A Hypothesis of Epiarachnoidal Growth of Vestibular Schwannoma at the Cerebello-Pontine Angle: Surgical Importance

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Abstract:
AIMS: The purpose of this study is to clarify the rearrangement of the arachnoid membrane on the vestibular schwannoma during its growth in relation to adjacent neurovascular structures for a better understanding of dissecting plane of arachnoid during surgery. METHODS: Arachnoid membrane over the tumour was investigated during surgery with suboccipital transmeatal approach in twenty-six tumours. All microsurgical procedures were recorded with a video and reviewed. The tumour growth was classified into five stages depending upon the tumour diameter in the cerebello-pontine (CP) angle: Stage 1; purely intracanalicular (2 cases), Stage 2; less than 5 mm (2 cases), Stage 3; ≥ 5 and <15 mm (8 cases), Stage 4; ≥ 15 and <25 mm (9 cases) and Stage 5; ≥ 25 mm (5 cases). Rearrangement of the arachnoid on the tumour was conceptualised throughout all stages. RESULTS: All tumours of Stage 1 and 2 were entirely located in the subarachnoid space of the cerebello-pontine cistern without arachnoidal rearrangement, while all tumours of Stages 3 to 5 were enveloped, in the CP angle, with invaginated arachnoid membrane consisting of cerebello-pontine cistern except two surfaces; the medial pole and the tumour surface under the facial and cochlear nerves near the porus. CONCLUSION: The tumour originates subarachnoidally within the internal auditory meatus (IAM) and grows epiarachnoidally in the CP angle. Rearrangement of the arachnoid begins with its adhesion on the medial pole of the tumour along the porus, resulting in the arachnoidal invagination into the cerebello-pontine cistern with further growing of the tumour. (J Postgrad Med 2002:48:253-259)

Key Words: Vestibular Schwannoma, Arachnoid Membrane, Cerebello-Pontine Angle, Epiarachnoidal Growth, Rearrangement

Surgical procedures for removal of the vestibular schwannoma have been described in literature by various authors.1-8 Several authors have described the existence of the arachnoid planes between the tumour surface and the brain in the cerebello-pontine (CP) angle with schematic drawings.3-6,8 Yasargil detailed the rearrangement of arachnoid membranes on the tumour surface in relation to its growth. He conceptualised that the vestibular schwannoma originates epiarachnoidally in the internal auditory meatus (IAM) and pushes the arachnoid membrane of the cerebello-pontine cistern medially causing a folding of the arachnoid between the tumour and the brain. From the schematic drawings of different authors, it appears that Yasargil’s concept has remained essentially unchanged for the past 25 years.

The purpose of this study was to clarify the rearrangement of the arachnoid membrane on the tumour surface during its growth in relation to adjacent neural structures. In addition to the operative findings of our sequential cases, literature concerning the normal anatomy of the CP cistern and the origin of vestibular schwannoma was reviewed and taken into special consideration.

Patients and Methods
Twenty five patients operated on for 26 vestibular schwannomas were included in the study to investigate the arachnoid planes around the tumours in the CP angle. Pre-operative computerised tomography (CT) scan and magnetic resonance imaging (MRI) were done for all the patients.

Based on imaging features, the tumour was classified depending on either the medial extent in the CP angle or the lateral extent in the IAM.

To define stages of the tumour growth, the medial extent of the tumour was classified into five stages (Table 1). For stage definition, the maximum diameter for the tumour in the CP angle was taken into con-
The maximum diameter was determined by drawing a perpendicular line on the posterior surface of the petrous bone in the axial plane in the post-gadolinium enhanced T1-weighted images. The dimension of the perpendicular line constituted the maximum dimension of the tumour.

The tumour was further classified into five types depending on its lateral extent in relation to the fundus of the IAM. T1- and T2-weighted MRI images and bone window CT scan were used for the presumptive determination of the tumour origin relating to the lateral end of the arachnoid membrane of the cerebello-pontine cistern:- Type A: lateral extent being at the fundus with involvement of the bony foramen, Type B: lateral extent being at the fundus without involvement of the bony foramen, Type C: lateral extent being within the lateral half of the IAM with a tumour-free space near the fundus, Type D: lateral extent being within the medial half of the IAM, Type E: lateral extent being at the porus acousticus internus without enlargement of the IAM. Surgery was performed via a lateral suboccipital transtemporal approach in sitting position for 4 cases, and in park bench position for 22 cases. Surgical procedures were recorded in all cases with a digital video recording system (SONY, Tokyo, Japan), and reviewed several times and documented to confirm the arachnoidal relation and extension in each case.

