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Microstructure and Reasonable Management of the Arachnoid Associated with the Infrafloccular Approach for Microvascular Decompression of the Facial Nerve

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ABSTRACT

AIM: Arachnoid dissection is a basic step in facial nerve microvascular decompression (MVD). However, the literature focusing on the arachnoid microstructure in this region is scarce, and there are different views on how to handle the arachnoid around the cochlea nerve in order to protect the cochlea nerve. In order to provide a valuable reference for minimally invasion during facial nerve MVD, the arachnoid microstructure during the infrafloccular approach was studied in this paper.

MATERIAL and METHODS: This study recruited 55 patients with hemifacial spasm who underwent MVD. Retrospective analyses of the MVD surgical videos were performed to reveal the arachnoid microstructure during the procedures. Cadaveric head specimens (n=8, on 16 sides) were dissected for observation of the microstructure of the arachnoid in the cerebellopontine angle.

RESULTS: The arachnoid membrane surrounding the facio-cochleovestibular and lower cranial nerves forms two arachnoid sheaths. Both arachnoid sheaths contain two parts: the outer membranous and inner trabecular part. The membranous part is an intact and translucent membrane that wraps around nerves. The inner trabecular part is located beneath the membranous part and forms a trabecular network that connects the membranous arachnoid, nerves, and blood vessels to form a physical structure.

CONCLUSION: The arachnoid connects the facio-cochleovestibular and lower cranial nerves, blood vessels, and cerebellum as a complex physical entity. Therefore, during MVD surgery, sharply dissecting the arachnoid before retracting the flocculus and relocating the offending vessels helps reduce nerve injury.

KEYWORDS: Arachnoid, Microvascular decompression, Facial nerve

ABBREVIATIONS: MVD: Microvascular decompression, **REZ:** Root exit zone.

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INTRODUCTION

Arachnoid dissection is a basic step in facial nerve microvascular decompression (MVD) and the key to reduce complications during surgery (15). Nevertheless, no consensus has been reached regarding arachnoid dissection around the vestibulocochlear nerve. Whereas some researchers believe that intraoperative dissection of the arachnoid around the vestibulocochlear nerve is necessary to protect the nerve during surgery (22), other researchers tend to keep the associated arachnoid intact for the same purpose (2,10). To determine which approach is better, detailed observation of the arachnoid microstructure in the cerebellopontine angle is necessary.

Precise dissection of the arachnoid membrane and moving from one cistern to another is the gold standard of minimally invasive neurosurgery (21). During this process, any improper arachnoid stretching may lead to accidental intraoperative injury or postoperative complications. Therefore, our knowledge of the microstructural anatomy of the arachnoid is crucial to understand cochlear nerve protection during minimally invasive surgery for facial nerve MVD. After Yasargil described the cistern system during microsurgery, the posterior fossa cisterns and arachnoid were described by different scholars from different aspects (12-14,16,19-21). However, no studies describe the arachnoid microstructure from the infrafloccular approach. In the present study, by reviewing hemifacial spasm MVD surgical videos and dissecting cadaver specimens, the characteristics of the arachnoid involved in the infrafloccular approach for facial nerve MVD are described in detail. Furthermore, reasonable treatment of the associated arachnoid microstructure is discussed. This study may provide a valuable reference for facial nerve MVD surgery.

MATERIAL and METHODS

Retrospective Review of Surgeries

This study was in accordance with the ethical standards of the ethics committee of the Second Hospital of Xi'an Jiaotong University and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all the participants included in this study. A retrospective review was performed on hemifacial spasm patients who underwent MVD in our group from February to December 2016. The surgical procedures were performed based on the methods reported by previous researchers (6,18). Only patients undergoing MVD surgery for the first time were included. The intradural process of MVD was performed under a microscope and recorded simultaneously. Clinical data including surgical videos were collected and analyzed by the author who also performed all the MVD surgeries. The following specific characteristics were observed: the arachnoid and its connections with the cerebellum, brainstem, facio-cochleovestibular nerve, lower cranial nerves, and offending vessels.

Cadaver Craniotomy

Eight cadaveric head specimens from deceased individuals of Han nationality were obtained from the Department of Human Anatomy and Histoembryology, Xi'an Jiaotong University School of Basic Medical Sciences. The distribution of the arachnoid in the cerebellopontine angle and its relations with the adjacent nerves, cerebellum, brainstem, and vessels were observed by craniotomy.

RESULTS

Clinical Outcomes

We analyzed 55 patients (40 females, 15 males) who met the inclusion criteria. The mean length of clinical follow-up was 10.3 ± 3.2 months (range: 6–16 months). The symptoms of 49 of the 55 patients disappeared immediately after MVD surgery. Among the remaining six patients, five benefited from the disappearance of their symptoms within 6 months, and one exhibit relieved symptoms after 8 months of follow-up. No permanent deafness, facial paralysis, or impairment of the lower cranial nerves was found in these patients.

