managing concurrent meningioma and IA cases. By considering individual patient intricacies, the feasibility of simultaneous management, aneurysm rupture risk, and symptomatology, this framework is a valuable tool for clinical decision-making in these complex scenarios.

Keywords: Case report, Intracranial aneurysms, Management, Meningioma, Systematic review

INTRODUCTION

Intracranial meningiomas, recognized as the most prevalent benign tumors within the cranial vault, represent a significant portion of neurosurgical cases, underscoring their clinical importance.[22] Despite their benign nature, managing meningiomas can be complicated by their size, location, and growth rate. Concurrently, intracranial aneurysms (IAs), another common intracranial pathology, pose a risk of rupture, often resulting in catastrophic outcomes.

The coexistence of IAs and brain tumors is not a new phenomenon, and the association between the two remains debated.[13] Intracranial meningiomas have been reported as the most likely tumors to facilitate the formation of an IA.[59] The coexistence of these two entities within the same patient introduces a complex clinical scenario, requiring a nuanced and well-informed approach to management. Despite increased recognition of this co-occurrence, a definitive management strategy has not yet been established, mainly due to the rarity of this condition and the variability in clinical presentation, anatomical considerations, and patient-specific factors.[13] A meningioma may influence the hemodynamics and, thus, the natural history of an existing IA, further complicating the treatment decisions regarding timing and modality. The diagnostic process itself can be challenging, as symptoms may overlap or be attributed to one pathology over the other, potentially obscuring the dual nature of the patient's condition.[28]

As advancements in diagnostic imaging, surgical techniques, and endovascular interventions have evolved, we sought to offer a clear and comprehensive approach to managing concurrent meningiomas and IA. Building on the foundation laid by De Souza *et al*., this study aims to bridge the gap in the existing literature by offering an updated systematic review focused on managing patients with this dual pathology.[13] By analyzing a wide range of treatment strategies and their reported outcomes, we propose an algorithm to help guide clinical decision-making and management strategies. We also describe a case of concurrent meningioma and IA and present the rationale behind our management strategy.

METHODS

Literature search

A comprehensive literature search was conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines using three significant databases: PubMed, Embase, and Web of Science. The search strategy was designed to encompass a broad range of terms and their variations to ensure a thorough retrieval of relevant articles. Key search terms included combinations of the following: "(Brain tumor OR Meningioma) AND (aneurysm) AND (coexistent OR simultaneous or concurrent)." To capture the broadest possible range of studies, variations and synonyms for these terms, such as "brain tumor," "co-exist," and "coexisting", were also employed. The search was conducted without applying any filters or limitations and included all records up to October 2023.

Study selection

Following the search, all identified records were imported into Covidence, a software tool designed to streamline the management of systematic reviews. Covidence facilitated the automatic removal of duplicate entries, ensuring the efficiency of the screening process. Two independent reviewers (T.AM and L.S.M) meticulously screened the articles. Each article was independently evaluated for relevance, with any remaining duplicates manually removed. Predefined inclusion and exclusion criteria were applied. Only original research articles written in English that detailed the management and outcomes of patients with concurrent meningioma and IAs were included in the study. Exclusion criteria included studies on other tumor types or vascular malformations, articles in languages other than English, those lacking sufficient details on treatment strategies or patient outcomes, and review articles.

Data extraction

Extracted data included patient demographics, tumor characteristics (location and size), aneurysm specifics (number, size, location, rupture status, and anatomical relationship with the tumor), clinical presentation, treatment details (number and type of procedures, order and time interval between interventions), as well as outcomes (intra- and postoperative complications, follow-up duration, and patient status at last follow-up). The aneurysm's anatomic relationship to the tumor was extracted as described in the paper, distinguishing between feeder artery aneurysms (IA on artery feeding the tumor), embedded aneurysms (IA encased by tumor), proximal aneurysms (IA bordering the tumor, adjacent, or located on an artery close to the meningioma), and distal/remote aneurysms (IA on the artery that is far from the tumor, in a distant ipsilateral location in the brain, or situated in another hemisphere). This classification schema was consistently applied, even when the paper did not explicitly state the anatomical relationship between the IA and meningioma. A visual representation of these anatomic relationships is provided in Figure 1.

Statistical analysis

Descriptive statistics were performed to summarize the findings from the literature review. Given the nature of our study as a systematic review, no comparative statistical analysis was performed. Instead, the goal was to interpret findings across the included studies and formulate a comprehensive treatment framework for managing this dual pathology.

RESULTS

Case presentation

A 54-year-old woman with a history of hypertension was being followed for an asymptomatic right sphenoid wing

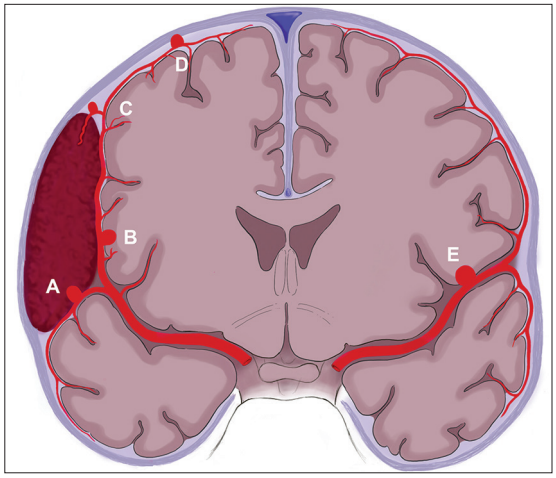

Figure 1: Illustration showing the different anatomic relationships of aneurysms in relation to a meningioma: (A) embedded, (B) proximal, (C) feeder artery, (D) distal, and (E) remote.

