Development of Posterior Fossa Dural Sinuses, Emissary Veins, and Jugular Bulb: Morphological and Radiologic Study

Toshio Okudera, Yun Peng Huang, Tatsuhiko Ohta, Akira Yokota, Yasuhiro Nakamura, Fumiaki Maehara, Hidetsuna Utsunomiya, Kazuo Uemura, and Hitoshi Fukasawa

PURPOSE: To report the anatomic and radiologic development of the transverse, sigmoid, and occipital sinuses, the emissary veins, and the jugular bulb formation from the jugular sinus in humans before and after birth. METHODS: Roentgenograms of 33 injected brains showing the cranial venous system in human fetuses from 3 to 7 months of gestational age and cerebral angiograms of newborns and infants up to 6 years of age (23 clinical cases) were made and analyzed in detail. Special attention was focused on the inner diameters of the transverse and sigmoid sinuses and of the internal jugular veins, particularly at the sigmoid sinus–internal jugular vein junction. RESULTS: Marked increase in venous flow from the rapidly growing cerebral hemispheres leads to ballooning of the transverse sinuses in the absence of an increase in the inner diameters of the sigmoid and jugular sinuses. The ballooning also results in formation of the occipital sinus, marginal sinus around the foramen magnum, and emissary veins. The formation of the jugular bulbs from the jugular sinuses begins after birth when a shift from a fetal to a postnatal type of circulation (or from a lying-down position to an erect posture) takes place. CONCLUSION: The morphological changes of the posterior fossa dural sinuses, emissary veins, and jugular bulb are closely related to the development of the brain, shift to postnatal type of circulation, and postural hemodynamic changes.

Index terms: Fetus, growth and development; Dural sinuses; Posterior fossa; Veins, jugular; Veins, anatomy

With recent advances in the care of premature infants, it is possible for extremely premature infants (600 gm in weight, 6-month-old fetuses) to survive the critical postnatal period.

It is therefore important to understand the anatomic development of the dural sinuses in infants of this age.

We report gross morphological findings based on: (a) dissection of injected fetal brains of 3 to 7 months of gestational age; (b) multi-directional stereoroentgenograms of injected specimens; and (c) cerebral angiograms of neonates and infants up to 6 years of age. Particular attention has been paid to the development of the posterior fossa dural sinuses (the transverse, sigmoid, and occipital sinuses), the emissary veins, and the (superior) jugular bulb. We describe the cause of (a) enlargement (or ballooning) of the transverse sinuses, (b) marked but transient enlargement of the occipital and marginal sinuses, (c) development of the emissary veins, and (d) formation of the (superior) jugular bulb from the jugular sinus.

Materials and Methods

Injected Aborted Fetuses

Thirty-three brains of aborted fetuses ranging from 3 to 7 months of gestational age were obtained. Contrast material was injected into the venous system through a catheter introduced into the superior vena cava or into both internal jugular veins. Gestational ages of the aborted injected fetal brains were at latter half of third month (3 brains), at fourth month (8 brains), at fifth month (12 brains), at sixth month (7 brains) and at seventh month (3 brains). The gestational ages of the aborted fetuses were determined using Böving's chart (1), measuring the crown-rump length, body weight, and foot length, and expressed in months from the first day of the last menstrual period. The contrast materials used were water-suspension of fine-grain barium sulfate containing 1.5% gelatin or microfil silicone rubber. Injections were performed either gently by hand or by using a 500-mL irrigator with an average pressure of 34 mm of water. After injection of contrast material, stereoroentgenography was carried out in multiple directions using soft-tissue techniques. After opening of a part of the skull with scissors, we fixed the fetus in a 10% formalin solution for 3 months. This was followed by multidirectional stereoroentgenography of the dural sinuses and veins, dissection, and further photography. In some brains serial frontal, horizontal, or sagittal sections were made.

Clinical Material

Cerebral angiograms (taken in stereoscopic pairs) of 23 children were analyzed: 8 less than 1 year of age; 2 between age 1 and 2 years; 6 between age 2 and 3 years; 2 between age 3 and 4 years; 2 between age 4 and 5 years; 2 between age 5 and 6 years; and 1 more than 6 years of age. The transverse and sigmoid sinuses, emissary veins, jugular sinuses (from which the jugular bulbs develop), and internal jugular veins were systematically investigated on both sides, especially as to course, caliber, and mode of drainage.

Radiologic measurements of the inner diameters of these veins and sinuses were made in the anteroposterior projection (Towne view). These include measurements of the inner diameters of the transverse sinuses, sigmoid sinuses, jugular sinuses (jugular bulbs over age 2), and internal jugular veins on both sides.

Results

Transverse Sinus

The terms *transverse sinus* and *lateral sinus* are confusing and have been used interchangeably in the past. For the sake of clarity, the term *lateral sinus* is best used to include both the transverse and sigmoid sinuses.

At the fetal age of 3 months (11th and 12th weeks), the transverse sinus (on each side) is small (Fig 1). It can be said to begin at the junction with the straight sinus and run inferolaterally before turning inferomedially and posteriorly to become the sigmoid sinus. Its position, represented by the outer tentorial margin, continues to descend with growth of the cerebral hemispheres. On each side, the superior sagittal, the transverse, and the sigmoid sinuses form a single narrow curved course that is continuous inferiorly with the internal jugular vein. The superior sagittal sinus is divided posteriorly into right and left limbs. The straight sinus, located rather high at this age, drains mainly into the left limb.

