Variability in Wall Thickness and Related Structures of Major Dural Sinuses in Posterior Cranial Fossa: A Microscopic Anatomical Study and Clinical Implications

Vladimir Balik, MD, PhD*
Ivo Uberall, PhD‡
Igor Sulla, DVM, PhD¶
Jiri Ehrmann, MD, PhD‡
Yoko Kato, MD, PhD||
Igor J. Sulla, MD, PhD#
Katsumi Takizawa, MD§§

*Department of Neurosurgery and Institute of Molecular and Translational Medicine, Faculty of Medicine and Dentistry, Palacky University and Faculty Hospital Olomouc, Olomouc, Czech Republic; ‡Department of Clinical and Molecular Pathology and Institute of Molecular and Translational Medicine, Faculty of Medicine and Dentistry, Palacky University and Faculty Hospital Olomouc, Olomouc, Czech Republic; ¶Department of Anatomy, Histology and Physiology, University of Veterinary Medicine and Pharmacy in Kosice, Kosice, Slovak Republic; ||Department of Neurosurgery, Fujita Health University, Banbuntane Hotokukai Hospital, Aichi, Japan; #Department of Surgery, World of Health, Hospital of Slovak Railways, Kosice, Slovak Republic; §§Department of Neurosurgery, Japanese Red Cross Asahikawa Hospital, Hokkaido, Japan

Correspondence:
Vladimir Balik, MD, PhD,
Department of Neurosurgery,
and Institute of Molecular
and Translational Medicine,
Faculty of Medicine and Dentistry,
Palacky University and
Faculty Hospital Olomouc,
Hněvotínská 1333/5,
I. P. Pavlova 6,
779 00 Olomouc, Czech Republic.
E-mail: balik.vladimir@gmail.com

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BACKGROUND: Regional variability in dural sinus (DS) wall thickness in posterior cranial fossa (PCF) have not been studied in detail yet.

OBJECTIVE: To clarify the possible regional variability in DS wall thickness and determine the occurrence and localization of the chordae Willisii (CW) in PCF.

METHODS: Fifty-nine human cadaveric DSs of PCF were investigated. A measurement of the DS walls/dura mater/CW thickness of parafin-embedded/hematoxylin-eosin stained axial sections was performed by using Cell Sens Science Imaging Software (Olympus Corporation, Tokyo, Japan).

RESULTS: The osseus wall (OW) was the thickest one in the confluens sinuum (CS) and the thinnest one in the jugular bulb (JB) and sigmoid sinus ($P < .05$). The biggest differences between individual walls were observed in the JB where the superior wall was almost twice as thick as the OW. At the transverse-sigmoid junction, the thickness of the walls was comparable. In the CS and transverse sinuses, the OW was even thicker than the surrounding dura mater. The occurrence and thickness of the CW increased from the JB towards CS and prevailed on the right side. An overall number of the CW in PCF was comparable to that observed in the superior sagittal sinus.

CONCLUSION: The present study displayed for the first time the regional variability in the DS walls thickness and occurrence of the CW in PCF. Application of these findings may afford greater freedom in exposure of the DSs or neoplasms adhering to the DSs.

KEY WORDS: Dural sinus, Wall thickness, Chordae willisii, Posterior cranial fossa

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Besides manipulating vital neural structures, a peculiarity of many surgical procedures in posterior cranial fossa (PCF) is the presence of major DSs the surgeon encounters either initially while performing craniotomy[1-10] or later on during resection of closely related lesions.[11-13] Their critical role in drainage of blood coming off the brain[14] is best demonstrated by the fact that their injury may lead to serious complications with possible fatal consequences for patient.[1,11,15-17] It takes on even more significance if one TS is largely predominant or unique.[18] A rather symmetrical drainage in both TSs is observed in only about 65% of cases.[18] Surgical exposure of the DSs in PCF is therefore still challenging unless their anatomy and variability are thoroughly understood. The DSs in PCF are best appreciated under macroscopic considerations such as their shape, size, and location[7,19-25]; however, the regional variability in thickness of their walls has not been studied in detail so far. The present study therefore aimed at a clarifying these ambiguities and defining measurements and regional diversities of the DS walls. Moreover, the study focused on occurrence and distribution of the chordae Willisii (CW) in these DSs.