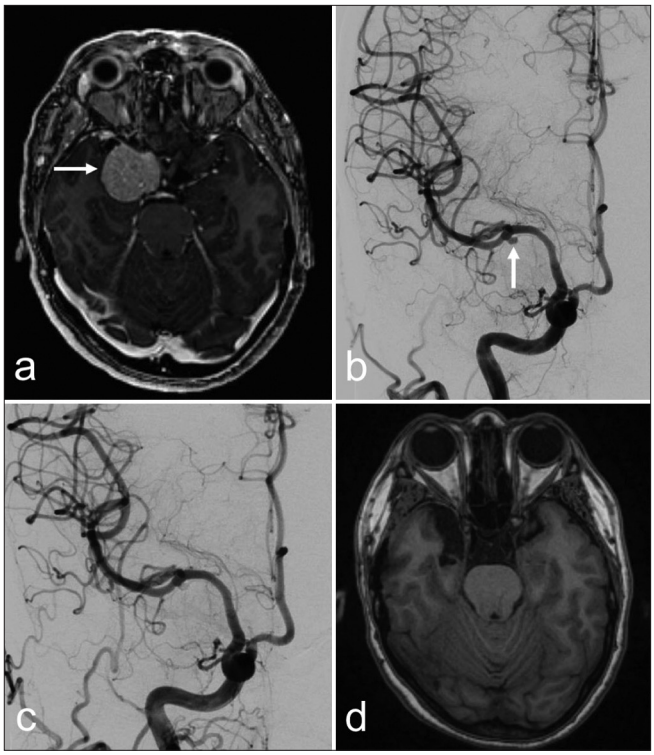

Figure 2: Axial (a) magnetic resonance imaging (MRI) view depicting a right sphenoid wing meningioma (white arrow) with extension to the cavernous sinus. (b) Digital subtraction angiography view showing an aneurysm at the right middle cerebral artery bifurcation (white arrow). Postoperative angiogram (c) showing resolution of the aneurysm, and (d) MRI showing complete resection of the brain lesion.

meningioma. The tumor was found to encase the right supraclinoid and cavernous segments of the internal carotid artery (ICA), along with the proximal M1 segment with extension to the cavernous sinus [Figure 2a]. On follow-up imaging, the meningioma was found to be growing. She had a normal physical examination, including an ophthalmological exam. A diagnostic cerebral angiogram revealed a 2.5 × 2.5 mm right middle cerebral artery bifurcation aneurysm with blebs directed inferiorly and toward the meningioma [Figure 2b]. Given the high complexity of this architecture and the risk of intraoperative aneurysm rupture, a staged approach with preoperative endovascular management of the aneurysm was recommended [Figure 2c]. One month after the endovascular coiling of the aneurysm, the patient underwent tumor resection. The patient tolerated the procedure well, with mild postoperative diplopia. Postoperative imaging showed complete tumor resection, and a follow-up angiogram 2 months later demonstrated complete aneurysm occlusion [Figure 2d]. The Institutional Review Board approval was obtained for the case.

Search results

The literature search yielded a total of 1521 articles. After removing duplicates, 1186 articles were screened. A total of 1073 were excluded based on title and abstract screening, leaving 113 articles for full-text assessment. After applying inclusion and exclusion criteria and adding articles identified through reference searches and citation tracking, 69 articles involving 115 patients were included in the study. The article screening and selection process is illustrated in the research flowchart, as shown in Figure 3.

Patients characteristics

The cohort was predominantly female (n = 92, 80%), with an average age of 56 years (±13). The most common presenting symptoms were headache (n = 44, 38%) and visual impairment (n = 32, 27.8%). Nineteen patients presented with a ruptured aneurysm. In addition, a notable subset of patients exhibited multiple pathologies: 10 had more than one meningioma, and 23 had multiple aneurysms. Most meningiomas were supratentorial, with only four infratentorial cases. Meningioma locations ranged from the convexity to the skull base, with the temporal/sphenoid region being the most common site. The majority of aneurysms were located in the anterior circulation (n = 85, 74%), with 14 patients having aneurysms in the posterior circulation, 11 in both anterior and posterior circulations, and 5 involving the middle meningeal artery (MMA). Follow-up durations ranged from 10 days to 14 years. A comprehensive overview of patient characteristics is described in Table 1.

Meningioma with ruptured aneurysm

Nineteen patients presented with meningioma and concurrent ruptured IA. This subgroup comprised