Until the age of 4½ fetal months (17th and 18th weeks), the transverse sinus has a relatively even caliber. At this age, it begins to enlarge from its lateral border on each side (Figs 2 and 3). This enlargement (or ballooning) (4, 7) rapidly progresses medially and reaches the primitive torcular approximately 1 to 1½ months later (Fig 4). This ballooning may be most conspicuous at the age of the 5th month (19th and 20th weeks) and may further extend into the posterior portion of the superior sagittal and superior petrosal sinuses. With the increasing volume of the telencephalon, the area where the straight sinus joins the superior sagittal sinus gradually descends. As a result, the inferior inclination of the lateral portion of the transverse sinuses is less marked with the aging of the fetus. This period corresponds with the rapid development of the veins over the cerebral convexity and cerebellar surface, and hence to the period of increased venous drainage of the brain. Although the transverse sinus continues to enlarge, it gradually regains a relatively even caliber (Figs 5 and 6) in the 6th month. At the age of 7 fetal months, enlargement of the sinus practically ceases. Rapid increase and decrease in the inner diameter of the transverse sinuses frequently results in irregular inner diameters and irregular margins of the transverse sinus. A part of the sinus may be missing completely. In some cases, septum formations may be observed (Fig 2C). A pouch or pouches of the dural sinus may be formed and may extend from the transverse sinus into the convexity dura or the tentorial dura. These pouches may receive cortical veins from the convexity or from the undersurface of the temporooccipital lobe. In some cases, the vein of Labbé may drain into this dural pouch.
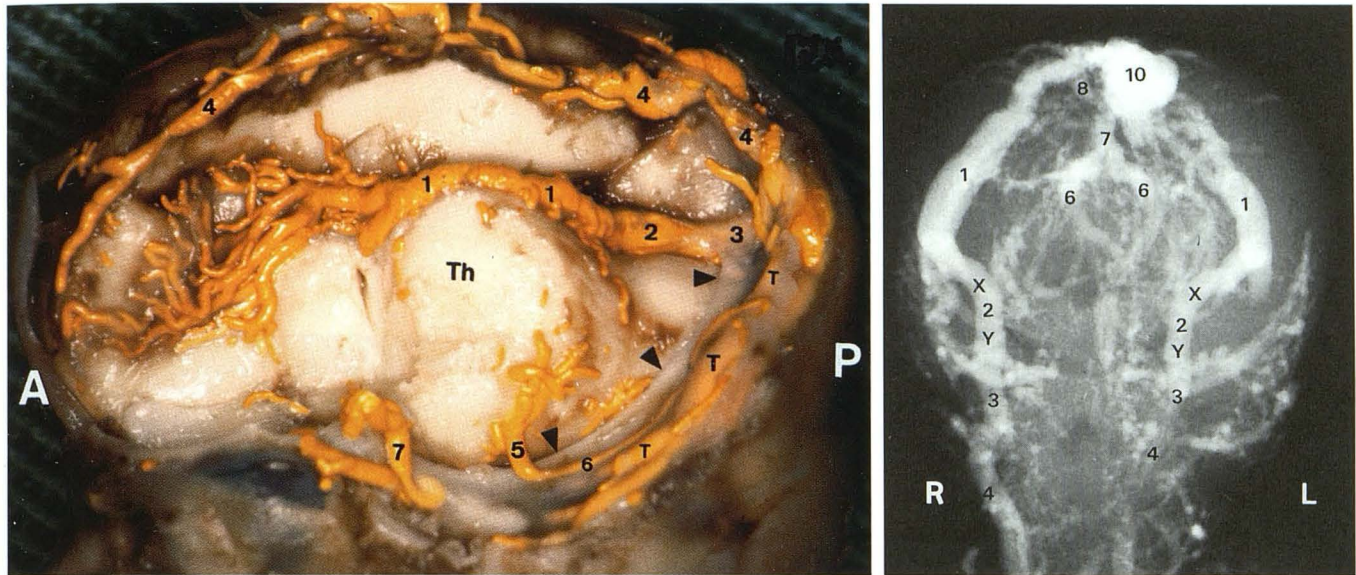
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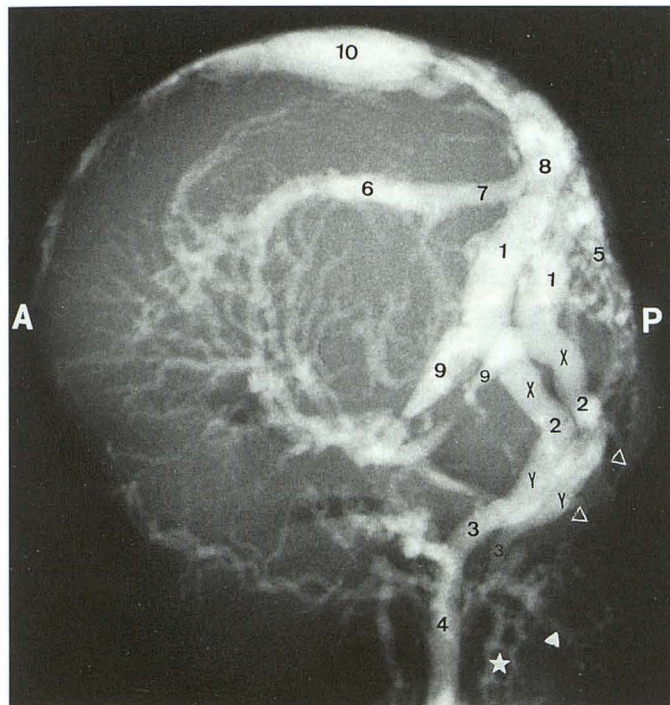
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Fig 1. A 12-week-old fetus (65-mm crown-rump length).

A, Photograph of the brain showing injected veins and dural sinuses. The left cerebral hemisphere has been removed except for the left thalamus (*Th*) so that the transverse sinus (*T*), the free margin (*row of arrowheads*) of the tentorium, the internal cerebral vein (*1*), the great cerebral vein of Galen (*2*), and the straight sinus (*3*) can be well demonstrated. The superior sagittal sinus (*4*), the ventral diencephalic vein (*5*) (draining into the tentorial sinus [*6*]), and the stem of the middle cerebral vein (*7*) are also labeled. The relatively small transverse sinus (*T*) is somewhat obscured by the superimposed tentorial sinus (*6*) and other adjacent veins.

B, Towne view and *C*, lateral view roentgenograms. The transverse (*1*) and sigmoid (*2*) sinuses on each side form a continuous narrow gentle curve that is continuous inferiorly with the jugular sinus (*3*) and the internal jugular vein (*4*). In the Towne projection, the segment of the sigmoid sinus, which lies behind the petrous pyramid (retropyramidal segment [*X*]) courses inferomedially in an arcuate fashion convex superomedially, whereas the infrapyramidal segment (*Y*), which runs below the petrous pyramid courses almost vertically. The mastoid and condylar emissary veins (*open white arrowheads*, mastoid above, condylar below) originate from the sigmoid sinus on each side. The occipital sinuses (*5*) are plexiform in shape and are not dilated at this stage. The primitive internal cerebral vein (*6*), great cerebral vein of Galen (*7*), straight sinus (*8*), superior petrosal sinus (*9*), superior sagittal sinus (*10*) and internal vertebral venous plexus (*asterisk*), deep cervical vein (*arrowhead*), and inferior petrosal sinus (*11*) are labeled.