Surgical Findings

The Arachnoid Sheath

In the subdural space, the arachnoid membrane surrounding the facio-cochleovestibular and lower cranial nerves forms two arachnoid sheaths. Following the corresponding nerves, the two arachnoid sheaths extend into the internal acoustic meatus and jugular foramen, respectively. The arachnoid sheaths are composed of two parts: the outer membranous part and the inner trabecular part. The outer membranous part is a completely translucent and intact arachnoid membrane, whereas the trabecular part is beneath the membranous arachnoid and predominantly of linear appearance (Figure 1A).

The outer membranous part forms the outer wall of the two arachnoid sheaths, which meet at the top of the flocculus (Figure 1B). The subarachnoid spaces under the sheath of the facio-cochleovestibular and lower cranial nerves are part of the cerebellopontine cistern and lateral cerebellomedullary cistern, respectively. For convenience of description, the two spaces will hereafter be referred to as the facio-cochleovestibular and lower cranial nerve cavity. The lateral wall of the facio-cochleovestibular nerve cavity is the extension of the cerebellar hemisphere membrane and the medial wall formed by the cerebellopontine membrane. The lateral and medial arachnoid walls of the lower cranial nerve cavity are formed by the ventral and dorsal cerebellomedullary membrane, respectively.

Arachnoid Trabeculae Around the Nerves

The inner trabecular arachnoid forms an arachnoid network connecting the structures inside the two nerve cavities. There are individual differences between arachnoid trabeculae. Some individuals have a densely distributed pattern (Figure 1A), while others have sparse arachnoid trabeculae (Figure 1B). Around the facio-cochleovestibular and lower cranial nerves, trabeculae are mostly distributed on the side of the cerebellum and attach the nerves to the cerebellar flocculus, cerebellar tonsil, or membranous wall of the two nerve cavities. In this