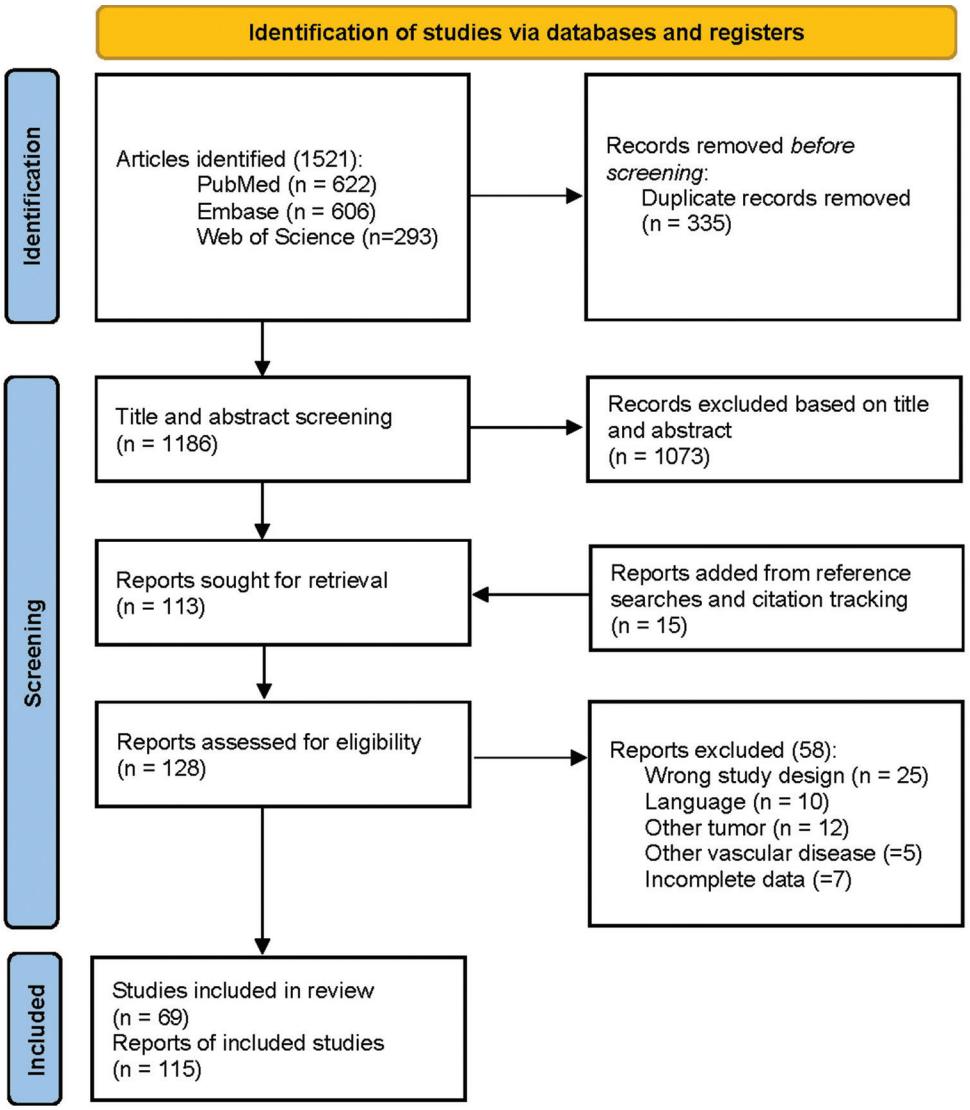

Figure 3: Flow-chart representing a stepwise guide for how relevant articles for the systematic review were obtained.

predominantly females (*n* = 15/19, 79%), with an average age of 56 (±16). The frontal region emerged as the most common meningioma location, with five cases in the frontal convexity and 4 in the clinoidal region. Ruptured IAs were almost exclusively found in the anterior circulation (*n* = 18/19, 95%), with the anterior communicating artery being the most frequently involved (*n* = 9/18, 50%). Moreover, most IAs were close to the meningioma, with ten aneurysms being adjacent and six others embedded within the tumor mass. Treatment was administered to 16 out of the 19 patients, with the majority (*n* = 15/16, 94%) undergoing a single surgical procedure addressing both pathologies simultaneously. Within this subset, the aneurysm was clipped in 11 cases (*n* = 11/15, 73%). There was one operation-related complication. All the patients who did not receive treatment expired within days of presentation. Further details on these cases are provided in Table 2.

Meningioma with unruptured aneurysms

Ninety-six cases presented with a co-occurrence of meningioma and unruptured IA. Among them, 11 patients had aneurysms in the feeder artery of the meningioma, seven had aneurysms embedded within the tumor, and the rest involved proximal or distal aneurysms. The anatomical relationship between these two pathologies influenced the feasibility of simultaneous management in most cases and guided the treatment approach.

Eleven cases involved meningiomas with feeder artery aneurysms (FAA) [Table 3]. Of these, five cases had FAAs

Table 1: Patient demographics and tumor/aneurysm characteristics.

Characteristic	*n* (%)
Age (SD)	56 (± 13) years
Sex	
Female	92 (80%)
Male	23 (20%)
Meningioma location	
Olfactory groove	8
Clinoid/optic rim	9
Cavernous	1
Sellar/parasellar	14
Clival/petroclival	2
Falcine	6
Parasagittal	5
Temporal/sphenoid wing	27
Frontal	17
Parietal	7
Tentorial	4
Cerebellopontine angle	2
Infratentorial	4
Meningioma number	
1	105
2 or more	10
IA artery	
Anterior circulation	85
Posterior circulation	14
Both anterior and posterior	11
MMA	5
IA Number	
1	98
2 or more	23
Patients with ruptured IA	
Yes	19
No	96
Treatment	
Single surgery, tumor	23
Single surgery, IA	5
Single surgery, both	45
Two-step surgery	36
No treatment	6
Outcome	
Good	85
Complications	18
Death	10
Follow-up	10 days–14 years

SD: Standard deviation, IA: Intracranial aneurysm, MMA: Middle meningeal artery

within the extracranial circulation (specifically in the MMA), while six involved intracranial vessels. Most patients (73%) had preoperative aneurysm embolization followed by tumor resection, with no postoperative complications. The remaining three patients underwent a single procedure for tumor resection only, with varying postoperative outcomes: one experienced IA rupture requiring balloon-assisted coiling, one had spontaneous aneurysm resolution, and one had a stable aneurysm.

Seven cases involved aneurysms embedded within the tumor [Table 4]. Most (57%) underwent a single procedure for tumor resection with concurrent aneurysm clipping, with only one case of mild postoperative neurological complications. Two patients who underwent tumor resection only experienced significant complications, including postoperative subarachnoid hemorrhage and delayed IA rupture.

Treatment approaches for the remaining 78 patients varied [Table 5]. In 29 cases (37%), a single surgery addressed both pathologies simultaneously, with 86% receiving aneurysm clipping (one mild complication reported), while others underwent aneurysm wrapping or *en bloc* resection. Thirteen patients (17%) underwent a staged treatment, starting with preoperative aneurysm embolization followed by tumor resection, with or without aneurysm clipping. The interval between procedures ranged between 2 and 178 days. Postoperative complications included transient neurological deficits (n = 3/13, 23%), hematoma (n = 1/13, 8%), infection (n = 1/13, 8%), and hydrocephalus (n = 1/13, 8%), none of which persisted. For cases where simultaneous management was not feasible (n = 33, 42%), aneurysm treatment was prioritized in 11 cases (33%). Six had aneurysm clipping followed by tumor resection, while five had sole aneurysm treatment with clipping or embolization due to the meningioma being asymptomatic. Tumor management was prioritized in 22 cases (67%), with 19 patients receiving tumor resection and having their aneurysms followed up, while only three had subsequent IA management. Among these 22 patients, 5 (23%) suffered from aneurysm rupture and died. Finally, a small cohort of patients (n = 3/78, 4%) received no treatment for either pathology and had continuous follow-up only. In summary, among all cases of concurrent meningioma and unruptured aneurysms (feeder artery, embedded, or other), 24 patients underwent tumor treatment only, and 8 (33%) suffered from postoperative aneurysm rupture, highlighting the complexity and need for individualized management of dual pathologies.