Sigmoid Sinus and Jugular Bulb

The sigmoid sinus begins at the junction of the transverse sinus and the superior petrosal sinus. It runs inferiorly along the posterior portion of the petrous pyramid (retropyramidal segment). The sinus then runs anteroinferiorly along the inferior border of the petrous pyramid (infrapyramidal segment). At the fetal age of 3 months the sigmoid sinus is small in caliber. Because the cerebellar tentorium is located rather high in this stage, undulation in the course of the sinus seen in an adult is less marked. The transverse sinus therefore extends into the sigmoid sinus with an obtuse angle. The sigmoid sinus continues inferiorly and communicates with the internal jugular vein through the narrow, not yet developed, primitive jugular bulb. Because there is no bulbous enlargement at this stage, it is more appropriate to call this segment the jugular sinus rather than the (primitive) jugular bulb. Radiologically the retropyramidal segment at
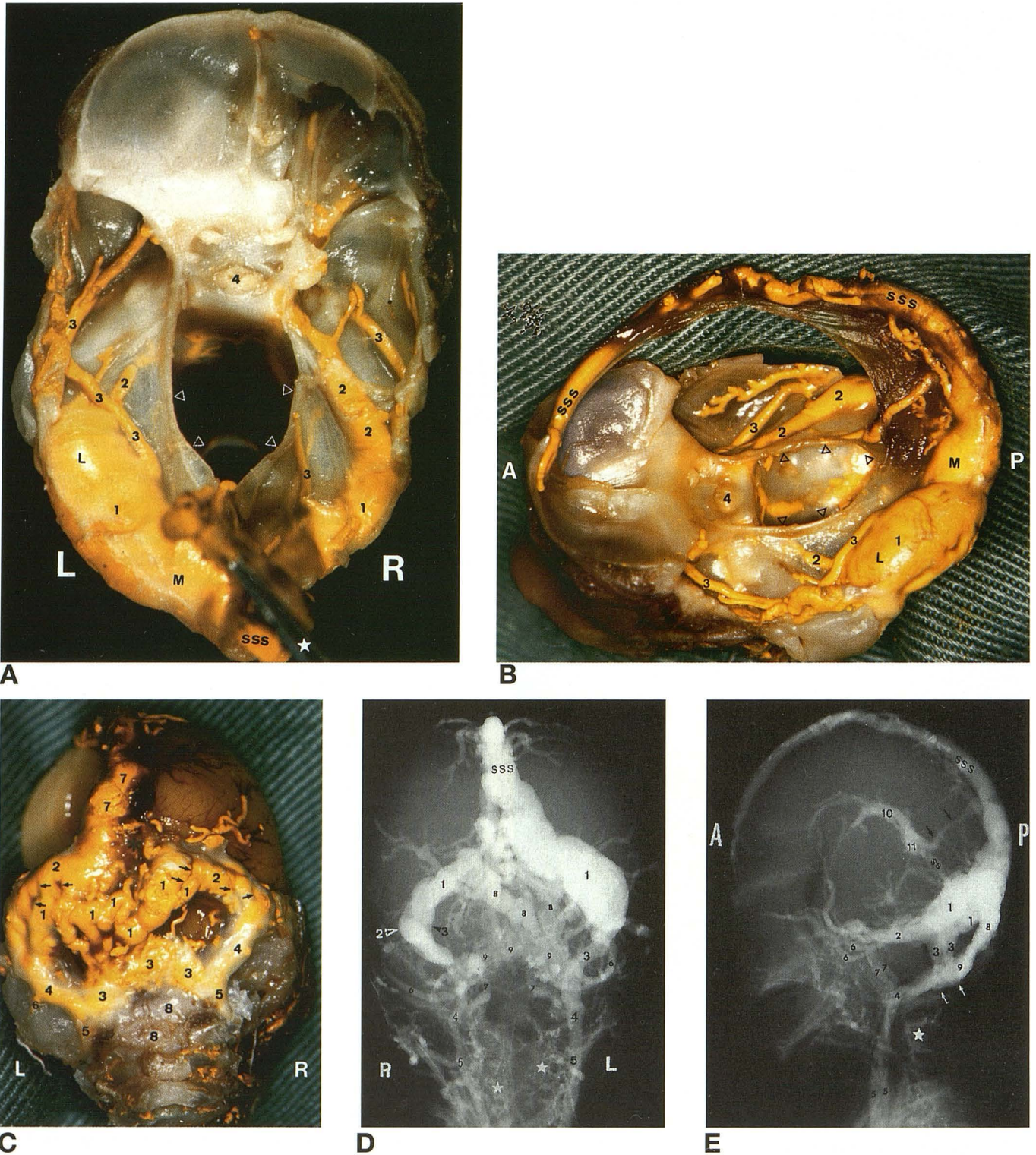
Fig 2. A 16-week-old fetus (115-mm crown-rump length). Photographs of the base of the skull (anterior, middle, and posterior fossa) showing the contrast-filled dural venous sinuses.

A, View from above and *B*, view from above and side. The transverse sinuses (*1*) are ballooned, more so on the left; the lateral part (*L*) is more dilated than the medial part (*M*). The transverse sinus begins to dilate from its lateral part and continues medially to reach the torcular at the fifth to sixth fetal month. This ballooning also extends into the superior petrosal sinus (*2*) on the right, whereas it fails to reach the latter on the left, which remains small. The free margin (*radiating open arrowheads*) of the tentorium, the superior sagittal sinus (*SSS*), the tentorial sinuses (*3*), and the pituitary gland (*4*) are also labeled. A forceps holding down the torcular is labeled (*star*). *Continues.*
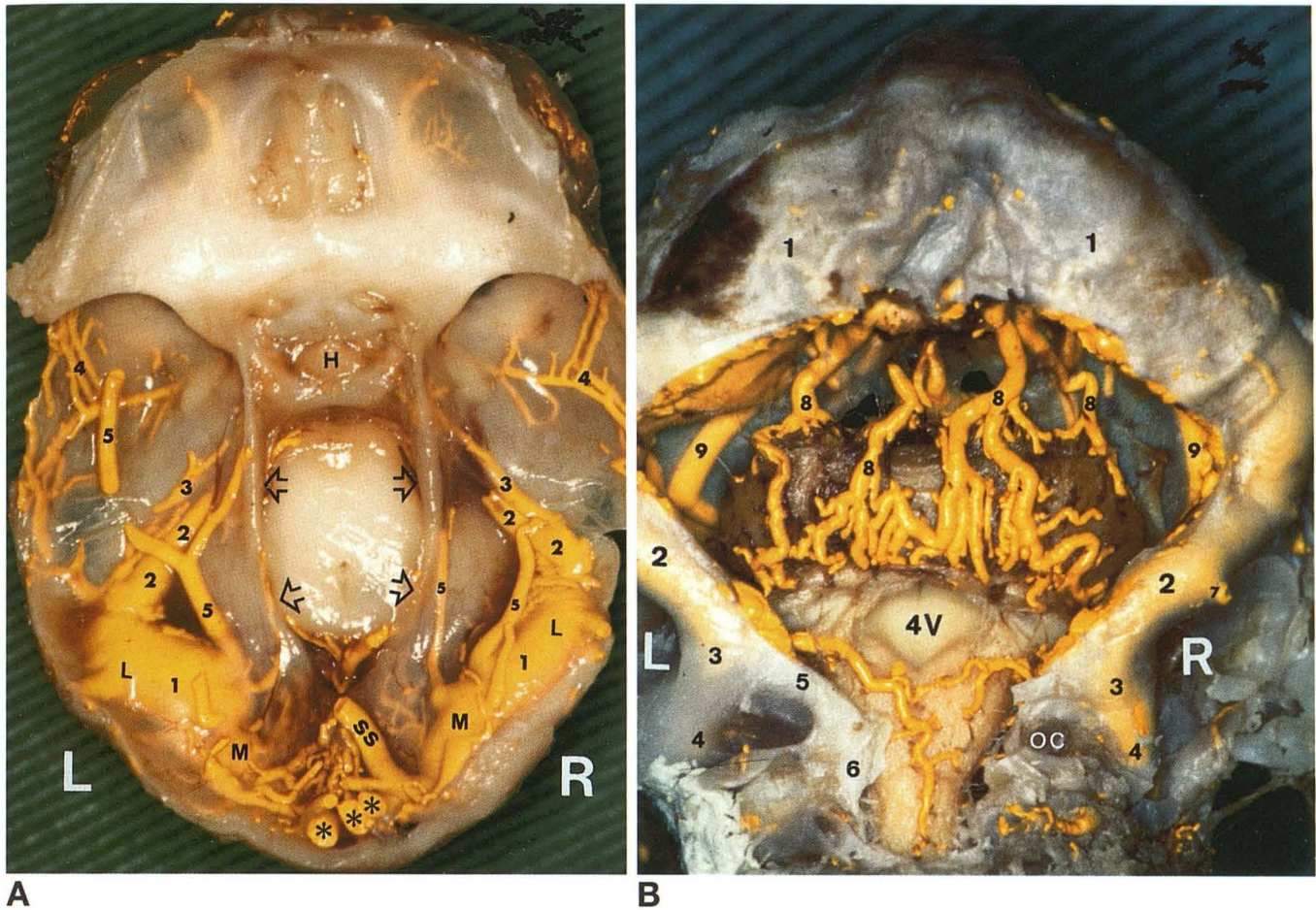
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Fig 3. Photographs of the brain of a 17-week-old fetus (130-mm crown-rump length) showing injected dural sinuses.