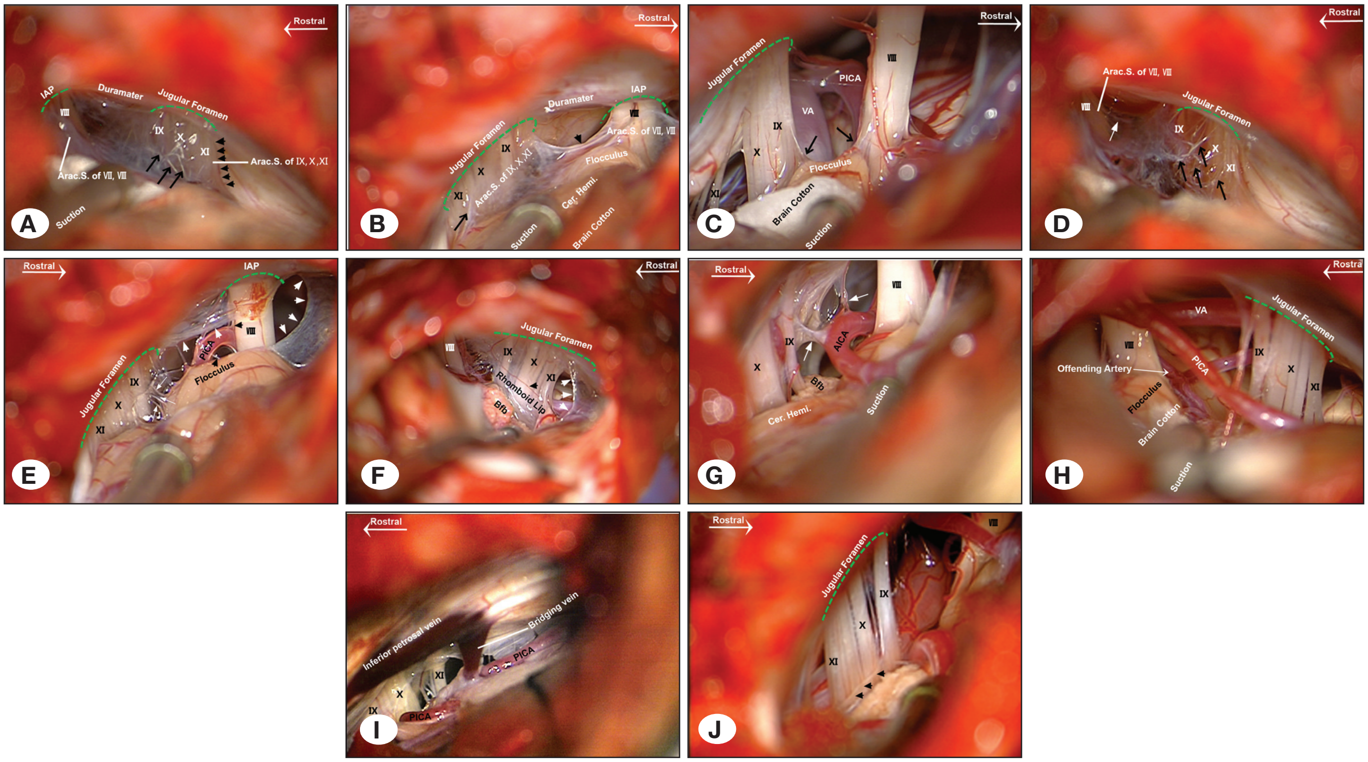

Figure 1: Intraoperative view of the microstructure associated with the infrafloccular approach for microvascular decompression of the facial nerve. A) The arachnoid membrane surrounding the facio-cochleovestibular and lower cranial nerves forms two arachnoid sheaths. Following the corresponding nerves, the two arachnoid sheaths extend into the internal acoustic meatus and jugular foramen, respectively. The arachnoid sheaths are composed of two parts: the outer membranous part (arrowheads show the outline of the lower cranial nerve sheath) and the inner trabecular part (arrows show the trabeculae beneath the membranous arachnoid). **B)** The outer membranous part is a completely translucent and intact arachnoid membrane, whereas the trabecular part beneath the membranous arachnoid is mostly of linear appearance (arrow). The two nerve sheaths meet at the top of the flocculus (arrowhead). **C)** The outer membranous arachnoid is removed, and the trabeculae are exposed. In the proximal segment of the nerve root, there are usually short and dense trabeculae closely connecting the facio-cochleovestibular and lower cranial nerves to the cerebellar flocculus (arrows). **D)** Around the distal segment (close to the internal acoustic pore or jugular foramen) of the nerve roots, the trabeculae (white arrow) in the facio-cochleovestibular nerve cavity are usually sparser than those in the lower cranial nerve cavity (black arrows). **E)** After removal of the membranous sheath (white arrowheads indicate the cutting edge of the membranous sheath), dense trabecular connections (white arrows) between the lower cranial nerves and flocculus and sparse connections (black arrowheads) around the PICA are exposed. **F)** After removal of the membranous sheath (white arrowheads indicate the cutting edge of the membranous sheath), a big rhomboid lip with blood supply (black arrowhead) obscures the root of the lower cranial nerves. Few trabeculae are observed around the Bochdalek's flower basket. **G)** Thick band-like trabeculae (white arrows) attaching the AICA to the outer membranous arachnoid. **H)** After separation of the PICA, the offending artery (white arrow) is exposed. **I)** A bridging vein often passes the lateral arachnoid wall of the lower cranial nerve cavity and is drained into the inferior petrosal vein. **J)** Small rhomboid lip (black arrowhead) with few arachnoid trabeculae connected to the adjacent structures. **VIII:** vestibulocochlear nerve; **IX:** glossopharyngeal nerve; **X:** vagus nerve; **XI:** accessory nerve; **AICA:** anterior inferior cerebellar artery; **VA:** vertebral artery; **Arac.S.:** arachnoid sheath; **IAP:** internal acoustic pore; **Cer. Hemi.:** cerebellar hemisphere; **Bfb:** Bochdalek's flower basket.

way, the nerves are anchored by the arachnoid at a specific location. As observed during surgery, in the proximal segment (close to the root exit zone (REZ) and against the cerebellum) of the nerve roots, there are usually short and dense trabeculae connecting the facio-cochleovestibular and lower cranial nerves closely to the cerebellar flocculus (Figure 1C). As such, the flocculus, located between the vestibulocochlear and lower cranial nerves, is tightly connected with the vestibulocochlear nerve at the medial-cranial side and with the lower cranial nerves at the medial-caudal side by arachnoid trabeculae. The cerebellomedullary fissure, a cleavage plane between the cerebellar hemisphere and medulla oblongata, is closed by the arachnoidal connection. Around the distal segment (close to the internal acoustic pore or jugular foramen) of the nerve roots, the trabeculae in the facio-cochleovestibular nerve cavity are usually sparser than those in the lower cranial nerve cavity (Figure 1D, E). We observed that 48/55 (87%) individuals have few trabeculae connections in the facio-cochleovestibular nerve cavity. Conversely, in the lower cranial nerve cavity, trabeculae are dense and interwoven into webs like sponges for most individuals (48/55, 87%). Trabeculae that connect to the choroid plexus (referred to as the Bochdalek's flower basket protruding from the lateral recess of the fourth ventricle) are rare (Figure 1F). When there are vessels passing through the two arachnoid cavities, dense trabeculae often connect the nerves, outer membranous arachnoid, cerebellum, and vessels (see specifically the perivascular arachnoid trabeculae). Furthermore, there are also arachnoid trabecular connections between nerves inside the arachnoid sheaths, such as those between the facial and vestibulocochlear nerves and those between the lower cranial nerves.

