# The role of the basal cisterns in the development of posterior fossa skull base meningiomas

**Ioan Stefan Florian[1,2], Gheorghe Ungureanu[1], Alexandru Florian[2]**

[1]Neurosurgery Department, Cluj County Emergency Hospital, Cluj-Napoca, ROMANIA
[2]University of Medicine and Pharmacy "Iuliu Hatieganu" Cluj-Napoca, ROMANIA

**Abstract**: Meningiomas account for more than 30% of all intracranial brain tumors, with 25% of them originating somewhere along the skull base and about 20% of these located in the posterior fossa. The intimate relation of these tumors with neural and vascular structures make them difficult to treat, both surgically and nonsurgically. Their treatment is further hampered by the lack of definitive recommendations, which is partially due to the fact that there is no general accepted model of classification. The present report proposes a new concept of classification of posterior fossa skull base meningiomas, one that takes into account the intimate relation of these tumors with arachnoid structures, simplifies the overcrowded landscape of their systematization and can be extended to oher skull base locations.

## Introduction

Meningiomas are the most frequent type of primary brain tumors, accounting for more than 30%, with an estimated prevalence of 6.0 in 100000 in the US (1). These tumors can originate in any cranial and spinal region where there are arachnoid cells, with about 25% of them originating somewhere along the skull base (2). The treatment philosophy changed significantly during the last two decades (3). Because of their intimate relation with neural and vascular structures, their treatment is challenging and gross total removal is not feasible in some cases, so a combination of surgery, endoscopy and SRS is employed to achieve a good outcome (4).

The terms used in the various classifications of skull base meningiomas are a subject of debate, as diverse locations are subjected to various terminologies with no accepted classification (5). From anterior to posterior these tumors are classified according to bony landmarks and include olfactory groove, planum sphenoidale, tuberculum sellae, optic nerve sheath, sphenocavernous, sphenoorbital, cavernous sinus, tentorial, clival and petroclival, cerebellopontine angle, jugular foramen, lower clivus and foramen magnum tumors (2). This classification is often confusing and doesn't provide a clear grouping of skull base meningiomas, although various studies have tried to offer different sorting systems (5, 6, 7, 8). Because of the complexity of the categories of these classifications, it is difficult to assign tumors to a certain group. For example, cerebellopontine angle tumors are included in the larger group of petroclival meningiomas in some studies, and this is debated by other authors (6). Simmilarly, meningiomas originating in the lower clivus are not distinguishable from foramen magnum ones, because of the anatomical continuity of these areas (9).

The present report focuses on proposing a novel model for the classification of posterior skull base meningiomas, one in which tumors are grouped according to the perilesional subarachnoid cysterns.

## Concept

### *1. Rationale of the classification*

a) Origins of meningiomas

Meningiomas originate in the progenitor cells of the arachnoid cap cells, which are positioned ouside the arachnoid membrane (10). The main function of these cells is the reabsorbtion of CSF, and in order to carry out this task, they exibit numerous forms of cellular junctions (11, 12). The reason that meningiomas are thought to originate from these cells is the fact that they both express similarities in function and ultrastructure (10). Tight junctions, desmosomes, pynocitic vesicles, extracellular spaces resembling cisterns, are for example, some of the features found in both cells (13, 11). Current knowledge regarding adhesion, cell-to-cell communication, cell survival, homeostasis in meningiomas is still lacking, although new research gives hope in understanding the multiple singnaling pathways and mechanisms implicated in the development of these tumors and their similarities with arachnoid cap cells (13).

b) Subarachnoid cysterns

Under the brain, around the brainstem and in the tentorial incisura, the subarachnoid space expands, forming cavities filled with CSF, which are separated through a large number of septae, trabeculaes and membranes into cisterns (14). These cisterns offer the pathway through which all the major vessels and cranial nerves pass and are also corridors for the neurosurgeon as most procedures can be performed noninvasevely by using these natural access routes (15). The cisterns of the posterior fossa, the vessels and nerves that pass through them are detailed in Figure 1. The arachnoid membranes provide landmarks for dissection and provide the “need-to-know” limits for neurosurgeons, both in transcaranial and, more importantly, endoscopic procedures (16). The membranes of the posterior fossa are (14):

- Liliequist’s membrane, separating the chiasmatic and interpeduncular cisterns;
- anterior pontine membrane, between the prepontine and cerebellopontine cisterns;
- lateral pontomesencephalic membrane, between the ambient and cerebellopontine cisterns;
- medial pontomedullary membrane, between the premedullary and prepontine cisterns;
- lateral pontomedullary membrane, between the cerebellopontine and cerebellomedullary cisterns.