A, Base of the skull (view from above). The ballooned transverse sinuses (1) are uneven in size. The lateral parts (L) are larger than the medial parts (M). The superior petrosal sinus (2) are slightly dilated posteriorly because of anterior extension of ballooning of the transverse sinus into the posterior part of the superior petrosal sinus. The torcular is plexiform, showing many cut surfaces of the veins (asterisks). The straight sinus (SS) opens into the medial portion (M) of the transverse sinus on the right side. The prootic sinus (3), middle meningeal vein (4), tentorial sinus (5), hypophysis (H), and free margins of the tentorium (open arrows) are labeled.

B, Posterior fossa dural sinuses (same specimen, view from behind and below). The markedly dilated transverse sinuses (1) are seen. This ballooning continues medially to reach the torcular at the age of the fifth fetal month (Fig 4). The inner diameters of the sigmoid (2) and jugular sinuses (3) and internal jugular veins (4) remain unchanged since the 3rd fetal month (Fig 2C). The right anterior condylar vein (5) emerging from the jugular sinus (3) runs medially and inferiorly through the hypoglossal canal and joins the internal vertebral venous plexus (6). The mastoid emissary vein (7) emerging from the sigmoid sinus (2) can be identified on the right. The well-developed dorsal cerebellar veins (8) running upward on the dorsal aspect of the cerebellum, the lower part of the fourth ventricle (4V), the tentorial sinus (9), and part of the occipital condyle (oc) are also labeled.

Fig 2, cont'd. C, View from behind. The occipital sinuses (1) are markedly increased in number and size—five to seven large venous channels. They stream inferiorly (from the primitive torcular area as well as from the medial portions of both transverse sinuses [2]) toward the developed marginal sinus (3) around the foramen magnum. The marginal sinus then drains into the deep cervical veins (8) (not well opacified on this specimen) and/or the internal vertebral venous plexus. The sigmoid sinuses (4) are not dilated, and the jugular sinuses (5) are small. The dilated transverse sinuses with incomplete multiple septations (arrows), mastoid emissary veins (6), and the dilated posterior part of the superior sagittal sinus (7) are labeled. The medial part of the transverse sinus is defective on the left (asterisk).

D, Towne view and E, lateral view roentgenograms. The transverse sinuses (1) are dilated, particularly on the left. This ballooning begins from the lateral end of the sinus and proceeds medially to reach the torcular. Occasionally it further involves the posterior part of the superior sagittal sinus (SSS). The sigmoid (3) and jugular sinuses (4) are not yet developed, and their diameters remain small (1 to 2 mm), showing little changes in calibers as compared with those of a 3-month-old fetus. The occipital sinuses (8) are, on the other hand, prominent, numerous, some of them huge, and connect the transverse sinuses with the already moderately developed marginal sinus (9) around the foramen magnum. The mastoid and condylar emissary veins (white arrows) are seen. Also labeled are the superior (2) and inferior petrosal sinuses (7), tentorial sinus (6), internal cerebral vein (10), great cerebral vein of Galen (11), and straight sinus (SS). The internal vertebral venous plexuses (asterisk) and the persistent falcial sinus (black arrows) are also labeled.
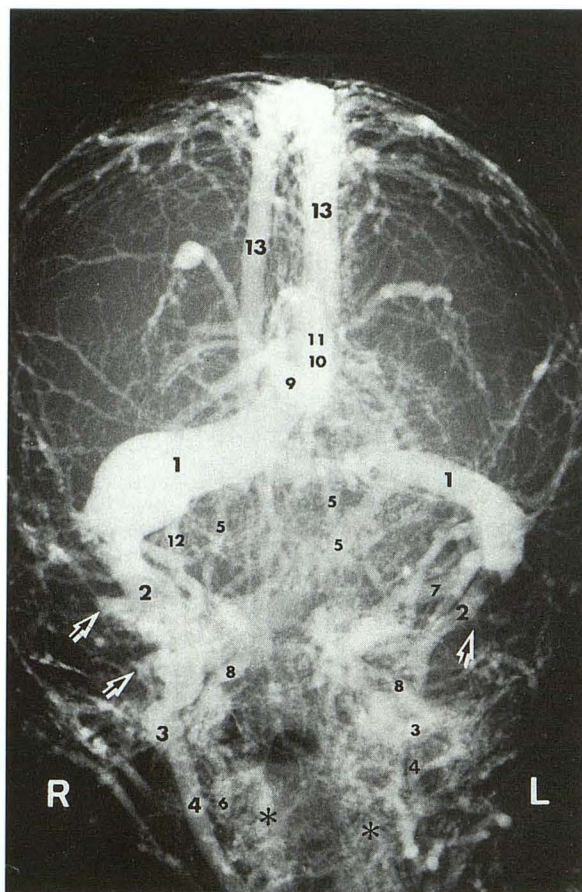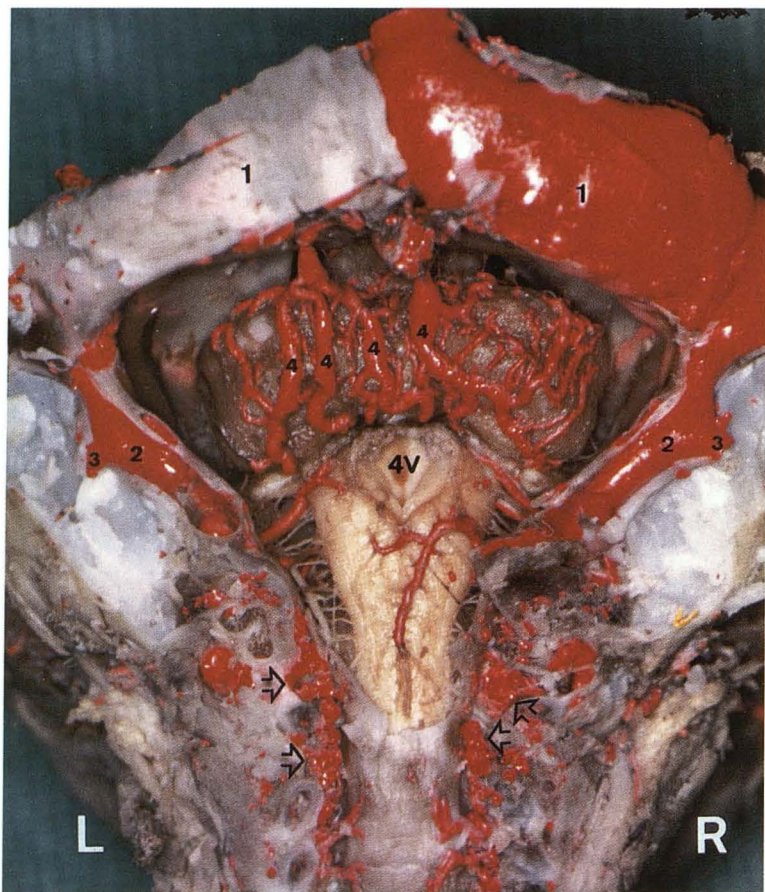
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Fig 4. A 20-week-old fetus (130-mm crown-rump length).

A, Photograph of an injected brain showing the dural sinuses of the posterior fossa (view from behind and below). The ballooning of the transverse sinuses (1) have just reached the midline. The dilated transverse sinuses are now even in caliber (the sinus is covered with the dura mater on the left, whereas the overlying dura mater has been stripped away on the right). The sigmoid sinus (2) has not yet developed, and its inner caliber remains small on both sides. The mastoid emissary veins (3) are slightly dilated. The internal vertebral venous plexus (row of empty arrows), dorsal cerebellar veins (4), and fourth ventricle (4V) are indicated.

