



# The myodural bridge complex defined as a new functional structure

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## Abstract

**Purpose** The connective tissue between suboccipital muscles and the cervical spinal dura mater (SDM) is known as the myodural bridge (MDB). However, the adjacent relationship of the different connective tissue fibers that form the MDB remains unclear. This information will be highly useful in exploring the function of the MDB.

**Methods** The adjacent relationship of different connective tissue fibers of MDB was demonstrated based upon three-dimensional visualization model, P45 plastinated slices and histological sections of human MDB.

**Results** We found that the MDB originating from the rectus capitis posterior minor muscle (RCPmi), rectus capitis posterior major muscle (RCPma) and obliquus capitis inferior muscle (OCI) in the suboccipital region coexists. Part of the MDB fibers originate from the ventral aspect of the RCPmi and, together with that from the cranial segment of the RCPma, pass through the posterior atlanto-occipital interspace (PAOiS) and enter into the posterior aspect of the upper cervical SDM. Also, part of the MDB fibers originate from the dorsal aspect of the RCPmi, the ventral aspect of the caudal segment of the RCPma, and the ventral aspect of the medial segment of the OCI, enter the central part of the posterior atlanto-axial interspace (PAAiS) and fuse with the vertebral dura ligament (VDL), which connects with the cervical SDM.

**Conclusions** Our findings prove that the MDB exists as a complex structure which we termed the ‘myodural bridge complex’ (MDBC). In the process of head movement, tensile forces could be transferred possibly and effectively by means of the MDBC. The concept of MDBC will be beneficial in the overall exploration of the function of the MDB.

**Keywords** Myodural bridge · Three-dimensional visualization model · P45 plastinated slices · Suboccipital region

## Introduction

The suboccipital region is one of the most complicated areas in the human body. In this region, studies by Hack et al. [5] revealed that there were dense fibrous connective tissues between the rectus capitis posterior minor muscle (RCPmi) and the posterior atlanto-occipital (PAO) membrane, and between the PAO membrane and the cervical spinal dura mater (SDM). Hack et al. named these connective fibers between the muscles and the SDM as the ‘myodural bridge’ (MDB). In recent years, multiple studies [1, 6, 8, 9, 11, 12, 16, 17] have shown that the MDB also exists between the rectus capitis posterior major muscle (RCPma), the obliquus capitis inferior muscle (OCI), the nuchal ligament (NL) and the cervical SDM in the atlanto-axial interspace. Furthermore, connective fibers between the SDM and the posterior wall of the vertebral canal at the level of the atlas to the axis were also found. This band of connective tissue

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was identified as the vertebral dura ligament (VDL) [22]. Based on a morphological research on five different mammalian orders, including tree-dwelling primates (*Macaca mulatta*), land-based carnivores (*Canis familiaris* and *Felis catus*), Cave-dwelling lagomorpha (*Oryctolagus cuniculus*) and rodentia (*Ratus norvegicus* and *Cavia porcellus*), and aquatic cetaceans (*Indoasian finless porpoise*), Zheng et al. [21] proposed that the MDB is an evolutionally conserved structure present in many mammals. This offers an insight for understanding the physiological significance of the MDB, especially in humans.

According to morphological studies, the MDB is speculated to be associated with the transmission of proprioception [7, 13], keeping the subarachnoid space and the posterior cerebellomedullary cistern patent [17]. Recently, Zheng et al. [22] and Xu et al. [19] speculated that the MDB may be one of the factors which could affect the dynamic circulation of the cerebrospinal fluid (CSF). In addition, clinicians have found that pathologic MDB might cause a cervicogenic or chronic tension-type headache [2, 3, 10, 15, 20].

Although previous studies have confirmed the existence of the MDB from the deep suboccipital muscles excluding the oblique capitis superior muscle (OCS), the inter-relationships among the MDB fibers originating from the different suboccipital muscles remain unclear. We investigated in this study the adjacent relationship and organization of the fibers of the MDB originating from different suboccipital muscle sources. This information will be highly useful in exploring the functions of the MDB.

## Materials and methods

### Three-dimensional reconstruction of structures in suboccipital region

#### Images acquisition

The images were obtained from the Visible Korean project—an anatomical photographic digital images database [14]. Images from one middle-aged male having the suboccipital structure were selected and a total of 222 images were obtained.

#### Images segmentation

Structural segmentation of the suboccipital region was performed by six anatomical experts using Photoshop software. The structures of interest (SOI) are RCPma; RCPmi; OCI; Atlas; Axis; Occipital bone; SDM and MDB. Each expert segmented one SOI according to its anatomical location, color and texture. Each structure was established as a layer and filled with a different RGB color (Fig. 1).

### Calculating three-dimensional (3D) models

Mimics Innovation Suite 18.0 software was employed for making 3D calculations and models. The segmented images were imported into Mimics software. The set pixel size and layer thickness were maintained at  $x = 0.1$  mm,  $y = 0.1$  mm,  $z = 0.2$  mm. The threshold segmentation feature of the soft was used to segment the structures and then the 3D model calculations were carried out.

The 3D model of structures in the suboccipital region was established. This 3D model did not only show the morphology of the occipital bone, axis and atlas but also showed the adjacent relationships among the SOI.

### 3D models observations and recordings

The adjacent location relationships between muscles and PAOiS, PAAiS were observed and recorded. These include the inter-relationships among MDBs originating from different muscles and their adjacent location when passing through the atlanto-occipital and atlanto-axial interspaces.