Blood Vessels and the Associated Arachnoid Trabeculae

Based on the clinical significance, we mainly focused on the arachnoid trabeculae associated with the arteries passing through the facio-cochleovestibular and lower cranial nerve cavities. The involved arteries, including both the anterior and posterior inferior cerebellar arteries, as well as the basilar artery, are generally attached to adjacent structures by arachnoid trabeculae in these two cavities. Usually, linear (Figure 1E) or thick band-like (Figure 1G) trabeculae attach the vessels to the outer membranous arachnoid, nerves, or flocculus when the artery is close to these structures.

Vessels passing through the lateral space of the two nerve cavities (passing through the lateral sides of the two groups of nerves) will form an obstacle to the REZ of the facial nerve (Figure 1G, H). We observed 18/55 (33%) cases with vessels passing through the lateral space of the lower cranial nerve cavity, and two of these vessels gave off small branches inside this area. Furthermore, we observed 15/55 (27%) cases with vessels passing through the lateral space of the facio-cochleovestibular nerve cavity, and six cases have small branches arising from the vessels inside this space. When the artery is close to the brainstem, the arachnoid connection between the arteries and brainstem is usually thin and sparse. A bridging vein often passes the lateral arachnoid wall of the lower cranial nerve cavity and is drained into the inferior petrosal vein (Figure 1I).

The Rhomboid Lip

The rhomboid lip is a sheet-like layer of neural tissue protruding from the lateral angle of the fourth ventricle together with the choroid plexus. It is a thick membranous structure distinct from the arachnoid membrane. In this study, two cases of rhomboid lip were found among the 55 patients. The large one was tightly connected with the lower cranial nerves and cerebellar flocculus (Figure 1F). The small one exhibited only few arachnoid trabeculae that were connected with the adjacent structures (Figure 1J).

Craniotomy Findings

For further exposure and observation, we performed a detailed craniocerebral dissection. As observed during surgery, the intact membranous arachnoid formed the sheaths of the facio-cochleovestibular and lower cranial nerves (Figure 2A). Abundant trabecular arachnoid attachments were observed beneath the membranous arachnoid (Figure 2B). The arachnoid trabecula connects the nerve to its surrounding structures beneath the membranous layer at the proximal segment of the nerve (close to the exit site). Furthermore, dense arachnoid trabecular connections between the nerve

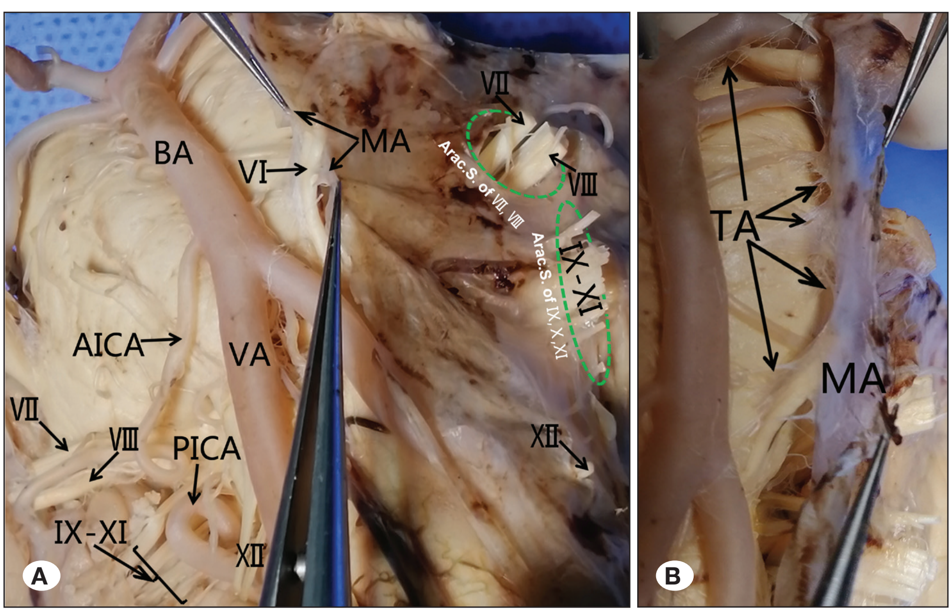

Figure 2: Two components of the arachnoid membrane: membranous and trabecular arachnoid. A) The right-side membranous arachnoid of the pons and medulla oblongata was removed, and the nerves and blood vessels are clearly visible. The left-side membranous arachnoid was left intact, with the nerves and vessels beneath it obscured. Green circles indicate the cross-section of the facio-cochleovestibular and lower cranial nerve sheath, which were formed by the membranous arachnoid. **B)** The trabecular arachnoid is shown connecting the nerves, blood vessels, and ventral surface of the pons after the membranous arachnoid was turned over. **VI:** abducent nerve; **VII:** facial nerve; **VIII:** vestibulocochlear nerve; **IX–XI:** glossopharyngeal-vagal accessory nerve complex; **XII:** hypoglossal nerve; **AICA:** anterior inferior cerebellar artery; **PICA:** posterior inferior cerebellar artery; **BA:** basilar artery; **VA:** vertebral artery; **Arac.S.:** arachnoid sheath; **MA:** membranous arachnoid; **TA:** trabecular arachnoid.