ABBREVIATIONS: CW, chordae Willisii; **CS,** confluens sinuum; **DS,** dural sinus; **IW,** inferior wall; **JB,** jugular bulb; **OS,** occipital sinus; **OW,** osseus wall; **PCF,** posterior cranial fossa; **PHV,** primary head vein

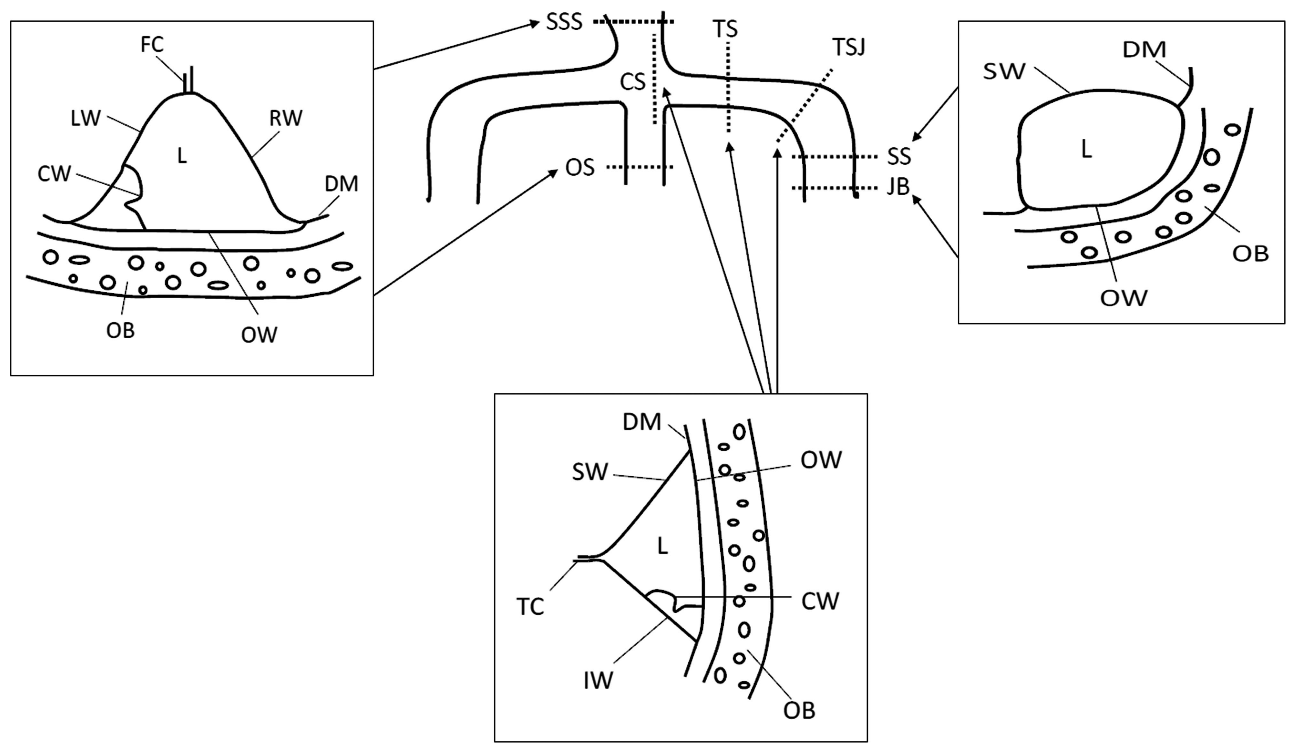

FIGURE 1. *Schematic drawing of transverse sections of the DS in the PCF. Dotted lines show places of displayed axial sections. The SS and JB have the SW and OW. The CS, TS, and TSJ have the SW, IW, and OW. Finally, the posterior part of the SSS and OS have the RW, LW, and OW. The OW in PCF faces bone structures such as the occipital bone (OB) in the region of CS, TS, and TSJ, and the occipitomastoid suture in the region of SS and JB. The CW occurred most frequently in the region of CS. DM, dura mater; FC, falx cerebri/cerebelli; L, lumen; TC, tentorium cerebelli.*