### P45 plastinated sheets production of the head and neck specimens

Formalin-fixed head and neck of seven middle-aged male specimens were used for P45 sheet plastination [4, 18]. Two were prepared for sagittal slices, two were prepared for frontal slices and three were prepared for transversal slices.

P45 plastinated sheets production steps are as follows:

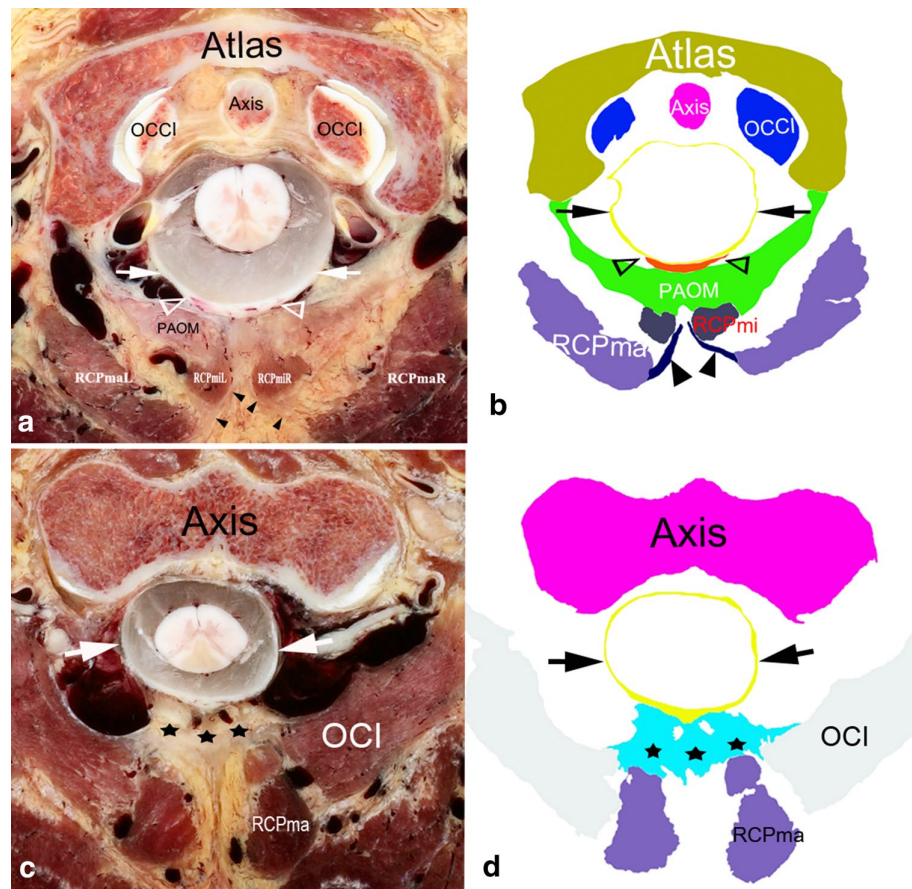
#### Slicing

The embalmed specimens of the head and neck were frozen at  $-70$  °C for 2 weeks and then embedded in polyurethane foam and kept at  $-70$  °C for another 2 days. After freezing, 3-mm sagittal slices were made with a high-speed vertical band saw machine (MJ329Z, Xingtai Yashida Machinery Manufacturing Co., Ltd, China).

#### Bleaching

All the slices were rinsed for 24 h in cold running water, and afterwards, the slices were immersed in 5% dioxogen for 24 h.

**Fig. 1** Suboccipital structures are segmentation in different colors: **a, b** photos of slice and segmentation at the level of PAOiS; **c, d** photos of slice and segmentation at the level of posterior PAAiS. empty circle fibrous connection between PAO membrane and SDM (**a, b**); filled circle fibers from RCPma run anteriorly and medially through the PAOiS to connect with the PAO membrane; filled star fibers from RCPma and OCI combine to run through the PAOiS and connect with the SDM (**c, d**). arrow Spinal dura mater. *CI* atlas, *C2* Axis, *OCI* obliquus capitis inferior, *OCCI* Occipital bone, *RCPma* the rectus capitis posterior major, *RCPmaL* the left rectus capitis posterior major, *RCPmaR* the right rectus capitis posterior major, *RCPmi* rectus capitis posterior minor, *RCPmaL* the left rectus capitis posterior minor; *RCPmiR* the right rectus capitis posterior minor



### Dehydration

After bleaching, the slices were dehydrated with 100% acetone by the freeze substitution method.

### Casting and forced impregnation

After dehydration, the casting mold was prepared. The slices were lifted from the acetone bath and placed between two glass plates. The molds were then filled with polyester (Hoffen polyester P45, Dalian Hoffen Bio-Technique Co. Ltd., Dalian, P. R. China.). The filled mold was then placed upright into a vacuum chamber at room temperature for impregnation. The large bubbles on the surface of the slices were removed manually with a 1-mm stainless steel wire. The absolute pressure was slowly decreased to 20, 10, 5, and 0 mm Hg, according to the bubble releasing. The pressure was maintained at 0 mm Hg until bubbling ceased. The impregnation step lasted for more than eight hours.

### Curing

After the vacuum was released, the air bubbles within the sheets were checked and removed. The alignment of the slices was checked and corrected using a stainless steel wire. The top of the mold was clamped with large fold back clamps, and the sheet was then ready for curing. The sheets were cured using a heated water bath and were placed upright in a water bath at 40 °C for 3 days.