DISCUSSION

The coexistence of IA and brain tumors, particularly meningiomas, is well-documented, though the exact pathological relationship remains elusive.[28] Advances in neuroimaging have improved the detection of incidental pathologies, leading to more frequent identification of these dual conditions. Historically, the prevalence of IAs among brain tumor patients was reported to be <0.9%,[51] but recent estimates suggest a range of 1–8%,[13] indicating a possible underdiagnosis due to the lack of routine angiographic imaging in these patients. Meningiomas, in particular, are frequently associated with IA formation, with some studies showing a higher prevalence of IAs in patients with meningiomas compared to those without.[28,51,59]

Our analysis indicates that IAs frequently occur in proximity to meningiomas, typically in feeder arteries or

Table 2: Cases of concurrent meningioma and ruptured aneurysm.

Author, Year	Age	Sex	Presenting symptom	Meningioma Location	Aneurysm		Meningioma-IA proximity	Intervention	Complications, F/u date
					Loc	*n*			
De Bonis *et al.*, 2023[12]	65	F	Headache, vomiting, dysphagia	Sphenoid wing	MCA	1	Embedded-Feeding artery	SP for EBR	None
Okuyama *et al.*, 2023[44]	69	M	Headache, AMS	Parasellar	ICA	1	Embedded	SP for GTR, bypass for IA	None, 3 m.o.
Algburi *et al.*, 2022[1]	48	F	AMS	Frontal convexity	Acom	1	Adjacent	SP for clipping, GTR	None, 6 m.o.
Balasubramanian *et al.*, 2022[4]	71	F	AMS, weakness	Frontal convexity, parasagittal	ACA	1	Adjacent	SP for GTR, coagulation IA	Death, 5 w from pneumonia
Sharma *et al.*, 2019[55]	46	F	Headache, AMS, visual impairment	Clinoid	Acom	1	Adjacent	SP for clipping, GTR	None, 3 m.o.
Meguins *et al.*, 2017[39]	65	F	Headache	Falcine	ACA	1	Adjacent	SP for clipping, GTR	None, 6 m.o.
Zhou *et al.*, 2017[77]	53	M	Headache, vomiting	Clinoid	Pcom	2	Adjacent	SP for clipping, GTR	None
Waqas *et al.*, 2015[70]	60	F	AMS, visual imp	Clinoid	ICA	1	Adjacent	SP for clipping, GTR	None, 3 m.o.
Yang and Huang, 2014[74]	52	F	Headache	Sphenoid wing	ICA	2	Embedded	SP for clipping, GTR	None, 1 m.o.
Alnaami *et al.*, 2013[2]	34	M	Headache	Falcine	ACA	1	Embedded	Pre-op embolization IA, then GTR	None
Javalkar *et al.*, 2009[23]	63	F	Headache, AMS	Sphenoid wing	Acom	1	Distant	SP for clipping, GTR	None
Najjar *et al.*, 2007[41]	47	F	Headache, vomiting	Sphenoid wing	Acom	1	Adjacent	SP for clipping, GTR	None
Ogino *et al.*, 1999[43]	70	F	Headache, nausea, aphasia	Tuberculum sellae	Acom	1	Embedded	SP for clipping, GTR	Bilateral anosmia, Hydrocephalus
Bloomgarden *et al.*, 1987[5]	65	F	Headache	Clinoid	ICA	1	Adjacent	SP for clipping, GTR	None, 6 w
Kandel *et al.*, 1986[27]	7	F	AMS, weakness, aphasia	Frontal	MCA	1	Embedded	SP for EBR	None, 6 yr
Licata *et al.*, 1986[35]	71	F	AMS	Frontal	Acom	5	Adjacent	No treatment	Death, 50 d
Licata *et al.*, 1986[35]	52	F	AMS	Infratentorial	Acom	1	Distant	No treatment	Death, 3 d
Licata *et al.*, 1986[35]	67	F	AMS	Frontal	Acom	1	Adjacent	SP for clipping, GTR	None, 1 yr
Licata *et al.*, 1986[35]	60	M	AMS	Infratentorial	Acom	1	Distant	No treatment	Death, 8 d

AMS: Altered mental status, Loc: Location, n: Number, F: Female, M: Male, SP: Single procedure, EBR: *En bloc* resection, GTR: Gross total resection, m.o.: Months, w: Weeks, yr: Year, d: Day, IA: Intracranial aneurysm, MCA: Middle cerebral artery, ICA: Internal carotid artery, Acom: Anterior communicating artery, Pcom: Posterior communicating artery, ACA: Anterior cerebral artery

Table 3: Cases of concurrent meningioma and feeder artery aneurysm.

Author, Year	Age	Sex	Presenting symptom	Meningioma Location	Aneurysm		Intervention	Complications, F/u date
					Loc	*n*		
Carlstrom *et al.*, 2023[6]	75	F	N/a	Frontal convexity	MMA	1	Pre-op embolization IA, then GTR	None
Tanaka *et al.*, 2022[64]	52	F	Headache	Frontal convexity	ICA	1	SP for tumor	IA rupture postop
Kuroda *et al.*, 2021[30]	55	F	N/a	Frontal convexity	ICA	1	Pre-op embolization IA, then GTR	None
Papadimitriou *et al.*, 2020[47]	55	F	Seizure	Falcine	ICA	3	Pre-op embolization IA, then GTR	None, 3 m.o.
Lee *et al.*, 2019[33]	61	F	Headache	Sphenoid wing	ICA	3	Pre-op embolization IA, then GTR	None
Takeda *et al.*, 2017[63]	58	F	Visual impairment	Clinoid	ICA	1	Pre-op embolization IA, then GTR	None
Maekawa *et al.*, 2009[37]	72	F	Dizziness	Frontal convexity	MMA	2	Pre-op embolization IA, then GTR	None
Tachikawa *et al.*, 2002[61]	51	M	Seizure	Olfactory groove	ACA	1	SP for tumor	None, the disappearance of IA
Lama and Mottolese, 2000[31]	69	F	AMS	Temporal	MMA	1	Pre-op embolization IA, then GTR	None
Muras *et al.*, 1999[40]	57	F	Headache, weakness	Parietal	MMA	1	SP for tumor	None
O'Neill *et al.*, 1995[42]	82	F	Headache, AMS, aphasia	Parietal	MMA	1	Pre-op embolization IA, then GTR	None

Loc: Location, *n*: Number, F: Female, M: Male, SP: Single procedure, GTR: Gross total resection, m.o.: Months, ICA: Internal carotid artery, MMA: Middle meningeal artery, IA: Intracranial aneurysm, ACA: Anterior cerebral artery

Table 4: Cases of concurrent meningioma and aneurysms embedded within the tumor.