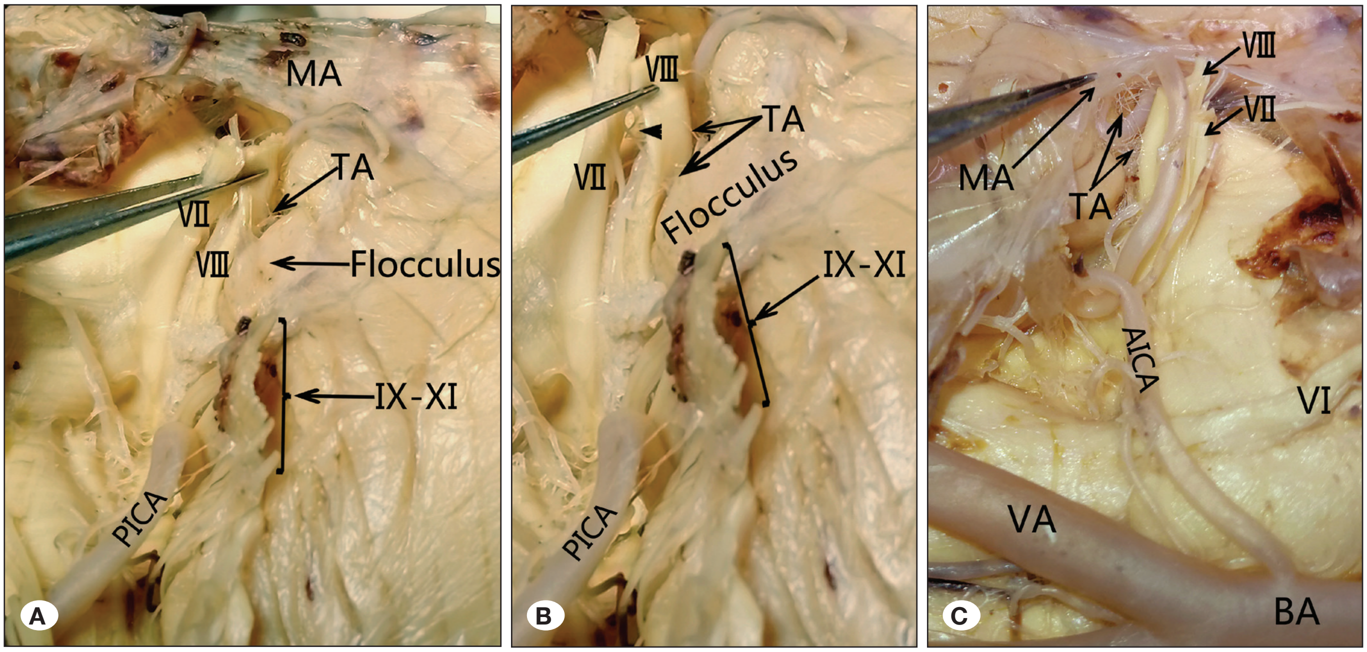

Figure 3: Dense trabecular arachnoid around the facio-cochleovestibular nerve and AICA. **A)** The trabecular arachnoid connection between the facio-cochleovestibular nerve and flocculus was exposed by pulling the nerves medially. **B)** Dissecting the superficial trabeculae and further pulling of the nerves exposed the tight trabecular connection between the nerves and flocculus, and the trabecular connection between the facial and vestibulocochlear nerve was also exposed (arrowhead). **C)** The dense trabecular arachnoid connection around the AICA is shown. **VI:** abducent nerve; **VII:** facial nerve; **VIII:** vestibulocochlear nerve; **IX–XI:** glossopharyngeal-vagal accessory nerve complex; **XII:** hypoglossal nerve; **AICA:** anterior inferior cerebellar artery; **PICA:** posterior inferior cerebellar artery; **BA:** basilar artery; **VA:** vertebral artery; **MA:** membranous arachnoid; **TA:** trabecular arachnoid.