METHODS

The study was approved by the Institutional Research Ethics Committee. Specimens of human DS walls of PCF were studied from 59 fresh cadavers (34 male and 25 female with a mean age 67.47 yr [range, 20-93 yr]) who died of nonintracranial tumor or infection disease. Having performed a standard craniotomy and removing the brain, the DM was incised at a distance of 1 cm from the edge of DS along the jugular bulb (JB), SS, TS, confluens sinuum (CS), posterior part of the SSS, and occipital sinus (OS) on both sides. Peeling of the DM along with the osseus wall (OW) of DS started from the JB on the right side and continued through the SS, TS, SSS, OS, and CS on the other side until the whole complex of DSs of the PCF was completely exposed epidurally and relieved off the occipital and petrosal bones. The obtained DSs were placed in a buffered solution of 10% formalin for 2 to 3 d before sectioning. Subsequently, a transverse section of 2 mm of the (a) middle part of the TS, SS, and OS; (b) CS and TSJ with their SW and inferior wall (IW); (c) JB just before entering the jugular foramen; and (d) and posterior part of the SSS were done (Figure 1). The segments were embedded in paraffin and histological axial sections were taken and stained with hematoxylin and eosin for light microscopic examination. The measurement of DS wall/parasinus DM/CW thickness was performed by using Cell Sens Science Imaging Software with measurement modul (Olympus Corporation, Tokyo, Japan). A charge-coupled device camera was mounted on a microscope BX43 with objectives adjusted at 20x/0.5 (magnification/numeric aperture). A standard calibration of the module was performed before each measurement. Each DS wall, parasinus DM and CW was measured in its widest, medium wide, and the thinnest part. Finally, the wall/DM/CW thickness was determined as the average value of these measurements in micrometers. CW were studied under light microscope following the axial sections of DS were taken and stained with hematoxylin and eosin. Structures were considered as the CW only if they created a septum dividing lumen of DS into two parts; and if, at least, one of the septum's end part was joined directly with DS wall (Figure 2A). For each variable analyzed, its mean, median, and range values were calculated using the IBM SPSS Statistics 23 (IBM Corporation, Armonk, New York). Statistical analysis was performed using Shapiro–Wilk test, Mann–Whitney *U* test, Friedman's test, and Post hoc test. For bivariate correlations between selected variables, the two-tailed Spearman's correlation test was employed. Statistical significance was considered to be present once P-value was $< .05$.