### Cutting and sanding the molds

After curing, the sheets were removed from the bath and cooled to room temperature in a rack. The slices were then removed from the flat chamber and covered appropriately with adhesive plastic wrap for protection. A mini-band saw was used to cut and trim the plastic along the edges approximately 1 mm outside the slices. Then, a wool sander was used to remove the sharp edges of the slices. After sanding, the adhesive plastic wrap was removed, and the slices were placed in non-adhesive plastic wrap to avoid scratches.

The different fibers that form the MDB, their coursing and inter-relationships at the PAOiS and PAAiS were observed and recorded.

### HE staining

Five formalin-fixed head and neck of middle-aged male specimens were used for histological study. Specimens were dissected at the nuchal region from the superficial layer to the deep layer, exposing the suboccipital muscles. The cranial attachment of the RCPmi, RCPma and pericranium were separated down from the occipital bone, until the margin of foramen magnum was exposed. The transitional dura mater between the cranial dura mater and SDM was exposed and incised. The lateral border of OCI which attaches to the transverse processes of the atlas was separated. A longitudinal cut was made along the lateral border of the RCPma and OCI, down to the interspace between the posterior arches of the axis and third cervical vertebra. A tissue sample that included the suboccipital muscles, posterior arch of the atlas, arch of the axis, and posterior part of the SDM was separated from the specimen.

The tissue samples were cleaned, and then placed in Ethylene Diamine Tetra acetic Acid (EDTA) for decalcification for about 2 months at 37 °C. After that, the tissue samples

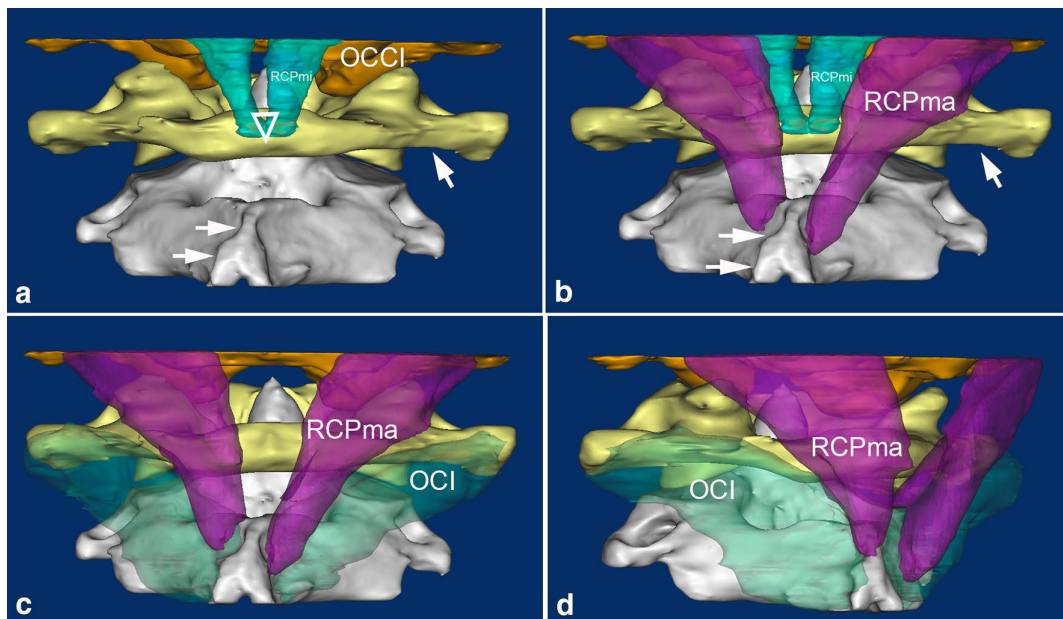
were washed in running water for 12–24 h. Regular dehydration, clearing and paraffin embedding procedures were applied. Sections of 13–15- $\mu$ m thickness were cut out with a rotary microtome and mounted on a glass slide. Hematoxylin and eosin staining was used to stain the sections. Sections were viewed and photographed with an NIKON research light microscope at 400 $\times$  magnification. Multiple images from each section were stitched together using the Microsoft image composite editor of NIKON Eclipse80i computer processing and analysis system.

The course and inter-relationship of the fibers that form the MDB at the PAOiS and PAAiS were observed and recorded.

### Results

#### Adjacent location relationships of muscles covering the posterior vertebral interspace showed in the 3D visualization model

The 3D morphology and the adjacent location relationships of the RCPmi, RCPma, OCI, SDM, PAOiS and PAAiS were clearly shown in the 3D visualization model.