### Results

Twenty five [13 females, mean age 44.6 years (range 21-67)] patients accounting for 26 vestibular schwannomas were studied. Table 2 shows the case summary of the tumour classification depending on medial and lateral extensions (Figure 1). In Stage 1 intracanalicular vestibular schwannomas, we found that each tumour was located in the subarachnoid space without any arachnoidal involvement. We saw that the arachnoid membrane of the cerebello-pontine cistern continued into the IAM accompanying the dura mater. In both cases the lateral margin was found at the fundus. The surface of the tumour was not covered by arachnoid membrane except for its posterior surface. It is presumed that the tumour grows subarachnoidly within the IAM and soon reaches to its wall in a very small space. Deeper structures like pia on the vestibular nerve at the origin of the tumour might form a capsule of the small tumour in this stage (Figure 2A).

In Stage 2 tumour, the protruding medial pole of the tumour in the cerebello-pontine cistern was covered with a thin membrane looking like pia (henceforth called "pia-like membrane" for convenience), and there was slight adhesion between the tumour surface, arachnoid and dura at the circumference of the porus acusticus. It is presumed that the tumour becomes adherent to the arachnoid membrane and the dura mater in the circumference of the porus as the tumour grows further. This meningeal adhesion to the tumour surface, however, is interrupted at the anterior pole of the porus, since the arachnoid membrane in front of the facial and cochlear nerves is not able to adhere to the tumour surface due to the presence of these nerves. The medial surface of the tumour facing the CP angle is covered by the "pia-like membrane" in continuity from the tumour in the IAM, and the membrane can be called the tumour capsule. The tumour grows subarachnoidly at this stage (Figure 2B).

In Stage 3 tumour, a small fold of arachnoid was seen behind the tumour near the porus acusticus (Figure 3A). The outer layer of this arachnoidal fold was found to be continuous with the arachnoid over the cerebellar hemisphere. The inner layer looked adherent to the medial surface of the tumour.

### Table 2: Case Summary according to Tumour Classification depending on Medial and Lateral Extent

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Figure 1: Schematic drawings of the tumour classification depending on the lateral extent of the tumour in the IAM.
Figure 2: Schematic drawings of the rearrangement of the arachnoid plane in relation to the tumour growth. Left; 3-dimensional views from the anterior aspect in the cerebello-pontine cistern. Centre; axial sections through the facial and cochlear nerves. Right; sagittal sections through the internal auditory meatus (IAM). Arrowheads indicate the tumour-arachnoid adhesion that takes place at Stage 2 and moves medially as the tumour growth. AICA, anterior inferior cerebellar artery; AM; arachnoid membrane, V; trigeminal nerve, VII-VIII; facial-cochlear nerves, IX-X; glossopharyngeal-vagus nerves.

Figure 3: Schematic drawings of operative findings of membranous structures on the tumour in Stage 3 (A) and Stage 4 (B). Asterisk = arachnoid fold caused by the retractor (R).
mourn, where this arachnoid appeared to turn laterally and reached the porus continuous to the arachnoid membrane of the IAM. This innermost arachnoid covered the tumour like a thin sheet of floss silk (to be referred as “floss” subsequently). The inner layer of the arachnoid fold could be easily peeled off from the “floss”. These layers over the surface of the tumour could be peeled off together and an almost avascular surface of the tumour became visible at the CP angle. Presumably, the arachnoid membrane which has been adherent to the tumour along the circumference of the porus acusticus in Stage 2, shifted medially into the CP angle during tumour growth, forming the arachnoidal invagination around the porus (Figure 2C). The inner layer of the invaginated arachnoid (“floss”) is stretched between the porus and the medial side of the tumour and loses its normal anatomy, except anterior to facial and cochlear nerves where the arachnoid was not adherent to the tumour at Stage 2. A basic form of arachnoidal rearrangement in the CP angle has been theoretically completed in this stage. In later stages, surgical procedure and anatomy are modified with the enlargement of the tumour.