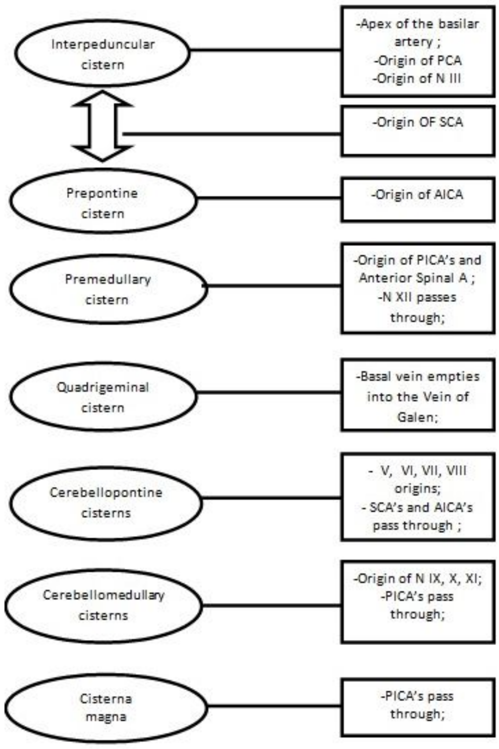


**Figure 1** - Posterior fossa cysterns and their neurovascular content

## *2. The Concept of the classification*

Our concept of classification proposes to classify skull base meningiomas according to the subarachnoid cisterns proximal to the tumors. It is based both on our clinical experience and a wide study of literature. In a retrospective study conducted over a period of 15 years, including 934 new cases of meningioma, with 985 locations (some cases with multiple meningiomas), 51 tumors were located in the petro-clival region and 11 cases in the anterolateral portion of the Foramen Magnum. Posterior fossa meningiomas accounted for 144 cases, 15.4% of all new cases. Petro-clival meningiomas represent 34.5% of the posterior fossa meningiomas, while those located in the Foramen Magnum around 10%.

As it has been shown previously, meningiomas originate from the arachnoid capp cells. As Yasargil stated more than twenty years ago "Meningiomas and schwannomas originate in the subdural space and extend subdurally, but epiarachnoidally. They are covered by two or more cisternal layers depending on the number of cisterns traversed" (17). The cisterns of interest for the development of meningiomas of the posterior fossa skull base are the interpeducular cistern, prepontine cistern, cerebellopontine cisterns, cerebellomedullary cisterns and the premedullary cistern.

The limitations of meningiomas into a specific cistern are demonstrated by the similar aspects of the tumors, for a period of time, regardless of factors like age, gender, histology. In time, maligancny influences the growth pattern, but the membranes and other arachnoidal structures, along with the neurovascular structures, will conduct the further expansion of the tumors. Below are some examples of how tumors follow growth patterns with a relative respect to the arachnoid and neurovascular surrounding structures:

- tumors originating at the level of the prepontine cistern will grow predominantly on the median line, with a lateral extension depending on the location of the basilar artery, their upward expansion being limited by Liliequist's membrane;

- meningiomas originating at the level of the superior cerebellopontine cistern, predominantly grow laterally and superiorly along the oculomotor nerve, into Meckel's cave, displacing laterally the acusticovestibular and facial bundle;

- meningiomas originating outside the cerebellopontine cistern, on the petrous bone, will displace medially the facial and acusticovestibular cranial nerves, and in larger tumors also the glosopharingeal and vagus nerve and can be included in the category of posterior petrous meningiomas, in order to be distinguished by those located in the middle fossa;

- meningiomas originating at the level of the premedullary cistern will further develop anteromedially, in an ascending and descending direction, their growth being limited posteriorly by the dentate ligament. As they grow, they will displace laterally the glosopharingeal, vagus and accessory nerves;

- those tumors mostly located in the cavernous sinus, with a secondary involvement of the posterior fossa cisterns are those included in the current sphenopetroclival category;