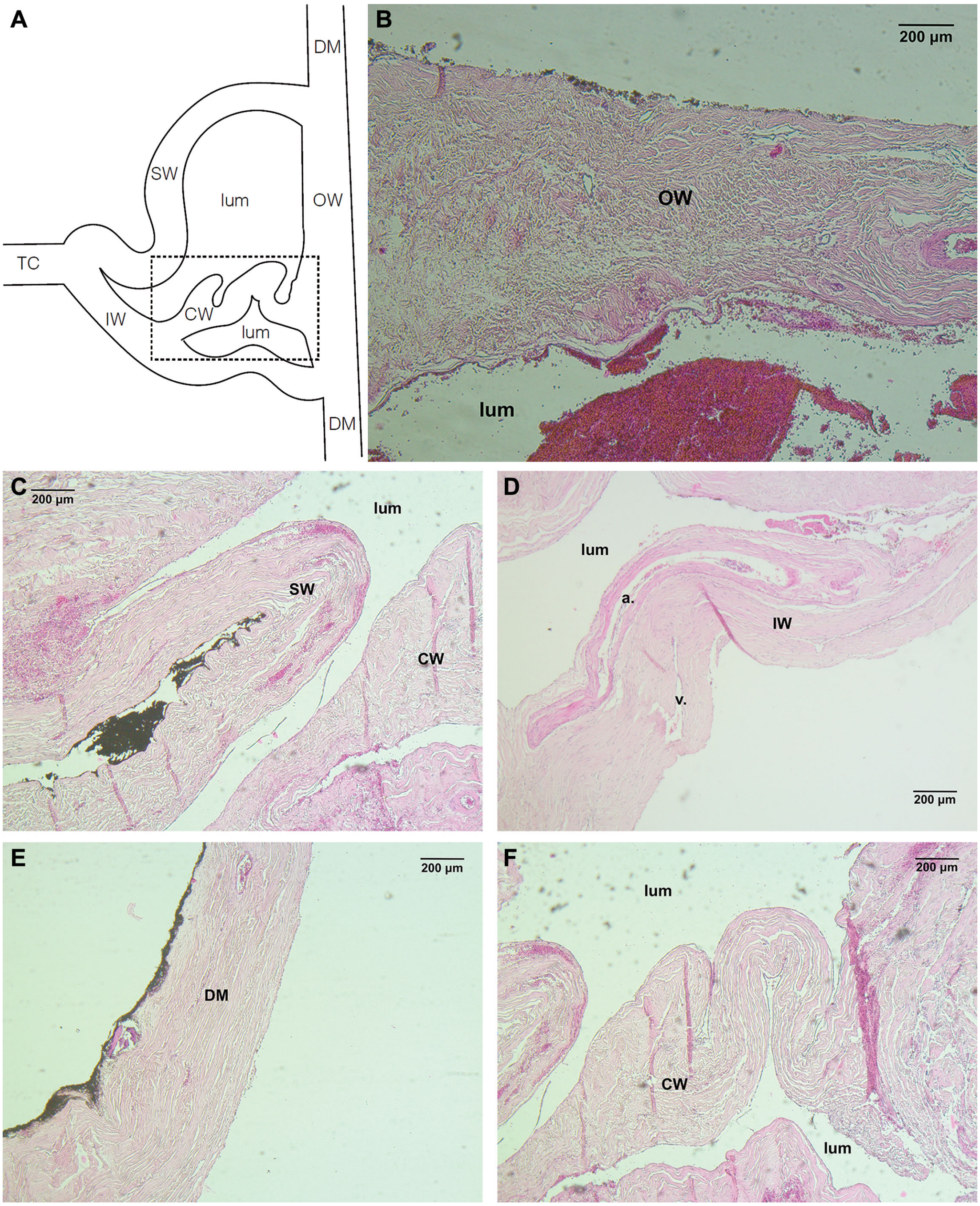

FIGURE 2. **A**, *schematic drawing of transverse section of the CS demonstrating a relationship between the CW and DS walls. The CW bridges the IW and OW, thus dividing the lumen (lum) of the DS into two separate parts. Dotted rectangle indicates a schematic drawing of the CW shown in **F**. Histopathological axial sections (hematoxylin and eosin; original magnification, × 50) of the OW* **B**, *SW* **C**, *IW* **D**, *DM* **E**, *and CW* **F**, *in the region of the CS. The DS walls and CW predominantly consist of collagen tissue and contain a few endothelial lined vascular channels, such as dilated arteries and collapsed veins. The vessels occur more frequently in DS walls while they are found rarely in the CW. The interior surface of DS including CW is smooth and covered with a single layer of endothelial cells. The OW adheres to an inner periosteal lining of skull bones. a., dural sinus wall artery; v., dural sinus wall vein.*

RESULTS

Jugular Bulb

The JB has SW and OW. The OW facing the suboccipital bone was almost twice as thin as the SW bilaterally. DM at a join of the SW and OW was thicker than the SW but it did not reach the thickness of the sum of the SW and OW. The CW were observed in 7 out of 59 right JB and its thickness was almost half of the thickness of the OW. On the left side, CW were observed only in 3 out of 59 cadavers.

Sigmoid Sinus

The SS has SW and OW which faces the occipitomastoid suture. The SW was thicker than the OW on both sides. The DM along the SS was thicker than the SW but it did not reach the thickness of the sum of its two walls. The CW were observed in 12 and 10 out of 59 right and left SS lumens, respectively, and their thickness was similar to the thickness of both DS walls, however on the left side they were thinner. Post hoc tests of multiple comparison showed that OWs of the JB and SS on both sides were significantly thinner in comparison with other sites ($P < .05$).

Transverse-Sigmoid Junction

At the place where the TS runs into the SS, the sinus has 3 walls including IW, OW, and SW. These walls were approximately equal regarding their thickness although the IW was a little thinner than the other two ones. The CW were observed in 15 out of 58 cadavers and their thickness was approximately half of the thickness of the sinus walls on the right side. A number of the CW and their thickness on the left side were comparable to the right side. The DM was thicker than DS walls in the region, but just a little more than the OW or SW.

Transverse Sinus

Out of its walls (superior, inferior, and osseus), the OW was the thickest one on both sides, although none of the walls was thicker by 50% or more than the other one. The CW on the right side were observed in 44% of cases and reached approximately 50% of the OW thickness, while the number of the CW on the left side decreased to the rate of 31% and reached the IW thickness. Interestingly, the DM along the TS was thinner than the OW. An aplasia of the TS was not found, while its side dominance was observed in more than 40% of cases (60% on the right side).

Confluens Sinuum

The CS was the place with the highest number of the CW (in 59% of cases); and with the thickest OW, SW, and IW comparing to other sites of PCF. The thickness of the SW and IW of the CS was almost equal, but the OW was the thickest one and even thicker than the DM in the region (Figures 2B-2F and 3).

Posterior Part of the SSS

The SSS has right (RW), left (LW), and OW. The OW was the thickest one whereas the RW and LW were comparable to each other. Interestingly, the thickness of the CW was even greater than the OW. A number of the CW was lower comparing to the CS. Finally, the thickness of DM around the DS was the same as the walls of the SSS.