In Stage 4 tumour, a fold of arachnoid behind the tumour near the porus acusticus was obvious and a medial loop of the anterior inferior cerebellar artery was occasionally found in the subarachnoid space within this fold (Figure 3B). The “floss” under the arachnoid fold, which was observed in Stage 3 was undetectable on the tumour surface. The outer layer of the duplicated arachnoid between the surgeon and the tumour extended towards the cerebellar hemisphere under the retractor, and its inner layer continued to overlie the tumour surface medially. The peeling of the inner layer was done meticulously on the tumour capsule. However, at the medial pole, there was a likelihood of losing the continuity of this arachnoid layer and of opening the subarachnoid space. The facial nerve could be separated from the tumour and the adhesive arachnoid beneath it at the medial side in the CP angle. Lateral to this adhesion, isolated facial nerve was found to be enveloped by this arachnoid inside and the arachnoid of the cerebello-pontine cistern outside. Around the porus, however, there was no arachnoid layer intervening between the facial nerve and the tumour surface. So, the adhesion between the facial nerve and the tumour had to be separated at times with sharp dissection, rather than peeling off. The arachnoid fold seen near the porus between the tumour and the surgeon during surgery at Stage 3 and 4 is an artifact caused by retraction of the cerebellum. Presumably, the inner layer of the invaginated arachnoid (“floss”) has been already organised to be the tumour capsule or has disappeared due to overstretching (Figure 2D). The tumour capsule at this stage may consist of the “pia-like membrane”, the reactive tissue from the dura of the porus and the organised “floss”. As a result, a single layer of the invaginated arachnoid covers almost the entire tumour capsule except the two surfaces: the medial pole and the tumour surface under the facial and the cochlear nerves near the porus, where the arachnoid membrane outside those nerves is neither adherent to the tumour surface nor invaginated as in the previous stages. Consequently, near the porus the facial and the cochlear nerves lie in contact with the tumour capsule directly and most tightly adhere to it. More medially, the facial and cochlear nerves run within the subarachnoid space in between the pia of the brainstem and the invaginated arachnoid on the tumour.

Minor exceptions were found in two cases of Type E, where the subarachnoid space of the cerebello-pontine cistern in the CP angle communicated with that in the intrameatal portion under the facial and cochlear nerves at the porus, although the invaginated arachnoid covered the tumour in the CP angle as in others. Therefore, preservation of these nerves at the porus was relatively easy. In Type E tumour, the origin of the tumour could be around the porus, where the adhesion of the arachnoid of the cerebello-pontine cistern to the tumour and consequent arachnoidal invagination occurs as in others. However, the compression force of the tumour against the porus might not be enough to cause the adhesion around the facial and cochlear nerves at the porus. As a result, the communication of the subarachnoid space between the CP angle and the IAM remains around these nerves, and the preservation of these nerves at the porus becomes relatively easy.

In Stage 5 tumour, the arachnoid fold near the porus was seen to be flattened, stretched and pinched between the postero-lateral pole of the tumour and dura mater of the posterior surface of the petrous bone, where duplicated layer of arachnoid observed during the surgery of Stage 3 and 4 tumours was adherent to each other and looked like a single layer without any CSF space in it. Though it was not always easy to identify the arachnoid on the tumour surface, we could peel off a layer from the surface, which was most likely to be the arachnoid. There was no essential difference in operative findings between Stages 4 and 5. Presumably, the invaginated arachnoid becomes more stretched and more adherent to the tumour capsule as the tumour grows further (Figure 2E). The antero-lateral surface of the cerebellar hemisphere, compressed...
by the tumour, is displaced backwards, while the invaginated arachnoid including its lateral corner around the lateral pole of the tumour near the porus is left on the tumour capsule. Consequently, the arachnoid on the lateral surface of the cerebellar hemisphere is stretched, causing the arachnoidal duplication around the lateral pole of the tumour near the porus with the invaginated arachnoid membrane and the stretched arachnoid membrane originally covering the lateral surface of the cerebellar hemisphere. This arachnoid duplication exists between the posterior petrosal dura and the tumour capsule.

Discussion

Yasargil reported that vestibular schwannomas originate epiarachnoidally in the IAM and grow there inside the IAM. If this concept is true, the following situations might happen: first, the surface of the intracanalicular tumour is covered with a reflected arachnoid except for the side of origin at the fundus; second, the fundus at the origin is fully occupied by the tumour in most cases.