Author, Year	Age	Sex	Presenting symptom	Meningioma Location	Aneurysm		Intervention	Complications, F/u date
					Loc	*n*		
Ding *et al.*, 2021[15]	46	F	Headache, dizziness, seizure	Sphenoid wing	ICA	2	SP for clipping, GTR	Mild reduction in lateral vision, 2 yrs.
Takeda *et al.*, 2017[63]	75	F	Visual impairment	Parasellar	ICA	1	SP for clipping, GTR	None
Von Spreckelsen *et al.*, 2017[69]	57	M	Visual impairment	Parasellar	ICA	2	SP for tumor	SAH postop
Chen *et al.*, 2015[8]	65	F	Visual impairment	Tuberculum sellae	Acom	1	SP for clipping, GTR	None, 5 yrs.
Dumitrescu and Gorgan, 2011[17]	64	M	Headache, dizziness, visual impairment	Tuberculum sellae	Acom	1	SP for clipping, GTR	None
Hoya *et al.*, 2011[21]	56	F	Visual impairment	Clinoid	ICA	1	SP for tumor	IA rupture, 2 m.o.
Tancioni *et al.*, 1998[65]	58	F	Headache, nausea, visual impairment	Temporal	MCA	2	Pre-op embolization of feeder, then SP for clipping, GTR	None

Loc: Location, *n*: Number, F: Female, M: Male, SP: Single procedure, GTR: Gross total resection, m.o.: Months, yrs: Years, MCA: Middle cerebral artery, ICA: Internal carotid artery, Acom: Anterior communicating artery, IA: Intracranial aneurysm, SAH: Subarachnoid hemorrhage

embedded within the tumor, highlighting the potential impact of hemodynamic stress. Meningiomas, known for their high vascularity, may increase cerebral blood flow, thereby imposing additional stress on arterial walls.[28,51,62] This is supported by a study that showed that larger tumor volumes contribute to the formation of IAs, possibly due to increased arterial pressure to counteract raised intracranial pressure caused by the tumor volume.[28] This hypothesis could also account for distally located aneurysms, as the entire brain vasculature is subjected to increased stress. In

Table 5: All other cases of meningioma and unruptured aneurysm.

Author, Year	Age	Sex	Meningioma Location	Aneurysm Loc	n	Meningioma-IA proximity	Intervention	Complications, F/u date
Ma *et al.*, 2023[36]	49	F	Tuberculum sellae	MCA, ICA, ACA	3	Adjacent	SP for clipping, GTR	None, 3 m.o.
Onyia *et al.*, 2023[45]	48	F	Tuberculum sellae	Pcom	1	Adjacent	SP for clipping, GTR	None, 2 m.o.
Lara-Olivas *et al.*, 2022[32]	61	F	Infratentorial	Pcom	1	Distant	2 surgeries: GTR then IA	Death (vasospasm)
Wei *et al.*, 2022[72]	38	M	Falcine, temporal convexity, Olfactory groove	ACA (2), Acom	3	Adjacent	SP for clipping, GTR	None, 3 m.o.
Wu *et al.*, 2021[73]	52	F	Temporal	ICA-Opth	1	Adjacent	SP for clipping, GTR	None
Kinali *et al.*, 2021[29]	61	F	Cavernous sinus	ICA-Opth	1	Adjacent	Pre-op IA coiling, then SRS	None, 1 year
Takeda *et al.*, 2017[63]	52	F	Falcine	ICA	1	Adjacent	SP for clipping, GTR	None
Takeda *et al.*, 2017[63]	52	F	Parietal convexity	ICA-Pcom	1	Adjacent	SP Tumor	None, 5 years
Takeda *et al.*, 2017[63]	63	F	Tentorial	ICA-Pcom	1	Distant	SP Tumor	None, 10 years
Takeda *et al.*, 2017[63]	84	M	Parasagittal	PICA-VA	1	Distant	SP Tumor	None, 4 years
Takeda *et al.*, 2017[63]	63	F	Parasagittal	MCA	2	Distant	SP Tumor	None, 6 years
Eulate-Beramendi *et al.*, 2017[18]	71	F	Tentorial	Pcom	1	Distant	Pre-op IA embo, then GTR	Dysmetria
Eulate-Beramendi *et al.*, 2017[18]	67	F	Sphenoid wing	Paraclinoid	1	Distant	SP Tumor	Death (IA rupture)
Chiriac *et al.*, 2016[9]	62	F	Sphenoid wing	Acom	1	Adjacent	SP for clipping, GTR	None
Park *et al.*, 2016[49]	69	F	NA	ACA	1	NA	Pre-op IA embo, then GTR	None, 29 m.o.
Park *et al.*, 2016[49]	47	F	NA	ICA	1	NA	Pre-op IA embo, then GTR	None, 29 m.o.
Park *et al.*, 2016[49]	51	F	NA	ICA	1	NA	Pre-op IA embo, then GTR	None, 29 m.o.
Park *et al.*, 2016[49]	72	M	NA	ICA-Ach	1	NA	Pre-op IA embo, then GTR	Hemorrhage
Park *et al.*, 2016[49]	69	F	NA	ICA-PCA	1	NA	Pre-op IA embo then GTR	Hemiparesis
Park *et al.*, 2016[49]	62	F	NA	MCA	1	NA	Pre-op IA embo, then GTR	Subdural hematoma infection
Park *et al.*, 2016[49]	63	F	NA	PCA	1	NA	Pre-op IA embo, then GTR	Hydrocephalus
Yildirim *et al.*, 2015[75]	72	F	Tuberculum sellae	Acom	1	Adjacent	SP for clipping, GTR	None, 6 m.o.
Papacci *et al.*, 2015[46]	44	F	Sphenoid wing	MCA	1	Adjacent	Pre-op IA embo, then GTR	None, 3 years
Zhong *et al.*, 2013[76]	56	F	Parietal	ICA	1	Adjacent	SP, IA embolization	None

(Contd...)