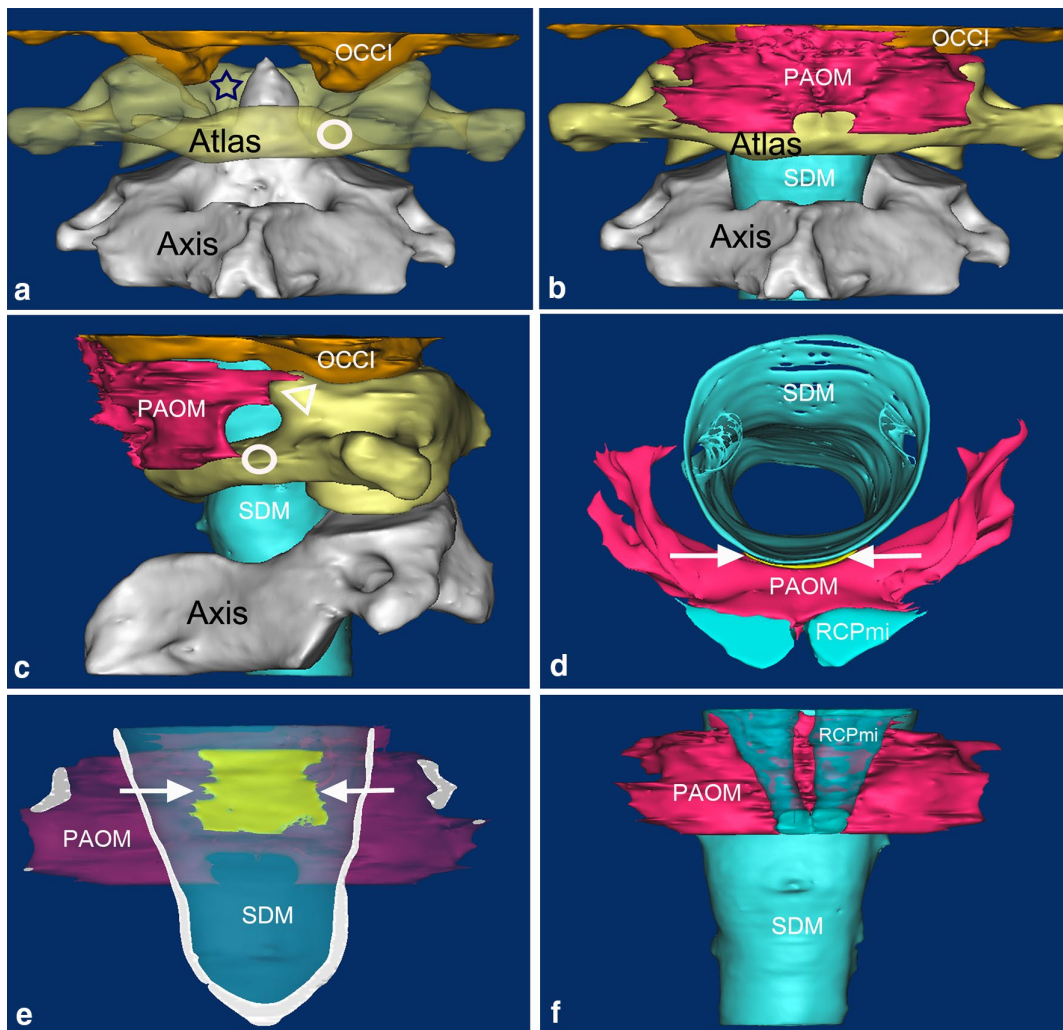


**Fig. 2** Three-dimensional visualization models of muscles and bones in the Suboccipital Region (dorsal view): The RCPmi connects with the posterior tubercle of the atlas (empty triangle), and the occipital bone (a, b). It is anterior to RCPma and crosses the PAOiS. The RCPma connects with the superior half of the spinous process of the axis (arrow) and the occipital bone (c). It crosses two interspaces, the

PAOiS and PAAiS. The OCI connects with the dorsal aspect of the transverse process of the atlas (North West arrow), the spinous process and the posterior arch of the axis (c). It is located inferolateral to the RCPma and crosses the PAAiS. *OCI* obliquus capitis inferior, *RCPma* rectus capitis posterior major, *RCPmi* rectus capitis posterior minor

The 3D visualization model showed that the RCPmi connects with the posterior tubercle of the atlas and the occipital bone. It crosses the PAOiS and is located anterior to the RCPma. The RCPma connects with the superior half of the spinous process of the axis and the occipital bone (Fig. 2a, b). It crosses two interspaces, the PAOiS and the PAAiS. The OCI connects with the dorsal aspect of the

transverse process of the atlas, the spinous process and the posterior arch of axis (Fig. 2c). It is located laterocaudal to the RCPma and crosses the PAAiS. The medial half of the PAOiS is covered by the RCPmi (Fig. 2a, b), while the lateral half is covered by the RCPma. The medial half of the PAAiS is covered by RCPma, while the lateral half is covered by the OCI. No muscle directly covers the space in the middle of the PAAiS (Fig. 2c).



**Fig. 3** Three Dimensional Visualization Models of PAOiS and PAO Membrane in Suboccipital Region: **a** PAOiS (dorsal aspect view); **b** PAO membrane (dorsal aspect view); **c** PAO membrane (right aspect view); **d** PAO membrane (cranial aspect view); **e** coronary section of SDM (anterior aspect); **f** connection between RCPmi and PAO membrane (posterior aspect) PAOiS (empty star) is located between the posterior margin of the foramen magnum and the superior margin of the posterior arch of the atlas. It is occupied by the PAO membrane which blends with the atlanto-occipital joint capsules at the cranial and caudal ends (b). The lateral ends of the PAO membrane are bifur-

cated and attach to the medial aspect of the articular surface of the atlas (empty triangle) and the superior margin of the posterior arch of the atlas (empty circle), respectively. The bifurcated ends of the PAO membrane leave a space for the passage of the vertebral artery (c). The mid-dorsal aspect of PAO membrane is covered by the RCPmi (d, f). Dense tissue bands (meeting arrows) connect with the SDM in the mid-ventral part of PAO membrane (d, e). OCCI occipital bone, PAOM posterior atlanto-occipital membrane, RCPma rectus capitis posterior major, RCPmi rectus capitis posterior minor, SDM spinal dura mater

### 3D visualization model of the posterior atlanto-occipital membrane

PAOiS is located between the posterior margin of the foramen magnum and the superior margin of the posterior arch of the atlas; and bound laterally by the atlanto-occipital joint (Fig. 3a). PAO membrane occupies this space and blends with the atlanto-occipital joint capsule (Fig. 3b). The lateral ends of the PAO membrane are bifurcated and attach to the medial margin of the articular surface of the atlas and the superior margin of the posterior arch of the atlas, respectively. These two bifurcated ends of the PAO membrane leave a space for the vertebral artery to pass (Fig. 3c).