B, Towne view and C, lateral view roentgenograms. Ballooning of the transverse sinuses (1) is more prominent on the right side. The caliber of the sigmoid sinuses (2), the jugular sinuses (3), and the internal jugular veins (4) remain small on both sides, particularly at the level of the jugular sinuses, which have an inner diameter of only 1 mm at their narrowest parts (empty arrowheads). The occipital sinuses (5) are also prominent. The emissary veins (unlabeled arrows) and the deep cervical veins (6) are dilated. The superior (7) and inferior petrosal sinus (8), the internal cerebral (9) and vein of Galen (10), straight sinus (11), tentorial sinus (12), superior sagittal sinus (13), and internal vertebral venous plexus (asterisk) are also labeled. The anterior portion of the straight sinus is displaced inferiorly indicating the rapidity of development of the telencephalon.
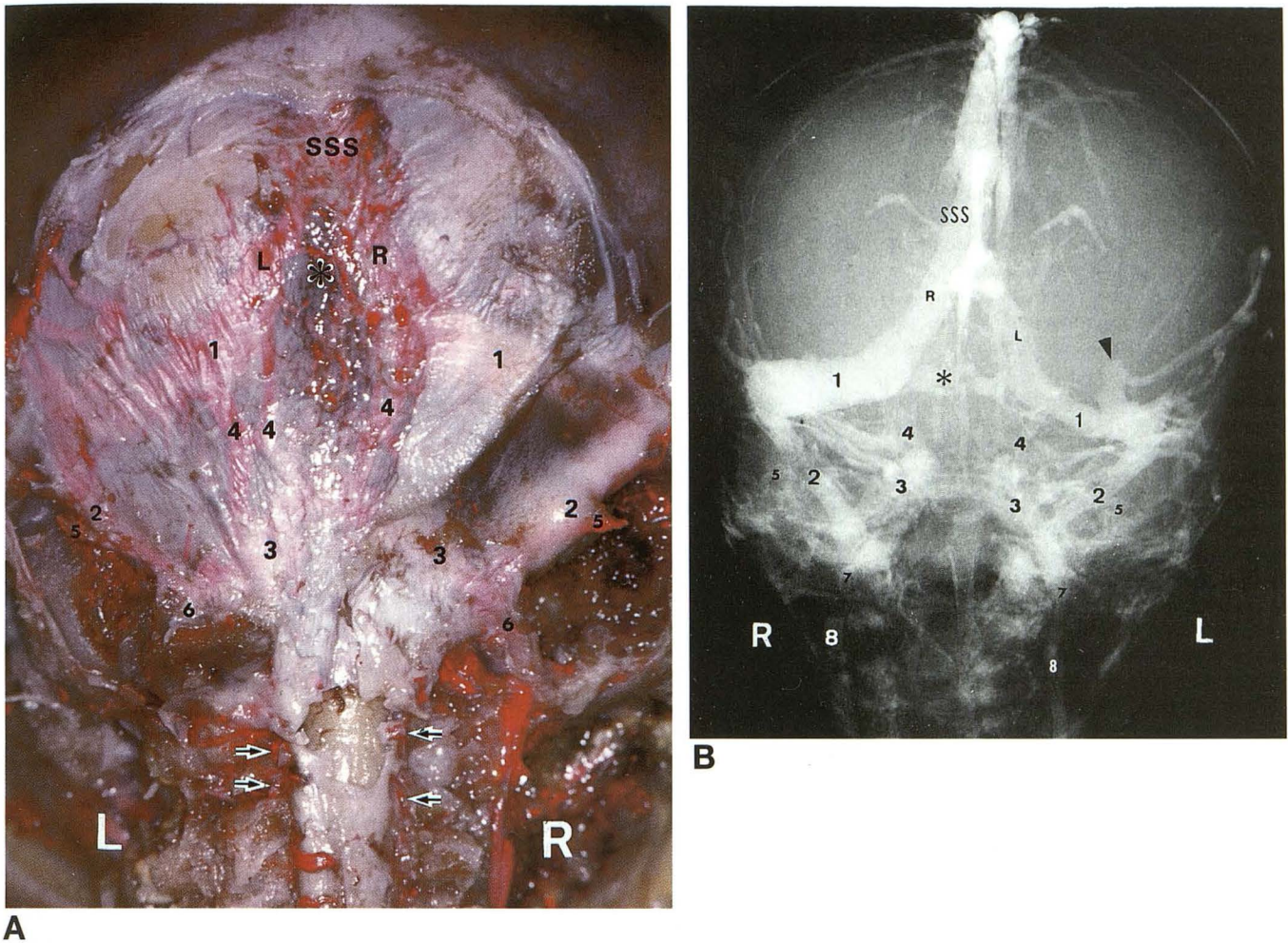

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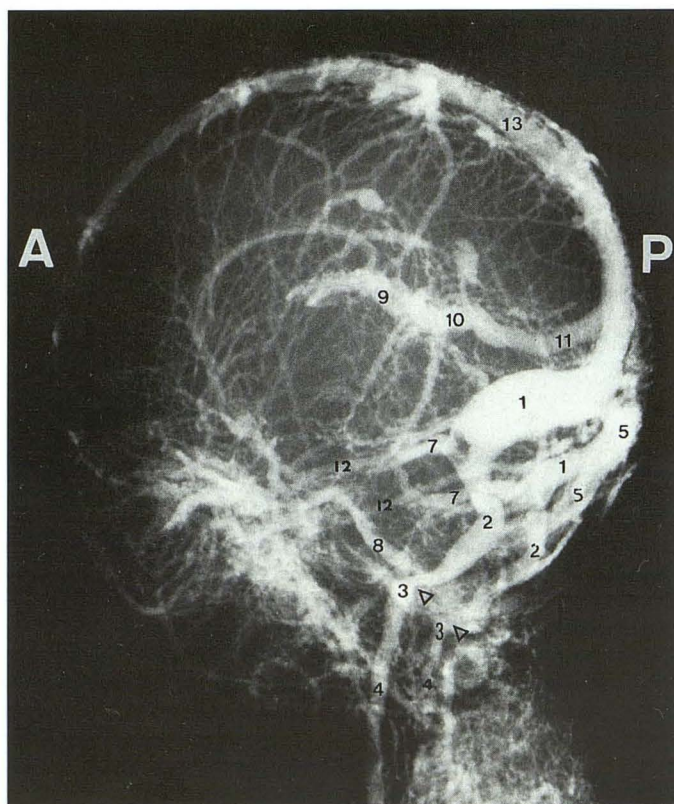
Fig 5. A 24-week-old fetus (215-mm crown-rump length).

A, Photograph of an injected brain showing the occipital sinuses. The posterior fossa dura is left intact. The occipital sinuses (4) show a marked regression in caliber and in number. The caliber of the sigmoid sinuses (2) remain narrow. The marginal sinus (3) around the foramen magnum also shows regression. The transverse sinus (1) is labeled. The superior sagittal sinus (SSS) is divided posteriorly into the right (R) and left (L) limb. The mastoid (5) and condylar (6) emissary veins, internal vertebral venous plexus (arrows), and plexiform torcular (black asterisk) are also labeled. Internal vertebral venous plexus are located in the wall or periphery of the spinal canal.

