

MICROANATOMY OF THE CLIVUS: DURAL ARCHITECTURE AND VENOUS PATHWAY

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The extradural venous system and dural sinuses around the clivus were examined using cadaver heads, especially from the viewpoint of the venous drainage pathway at the basilar plexus and microanatomy of the dural texture. Moreover, histological sections of the clivus were studied in order to disclose the dural architecture consisting of basilar plexus.

Key words: clivus, basilar plexus, cadaveric dissection, microanatomy, dural architecture, histological study

INTRODUCTION

The dural architecture and venous pathway of the clivus are complicated and occasionally variant. Despite several articles describing the venous system around the clivus from the viewpoint of the surgical approach to the cavernous sinus and craniovertebral junction (1-13), there are few reports systematically describing this region. In the present study, we investigated the venous drainage pathway and dural texture around the clivus using cadaver heads.

MATERIALS AND METHODS

Cadaveric dissection

Ten formalin-fixed and two fresh human adult cadaver heads were provided for this study. All procedures used in this study were performed in accordance with the Helsinki Declaration. Before dis-

section, colored latex was injected through the jugular veins and fixed for 24 hours. In 10 out of 12 cadaver heads, a posterior approach was selected. After performing lamino-facetectomy and partial foraminotomy of C1-C3 vertebra with various lateral suboccipital transcondylar approaches (1,2,5,11,12) followed by posterior fossa and carverial craniotomy, entire removal of the spinal cord, cerebellum, brain stem and bilateral cerebrum was carried out. The anterior approach was performed in two out of 12 specimens by transoral-transmandibular approach. After splitting the mandible and pharyngeal mucosa followed by removal of the arch of the C1 and odontoid process of C2 and clivectomy, the anterior aspect of the clival dura could be observed. Subsequently, microscopical observation was carried out under a surgical microscope at $\times 3$ to $\times 40$ magnification.

Histological study

Histological specimens of the clivus were made at upper, middle and lower parts of the sagittal section. Nitric acid solution (10%) was used for decalcification of the clival bone after 10 % formalin solution for fixation. After marking the histological section with Masson trichrome staining to realize the architecture of the vessels and connective tissue like collagen and elastic fibers, we inspected these specimens by light microscope at $\times 2$ to $\times 5$ magnification.

Statistical Analysis

All data are presented as the mean \pm SEM (standard error of the means). Statistical analyses of the anatomical variables were performed using the unpaired t-test. A *P* value less than 0.05 was considered significant.

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RESULTS

Cadaveric dissection

After peeling off the meningeal dura from the dorsum sellae, we could see the coarse fibrous tissue under the meningeal dura and true venous pooling in the basilar plexus (Fig.1). This fibrous tissue is supposed to be a periosteal dura because it is continuous from the deep layer of the lateral wall of the cavernous sinus (14).

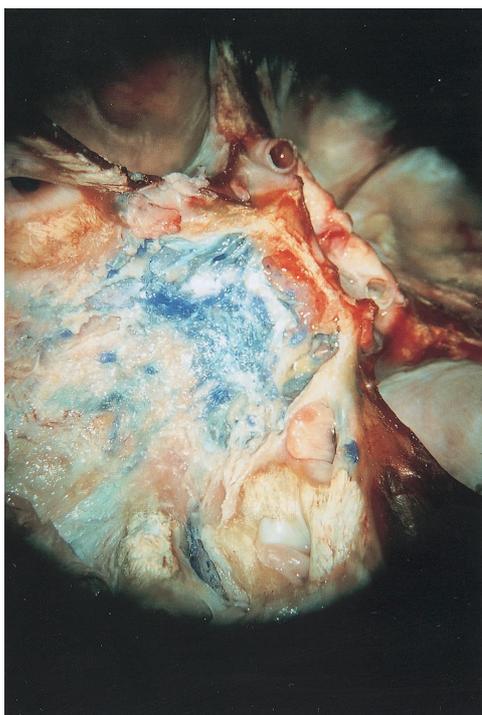


Fig. 1. Microphotograph showing basilar plexus after peeling off the meningeal dura.

The meningeal dura continues to the superficial layer of lateral wall of the cavernous sinus, composed of meningeal dura of the middle fossa.

