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

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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 other 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, cerebello-
pontine angle tumors are included in the larger group of petroclival meningiomas in some studies, and this is debated by other authors (6). Similarly, 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 cisterns.

**Concept**

1. **Rationale of the classification**
   
a) Origins of meningiomas

Meningiomas originate in the progenitor cells of the arachnoid cap cells, which are positioned outside the arachnoid membrane (10). The main function of these cells is the reabsorption of CSF, and in order to carry out this task, they exhibit 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, pynocytic 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 signaling pathways and mechanisms implicated in the development of these tumors and their similarities with arachnoid cap cells (13).

b) Subarachnoid cisterns

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 noninvasively 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 cisterns 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.
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, malignancy 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 through 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.
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 wrapping, 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

Figure 2 - Schematic representation of posterior fossa cisterns and case examples
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 inappropriate 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, straightforward 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 these 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.

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References