Occipital Sinus

The thickness of all its walls (RW, LW, and OW) was equal to each other and it was comparable to the thickness of the DM along the OS. A number of the CW was similar to that observed in the SSS; however, their thickness was half of the thickness of the OS walls.

Thickness of DS Walls/CW vs Gender and Side Distribution

Males had significantly thicker CW and OW in the CS (Mann-Whitney *U*-test, P .006) and OS (Mann–Whitney *U*-test, P .042) compared to females. Significant difference between DS wall thickness on the right and left side was not confirmed (Wilcoxon test, $P > .05$).

A Thickness of DS Wall/CW vs Age

By using Spearman's rho test, we estimated that thickness of the IW of the CS (Correlation Coefficient .434; Sig. [2-tailed] .013; n = 32); OW of the left TS (Correlation Coefficient .664; Sig. [2-tailed] .003; n = 18); and CW of the right JB (Correlation Coefficient .786; Sig. [2-tailed] .036; n = 7), left TS (Correlation Coefficient .298; Sig. [2-tailed] .022; n = 59), and SSS (Correlation Coefficient .766; Sig. [2-tailed] .002; n = 13) correlated with age of the patients.

Table lists the results of measurement of the DS walls, DM, and CW in PCF.

DISCUSSION

Dural Sinus Walls

According to our knowledge, the present study for the first time displays the regional differences in DS wall thickness in PCF. The thickness of the DS walls, especially the OW decreases with the direction of blood flow in the DSs. While in the region of the CS and TS it is the thickest one and even thicker than the surrounding DM, the thickness of the OW further distally decreases and in the SS and JB is significantly thinner and reaches only the half of the thickness of the OW in the midline region of PCF. On the other hand, such differences in thickness of the SW or IW were not observed. Comparing the individual walls in certain region, the biggest differences were observed between OW and SW and between OW and DM in the JB where the SW was almost twice as thick as the OW. The differences faded towards the TSJ where the thickness of the both walls was almost equal. Amato et al[26] reported similar difference between lateral and IW of the straight sinus. The IW was thicker and exhibited less collagen but more elastic and nerve fibers, connective tissue and vessels. Moreover, they found that the wall

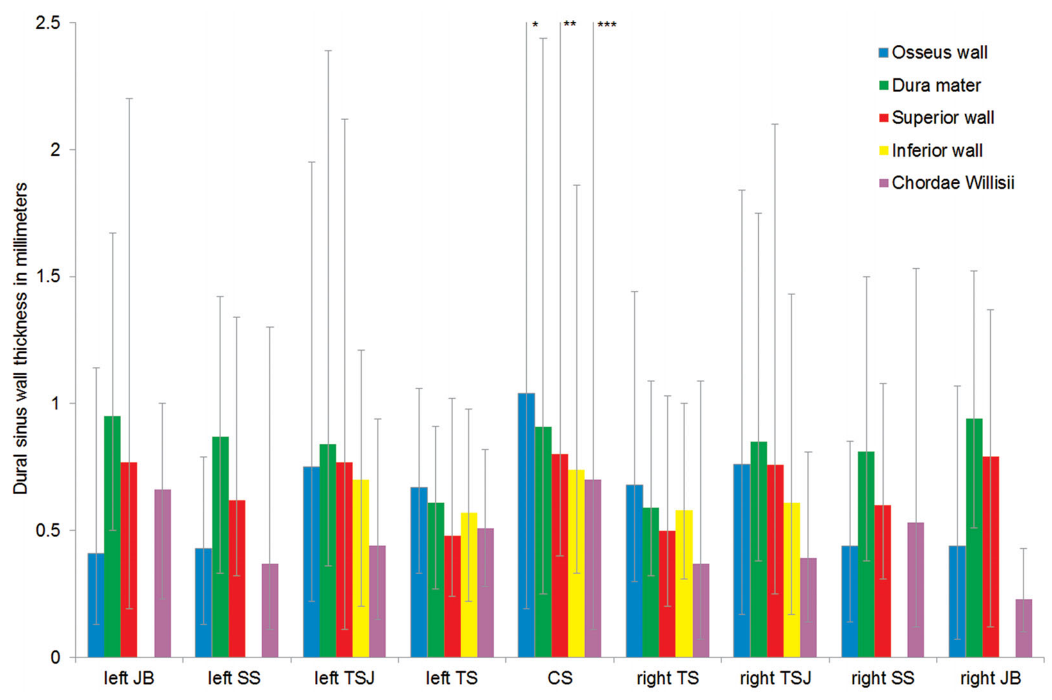

FIGURE 3. *A relative comparison of median and range of values of dural sinus wall/dura mater/chordae Willisii thickness of the JB, SS, TSJ, TS, and CS. *, 6.95 millimeters; **, 2.8 millimeters; ***, 2.83 millimeters.*