Little documentation regarding the magnified appearance of the small tumour in relation to its adjacent structures including the meninges is available. Stewart et al described valuable findings in pathological specimens of four occult schwannomas within the IAM, which showed “a poorly defined capsule surrounding the tumour” in two cases, the other with “no attempted capsule formation”, and another with “very few collagen fibers throughout the tumour.” No arachnoidal reflection at the fundus or newly formed arachnoid covering the tumour was found in their series. Neely et al reported microscopic characteristics of a small vestibular schwannoma. They were: 1) the tumour and the nerve of its origin appeared to be surrounded with the same perineurium, 2) a distinct margin, composed of a delicate layer of fibrous tissue, existed between this portion of the tumour and the compressed nerve, 3) the schwannoma characteristically has a thin fibrous capsule. The capsule probably consists of the perineural tissue, such as pia mater and endoneurium, initially and the reactive tissues additionally as the tumour grows.

Regarding the lateral extent of the tumour in the IAM, 10 tumours in our series were classified as Type C, D or E radiologically. Those tumours had tumour-free space inside the IAM between the fundus and the lateral pole of the tumour, regardless of the medial extent. Compared to Yasargil’s concept of epiarachnoidal origin, we would like to put forward the concept of subarachnoidal origin of vestibular schwannoma. There may be theoretically two other sites of origin of vestibular schwannomas, since the Schwann cells are present also distal to the fundus of the IAM and at the cerebello-pontine cistern medial to the porus. In those cases where the tumour originates distal to the fundus, it may develop epiarachnoidally even within the IAM as Yasargil described. On the other hand, when the tumours originate from the latter site, it might be conceptualised that those might grow subarachnoidally within the cerebello-pontine cistern though this was not noted in our series.

During surgery, it is not easy to distinguish the tumour capsule from the arachnoid overlying of the dura in the IAM. Although some cases of tumours may have their origins inside the foramen lateral to the bony fundus or intra-labyrinthine segment of vestibular nerves, most of vestibular schwannomas originate and grow subarachnoidally in the IAM.

**Epiarachnoidal growth in the CP angle**

The relationship between the tumour and the arachnoid in the CP angle was reported by several authors. Yasargil put forward the following: 1) the vestibular schwannoma originates epiarachnoidally in the fundus, 2) as it enlarges, the tumour pushes the arachnoid of the IAM medially into the CP angle, 3) the tumour further grows epiarachnoidally in the CP angle, and 4) the tumour and the brainstem are covered by their own arachnoid membrane. With this understanding, Yasargil described the surgical technique as follows: as long as it is possible to remain in the subarachnoid space, leaving a layer of arachnoid on the tumour and a layer on the pons, even where the tumour has extended deep into the pons, successful extirpation can be achieved without injury to the pia mater, or pontine veins and arterioles. Although this was an outstanding description about the importance of the two arachnoid layers during dissection of the tumour, it did not describe clearly the origin of the arachnoid on the pons. From the available description, it is not always clear whether the dissection was done in the epiarachnoid or in the subarachnoid space.

Tarlov published another view of the arachnoidal relation to the tumour in the CP angle. The end stage of the arachnoidal rearrangement is almost similar to one of ours. He, however, considered the normal anatomy of the arachnoid as follows: 1) the vestibular nerve perforates the arachnoid membrane of the cerebello-pontine cistern at the glial-Schwann cell junction which is located at the CP angle near the porus acusticus, 2) a fold of arachnoid exists over this junction toward the porus. Therefore, he believed that the tumour origi-
nates epiarachnoidally in the IAM and it pushes the folded layer of arachnoid with enlargement, resulting in the formation of a second layer of arachnoid between the tumour and the surgeon. He recommended that the double layers of the arachnoid should be separated from the tumour capsule to allow dissection of the tumour and capsule within this arachnoid envelope, as also we have mentioned. However, he suggested that the tumour should be separated from the pons subarachnoidally in the same way as Yasargil described. It is not clear where and why the subarachnoidal dissection is required between the tumour and the pons. It was also difficult to delineate the relationship of the facial and cochlear nerves to the arachnoid near the porus acusticus in the concepts of the above mentioned authors.