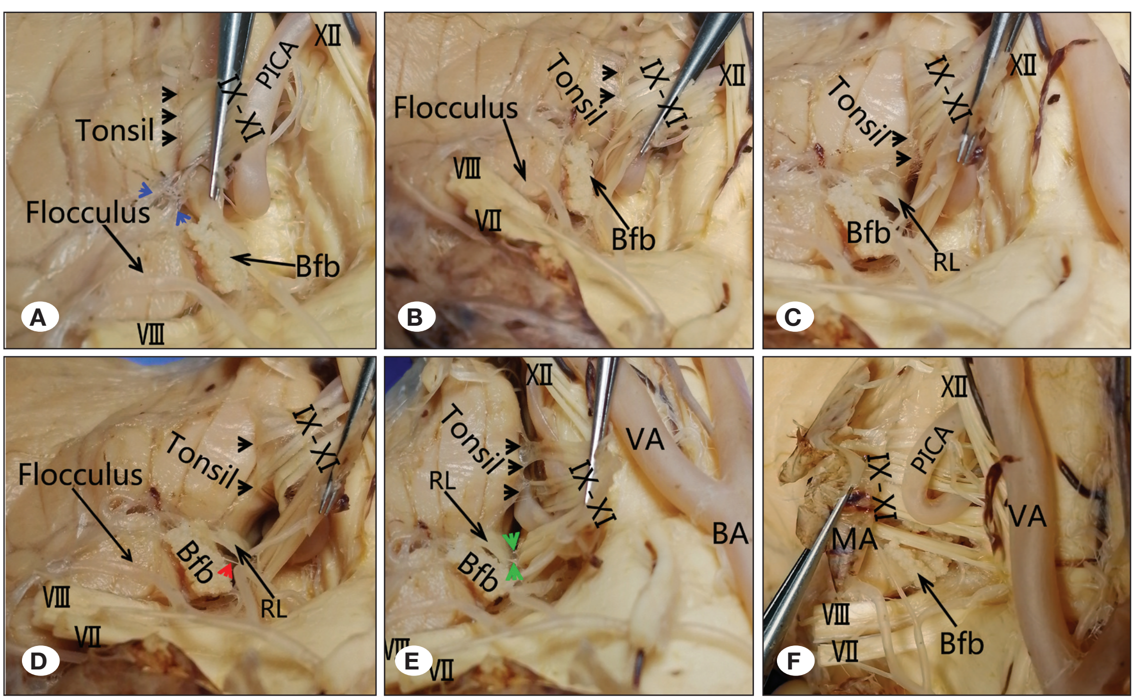

Figure 4: Trabecular arachnoid around the lower cranial nerves: A–E) Continuous separation and exposure of the proximal segment of the lower cranial nerves from their lateral side shows the tight trabeculae connecting the nerves to the cerebellar flocculus (blue arrowhead) and cerebellar tonsil (black arrowhead) and the sparse trabeculae connecting the nerves to Bfb (red arrowhead) and the rhomboid lip (green arrowhead). **F)** Few trabeculae were found on the nerves' medial side. **VII:** facial nerve; **VIII:** vestibulocochlear nerve; **IX–XI:** glossopharyngeal-vagal accessory nerve complex; **XII:** hypoglossal nerve; **Bfb:** Bochdalek's flower basket; **PICA:** posterior inferior cerebellar artery; **BA:** basilar artery; **VA:** vertebral artery.

and the cerebellar flocculus were observed laterally (cerebellar side) to the facio-cochleovestibular nerve (Figure 3A, B). Laterally (cerebellar side) to the lower cranial nerves, there were dense arachnoid trabecular connections between the nerves and the cerebellar flocculus rostrally, and dense arachnoid trabecular connections between the nerve and the cerebellar tonsil caudally (Figure 4A–E). On the medial (brainstem) side of these nerves, the arachnoid trabeculae that attach to the nerves were sparser than those on the lateral (cerebellar) side; only a few linear arachnoid trabeculae connected the nerves to the brainstem or adjacent blood vessels (Figure 4F).