was thicker than walls of the TSs, whereas no such differences were observed in case of SSS.[26] Some surgical procedures in the PCF[1-10] when associated with lesser experience may be differently demanding just due to these regional differences in the DS wall thickness. Comparing the midline suboccipital,[10] bioccipital,[9] posterior transpetrosal,[1,3,4,6,8] transcondylar approach,[2,5,10] or surgical approaches to the jugular foramen[10] where the CS,[9] TS,[9] or JB/SS[1,4,10] are exposed, craniotomies done over OW of the JB and SS may be more demanding and require particular care to avoid their injury because of their thinner and thus more fragile OW compared to the craniotomies performed over the CS or TS/TSJ. Moreover, a resistance of the OW and DM to being separated from the inner skull surface increased from the CS up to the JB, where the OW and DM adhered most to the skull. Thus, an incidental tear of the DM around the CS due to its stronger adherence and resistance to the separation does not have to mean that the OW is thin and susceptible to injury, since its wall thickness was found to be even higher than the DM surrounding the CS in some cases. On the other hand, the DM along the JB, SS, and TSJ was thicker than their OW. An accurate placement of burr holes or initial drilling just over the thicker DM may decrease the risk of tear of the DS,[27] and thus facilitates elevation of the OW. Regarding the thickness of the SW, a peeling off the posterior petrosal, lateral foramen magnum,[10] or tentorial meningiomas[28] from the SS, JB, or TS/TSJ, respectively, may be comparatively risky since the thickness of their SWs is almost the same. Likewise, the regional differences in difficulties of peeling of neoplasms from the straight sinus have been reported depending on whether the lesion occupies supratentorial or infratentorial compartment, and thus adheres to the thinner lateral or thicker IW, respectively.[26] Since we observed a correlation between age and DS wall/CW thickness, and the mean age of our cohort was higher by 10 yr than that observed in patients with meningiomas affecting dural sinuses (DSs),[17] it seems reasonable to suppose that DS walls/CW may be even thinner in actual surgery of such patients. Even frequently described outer layer peeling of the DS wall in the setting of meningioma attached to DS wall,[17] clearly distinct two layers of the DS walls in PCF were not observed. Since quite large endothelial lined channels were observed in some part of the walls, it can be assumed that the tumor invading the DS wall may cause further proliferation and enlargement of the channels, which when the peeling of the tumor from the DS wall may give the impression of peeling of its outer layer. Moreover, DS wall delamination may be supported by a presence of vacuoles among the collagen fibers in DS walls.[26]

TABLE. Jugular Bulb, Sigmoid, Transverse, Superior Sagittal, and Occipital Sinus, Transverse-Sigmoid Junction, Confluens Sinuum, Dura Mater, and Chordae Willisii Measurements