According to our observation, principally two layers of the arachnoid membrane, which correspond to the inner ("floss") and the outer layer of the invaginated arachnoid at Stage 3, are subsequently formed over the "pia-like membrane" on the tumour at the CP angle, except at two sites; beneath the facial and cochlear nerves near the porus and at the medial pole of the tumour facing the pons. Furthermore, one should be cautious not to mistake these double layers of invaginated arachnoid for the arachnoid fold seen near the porus between the tumour and the surgeon during surgery at Stage 3 and 4. The inner layer of the fold seen during surgery is corresponding to the outer layer of the invaginated arachnoid. The outer layer of the fold is originally the arachnoid over the cerebellum, formed due to retraction of the cerebellum causing the arachnoid to be stretched. We believe that the existence of the arachnoid fold at the postero-lateral surface of the tumour, that has been mentioned in literature, has most reasonably been explained by our concept.

The definition of "tumour capsule" herein is obscure and changed with tumour growth. In Stage 1 and 2, it may consist of the "pia-like membrane" and secondary reactive tissue around it. In Stage 3 the "floss" and the reaction from the dura of the porus and the tumour are further added according to circumstances. In Stage 4, those are considered as parts of the capsule. In Stage 5, it may include the outer layer of the invaginated arachnoid in case of a huge tumour. From a surgical point of view, the authors peeled off the layer as close as possible to the tumour, which is most likely a part of the tumour capsule.

Applying our concept of the epiarachnoidal growth of vestibular schwannoma at the CP angle during surgery, we could shorten the operation time, and preserve the facial and cochlear nerves much better and on more occasions. Although this concept is obtained from our operative findings, we hope laboratory confirmation may be obtained in near future. We hope our findings will reduce the confusion and improve understanding of vestibular schwannoma surgery.

References

Expert’s Comments
From our personal experience and from various literature reviews, it is clear that the spread and growth of any tumour is along a specific pattern and that, in general (unless highly malignant), no tumour will directly transgress any anatomic membrane. The characteristic mode of growth of each tumour and the displacement of adjoining blood vessels and neural structures helps in differentiating one tumour from the other. It is crucial to understand the ‘anatomy’ of the tumour growth so that a preoperative impression of the nature of the tumour can be made and accordingly the surgical strategy can be planned. The anatomical membranes are more primitive embryologically and are physically stronger than many.
other tissues in the body. The growth of any tumour is set within a fixed confine and between the membranes. It may appear from an external appearance that the tumour has broken into the anatomical membrane, but on a ‘closer’ look it can be clear that the membrane may be thinned out or rolled over but never actually torn and transgressed. For instance, in trigeminal neurinomas, the tumour remains within the dural confines of the lateral wall of the cavernous sinus and in the intradural space anterior to the brainstem. The dura is firmly adherent to the divisions of the fifth nerve at the foramen ovale and rotundum and it is very rare to find tumours growing extracranially. No matter how big the tumour becomes, it will seldom actually pierce the dura and enter into the venous spaces of the cavernous sinus or engulf the internal carotid artery. On this treatise, small exposures for such tumours have been advocated and by working within the dural confines, tumour resection is performed.\textsuperscript{4,5} Chordomas have a specific and well-defined extradural location and a constant relationship with the cavernous sinus and internal carotid artery.\textsuperscript{6,7}

All cranial nerves carry a sheath of piamater, arachnoid and dura along with them as they exit the cranial cavity. The meninges then merge with the cranial nerves and are then labeled differently as perineurium and endoneurium. The continuity of the anatomical membrane is never lost. The exact site of origin of the acoustic neurinoma in relationship to the internal auditory canal has been a subject of discussion and controversy. From our observations, it appears that the origin of the acoustic neurinoma is from within the nerve fibre and from a subarachnoid-subpial location. The tumour is always covered by this membrane irrespective of it size. As the tumour enlarges and emerges into the cerebellopontine angle, the arachnoid membrane, which covered the tumour within the canal doubles up and comes in proximity to the arachnoid membrane in the cerebellopontine angle. The tumours adjoining cranial nerves have their own discrete arachnoid sheath. As the tumour grows in size the adjoining cranial nerves become more and more flattened over its dome, but the arachnoid sheath is always preserved.

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