B, Roentgenogram (Towne view). Although the transverse sinuses (1) are asymmetric (the right one being larger), they are relatively even in caliber on each side. On the left, the transverse sinus has irregular dural pouches (arrowhead), which receive several superficial cortical veins. The sigmoid (2) and jugular sinuses (7) and the internal jugular vein (8) are still poorly developed and small calibers. Unlike in the younger fetus (3 to 4 months), the retropyramidal portion of the sigmoid sinus has a gentle curved course convex slightly inferolaterally (instead of superomedially); its course begins to resemble that of an adult, because of more rapid development of the flat bones of the posterior fossa relative to the growth of the petrous pyramids. The occipital sinuses (4) are less prominent than those of earlier stages. The marginal sinus (3) around the foramen magnum is also smaller and less conspicuous. Note the connecting (somewhat plexiform) dural sinus (black asterisk), which is located in the region of torcular bridging between the two posterior limbs of the superior sagittal sinus (R, L). Several small occipital sinuses originating from the connecting sinus run toward the marginal sinus. The mastoid emissary veins (5) and the superior sagittal sinus (SSS) are also labeled.

this stage takes a gentle inferomedial curve convex superomedially and the infrapyramidal segment courses almost vertically downward (Figs 1B and 2D). However, these changes become less obvious with increasing age (fourth and fifth month). Above the age of 6 months in the fetus, the sigmoid sinuses take gentle curves laterally and begin to resemble those in adults. The inner diameters of the sigmoid and jugular sinuses remain extremely small during the intrauterine life, only 1 to 2 mm (Fig 7).

Emissary Veins

Extracranial drainage of the posterior fossa dural sinuses, aside from the internal jugular

Fig 6. A 7-month-old (25-week) fetus (225-mm crown-rump length).

A, Photograph (view from above). The transverse sinuses (1) maintain their large shapes. Their calibers are large and are relatively even on each side. The cut surface (row of arrowheads) of the torcular (2), straight sinus (3), tentorial sinuses (4), and the superior petrosal sinus (5) are labeled.

B, Roentgenogram (anteroposterior view). The transverse sinuses (1) maintain their large size. They are of even inner diameters. The sigmoid sinuses (2), the jugular sinuses (3), and the internal jugular veins (4) are not yet developed. In comparison with those of earlier stages, each sigmoid sinus (2) at this stage takes a sharper medial curved course convex inferolaterally before reaching the jugular sinus. The occipital sinuses (5) and the mastoid emissary veins (7) are well seen. The internal vertebral venous plexus (asterisk) and the deep cervical veins (arrowheads) are also well demonstrated. The superior sagittal sinus (SSS), the marginal sinus (6), and the inferior petrosal sinus (8) are also labeled.
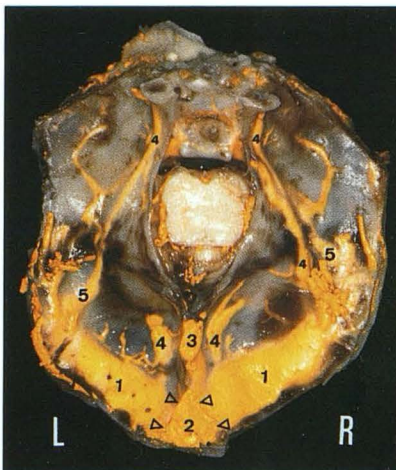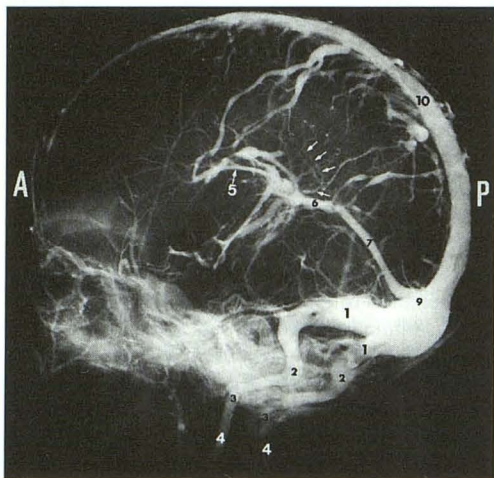

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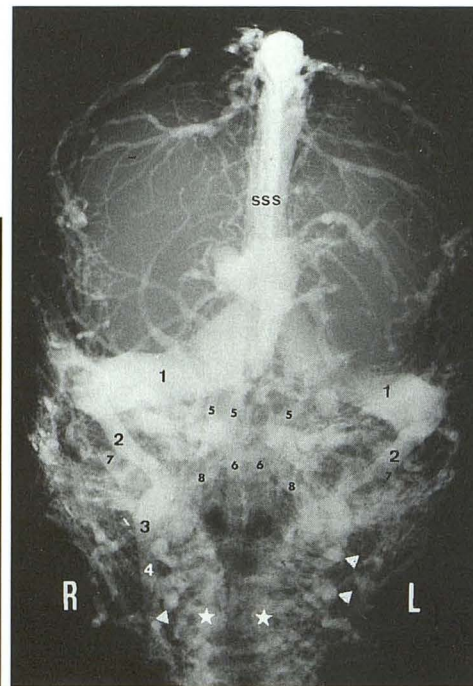
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Fig 7. Roentgenogram of injected cranium of a 8-month-old aborted fetus (lateral view). The relationships of the transverse (1), sigmoid (2), and jugular sinuses (3) and the internal jugular vein (4) are similar to those of the 7-month-old fetus (Fig 6), and their calibers remain small. Similarly the internal cerebral vein (5) and the straight sinus (7) and the torcular (9) have the relationships similar to those of an adult. The vein of Galen (6), however, takes a more horizontal course because of the somewhat short straight sinus (normal variation). Note the position of the splenial vein (row of arrows). The superior sagittal sinus (10) is also labeled.

vein, are (a) via the anterior condylar vein or the marginal sinus into the internal vertebral venous plexus, (b) via the posterior condylar vein into the posterior external vertebral vein or posterior jugular vein, (c) via the mastoid emissary, or (d) via the occipital emissary vein into the oc-

cipital vein. At the age of latter half of 3 fetal months, the mastoid emissary veins and the anterior and posterior condylar emissary veins are already easily discernible. They originate from the sigmoid sinus and communicate with the extracranial veins (Fig 2C). Usually, the anterior condylar emissary veins appear first and receive the venous blood of the sigmoid and marginal sinuses. They course through the hypoglossal canal and open into the vertebral, or paravertebral, veins, or the internal vertebral venous plexus. This is followed by the emergence of the posterior condylar emissary veins that receive venous blood from the same source as the anterior condylar veins, but frequently through the posterior condylar foramen. Those veins flow mainly into the deep cervical and/or the posterior jugular vein. Occasionally the occipital emissary vein originates from the torcular and penetrates the occipital bone inferiorly. This emissary vein appears below the external occipital protuberance to join a tributary of the occipital vein that eventually joins the external jugular vein. At the age of 4 months' gestation, the internal vertebral venous plexus is already well developed. At 5 months' gestation, these emissary veins become even larger and are seen on the posterior aspect of the mastoid (mastoid emissary veins) (Figs 2C and 3B) and along the foramen magnum (condylar emissary veins). At the sixth to seventh fetal month, the condylar emissary veins connect the sigmoid

sinus and/or the marginal (occipital) sinus with the vertebral, paravertebral, and/or deep cervical veins. On the other hand, the mastoid emissary veins connect the sigmoid sinus with the occipital (or posterior auricular) veins.