Table 5: *(Continued).*

Author, Year	Age	Sex	Meningioma Location	Aneurysm Loc	n	Meningioma-IA proximity	Intervention	Complications, F/u date
Zhong *et al.*, 2013[76]	46	F	Sphenoid wing	ICA	1	Adjacent	SP, IA embolization	None
Zhong *et al.*, 2013[76]	49	M	Falcine	ACA, Acom	2	Adjacent	SP for clipping, GTR	No complications
Zhong *et al.*, 2013[76]	59	M	Sphenoid wing	Pcom	1	Adjacent	SP for clipping, GTR	No complications
Zhong *et al.*, 2013[76]	44	F	Temporal	Pcom	1	Adjacent	SP for clipping, GTR	No complications
Zhong *et al.*, 2013[76]	41	F	Parietal	Pcom	1	Adjacent	2 surgeries: IA clipping, then GTR	No complications
Zhong *et al.*, 2013[76]	52	F	Petroclival	Pcom	1	Adjacent	2 surgeries: IA clipping, then GTR	No complications
Zhong *et al.*, 2013[76]	50	F	Parietal	MCA	1	Distant	2 surgeries: IA clipping, then GTR	No complications
Kanamori *et al.*, 2013[26]	64	F	CPA	ICA-Pcom	1	Adjacent	2 surgeries: IA clipping, then GTR	No complications
Paraskevopoulos *et al.*, 2011[48]	55	F	Clinoid	ACA, MCA	2	Distant	2 surgeries: GTR, then IA clipping	No complications
Suslu *et al.*, 2011[66]	41	F	Frontal convexity	ICA	1	Distant	SP Tumor	None, 2 years
Fischer *et al.*, 2009[19]	55	F	Frontal	Acom	1	Adjacent	SP IA clipping	No complications
Fischer *et al.*, 2009[19]	83	F	Tentorial	ICA	1	Adjacent	SP IA embolization	No complications
Fischer *et al.*, 2009[19]	66	F	Frontal, parietal	ICA	1	Distant	SP IA embolization	No complications
Fischer *et al.*, 2009[19]	41	F	Frontal	Acom	1	Adjacent	SP for clipping, GTR	No complications
Fischer *et al.*, 2009[19]	54	F	Tentorial	MCA	1	Adjacent	SP for clipping, GTR	No complications
Fischer *et al.*, 2009[19]	44	M	Infratentorial	Acom	1	Adjacent	SP for clipping, GTR	No complications
Fischer *et al.*, 2009[19]	72	F	Olfactory groove	Acom	1	Adjacent	None	Not good
Fischer *et al.*, 2009[19]	61	F	Olfactory groove	Acom	1	Adjacent	Pre-op IA embolization, then GTR	Psychotic symptoms
Fischer *et al.*, 2009[19]	44	M	Sphenoid wing	ICA	1	Adjacent	Pre-op IA embolization, then GTR	CN3 paresis
Fischer *et al.*, 2009[19]	59	F	CPA	ICA	M	Distant	SP Tumor	CN 7 paresis
Fischer *et al.*, 2009[19]	77	F	Sphenoid wing	ICA	M	Distant	SP Tumor	No complications
Petrecca and Sirhan, 2009[50]	81	F	Sphenoid wing	ICA	1	Adjacent	SP for clipping, GTR	No complications
Javalkar *et al.*, 2009[23]	61	F	Clinoid	Pcom	1	Adjacent	SP for clipping, GTR	No complications
Javalkar *et al.*, 2009[23]	37	F	Temporal	ICA	1	Distant	2 surgeries: GTR, then IA clipping	No complications
Javalkar *et al.*, 2009[23]	70	F	Temporal	Pcom	2	Adjacent	SP for clipping, GTR	No complications

(Contd...)

Table 5: *(Continued).*

Author, Year	Age	Sex	Meningioma Location	Aneurysm Loc	n	Meningioma-IA proximity	Intervention	Complications, F/u date
Curto *et al.*, 2007[11]	61	F	Frontal	ICA	1	Distant	None	No complications
Javadpour *et al.*, 2004[24]	61	F	Suprasellar	Acom	1	Adjacent	Pre-op IA embolization, then GTR	None, 18 m.o.
Ziyal *et al.*, 1998[78]	48	F	Frontal, sphenoid wing, tentorial	MCA, ACA, Basilar	3	Adjacent/Distant	SP for clipping (adj), GTR, then IA clip (Distant)	N/A
Dolenc *et al.*, 1998[16]	50	M	Tuberculum sellae	Acom	1	Adjacent	SP Tumor	None
Scamoni *et al.*, 1997[54]	65	F	Olfactory groove	ICA-Pcom	1	Adjacent	SP for clipping, GTR	None
Scamoni *et al.*, 1997[54]	50	F	Petroclival	ICA-Opth	1	Adjacent	2 surgeries: IA clip, then GTR	None
Spallone and Tcherekayev, 1996[58]	28	F	Multiple	ICA	1	Adjacent	SP Tumor	Tumor recurrence at 1 year
Shibuya *et al.*, 1995[56]	54	F	Parasellar	ICA	1	Adjacent	SP for clipping, GTR	Mild transient CN3 palsy
Wei *et al.*, 1994[71]	33	F	Temporal	MCA	1	Adjacent	SP for clipping, GTR	None, 4 m.o.
Stevenson *et al.*, 1994[60]	48	M	Temporal, parasagittal	SCA, MCA, ACA, ICA-Opth	4	Distant (SCA)/ Adjacent	2 surgeries: IA clip (SCA), then SP for clipping, GTR	Mild CN4 palsy and tinnitus
Maiuri *et al.*, 1992[38]	37	F	Olfactory groove	ICA	2	Adjacent	SP Tumor	None, 6 m.o.
Shigemori *et al.*, 1991[57]	49	M	Frontal	MCA	1	Adjacent	SP for clipping, GTR	None
Delfini *et al.*, 1990[14]	69	F	Frontal	ICA-Opth	1	Adjacent	SP for clipping, GTR	None, 8 m.o.
Delfini *et al.*, 1990[14]	61	F	Olfactory groove	ICA-Opth	1	Adjacent	SP for clipping, GTR	Bilateral anosmia
Delfini *et al.*, 1990[14]	53	F	Olfactory groove	Pcom	1	Adjacent	SP for clipping, GTR	None, 6 years
Licata *et al.*, 1986[35]	62	F	Sphenoid wing	ICA	1	Adjacent	SP for IA wrapping, GTR	None, 10 years
Licata *et al.*, 1986[35]	44	F	Multiple	ICA	1	Adjacent	None	None, 14 years
Licata *et al.*, 1986[35]	68	M	Tuberculum sellae	ICA	1	Adjacent	SP Tumor	None, 10 m.o.
Punto *et al.*, 1984[52]	26	F	Multiple	MCA	1	Adjacent	SP for IA wrapping, GTR	None
Handa *et al.*, 1976[20]	39	F	Sphenoid wing	ICA (2), ICA-Opth, PCA	4	Distant	SP Tumor	None
Arseni and Maretsis, 1973[3]	37	M	Olfactory groove	Acom	1	Distant	SP Tumor	Visual impairment, epilepsy
Arseni and Maretsis, 1973[3]	30	M	Sphenoid wing	Basilar	M	Distant	SP Tumor	Death (IA rupture, 1 m.o.)
Jimenez *et al.*, 1971[25]	44	F	Multiple	ICA	1	Adjacent	SP for clipping, GTR	None
Jimenez *et al.*, 1971[25]	28	F	Sphenoid wing, sellar	ICA	1	Adjacent	SP for clipping, GTR	Death, 3 days