The basilar plexus is also a dural sinus and exists at the dorsal surface of the clivus. The upper part of the meningeal dura covering the basilar plexus continues to the meningeal dura of the diaphragma sellae at the dorsum sellae and spreads laterally, shifting to the meningeal dura of the posterior fossa covering the posterior wall of the petrous bone. Furthermore, this continues inferiorly to the spinal meningeal dura.

The abducent nerve is only nerve penetrating the meningeal dura through Dollero's canal at the clivus. Dollero's canal never includes a venous drainage

pathway in the basilar plexus. There are some variations in the position of the Dollero's canal. In the present measurements, the length between the posterior clinoid process and Dollero's canal was 18.0 ± 0.8 mm on the right side and 16.9 ± 0.9 mm on the left side. Statistical analysis between them was not significant ($P=0.3552$ by unpaired t -test) (Table 1). The true venous space of the basilar plexus communicates to the bilateral cavernous sinus freely beyond the posterior petroclinoid ligament, which is a tough fibrous band between the posterior clinoid process and the apex of the petrous bone (15).

Table 1. Measurements of the length between posterior clinoid process and Dorello's canal in 20 sites

No	Right (mm)	Left (mm)
1	13.0	16.2
2	19.9	13.2
3	16.1	18.8
4	17.6	12.4
5	15.8	17.8
6	21.0	20.1
7	19.8	17.9
8	20.2	14.8
9	16.5	15.8
10	20.4	21.5
average	18.0 ± 0.8	16.9 ± 0.9
(range)	(13.0-21.0)	(13.2-21.5)

Inferiorly, this true venous pooling does not continue to the level of the foramen magnum but terminates at the level of the midclival region. The average length of the true basilar plexus is 26.9 ± 1.7 mm (57.8 ± 3.7 %), while the average length of the clivus is 46.7 ± 1.0 mm (Fig. 2) (Table 2). At the lower part of the clivus, we could see only a poor venous network coming from the anterior internal vertebral venous plexus. This coarse fibrous tissue, which might be periosteum, continues to the tectorial membrane which is transformed to the posterior longitudinal ligament (PLL) in the intraspinal canal.

The apical ligament is a thick fibrous tissue and connects with the anterior surface and lower margin of the anterior aspect of the foramen magnum and the superior surface of the dens. More posteriorly, the vertical portion of the cruciform ligament connects with the lower part of the clivus and dorsal part of the dens. The transverse part of the cruciform ligament (transverse ligament) crosses the vertical part of the cruciform ligament at the dorsal surface of the dens. The tectorial membrane is continuously

from the posterior longitudinal ligament at the level of foramen magnum and then terminates and fuses to the intracranial meningeal dura at about the midclival region.

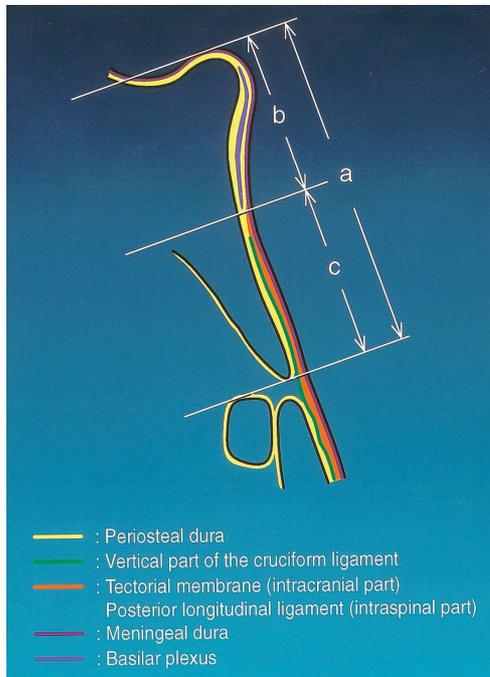


Fig. 2. Histological schematic drawing of midsagittal clival region. a: length of the clivus, b: length of the basilar plexus, c: a-b.