	Osseus wall (in millimeters)		Superior wall (in millimeters)		Inferior wall (in millimeters)		Right wall (in millimeters)		Left wall (in millimeters)		Intraluminal chordae Willisii (in millimeters)		Dura mater (in millimeters)	
Side	right	left	right	left	right	left	right	left	right	left	right	left	right	left
Jugular bulb*														
Mean (range)	0.44 (0.07-1.07)	0.41 (0.13-1.14)	0.79 (0.12-1.37)	0.77 (0.19-2.2)	–	–	–	–	–	–	0.23 (0.10-0.43)	0.66 (0.23-1.0)	0.94 (0.51-1.52)	0.95 (0.50-1.67)
Median	0.39	0.37	0.77	0.73	–	–	–	–	–	–	0.17	0.74	0.96	0.92
n	59	59	59	59	–	–	–	–	–	–	7	3	59	59
Sigmoid sinus*														
Mean (range)	0.44 (0.14-0.85)	0.43 (0.13-0.79)	0.60 (0.31-1.08)	0.62 (0.32-1.34)	–	–	–	–	–	–	0.53 (0.12–1.53)	0.37 (0.11-1.30)	0.81 (0.38-1.50)	0.87 (0.33-1.42)
Median	0.43	0.42	0.58	0.60	–	–	–	–	–	–	0.39	0.26	0.79	0.85
n	58	59	59	59	–	–	–	–	–	–	12	10	59	59
Transverse-sigmoid junction*														
Mean (range)	0.76 (0.17-1.84)	0.75 (0.22-1.95)	0.76 (0.25-2.1)	0.77 (0.11-2.12)	0.61 (0.17-1.43)	0.70 (0.2-1.21)	–	–	–	–	0.39 (0.14-0.81)	0.44 (0.15-0.94)	0.85 (0.38-1.75)	0.84 (0.36-2.39)
Median	0.72	0.70	0.70	0.69	0.57	0.72	–	–	–	–	0.37	0.46	0.81	0.73
n	57	59	58	59	35	37	–	–	–	–	15	14	58	58
Transverse sinus**														
Mean (range)	0.68 (0.30-1.44)	0.67 (0.33-1.06)	0.50 (0.20-1.03)	0.48 (0.24-1.02)	0.58 (0.31-1.00)	0.57 (0.22-0.98)	–	–	–	–	0.37 (0.07-1.09)	0.51 (0.28-0.82)	0.59 (0.32-1.09)	0.61 (0.27-0.91)
Median	0.65	0.62	0.47	0.46	0.55	0.55	–	–	–	–	0.31	0.49	0.57	0.60
n	59	59	59	59	59	58	–	–	–	–	26	18	59	59
Confluens sinuum**														
Mean (range)	1.04 (0.19-6.95)		0.8 (0.4-2.8)		0.74 (0.33-1.86)		–		–		0.70 (0.11-2.83)		0.91 (0.25-2.44)	
Median	0.73		0.70		0.67		–		–		0.49		0.88	
n	58		58		32		–		–		34		47	
Superior sagittal sinus**														
Mean	0.92 (0.33-4.00)		–		–		0.81 (0.34-2.18)		0.79 (0.18-3.28)		0.95 (0.22-3.59)		0.79 (0.42-1.98)	
Median	0.73		–		–		0.69		0.66		0.79		0.74	
n	56		–		–		58		57		13		57	
Occipital sinus**														
Mean	0.83 (0.39-2.35)		–		–		0.74 (0.24-1.99)		0.88 (0.19-3.49)		0.48 (0.13-1.06)		0.77 (0.44-1.50)	
Median	0.64		–		–		0.65		0.78		0.36		0.69	
n	44		–		–		46		46		11		48	

**bilateral structure;*
***midline structure*

Meningeal Histogenesis and Dural Sinus/Chondrocranium Development

The variability in the DS walls thickness may relate to a different meningeal histogenesis. As the meningeal layers covering the telencephalon arise from the neural crest cells, and those around the brainstem from the cephalic mesoderm,[29-31] a neural crest–mesodermal interface is located at the coronal suture between frontal neural crest-derived and parietal mesodermal-derived bones in the early stage of intrauterine life. However, as the cerebral hemispheres start to expand, they extend caudally, carrying with them the neural crest-derived meningeal layer covering the telencephalon that subsequently underlies the parietal bones.[32] This shift in the meningeal neural crest–mesodermal interface indicates that DSs located at the posterior/caudal edge of cerebral hemispheres (such as CS and TS) may be derived from two distinct embryonic sources. The CS and TS may have contribution from neural crest cells as well as cephalic mesoderm contrary to the SS and JB that arise only from the mesoderm. In addition, the variability in DS wall thickness may be associated with morphological changes of the DS itself taking place during prenatal and postnatal development. The main drainage system of the head at the very early prenatal stage represents the primary head vein (PHV). At the stage when the DM and the arachnoid spaces are forming, tributaries of the PHV are arranged in 3 plexiform groups. The middle dural plexus presents the first stage in the formation of the TS with its sigmoid portion, while the posterior dural plexus extends to become the OS. The anterior dural plexus annexes itself to the middle dural plexus, and, moreover, constitutes the SSS. The PHV, chiefly its trigeminal portion forms cavernous sinus while its cervical part, now completely interrupted with the trigeminal portion, becomes internal jugular vein. Their communication is now through a short channel that represents the original trunk of the middle dural plexus, and constitutes the superior petrosal sinus. With the alterations in the PHV, the anterior, middle, and posterior dural plexuses are drained by means of a new dorsal channel, which empties through the jugular foramen into the internal jugular vein. This channel can be recognized as the TS and SS.[33] At the fetal age of the 17th and 18th weeks, the TSs begin to significantly enlarge from their lateral border and reach the primitive torcular approximately 6 wk later.[14] Still, the SS and jugular sinus (in postnatal life known as the JB) remain extremely small throughout the whole intrauterine life and acquire the same diameter as the TSs (approximately 9 mm) at about 1 yr of age.[14] Moreover, an enlargement of the jugular sinus into the shape of the JB lasts at least another year, corresponding to the period when children change their lying down position to an erect posture.[14] Finally, variability in ossification of cranial synchondroses may also influence the OW thickness of the DSs in PCF. Whereas the mendosal suture, fusing much earlier,[34] overlies the TSJ, TS, and CS, the occipitomastoidal suture overlies the SS and the JB remains unossified till teenage years.[35]