The mid-dorsal aspect of the PAO membrane is covered by the RCPmi (Fig. 3d, f). Connective tissue bands originating from the RCPmi joins the mid-dorsal aspect of the PAO membrane; this part is thicker than its two lateral ends. Dense connective tissue from the mid-ventral part of the PAO membrane connects with the SDM (Fig. 3d, e).

### 3D visualization models of the MDB in the suboccipital region

In the PAOiS, connective tissue bands of the MDB originate from the medial part of RCPma, travel ventrally and medially through the interspace between the two RCPmi muscles and then connect with the PAO membrane (Fig. 4a, e). RCPmi and the mid-dorsal part of PAO membrane are closely connected. Connective tissue bands of the MDB originating from the ventral part of the RCPmi participate in forming the PAO membrane. There are bands of dense connection tissues between the PAO membrane and the dorsal part of SDM (Fig. 4b, e, f). Consequently, the RCPmi, RCPma and PAO membrane, as well as the PAO membrane and the SDM are closely connected with these dense connective tissue bands in the PAOiS (Fig. 4a, b, e, f).

In the PAAiS, connective tissue bands of the MDB originate from the inferior part of the RCPma and the medial superior part of OCI. These fibers run ventrally, and converge together, before penetrating the PAAiS; the fibers finally fuse tightly with the SDM (Fig. 4c–f).

### P45 plastinated sections showing the fibrous structure of differently originating MDB

In this study, the fibrous structures of the MDB were observed in the frontal, sagittal and transversal P45 plastinated sections, respectively.

In the frontal P45 plastinated sections, those fibers of the MDB originated from the lateral part of the RCPma, which

ran in parallel orientation and entered into the PAOiS. These parallel coursing fibers finally participated in forming the lower part of the PAO membrane and connect with the SDM (Fig. 5).

In the transversal P45 plastinated sections, fibers of the MDB originated from the medial part of RCPma, ran medially and then entered the PAOiS through the interspace between two RCPmi muscles. These fibers finally connected with the PAO membrane and the SDM (Fig. 6). Fibers of the MDB originate from the RCPmi ran anteriorly and connected with the PAO membrane and the SDM (Fig. 6).

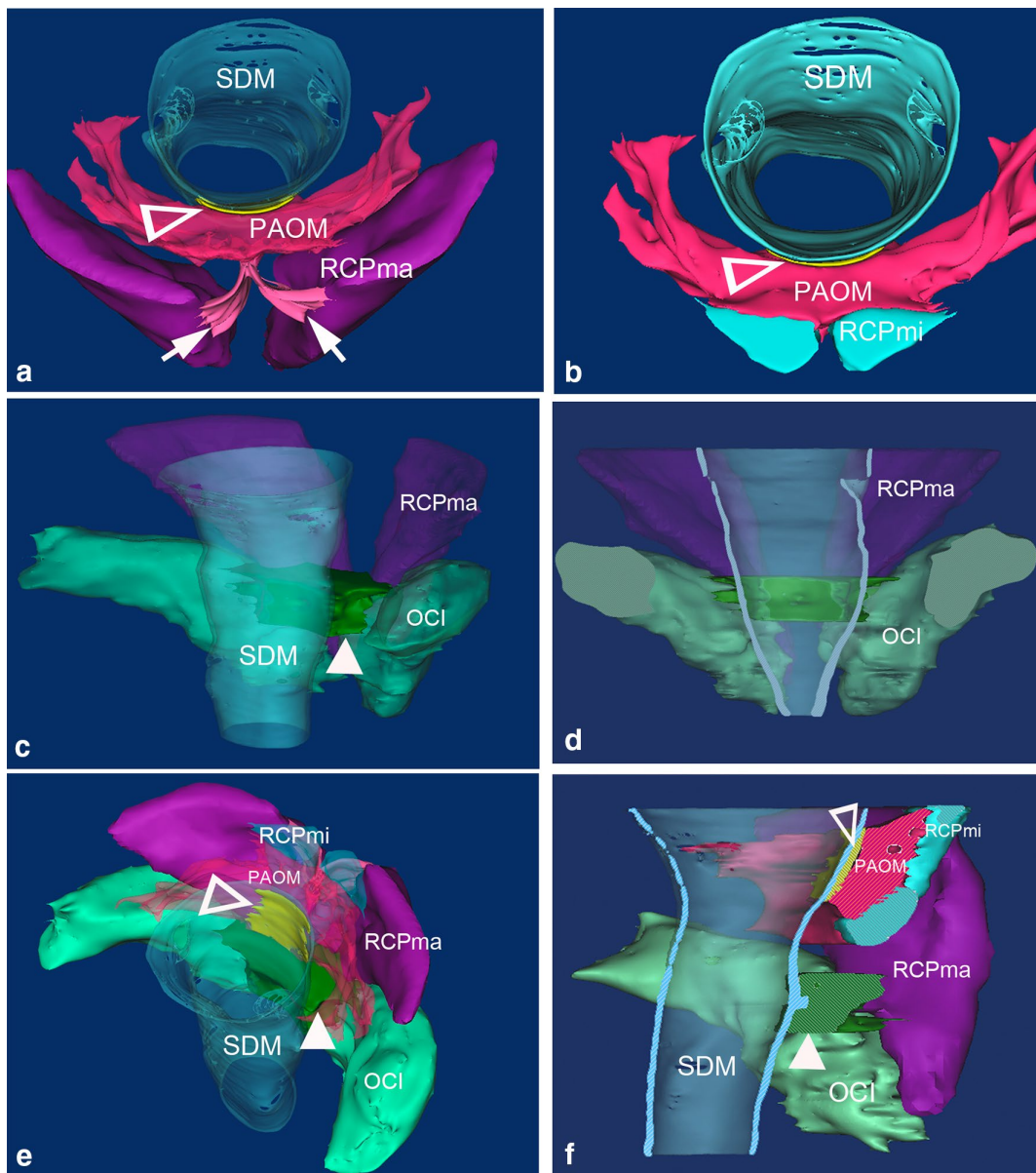
The medial sagittal section shows that in the PAOiS, fibers of the MDB originating from the RCPmi pass into the PAO membrane, forming the lower part of the PAO membrane and then connect with the SDM. In the PAAiS, fibers of the MDBs originating from the RCPma and the OCI fuse together, and through the VDL, this connective tissue connects with the SDM (Fig. 7).