Occipital Sinus

At the age of 3 fetal months (11 to 12 weeks), fine plexiform vascular channels originate from the primitive torcular plexus (and the medial portion of the primitive transverse sinus) and course towards the distal portion of the sigmoid sinus on each side. The occipital sinuses rapidly increase in caliber and exhibit the greatest development at the age of 4 to 5 months. Five to seven venous channels, some of them very large, originate from the primitive torcular area as well as from the medial portion of both transverse sinuses. They stream toward the already markedly developed prominent marginal sinus around the foramen magnum (Fig 2C). Some channels may, however, be connected to the distal portion of the sigmoid sinus or sinuses. They decrease in caliber and in number by diminution and fusion (Fig 5). By the time the fetus reaches the sixth or seventh month, only a few prominent occipital sinuses can be recognized. They connect the medial portions of the transverse sinuses to the well-developed marginal sinus or to the distal ends of the sigmoid sinuses.

Most of the findings described above are identical or nearly identical in the fetuses examined.

After Birth

Alterations with age in the diameters of the transverse and jugular sinuses (the latter become the jugular bulbs) are well demonstrated in Figures 8 and 9. From birth to age 1 year, the diameters of the transverse sinuses decrease somewhat compared with late fetal life. At 1 year of age, the transverse sinuses have their adult appearance. They increase by only a few millimeters in diameter by age six years.

After birth, the diameters of the sigmoid sinuses increase rapidly to 5 to 7 mm; the rate of increase is similar to that of the jugular sinuses.

The jugular sinuses grow rapidly and become approximately 9 to 10 mm in diameter at 1 year of age (Fig 10). Eventually, they acquire the same diameters as the transverse sinuses (Fig 9).
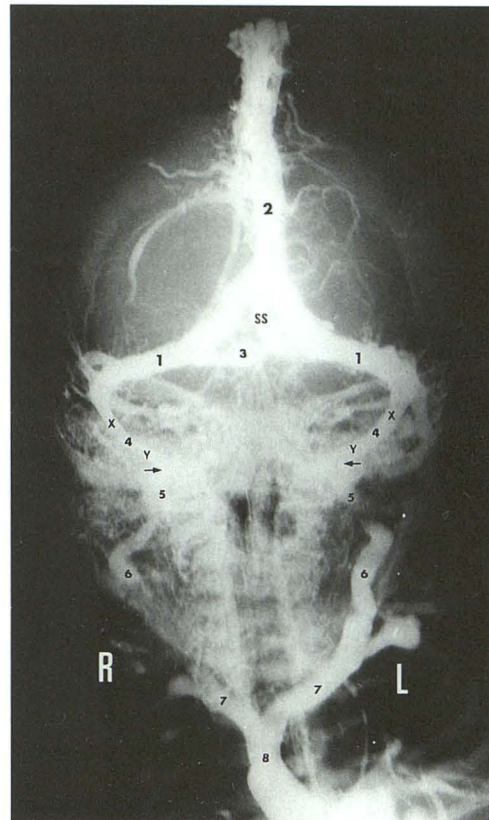

Fig 8. Roentgenogram of an injected full-term (40-week-old) neonate. The transverse sinuses (*1*) are relatively equal in caliber. The union of the posterior limbs of the superior sagittal sinus (*2*) is similar to that of an adult. The connecting sinus (*3*) and the posterior end of the straight sinus (*SS*) are labeled. The retropyramidal and infrapyramidal segments (*X* and *Y*) of the sigmoid sinus (*4*) take a smooth inferomedial curved course convex inferolaterally before reaching the jugular sinus (*arrow*). This inferomedial curved course has, however, a less inferolateral convexity than that of an adult, although it is more convex than that of an earlier fetus. Note the small calibers of the sigmoid sinus (*4*) and the internal jugular vein (*5, 6*), particularly at their junctions (the jugular sinus, *arrow*). The right and left innominate (or brachiocephalic) veins (*7*) unite to form the superior vena cava (*8*). Because of unusual tortuosity of the internal jugular veins (*5, 6*) on both sides and the shorter and more vertical course of the left innominate vein, the relatively straight course formed by the jugular sinus, internal jugular veins, innominate vein, and superior vena cava on the right is not demonstrated, compared with the more circuitous course made up by the corresponding veins on the left, which eventually has to join the superior vena cava located on the right side.

Discussion

Morphological Changes of the Transverse Sinuses

At the 35-mm stage, according to Padget (9, 10), drainage from the primitive transverse sinuses to the primitive sigmoid sinuses and then to the internal jugular veins already can be detected. After the 80-mm stage, the dural sinuses
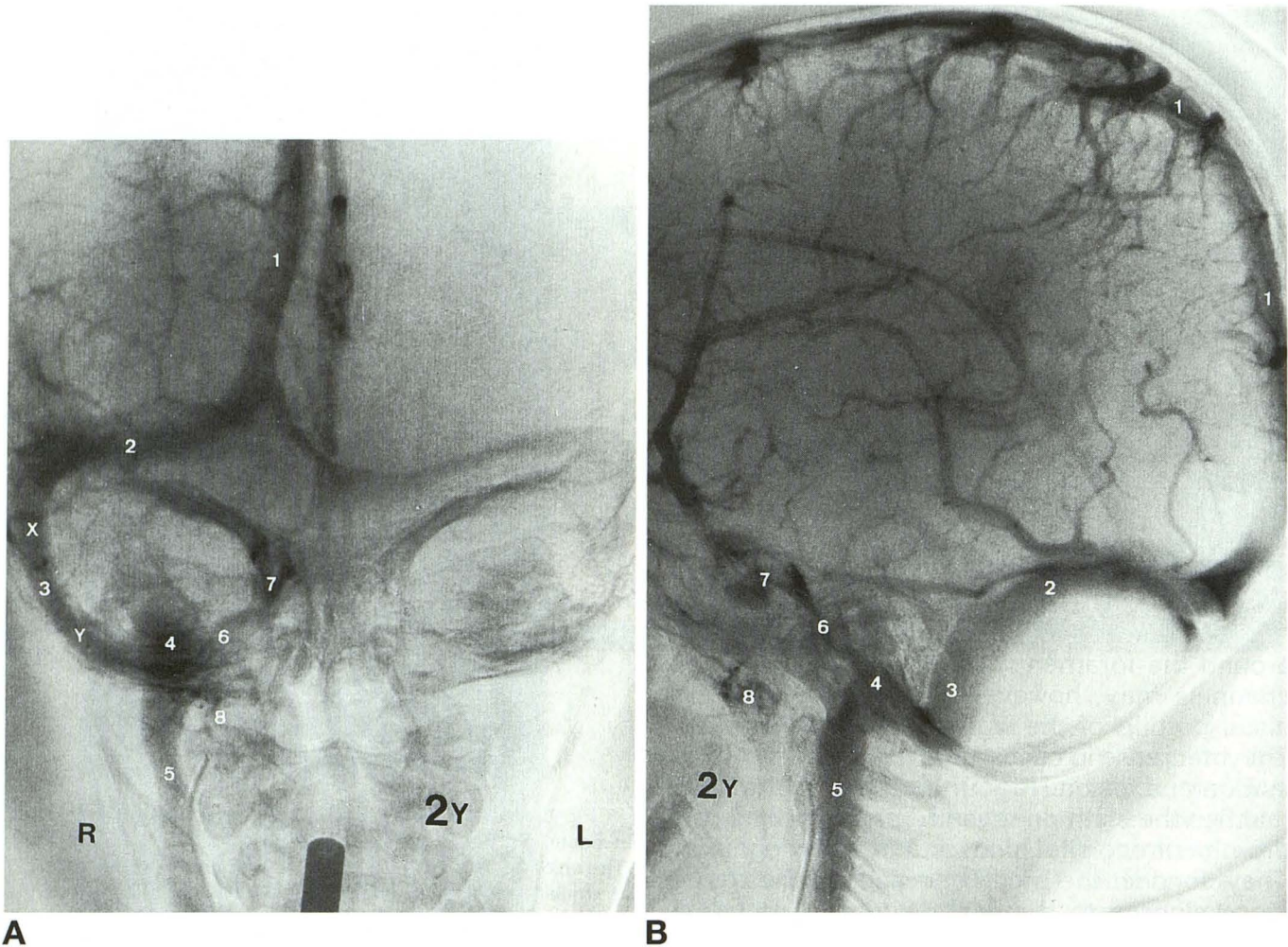
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Fig 9. Carotid angiogram of a 2-year-old boy, venous phase.