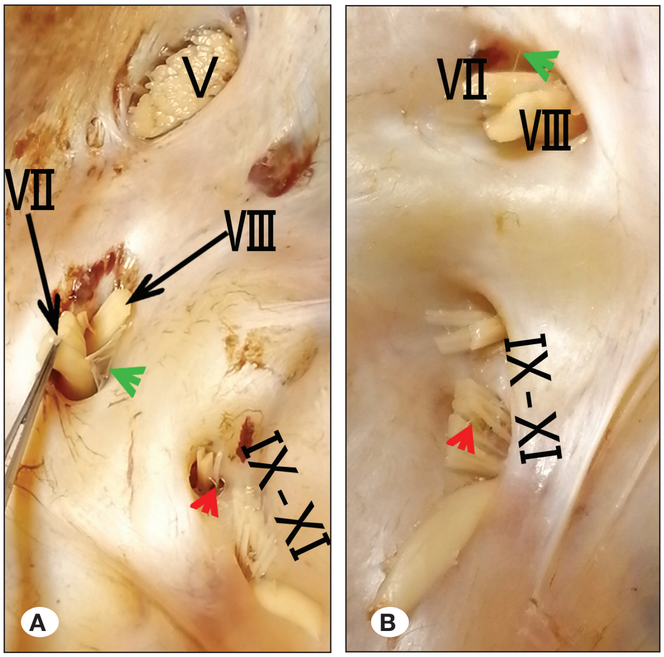

Figure 5: Trabeculae in the internal acoustic meatus and jugular foramen: A) Triangular trabeculae (green arrowhead) connecting the vestibulocochlear nerve to the inner wall of the acoustic meatus, and linear trabeculae (red arrowhead) connecting the glossopharyngeal nerve to the wall of the jugular foramen. **B)** Linear trabeculae (green arrow) connecting the facial nerve to the inner wall of the acoustic meatus, and a dense trabecular connection (red arrowhead) between vagus nerve fibers in the jugular foramen. **VI:** abducent nerve; **VII:** facial nerve; **VIII:** vestibulocochlear nerve; **IX–XI:** glossopharyngeal-vagal accessory nerve complex.

At the distal segment (in the inner acoustic meatus and jugular foramen) of the nerves, we observed trabeculae that attached the nerve to the inner wall of the acoustic meatus and jugular foramen (Figure 5A, B). In addition, arachnoid trabecular connections were observed between nerves (Figure 3B, 5B, 6A), blood vessels (Figure 3C), and blood vessels and the membranous arachnoid (Figure 6A, B). The rhomboid lips of various sizes and thicknesses were easily exposed in all cadaveric specimens. Sparse arachnoid trabecular connections were observed between the lower cranial nerves and rhomboid lip (Figure 4C–E).

DISCUSSION

Arachnoid dissection is a necessary and important step in MVD (8). Thorough insight into the microstructural anatomy of the arachnoid is crucial for minimally invasive facial nerve MVD. Although many studies have described the cisterns, arachnoid, and surgical anatomy for hemifacial spasms, few papers have focused on the microstructural anatomy of the arachnoid in this approach (13,14,16,19,21). By retrospectively reviewing video data of 55 patients subjected to facial nerve MVD and the dissection of eight cadaveric head specimens, we have provided a detailed presentation for the arachnoid from the infrafloccular approach. This provides an anatomical reference for the reasonable treatment of local arachnoid during facial nerve MVD.

Main Findings

The arachnoid microstructure around the facio-cochleovestibular and lower cranial nerve consists of two parts: the outer membranous part and the inner trabecular part. The membranous part forms two nerve sheaths, and the trabecular part

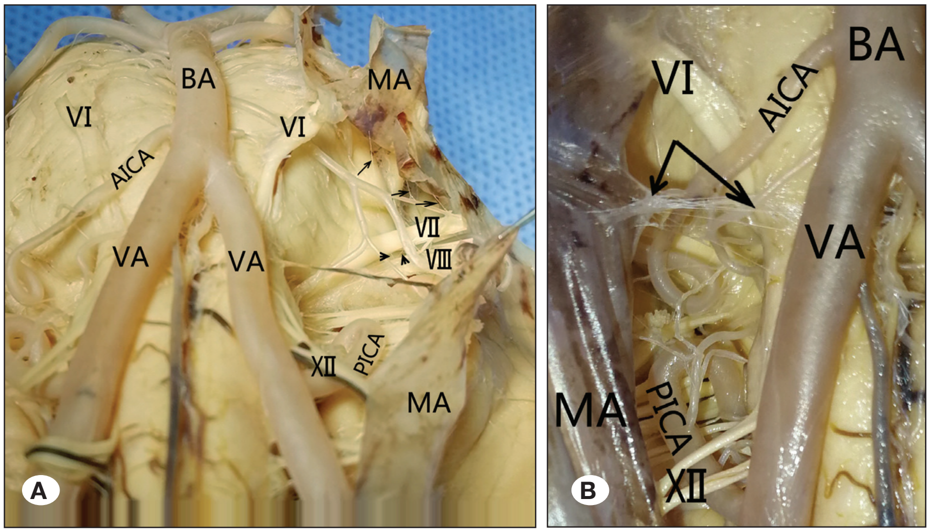

Figure 6: Trabecular connections between blood vessels, nerves, and the membranous arachnoid: A) Linear trabecular connections are seen between the AICA and membranous arachnoid (arrow) and between adjacent lower cranial nerves (arrowhead). **B)** A dense trabecular connection between the vertebral artery and membranous arachnoid (arrow). **VI:** abducent nerve; **VII:** facial nerve; **VIII:** vestibulocochlear nerve; **IX–XI:** glossopharyngeal-vagal accessory nerve complex; **XII:** hypoglossal nerve; **AICA:** anterior inferior cerebellar artery; **PICA:** posterior inferior cerebellar artery; **BA:** basilar artery; **VA:** vertebral artery; **MA:** membranous arachnoid.

below connects the nerves and blood vessels inside the two nerve cavities and forms a complex mechanical integrative unit.