### The course and inter-relationship of the MDB fibers from different muscle origin shown in HE-stained slices

The medial sagittal HE-stained slice showed that, in the PAOiS, a portion of the MDB fibers from RCPmi integrate into the PAO membrane and form the lower part of the PAO membrane which connects indirectly with the SDM, through the PAO membrane. A portion of the MDB fibers from the RCPmi passes through the PAO membrane, the ventral surface of atlas, and connects with the SDM. In the PAAiS, fibers of the MDB from the dorsal part of the RCPmi, ventral part of RCPma and medial part of the OCI fuse together and continue into the VDL. Finally, these dense connective tissues connect with the SDM through the VDL (Fig. 8).

### Discussion

In 1995, Hack et al. [5] described the MDB as a dense fibrous connection between the SDM and RCPmi. This definition was extended and enriched in subsequent researches. It is now known that the MDB originating from the RCPmi connects to the SDM indirectly, by means of the PAO membrane. The fibers of MDB originating from the OCI, RCPma and NL also connect with the SDM in the atlanto-axial interspace [1, 6, 8, 9, 11, 12, 16, 17]. Zheng et al. [22] showed that a compact ligament called the VDL connects with the SDM in the epidural space. The VDL consists of connective fibers band between the SDM and the posterior wall of the vertebral canal at the level of the atlas to the axis [22]. Fibers originate from RCPma, OCI and NL pass between the atlanto-axial interspace and form part of the VDL. The VDL



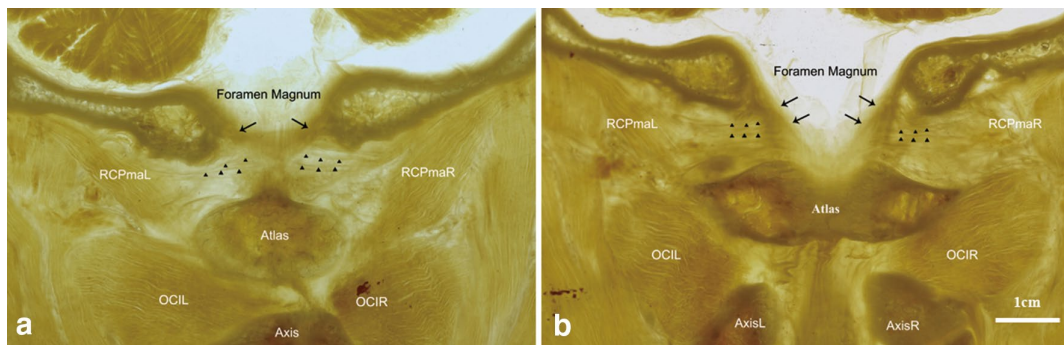
**Fig. 4** Three-Dimensional Visualization Model showing MDBs in the Suboccipital Region: **a, b** cranial aspect view; **c, e** left aspect view; **d** coronary section; **f** middle sagittal section. In the PAOiS, connective tissue bands of the MDB originate from the medial part of the RCPma (**a**, arrow) run ventrally and medially through the interspace between the two RCPmi muscles and the atlanto-occipital interspace to connect with the PAO membrane. RCPmi and the mid-dorsal part of the PAO membrane were closely connected. Dense tissue fibers

(empty inverted triangle) connect the PAO membrane with the dorsal part of the spinal dura mater. In the PAAiS, connective tissue bands of the MDB originates from the inferior part of the RCPma and the medial cranial part of OCI, run ventrally, converge and then fuse with the spinal dura mater tightly (**c, d** filled triangle). *OCI* obliquus capitis inferior, *PAOM* posterior atlanto-occipital membrane, *RCPma* rectus capitis posterior major, *RCPmi* rectus capitis posterior minor, *SDM* spinal dura mater

later connects with the SDM. So, the VDL is inferred as a “common or final pathway” for the MDB in the PAAiS [23].