***3. Importance for neurosurgeons***

The surgical implication of this classification relies in the fact that it offers a justification and reasoning for the idea that, with the exception of sphenopetroclival meningiomas, all other meningiomas in this location, could be resected trough a "classic" lateral posterior fossa approach, namely the retrosigmoidian approach, for those located superiorly, and a lateral approach, for those located inferiorly. Taking advantage of the surgical corridor created by the tumor growth, using progressive internal debulking, basal devascularization, mobilization of the nerves and arteries in their arachnoid layer, the surgeons can usually obtain a complete removal of the tumor. In some instances, in which the tumor invades the brainstem piamater, the concept of leaving in place some of the tumor, in order to preserve quality of life applies. A classification according to the basal cisterns allows, on one hand an easier anatomical framework and also offers an anticipation of tumor relations with neurovascular elements contained in a specific cistern, relations valid at least for medium size tumors. At the same time it allows an explanation of the pattern of tumor development. As the tumor grows, it will gradually exceed the natural barriers posed by arachnoidal membranes, invading the adjacent cisterns and consequently, the adjacent neurovascular structures.

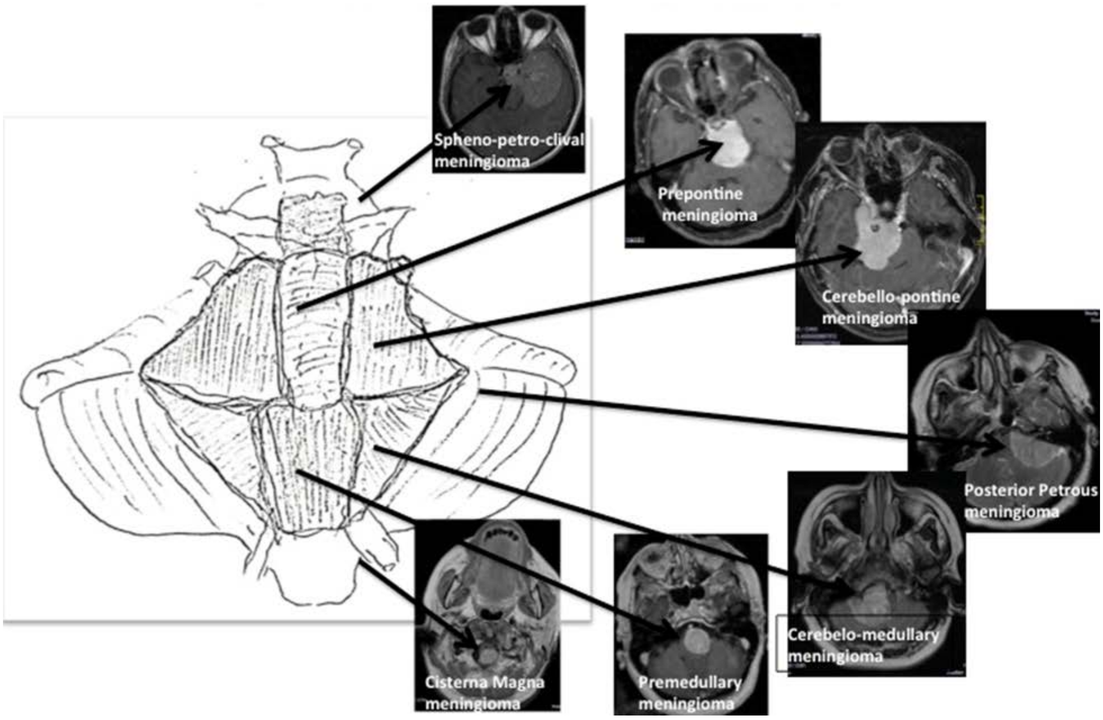


**Figure 2** - Schematic representation of posterior fossa cisterns and case examples

## Discussion

Our study offers a novel approach in classifying meningiomas of the posterior fossa skull base. Considering the origin of meningioma cells, the anatomic locations of these tumors, and the "simplicity" of relating these tumors to the subarachnoid cysterns, we see this as a viable classification system. The importance of the arachnoid membrane in the growth pattern and expansion of meningiomas is probably most visible in the case of clinoidal tumors. When meningiomas occur proximal to the carotid cistern, where the carotid lacks an arachnoid wraping, the meningioma will adhere directly to the vessel adventia (18). This is just an instance that proves that meningiomas cannot be viewed outside their relation with the arachnoid membrane that is both the origin of the tumors and also a very important surgical limit.