(Contd...)

Table 5: *(Continued).*

Author, Year	Age	Sex	Meningioma Location	Aneurysm Loc	n	Meningioma-IA proximity	Intervention	Complications, F/u date
Levin and Gross, 1966[34]	51	M	Frontal	Acom	1	Adjacent	SP Tumor	Death (IA rupture, 10 days)
Levin and Gross, 1966[34]	67	F	Temporal	MCA	1	Adjacent	SP Tumor	None, 2 years
Raskind, 1965[53]	44	M	Parasagittal	ICA	1	Adjacent	SP for clipping, GTR	None, 3 m.o.
Taylor, 1961[65]	54	M	Orbital	MCA	1	Adjacent	SP Tumor	IA rupture
Taylor, 1961[65]	38	F	Temporal	Pcom, Basilar	2	Adjacent (basilar distant)	SP Tumor	Death (IA rupture, 28 days)

Loc: Location, *n*: Number, F: Female, M: Male, IA: Intracranial aneurysm, SP: Single procedure, GTR: Gross total resection, m.o.: Months, SRS: Stereotactic radiosurgery, MCA: Middle cerebral artery, ICA: Internal carotid artery, Acom: Anterior communicating artery, Pcom: Posterior communicating artery, ACA: Anterior cerebral artery, PCA: Posterior cerebral artery, PICA-VA: Posterior inferior cerebellar artery vertebral artery, SCA: Superior cerebellar artery

addition, tumor cell invasion into vascular walls has been proposed as a potential factor in aneurysm formation.[76] Our systematic review revealed a notable predominance of female patients (80%), mirroring the gender distribution commonly observed in both meningiomas and IAs, suggesting a possible role of hormonal factors.[13] Despite these associations, the dual occurrence of meningiomas and IAs remains relatively rare, indicating a potential coincidental relationship that warrants further research.[67,68]

Vascular assessment in meningioma patients is crucial for identifying concomitant aneurysms, which might otherwise remain undetected until surgery. An intriguing observation from our study revealed that in some cases,[18,33,48] the IAs were not discernible on computed tomography or magnetic resonance angiography (MRA) but were subsequently identified during preoperative digital subtraction angiography, highlighting the limitations of non-invasive techniques. While routine angiographic studies for all meningioma patients may not be practical or necessary, targeted vascular assessments could be beneficial for those with high-risk factors such as female sex, hypertension, or smoking [10] as well as those with meningiomas exhibiting high-risk features such as high vascularity, arteriovenous shunt, or arterial encasement. In such cases, incorporating MRA sequences into brain tumor MR protocols may aid in evaluating the surrounding vasculature and detecting concurrent vascular malformations, potentially preventing intraoperative complications.

Previous work by De Souza *et al.* marked a significant step in understanding the prognosis and survival outcomes for patients with concurrent meningiomas and IAs.[13] However, their study did not provide clear management guidance for these complex cases. Our review addresses this gap by proposing a structured management algorithm based on an expanded analysis of 177 cases, including both ours and those from the literature. This algorithm offers guidance for clinical and surgical decision-making, optimizing treatment strategies to address both conditions effectively while minimizing patient risk.

Patients presenting with ruptured aneurysms alongside meningiomas require immediate intervention, often favoring simultaneous management strategies. Given the vascular nature of meningiomas, differentiating the source of hemorrhage becomes a critical component of the diagnostic and management strategy, especially when both pathologies are nearby. For unruptured aneurysms, treatment decisions hinge on the spatial relationship between the aneurysm and meningioma. A single surgical session can effectively address both conditions when they are in close proximity, minimizing patient exposure to multiple surgeries. However, a staged approach involving preoperative embolization followed by tumor resection also represents a viable option, especially for aneurysms in feeder arteries (73%). Advances in endovascular techniques offer a less invasive alternative that merits consideration based on individual patient criteria. For instance, in our case, although the IA and meningioma were proximal to each other and could have been treated in a single surgery, we opted for a pre-surgical embolization with endovascular coiling given the high-risk nature of the aneurysm to prevent intra-operative rupture. Therefore, for IA with features indicating a high risk of rupture intra-operatively (such as having a daughter sac or a bleb or being tightly adherent to the tumor),[7] endovascular management should be considered for preoperative IA protection. However, consideration must be given to whether the patient will require an antiplatelet regimen, which could influence the sequence of interventions.