Table 2. Measurements of the length of the clivus, basilar plexus and their proportion in 10 specimens

No	a (mm)	b (mm)	c (mm)	b/a×100 (%)
1	48.8	20.2	28.6	41.4
2	49.8	25.1	24.7	51.4
3	51.1	32.1	19.0	62.8
4	45.8	27.2	18.6	59.4
5	49.8	25.0	24.8	50.2
6	46.4	36.8	9.6	79.3
7	42.6	21.4	21.2	50.2
8	45.0	31.8	13.2	70.7
9	44.4	21.0	23.4	47.3
10	43.0	28.0	15.0	65.1
average	46.7±1.0	26.9±1.7	19.8±1.9	57.8±3.7
(range)	(42.6-51.1)	(21.0-36.8)	(9.6-28.6)	(41.4-79.3)

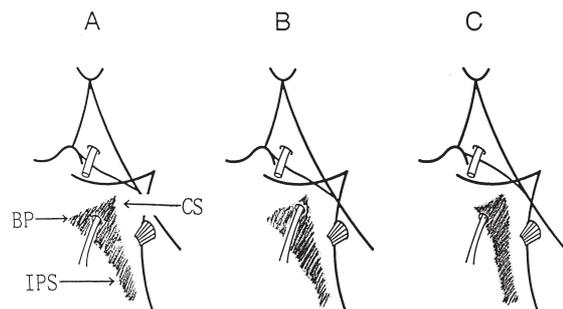
a : length of the clivus, b : length of the basilar plexus, c : a-b.

The anterior internal vertebral venous plexus also communicates with the marginal sinus, the posterior part of the jugular bulb and the distal sigmoid sinus, and then enters the inferior petrosal sinus and/or posterior internal vertebral venous plexus through the jugular foramen and hypoglossal canal (16-19). Even in the midsagittal section of the clival dura exposed by means of transoral-transmandibular approach, we could see the venous pool of the basilar

plexus only at the upper half of the clivus (Fig 2).

The superior petrosal sinus (SPS) starts from the anterior aspect of the transverse-sigmoid sinus junction and runs antero-medially just beneath the free edge of the cerebellar tentorium, and finally coming into the posterior part of the cavernous sinus at the crossing point between the anterior and posterior petroclinoid folds. This means that the SPS opens into not only the cavernous sinus but also the basilar plexus.

The inferior petrosal sinus (IPS) originates from the basilar plexus and/or posterior part of the cavernous sinus and runs postero-laterally just above the petro-occipital fissure (synchondrosis), finally coming into the jugular bulb at its anterior aspect through a multiple pathway between the IX and X-XI cranial nerves. In the present observations, we saw three patterns of venous drainage between the basilar plexus, cavernous sinus and IPS (Fig. 3). Type A (Fig.4-A) means that IPS comes equally from both the basilar plexus and postero-inferior part of the cavernous sinus. Type B (Fig.4-B) means IPS comes mainly from the basilar plexus. Type C means IPS comes dominantly from the postero-inferior part of the cavernous sinus. The most prominent drainage pattern was type A, seen in 15 out of 20 sites (75%) followed by 2 (10%) in type B and 3 (15%) in type C.



	A	B	C
Right n=10	6	2	2
Left n=10	9	0	1

Fig. 3. Three types of venous communication between cavernous sinus, basilar plexus and inferior petrosal sinus. BP: basilar plexus, CS: cavernous sinus, IPS: inferior petrosal sinus.



Fig. 4-A. Microphotograph disclosing the relationship of type A as shown in Fig.3 among the inferior petrosal sinus, basilar plexus and posterior part of cavernous sinus.

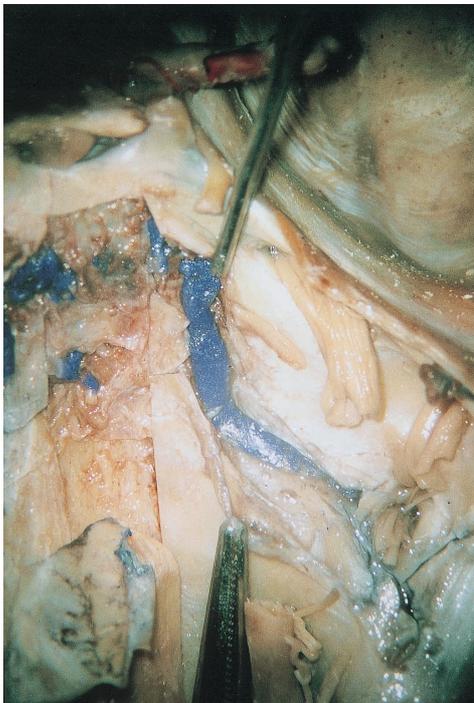
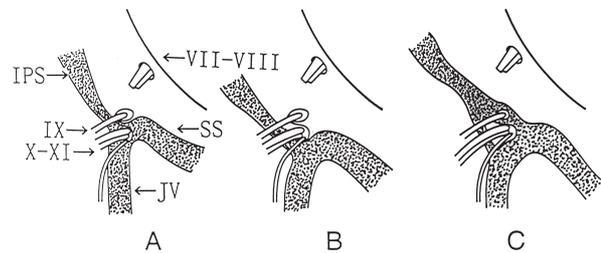


Fig. 4-B. Microphotograph disclosing the relationship of type B as shown in Fig.3 among the inferior petrosal sinus, basilar plexus and posterior part of cavernous sinus.