Skull base meningiomas probably represent one of the most formidable challenges to a neurosurgeon. With the development of microsurgery, came an initial enthusiasm, in which performing radical surgery for lesions previously seen as inoperable was viewed as a major advancement, even if this lead to major postoperative morbidity (19). In various series, surgery resulted in permanent cranial nerve deficits ranging from 20.3% to 86% (20). In time, as patients and physicians began asking for preservation of quality of life and deficit free survival, the treatment paradigm shifted towards subtotal removal combined with some kind of radiotherapy (21). Slowly, with the advent of endoscopic neurosurgery and radiosurgery, this evolved into a concept of "minimally invasive neurosurgery" (19, 21). This view was challenged, as an innapropriate treatment through a minimally invasive surgery can become maximally invasive for the patient, and so the concept of treatment slowly settled in applying a combination of skull base surgery, endoscopy and radiosurgery (19, 22, 23, 24). Usually, surgery can achieve GTR, but this should be a secondary goal of surgery, the first being the improvement or at least preservation of life quality.

Comparing results of various treatments coming from different groups, is complicated by the lack of a simple, straight forward classification system. It is impossible to compare outcomes of a certain medical procedure, as long as the understanding of the disease is different between those who compare the procedures. This is especially true in the case of skull base lesions. In an area of just a few centimeters, a variety of tumors can be encountered. Just in the clival region, some studies define tumors with distinct anatomical differences as "true" petroclival, sphenopetroclival, midclival, and posterior petrosal tumors (7). Other grading and classification systems that were proposed for tumors in this location have a different view and offer another perspective, providing other classifications and recommended approaches, frequently with conflicting opinions regarding similar tumors (25, 26, 27). The same difference in views is also encountered in foramen magnum lesions (28, 29, 30, 31, 32). As one would expect, differentiating between tumors originating in an area of a couple of cm is not easy, as the anatomical "landmarks" are not clearly defined, and furthermore it's easy to mistake one category for another. If treatment prognosis is different between these tumors, it's obvious to see why different groups will obtain different results even when comparing the same technique.

In the era of Evidence Based Medicine, the treatment of skull base tumors, has still not been the subject of prospective, randomized trials, applying similar therapies to similar lesions. A review found that their rarity, the variety of the reported data and treatment diversity of these tumors, only lead to a very complicated picture (24). The majority of recommendations come from "Master Surgeon" series, which do not reflect the overall quality of surgeons, and thereby may provide divergent results when applied to the entire community (33). Furthermore, these studies reach results by analyzing patients operated using various, preferred approaches by the surgeons (6) (34, 25, 35, 27, 26). This, combined with the various classification systems, make the decision process towards a certain therapy or approach even more difficult. Using a "simple" sorting mechanism like ours, would prove beneficial in this regard. The majority of posterior fossa meningiomas can be managed through "classic" approaches, with minimal traction of the neural and vascular elements, if one considers this cisternal classification.

Our classification concept offers the advantage of being a true "anatomical" and simple classification. It divides tumors using a constant peritumoral trait, the subarachnoid cisterns. Because the neurovascular elements are found in these cisterns, it's easy to look for the clinical deficits that the tumors will cause as they grow and compress them. The pericisternal location also anticipates the elements that will be encountered during surgery. The growth pattern of benign tumors could also be investigated using this system, as it's possible that they expand by these natural pathways. Last, but not least, this classification pattern can be applied to other skull base tumors, eg. sellar region tumors.

## Conclusion

Our report proposes a new classification system of posterior fossa meningiomas. It's, for the best of our knowledge, the first system of classification that divides this tumors using the subarachnoid cisterns and the various membranes as anatomical and clinical landmarks. Its simplicity and clarity make it easy to use and also applicable to other skull base lesions.