Chordae Willisii

The CW are classified into 3 types, namely the valve-like, trabecular, and laminar chordae.[23,36] Due to their different shape and localization, the CW are supposed to have different functions, such as prevention of backflow into the tributary veins, maintaining the shape of DS and thus prevent turbulent blood flow[23,36] or permit a laminar blood flow in a part of the SSS or CS where its diameter increases.[36] This assumption of their physiological function may also be applied to the CW in PCF as their overall number was comparable to that observed in SSS.[23] Their clinical significance is particularly pronounced in tumors growing inside the DS.[37] The tumor may displace or conform to the CW with occlusion of the lumen, but without extending through it. The chordae may thus provide a barrier to its spreading into adjacent DS.[9] On the other hand, if tumor enlarges and grows through the CW well behind, the chordae may make the procedure more demanding and represents itself a obstacle to get behind it and to remove the tumor completely. Incision of the DS wall, usually confined to the area where the tumor infiltrates the wall, does not have to yield an adequate exposure and thus it may require extension behind the CW. Finally, the CW may also prevent the introduction of a ballooned shunt intraluminaly[17,37] to bypass the area of tumor involvement during its resection.[38] Awareness of the regional variability in occurrence of the CW may thus be helpful in anticipating these potential difficulties which, if unexpected, may prolong the surgery while making it more demanding. As the CW were thicker in males and their occurrence and thickness increased from the JB towards CS, one should anticipate these complications rather in the region of TS or CS in male population.

CONCLUSION

The present study displayed for the first time the regional variability in the DS walls thickness and occurrence of the CW in PCF. Application of these findings may be helpful in anticipating of potential surgical difficulties and thus afford greater freedom in exposure of the DSs per se or neoplasms adhering to or growing inside the DS.

Disclosures

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COMMENTS

This is an important anatomical-surgical work, at a time when the intracranial venous system is more and more coming on the forefront in neurosurgery and interventional neuroradiology. Major dural venous sinuses are implicated in open neurosurgery, especially when dealing with traumatic lacerations, tumors invasions, and a number of cranial approaches (over the midline for the superior sagittal sinus) and all types of craniotomies to access the pineal region or the cerebello-pontine angle (for the torcular and the lateral sinuses).[1] Also, interventional neuroradiology has to frequently use retrograde navigation through the main dural venous sinuses for treating, with endovascular techniques, arteriovenous malformations or fistulas, and not infrequently idiopathic chronic intracranial hypertension due to sinus thromboses or hypertrophic arachnoid granulations, especially at lateral sinuses.[2] Dural venous sinuses are not simple conducts! Thickness/thinness (= fragility) of their walls are important surgical features.

Marc Sindou
Lyon, France

1. Sindou M, Auque J. The intracranial venous system as a neurosurgeon's perspective. *Advances and Technical Standards in Neurosurgery*. 2000;26:313-216.
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In this article, the authors have presented detailed anatomical investigation to clarify the wall thickness of the dural sinuses in the posterior fossa. As you see from the names of pre- and retro"sigmoid" approaches, these dural sinuses including the sigmoid sinus are one of the biggest obstacles during posterior fossa surgery, and their injury is a potentially life-threatening complication. Though there are several surgical preferences to expose/deal with these dural sinuses, their wall thickness/quality has not been clarified so far. Although it still remains uncertain to establish the safe management of these sinuses during surgery, this study advances our insufficient knowledge of the wall thickness/quality of the posterior fossa dural sinuses.

Ken Matsushima
Michihiro Kohno
Tokyo, Japan

The authors have studied an under-appreciated topic by analyzing the thickness of the posterior fossa dural sinuses. Practical experience shows that the thickness of the dura covering these sinuses is variable, but the authors have shown a pattern of decreasing thickness from medial to lateral around thin areas of the jugular bulb. This has useful implications for surgeons who have to expose these structures. It would be interesting to study in more depth the factors that predict sinus injury during exposure.

Richard W. Byrne
Chicago, Illinois