As for the correlation between the IPS and the IX and X-XI cranial nerves which are divided into the

anterior part of the glossopharyngeal nerve and the posterior part of the vagal and accessory nerves by the dural septum, we were able to clarify three patterns (Fig 5); Pattern A means IPS travels mainly between the IX and X-XI nerves. Pattern B means IPS is passes below the X-XI nerves. Pattern C means IPS takes multiple pathways among these nerves. The incidence was 2 (10%) in type A, 6 (30%) in type B, and 12 (60%) in type C. We did not see a pathway where the IPS ran only above the IX nerves. The IPS also exited through the jugular foramen to communicate with the anterior and posterior internal vertebral venous plexus.



	A	B	C
Right n=10	2	3	5
Left n=10	0	3	7

Fig. 5. Various patterns of the inferior petrosal sinus (IPS) avenue to the jugular bulb relative to the IX and X-XI cranial nerves.

JV: jugular vein, SS: sigmoid sinus.

Histological study

In the midsagittal histological section of the upper clivus, we recognized true venous space of the basilar plexus surrounding both the anterior and posterior periosteum (Fig.6-A). The anterior periosteum is a lining just above the clival bare bone, and the posterior one is firmly attached and fused with similar fibrous laminal tissue which is thought to be mainly meningeal dura and partly tectorial membrane. At the midclival region and inferior part of clivus, we were not able to detect any difference among these structures because they were fused firmly and appeared as interwoven collagen fibers (Fig. 6-B,C).

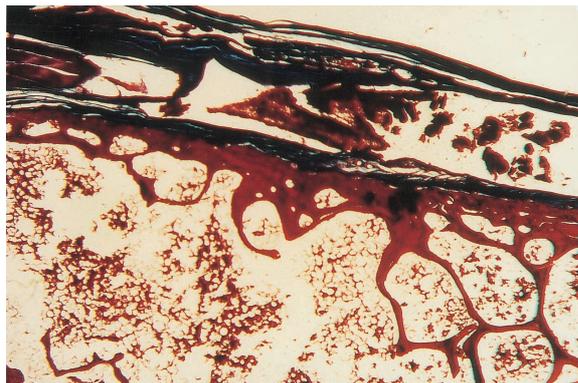


Fig. 6-A

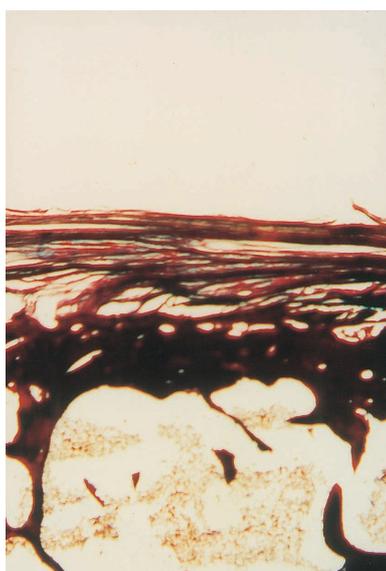


Fig. 6-B

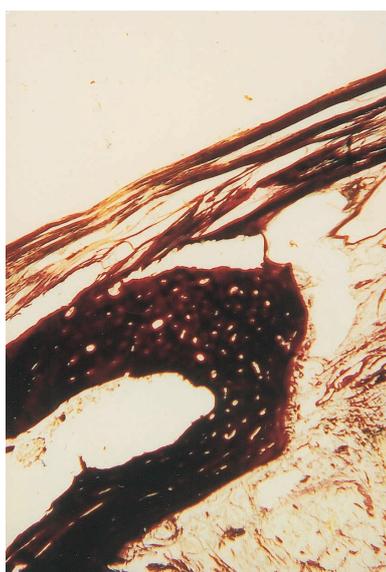


Fig. 6-C

Fig. 6-A,B,C. Microphotograph of the histological specimens of upper (A), middle (B) and lower (C) clivus. Obvious space of the basilar plexus is shown and limited in the upper and middle clivus. Masson trichrome staining, $\times 5$ magnification.