***Correspondence***
*Gheorghe Ungureanu*
*Victor Babes, no. 43/7, Cluj-Napoca, Cluj County, Romania*
*E-mail: ungureanugeorge@gmail.com*

## References

1. Porter KR, McCarthy BJ, Freels S, Kim Y, Davis FG. Prevalence estimates for primary brain tumors in the United States by age, gender, behavior, and histology. Neuro Oncol 2010; 12:520–7. doi: 10.1093/neuonc/nop066.
2. Di Maio S, Ramanathan D, Garcia-Lopez R, Rocha MH, Guerrero FP, Ferreira M, et al. Evolution and future of skull base surgery: The paradigm of skull base meningiomas. World Neurosurg 2012;78:260–75. doi:10.1016/j.wneu.2011.09.004.
3. Seifert V. Clinical management of petroclival meningiomas and the eternal quest for preservation of quality of life: Personal experiences over a period of 20 years. Acta Neurochir (Wien) 2010;152:1099–116. doi:10.1007/s00701-010-0633-6.
4. Nanda A, Javalkar V, Banerjee AD. Petroclival meningiomas: study on outcomes, complications and recurrence rates. J Neurosurg 2011;114:1268–77. doi:10.3171/2010.11.JNS10326.
5. Kawase T, Toya S. Developmental patterns and characteristic symptoms of petrolival meningiomas. Neurol Med Chir (Tokyo) 1996;36:1–6. doi:10.1016/j.wneu.2010.12.035.
6. Ichimura S, Kawase T, Onozuka S, Yoshida K, Ohira T. Four subtypes of petroclival meningiomas: Differences in symptoms and operative findings using the anterior transpetrosal approach. Acta Neurochir (Wien) 2008;150:637–45. doi:10.1007/s00701-008-1586-x.
7. Almefty R, Dunn IF, Pravdenkova S, Abolfotoh M, Al-Mefty O. True petroclival meningiomas: results of surgical management. J Neurosurg 2014;120:40–51. doi:10.3171/2013.8.JNS13535.
8. Boulton MR, Cusimano MD. Foramen magnum meningiomas: concepts, classifications, and nuances. Neurosurg Focus 2003;14:e10. doi:10.3171/foc.2003.14.6.10.
9. Kano T, Kawase T, Horiguchi T, Yoshida K. Meningiomas of the ventral foramen magnum and lower clivus: Factors influencing surgical morbidity, the extent of tumour resection, and tumour recurrence. Acta Neurochir (Wien) 2010;152:79–86. doi:10.1007/s00701-009-0511-2.
10.Yamashima T. On Arachnoid Villi and Meningiomas: Functional Implication of Ultrastructure, Cell Adhesion Mechanisms, and Extracellular Matrix Composition. Pathol Oncol Res 1996;2:144–9.
11.Arishima H, Sato K, Kubota T. Immunohistochemical and ultrastructural study of gap junction proteins connexin26 and 43 in human arachnoid villi and meningeal tumors. J Neuropathol Exp Neurol 2002;61:1048–55.
12.Mehta BC, Holman DW, Grzybowski DM, Chalmers JJ. Characterization of arachnoidal cells cultured on three-dimensional nonwoven PET matrix. Tissue Eng 2007;13:1269–79. doi:10.1089/ten.2006.0233.