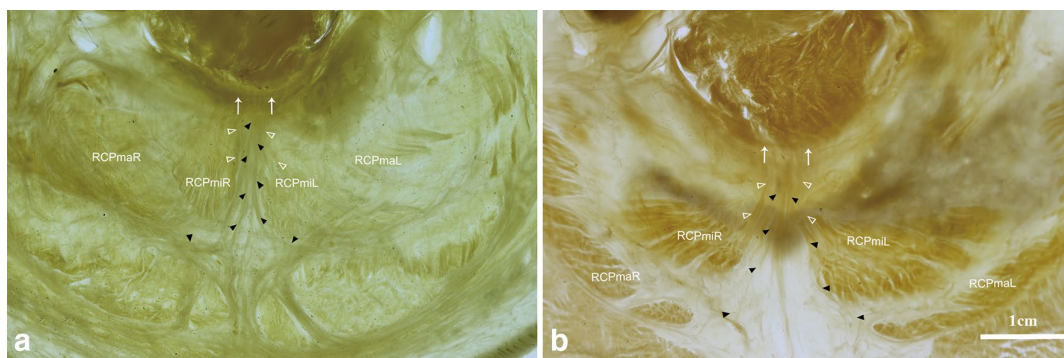
The MDB exists in the deep suboccipital region and its fibers have multiple origin. The adjacent location relationships of the MDB originating from the suboccipital region

structures have not yet been explored. This information is important for understanding the function of the MDB. This study verifies previous reports that the MDB originates from suboccipital muscles and passes ventrally to connect with the SDM. Furthermore, this study indicates that at every



**Fig. 5** P45 Plastinated Sections (frontal section) showing the Fibers of MDB originated from RCPma: Fibers of the MDB originating from the lateral part of RCPma run in parallel manner and enter into the PAOiS. These parallel coursing fibers finally participating in

forming the lower part of the PAO membrane and connect with the spinal dura mater. Arrow: spinal dura mater; filled triangle fibers originate from RCPma; *OCI* obliquus capitis inferior, *RCPma* rectus capitis posterior major, *RCPmi* rectus capitis posterior minor



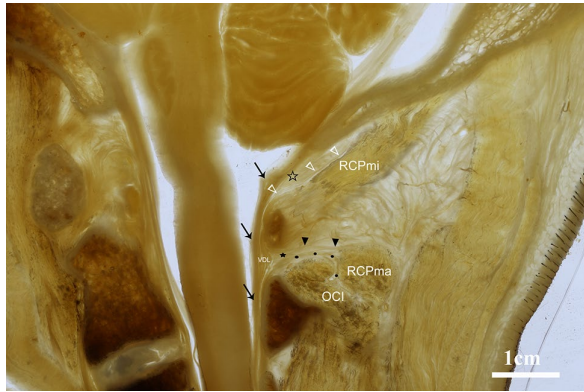
**Fig. 6** P45 Plastinated Sections (transversal section) showing that the fibers originating from RCPma and RCPmi connect with the PAO membrane and SDM: Fibers of the MDB originating from the medial part of the RCPma (filled triangle) run medially to RCPmi. These fibers enter into the PAOiS through the interspace between two RCPmi

muscles, and finally connect with the PAO membrane and the spinal dura mater. Arrow spinal dura mater; empty triangle: Fibers of MDB originating from RCPmi; *OCI* obliquus capitis inferior, *RCPma* rectus capitis posterior major, *RCPmi* rectus capitis posterior minor

instance, the MDB consists of fibers originating simultaneously from the RCPmi, RCPma, OCI muscles and NL. This study also shows that the MDB originating from the RCPma runs through the PAOiS in addition to the previously known RCPmi fibers. Fibers originating from the ventral part of the RCPmi and medial part of the cranial segment of the RCPma fused together and connect with the SDM through the PAO membrane. Meanwhile, fibers originating from the lateral part of the cranial segment of the RCPma passes anteriorly and medially into the lateral part of the PAOiS, and finally connect with the SDM. The MDB fibers passing through the PAAiS originates from the RCPmi, RCPma and OCI. Their fibers fuse together before passing through the central part of the PAAiS and finally continue as the VDL which connects with the SDM (Fig. 9).

The MDB is, thus, a complex structure whose fibers originate from diverse muscles and ligaments. It has different fibers of origin which are inter-linked and associated with each

other. Zheng et al. found that the MDB is mainly formed by parallel running collagen type I fibers thus, it can transmit the strong pull from the diverse suboccipital muscles or ligaments during head movement [23]. When the head is flexed or extended, the RCPmi, RCPma and NL's MDB fibers which pass through the PAOiS and PAAiS may act on the SDM by the contraction or relaxation of the RCPmi, RCPma and NL. When the head is flexed laterally, the MDB fibers originating from the lateral part of the cranial segment of RCPma which pass through the PAOiS may act on the SDM by the contraction or relaxation of the RCPma. When the head is rotated, the OCI's MDB fibers passing through the PAAiS may act on the SDM by the contraction or relaxation of the OCI. Muscles and ligaments participating in the formation of the MDB altogether act on the SDM or transmit proprioception from the SDM through the PAOiS and PAAiS. These structures form a functional unit. We showed in this study that this complex structure includes