DISCUSSION

According to a general textbook of the anatomy (20), the basilar plexus consists of several interconnecting venous channels located between the layers of dura matter and the clivus. It connects the two inferior petrosal sinuses and communicates with the anterior internal vertebral venous plexus. Krayenbühl and Yasargil (21) also described that the basilar plexus consists of a wide meshed venous plexus encased in the dura and lying against the clivus, and that it extends between the two cavernous sinuses and the inferior petrosal sinuses up to the foramen magnum. The venous plexus, hereafter called the occipital plexus, continues into the internal vertebral venous plexus.

In present microanatomical observation, the upper border of the basilar plexus was the dorsum sellae because the upper part of the meningeal dura covering the basilar plexus continues to the meningeal dura of the diaphragma sellae over the dorsum sellae, spreads laterally over the posterior petroclinoid fold, and continues to the meningeal dura of the lateral wall of the cavernous sinus. The lateral limit of the basilar plexus is supposed to be the posterior petroclinoid fold because this is the only visible landmark in this region before opening the meningeal dura.

The abducent nerve is the only cranial nerve which pierces the meningeal dura through Dorello's canal at the upper clivus. Umansky et al. (22) described the microanatomy of Dorello's canal in detail and showed that the inferior petrosal sinus opens in close proximity to but never with osteofibrous channel itself.

From our observation, the IPS communicates to the basilar plexus and/or posterior inferior part of the cavernous sinus not through Dorello's canal but just around Dorello's canal.

We clarified three types of communication between the IPS, posterior-inferior part of the cavernous sinus and the basilar plexus. As a result, the most usual type of drainage pattern was that of IPS draining from both inferior and posterior parts of the cavernous sinus and the basilar plexus. The location of Dorello's canal varied between specimens. The average length between the posterior clinoid process

and Dorello's canal was 18.0 ± 0.8 mm on the right side and 16.9 ± 0.9 mm on the left.

Concerning the relationship between the IPS and the IX, X-XI cranial nerves, Rhoton *et al.* (9) showed that IPS followed a variable course around the ninth, tenth and eleventh cranial nerves and left the skull through either the pars nervosa or venosa prior to entering the jugular bulb. They devised four patterns as A: Sinus passes below the IX, X-XI cranial nerves before entering the pars venosa. B: Sinus passes between the IX and X cranial nerves. C: Different branches of sinus pass around nerves. D: The sinus passes rostral to the IX cranial nerves, enters the pars nervosa, and passes extracranially to join the anteromedial part of the jugular bulb.

We showed that these were three different types of drainage pathway and that the most usual type of drainage pattern was a multiple pathway between these nerves. However, we did not recognize such a pathway as type D of Rhoton's classification.

After peeling off the meningeal dura of the clivus from the dorsum sellae, we could see the periosteum which is a coarse fibrous tissue continuing to the posterior longitudinal ligament at the vertebral region, and then we could also visualize the true venous pooling of the basilar plexus only at the upper clival region through the periostium and tectorial membrane.

In general, the basilar plexus is thought to be a wide venous lake over the clivus, also communicating with the anterior part of the marginal sinus and/or anterior internal vertebral venous plexus at the foramen magnum (16). However, from our histological observation, the true basilar plexus is limited to the upper clival region and is also surrounded by two layers of periosteum. Furthermore we could only see the poor anterior vertebral venous plexus at the lower clival region. The tectorial membrane fuses to the meningeal dura around the midclival region. In the histological section, we could not see any difference between the meningeal dura, tectorial membrane and periosteal dura, which explains why these fibrous components are thought to be the same histological structures at the midclival region in which the tectorial membrane terminates. We could also clarify this relationship between tectorial membrane and clival meningeal dura from anteriorly by means of transoral-transmandibular app-

roach.

Seeing the midsagittal section of the clival dura on histological specimens, the true venous space of the basilar plexus exists mainly around the upper clival region. At the lower half of the clivus, we could dissect the tectorial membrane from the meningeal dura and no obvious venous lake of the basilar plexus was identifiable at this area. That is, there is likely to be poor anastomoses between the basilar plexus and anterior internal vertebral venous plexus because the tectorial membrane acts as a barrier.

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