13.Pećina-Šlaus N, Kafka A, Lechpammer M. Molecular Genetics of Intracranial Meningiomas with Emphasis on Canonical Wnt Signalling. Cancers (Basel) 2016;8:67. doi:10.3390/cancers8070067.
14.Rhoton AL. Chapter10 The posterior fossa cisterns. Neurosurgery 2000;47:S287–97. doi:10.1097/00006123-200009001-00029.
15.Lü J. Arachnoid membrane: the first and probably the last piece of the roadmap. Surg Radiol Anat 2015;37:127–38. doi:10.1007/s00276-014-1361-z.
16.Anik I, Ceylan S, Koc K, Tugasaygi M, Sirin G, Gazioglu N, et al. Microsurgical and endoscopic anatomy of Liliequist's membrane and the prepontine membranes: Cadaveric study and clinical implications. Acta Neurochir (Wien) 2011;153:1701–11. doi:10.1007/s00701-011-0978-5.
17.Yasargil MG. Microneurosurgery. 1st ed. New York: Georg Thieme Verlag; 1984.
18.Al-Mefty O, Abdulrauf SI, Haddad GF. Meningiomas. In: Winn RH, editor. Youmans Neurol. Surg. Sixth Edit, Philadelphia: Elsevier B.V.; 2011, p. 1426–50.
19.Misra BK. The paradigm of skull base meningiomas: What is optimal? World Neurosurg 2012;78:220–1. doi:10.1016/j.wneu.2011.11.018.
20.Xu F, Karampelas I, Megerian C a, Selman WR, Bambakidis NC. Petroclival meningiomas: an update on surgical approaches, decision making, and treatment results. Neurosurg Focus 2013;35:1–10. doi:10.3171/2013.9.FOCUS13319.
21.Stippler M, Kondziolka D. Skull base meningiomas: Is there a place for microsurgery? Acta Neurochir (Wien) 2006;148:1–3. doi:10.1007/s00701-005-0667-3.
22.Brito H, Pridgeon JS. Skull Base Meningiomas: Aggressive Resection 2015;62:30–49. doi:10.1227/NEU.0000000000000803.
23.Li D, Hao SY, Wang L, Tang J, Xiao XR, Jia GJ, et al. Recurrent petroclival meningiomas: clinical characteristics, management, and outcomes. Neurosurg Rev 2015;38:71–87. doi:10.1007/s10143-014-0575-1.
24.Maurer AJ, Safavi-Abbasi S, Cheema AA, Glenn CA, Sughrue ME. Management of Petroclival Meningiomas: A Review of the Development of Current Therapy. J Neurol Surgery, Part B Skull Base 2014;75:358–67. doi:10.1055/s-0034-1373657.
25.M. P, S. V, M.R. P, D. K. Novel classification for surgical approach of petroclival meningiomas: A single-surgeon experience. Neurol India 2015;63:718–22. doi:10.4103/0028-3886.166551.
26.Tao J, Wang Y, Qiu B, Ou S, Wang Y, Wu P. Selection of surgical approaches based on semi-quantifying the skull-base invasion by petroclival meningiomas: A review of 66 cases. Acta Neurochir (Wien) 2014;156:1085–97. doi:10.1007/s00701-014-2084-y.
27.Steiger HJ. Surgical management of medium and large petroclival meningiomas: benchmark and limits. Acta Neurochir (Wien) 2016;158:407–8. doi:10.1007/s00701-015-2686-z.
28.Mostofi K. Foramen magnum meningioma: Some anatomical and surgical remarks through five cases. Asian Spine J 2015;9:54–8. doi:10.4184/asj.2015.9.1.54.
29.Dobrowolski S, Ebner F, Lepski G, Tatagiba M. Foramen magnum meningioma: The midline suboccipital subtonsillar approach. Clin Neurol Neurosurg 2016;145:28–34. doi:10.1016/j.clineuro.2016.02.027.
30.Bruneau M, George B. Classification system of foramen magnum meningiomas. J Craniovertebral Junction Spine 2010;1:10–7. doi:10.4103/0974-8237.65476.
31.Bruneau M, George B. Classification system of foramen magnum meningiomas. J Craniovertebral Junction Spine 2010;1:10–7. doi:10.4103/0974-8237.65476.
32.Wu Z, Ren C, Hao S, Wang L, Xiao X, Tang J, et al. Foramen magnum meningiomas: surgical results and risks predicting poor outcomes based on a modified classification 2016:1–4. doi:10.3171/2016.2.JNS152873.
33.Sughrue ME, Sayegh ET, Parsa AT. Towards a hypermodern theory of meningioma surgery. Clin Neurol Neurosurg 2014;126:69–75. doi:10.1016/j.clineuro.2014.06.002.
34.Yamahata H, Tokimura H, Hirahara K, Ishii T, Mori M, Hanaya R, et al. Lateral suboccipital retrosigmoid approach with tentorial incision for petroclival meningiomas: Technical note. J Neurol Surgery, Part B Skull Base 2014;75:221–4. doi:10.1055/s-0034-1373656.
35. Ambekar S, Amene C, Sonig A, Guthikonda B, Nanda A. Quantitative comparison of retrosigmoid intradural suprameatal approach and retrosigmoid transtentorial approach: Implications for tumors in the petroclival region. J Neurol Surgery, Part B Skull Base 2013;74:300–4.doi:10.1055/s-0033-1348025.