The variability in management approaches, particularly when aneurysms are distant from the tumor, underscores the need for individualized treatment strategies based on the immediate clinical needs and potential risks. This review has shown that patients treated solely for their tumor had a significant incidence of postoperative aneurysm rupture and mortality (33%), emphasizing the need for careful risk

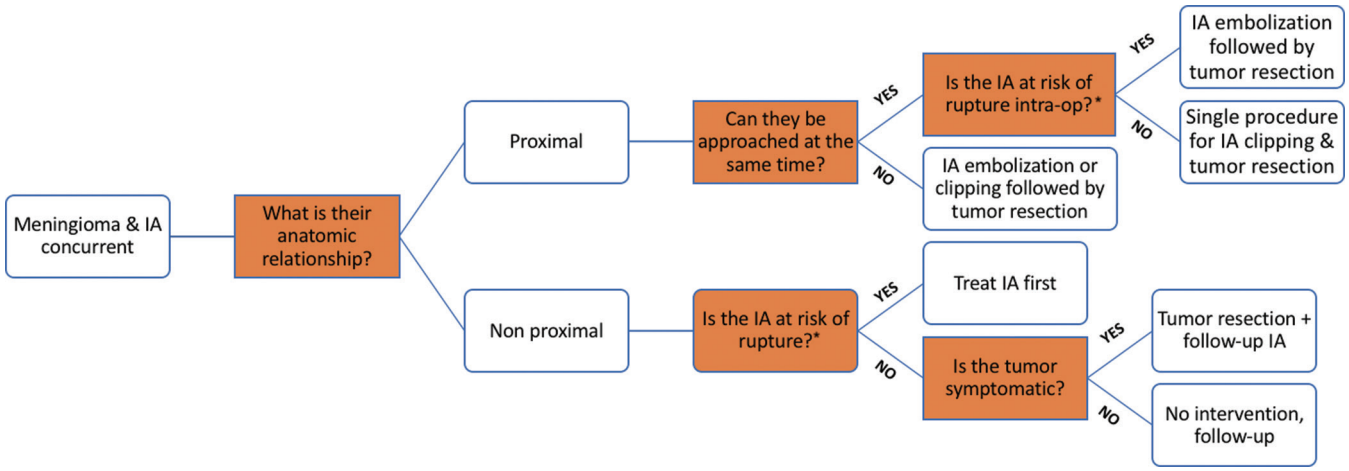

Figure 4: Algorithm for the management of concurrent intracranial aneurysm and meningioma. *Considering IA size, location, morphology, patient risk factors, etc.

assessment and follow-up. Increased cerebral circulation during surgery due to fluid replacement or changes in blood flow under anesthesia can destabilize the aneurysm wall, making even lower-risk aneurysms more prone to bleeding. Moreover, transient changes in brain architecture due to edema, surgical manipulation, or brain relaxation may alter the tension on the aneurysm or its parent vessel.[36]

Some authors advocate treating the symptom-causing pathology first.[76] However, we argue that aneurysms should be treated before tumor surgery if they present characteristics indicating a high risk of rupture and are amenable to endovascular or microsurgical treatment. The role of radiosurgery for small tumors in the cavernous region is a viable option, though the presence of an aneurysm complicates its use, requiring further study to assess its safety and efficacy in these cases.

Based on clinical expertise and study findings, Figure 4 presents an algorithm for managing concurrent unruptured aneurysms and meningioma. This algorithm considers the spatial relationship between the pathologies, the aneurysm's rupture risk, and the characteristics of the meningioma, aiming to provide clinicians with a structured approach for informed decision-making, balancing the potential risks and benefits of various treatment modalities. The algorithm initially emphasizes assessing the proximity of the aneurysm to the tumor. If proximally located, the possibility of addressing both simultaneously arises. In such cases, the risk of intraoperative aneurysm rupture guides decision-making; stable aneurysms may be addressed alongside tumor resection in a single procedure, while high-risk scenarios advocate for preoperative aneurysm embolization before tumor resection. Conversely, if the meningioma and aneurysm are distant, prioritizing treatment depends on the risk of aneurysm rupture. High-risk aneurysms necessitate precedence, followed by tumor resection if symptomatic or rapidly growing. Otherwise, in the absence of imminent aneurysm rupture, the decision hinges on the characteristics of the tumor. Symptomatic or rapidly growing tumors warrant intervention, whereas small, asymptomatic ones necessitate regular surveillance, with both pathologies monitored accordingly.

Limitations

While our review provides valuable insights into managing concurrent IA and meningiomas, several limitations should be acknowledged. There is a significant publication bias favoring studies with more favorable outcomes or unique clinical scenarios, as this dual pathology is rare and often underreported. The variability among included studies regarding patient population, reporting standards, treatment approaches, and outcomes poses a challenge to drawing definitive conclusions. For instance, the variability in follow-up periods, ranging from 10 days to 14 years, makes it difficult to assess the durability and long-term outcomes of the proposed treatment strategies. The study's retrospective nature, along with the lack of long-term follow-up data for many cases, especially those managed conservatively, further impacts the generalizability of the results. The absence of comparative statistical analysis is a notable weakness. Although justified by the nature of the systematic review, including some comparative statistics or meta-analysis could have added rigor and depth to the findings. While our review touches on potential pathophysiological links between meningiomas and IAs, it does not delve deeply into the underlying mechanisms, which could provide valuable insights for understanding and managing this dual pathology. Furthermore, the discussion of complications associated with different treatment approaches is brief; a more comprehensive analysis would be beneficial for informing clinical practice. Finally, the proposed algorithm does not incorporate aneurysm size, location, or morphology, as this information

was not consistently available in the literature. These factors should be considered, especially when determining an aneurysm's rupture risk. Moreover, our algorithm lacks full validation, highlighting the need for further refinement and prospective studies.

CONCLUSION

Concurrent IA and meningioma pose a unique challenge requiring a profound understanding of both pathologies and their dynamic interplay. Our proposed algorithm guides treatment by considering the spatial relationship between meningioma and IA, the risk of aneurysm rupture, and patient symptoms. When these pathologies are closely related, simultaneous management might offer a safe and effective treatment route. A staged approach can also be appropriate for some instances, with the decision heavily influenced by specific characteristics of the meningioma and aneurysm. The priority of treatment should be guided by the individual risk of IA rupture and the symptomatic burden of the meningioma. Continuous follow-up and monitoring are crucial, particularly for patients opting for no immediate treatment or managing the non-prioritized pathology in a staged approach. This analysis recognizes the complexity inherent in these situations and highlights the significance of tailoring treatment approaches to each patient's unique presentation. Future research should focus on prospective studies and standardized guidelines to further refine the proposed management algorithm, including the potential role of radiosurgery in treating small tumors in the cavernous region when an aneurysm is present.

Ethical approval

The research/study approved by the Institutional Review Board at the University of Illinois Chicago, number STUDY2024-0400, dated April 29, 2024.

Declaration of patient consent

Patient's consent was not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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