Manipulation of the Arachnoid Around the Lower Cranial Nerve

In the present study, we found dense arachnoid trabecular connections between the lower cranial nerves and cerebellar flocculus rostrally and between the nerve and cerebellar tonsil caudally. Separating the arachnoid connection (including both the membranous and trabecular parts) is the precondition for entering the cerebellomedullary fissure. As exposing the REZ through the cerebellomedullary fissure is the only option for the infrafloccular approach, full and sharp separation of the arachnoid (including both the membranous and trabecular parts) around the lower cranial nerves is necessary. As such, we agree with previous studies (1,6,9,11,19).

Manipulation of the Arachnoid Around The Facio-Cochleovestibular Nerve

As the facio-cochleovestibular nerve is connected to the membranous sheath of the lower cranial nerve along the surface of the flocculus, the retraction of the flocculus will inevitably lead to indirect and varying degrees of pulling on the facio-cochleovestibular nerve during the treatment of the membranous arachnoid, which forms the sheath of the facio-cochleovestibular nerve. Thus, to prevent likely pulling injuries to the nerves, a sharp separation of the membranous sheath before pulling the flocculus is necessary. The treatment of the arachnoid trabeculae around the facio-cochleovestibular nerve depends on the situation. If the offending vessel is in a deep position (meaning that only a slight pull of the flocculus cannot expose the offending vessel sufficiently and that a dramatic retraction of the flocculus is needed), then it is necessary to sharply separate the arachnoid trabeculae around the facio-cochleovestibular nerve, so as to avoid damaging the nerves via flocculus retraction. Conversely, if the offending vessel is in a shallow position (meaning that only a slight pull of the flocculus can clearly expose it through the cerebellomedullary fissure), retracting the flocculus will not lead to increased trabecular tension, indicating that there is no possibility of injury to the facio-cochleovestibular nerve. In this case, the arachnoid trabeculae around the facio-cochleovestibular nerve can be preserved intact. This may explain why different surgeons have different views on whether or not to separate the arachnoids surrounding the facio-cochleovestibular nerve (2,7,22).

Manipulation of the Arachnoid Around the Offending and Non-Offending Blood Vessels

In this study, we found various numbers of arachnoid trabecular attachments around the offending and non-offending vessels. Normally, these trabeculae play an important role in fixing the position of blood vessels. During decompression surgery, pulling and relocating the offending vessel is necessary; however, we strongly recommend full separation of the arachnoid trabecula around the offending vessel beforehand. On the one hand, if full separation is not performed, the residual arachnoid trabecula will contribute to incomplete decompression in neurovascular conflict. On the other hand, postoperative restoration under traction of the surrounding trabeculae may occur and lead to disease recurrence. For non-offending blood vessels, if exposure to the REZ is not affected, the surrounding arachnoid trabeculae can be preserved as much as possible to prevent the rupture of trabecular restrain, which can lead to overall mechanical imbalance and blood vessel displacement, potentially resulting in secondary complications. If exposure of the REZ is affected, sufficient separation of the arachnoid trabeculae around the blood vessels is recommended, as local separation may lead to traction imbalance and induce blood vessel displacement and secondary complications (5,18).

Manipulation of the Rhomboid Lip and Its Surrounding Arachnoid

The rhomboid lip is a sheet-like neural tissue and thicker than a normal arachnoid membrane (3). In the present study, rhomboid lips of various sizes and thicknesses were easily exposed in all cadaveric specimens during craniotomy; however, as a previous study reported (17), we found intraoperatively that it is not a constant structure (2/55, 3.6%). The rhomboid lip is highly variable in size and thickness (4), and the inconsistency of our findings with the previously reported incidence (26.5%) (17) is most likely because some of them were too small to be exposed during this procedure.

The craniotomy indicated dense arachnoid trabecular connections between the lower cranial nerves and rhomboid lip. The small rhomboid lip, which does not obstruct exposure of the facial nerve REZ, can be left intact. Conversely, the large rhomboid lip should be resected during surgery after sharply separating it from the lower cranial nerves to remove obstacles to the facial nerve REZ.

CONCLUSION

With the aid of arachnoid connections, the facio-cochleovestibular nerve, lower cranial nerve, and their surrounding structures form a physical structure. Based on the characteristics of the arachnoid microstructure and the variable positions of the offending vessels, individual protocols should be designed before surgery to prevent the occurrence of accidental injuries and secondary complications.

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