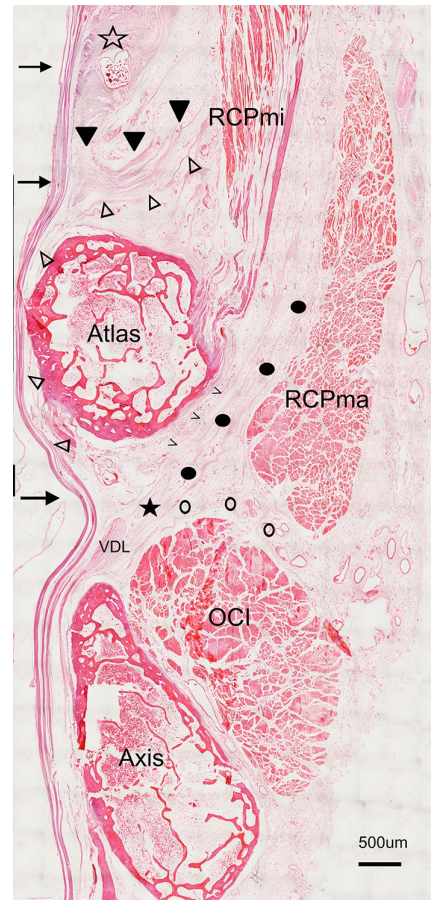
**Fig. 7** P45 Plastinated Sections (medial sagittal section) showing the fibers of the MDB which originate from the RCPmi, RCPma and OCI, and connect with the PAO membrane and the SDM: In the PAOiS, fibers of the MDB originating from RCPmi (empty inverted triangle) pass into the PAO membrane (empty star), forming the lower part of the PAO membrane and connect with the spinal dura mater. In the PAAiS, fibers of the MDB originated from the RCPma and OCI, fuse together and run into the VDL, which connects with the spinal dura mater; arrow: spinal dura mater; filled triangle fibers of MDB originated from RCPma; dots fibers of MDB originating from OCI; filled star Fusion of the MDB fibers that originate from the RCPma and OCI; *OCI* obliquus capitis inferior, *RCPma* rectus capitis posterior major, *RCPmi* rectus capitis posterior minor, *VDL* vertebral dura ligament

the RCPmi, RCPma, OCI, NL and VDL. We term this structure the 'Myodural Bridge Complex' (MDBC).

It was speculated that the function of the MDB might be related with proprioception transmission [7, 12], keeping the subarachnoid space and the posterior cerebellomedullary cistern patent [16]. Recently Zheng et al. [21] and Xu et al. [18] speculated that the MDB may be one of the factors that could affect the dynamic circulation of the cerebrospinal fluid (CSF). In addition, clinicians have shown that the pathologic change of the MDB might cause cervicogenic or chronic tension-type headache [2, 3, 9, 14, 19]. The results of present study also support the above speculated functions of MDB. As a functional unit, the MDBC may play a more important role in the dynamic circulation of CSF by transmitting motion forces from the head to the SDM in the PAOiS and PAAiSs.

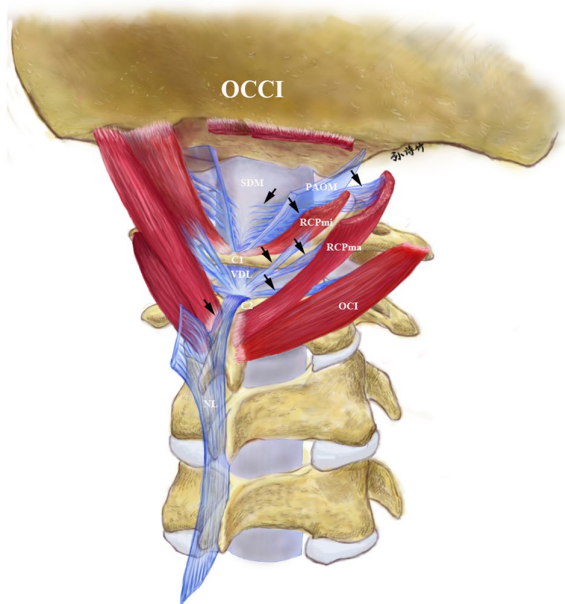
## Conclusion

This study shows that the MDB fibers originating from the RCPmi, RCPma, OCI and NL in the suboccipital region coexist and pass through the two interspaces. The different



**Fig. 8** HE-stained slice (medial sagittal section) showing the fibers of MDBs originated from RCPmi, RCPma and OCI connect with the PAO membrane and the spinal dura mater. *OCI* obliquus capitis inferior, *RCPma* rectus capitis posterior major, *RCPmi* rectus capitis posterior minor, *VDL* vertebral dura ligament, arrow spinal dura mater; filled inverted triangle fibers originating from RCPmi integrate into the PAO membrane, connect with the spinal dura mater indirectly though the PAO membrane, empty triangle fibers originating from RCPmi pass through the PAO membrane, and cross the ventral part of atlas connecting with the spinal dura mater, arrow heads Fibers originating from dorsal aspect of RCPmi, empty circle fibers originating from OCI; filled circle fibers originating from RCPma; empty star posterior atlanto-occipital membrane; filled star fusion fibers of MDB from RCPma, OCI and RCPmi

origin MDB fibers interrelate with each other, parts of these fibers fused together. The MDB from the RCPmi, RCPma, OCI, VDL, NL, thus, forms a structural and functional unit termed the MDBC. The concept of MDBC will be beneficial in the overall exploration of the function of the MDB.



**Fig. 9** Diagrammatic drawing of myodural bridge complex. MDB fibers originating from the ventral part of the RCPmi and medial part of the cranial segment of the RCPma fuse together and connect with the SDM through the PAO membrane. MDB fibers originating from the lateral part of the cranial segment of the RCPma pass anteriorly and medially into the lateral part of the PAOiS, and finally connect with the SDM. MDB fibers passing through the PAAiS originate from the RCPmi, RCPma and OCI. Their fibers fuse together before passing through the central part of the PAAiS and finally continue as the VDL which connects with the SDM. *CI* atlas, *C2* axis, *NL* nuchal ligament, *OCI* obliquus capitis inferior, *OCCI* occipital bone, *PAOM* posterior atlanto-occipital membrane, *RCPma* rectus capitis posterior major, *RCPmi* rectus capitis posterior minor, *SDM*: spinal dura mater, *VDL* vertebral dura ligament; arrow MDB fibers

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## Compliance with ethical standards

**Conflict of interest** The authors declare no conflicts of interest associated with this study.

**Ethical approval** All the procedures performed in this study which involves human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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