A, Anteroposterior view and *B*, lateral view. The superior sagittal sinus (*1*) drains mainly into the right transverse sinus (*2*). The diameter of the sigmoid sinus (*3*) is now equal to that of the transverse sinus (*2*). Note in the anteroposterior view the prominent jugular bulb (*4*), which projects upward. Because of a more rapid development of the occipital squama relative to that of the petrous pyramid, the retropyramidal segment (*X*) of the sigmoid sinus runs more vertically and is located more laterally. The infrapyramidal segment (*Y*) of the sinus (*3*), on the other hand, takes a much more horizontal course in the anteroposterior view before reaching the jugular bulb, so that the sigmoid sinus takes a smooth, large, curved-course convex inferolaterally before turning upwards to form a jugular bulb. The sinus then courses downward to emerge as the internal jugular vein (*5*). Also labeled are the inferior petrosal sinus (*6*), cavernous sinus (*7*), and pterygoid venous plexus (*8*).

from the transverse sinus down to the internal jugular vein are of roughly even diameter and are easily discernible. Between the latter half of the third and fourth fetal months, both the transverse and sigmoid sinuses have the same diameter (3, 7). However, there is a segment of narrowing between the sigmoid sinus and the internal jugular vein, particularly at their junction. We have designated this junction the *jugular sinus.* The latter eventually becomes dilated to form the *superior jugular bulb* on each side. After the fourth month (15 to 16 weeks) of gestation, there is ballooning of the transverse sinuses. This ballooning, according to Masaki (4), begins at the fifth fetal month and lasts until

the seventh month. He states that the ballooning starts from the midportion of the transverse sinus, gradually subsides, and finally disappears at 8 to 10 intrauterine months. Our observation, however, indicates that ballooning begins at 4½ fetal months in the lateral portion of the transverse sinus and proceeds medially on each side.

We found no reports explaining why the development of the ballooned transverse sinus takes place. On measuring the inner diameters of the dural sinuses (seen on roentgenograms of injected fetuses), we found that with the growth of the fetus, the transverse sinuses continue to enlarge minimally, even after completion of the
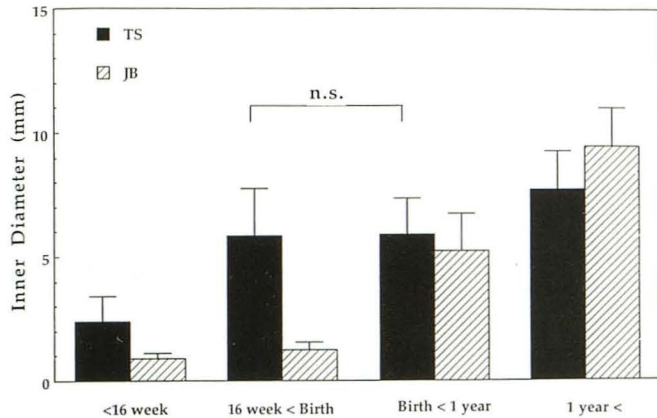
Fig 10. Diagram showing alterations with age in the inner diameters of the transverse sinus and the (superior) jugular sinus (or, later, the bulb). The maximum inner diameters of the transverse and the jugular sinuses were measured on the roentgenograms (in Towne view, taken in stereoscopic pairs) of injected fetal heads (3 to 7 months of age) and on cerebral angiograms (Towne view, taken in stereoscopic pairs) in clinical cases (newborn to infants up to age 6 years). Ballooning of the transverse sinuses (*TS*) is noted in fetus of 16 to 26 weeks (4 to 7 months). After 20 weeks, the inner diameter of the transverse sinus is gradually equalized. The diameter of the fetal jugular sinus (*JS*) (from which the jugular bulb [*JB*] develops postnatally) is approximately 1 to less than 2 mm with only 1 mm increase between the 11th and 26th weeks. From birth to age 1 year, the inner diameter of the transverse sinus decreases somewhat; however, after 1 year of age, the sinus has an adult appearance. It increases only slightly in diameter (a few millimeters) by 6 years of age. On the other hand, the inner diameter of the jugular sinus (*JS*) rapidly increases after birth, becoming approximately 9 to 10 mm at the age of 1 year, and becomes the jugular bulb at the age of 2 years. The jugular bulb and sigmoid sinus eventually acquire the same diameter as that of the transverse sinus.

ballooning. On the other hand, the sigmoid sinus–internal jugular vein junctional area (the jugular sinus) is poorly developed; their inner diameters usually remain at only 1 to 2 mm until the age of 7 fetal months in all fetuses examined (we have investigated fetuses only up to 7 months old). Beginning at 4½ to 5 fetal months, the superficial cortical veins of the expanding cerebral hemispheres rapidly increase in size and drain into the transverse sinus on each side (6–8). This corresponds to the period of ballooning of the transverse sinuses and to the rapid increase in the total blood draining into the transverse sinuses. The narrow internal lumens of the sigmoid sinuses and the internal jugular veins, particularly at their junctions (the jugular sinuses), results in physiologic intraluminal venous stasis, intraluminal venous hypertension, secondary ballooning of the transverse sinuses, and enlargement and some formation of multiple emissary veins for better extracranial drainage (formation of physiologic collateral venous

channels). Another outcome of the ballooning and followed by a relative decrease in the diameter of the transverse sinus is formation of dural outpouches, into which a cortical vein or veins may join. As the ballooned transverse sinuses gradually return to their normal size, small dural pouches (joining the transverse sinus on the side of the convexity dura or of the tentorial dura) are frequently formed. This is the reason that, in some cases, a cortical vein or veins indirectly join the transverse sinus through a small tentorial sinus or a dural sinus over the convexity. In addition, irregular ballooning and shrinkage of the transverse sinus frequently results in formation of septa, fenestration, or even defective or missing segment (particularity medial portion) of the transverse sinus (3, 7). The latter may also be caused by irregularity or defect in one of the posterior limbs of the superior sagittal sinus near the torcular. Also clinically those findings can be seen on the venous phase of routine cerebral angiograms. Poor communication between the two transverse sinuses at the level of the torcular is of paramount importance when one considers using a combined approach to resect a tumor that involves both the middle and posterior fossae and to ligate and sever the sinus surgically near its knee for a better exposure.

If one postulates that the torcular is located at the junction of the superior sagittal sinus and the straight sinus and that the superior sagittal sinus has right and left posterior limbs, the torcular may be said to be situated on one side depending on where the straight sinus joins. Usually, the straight sinus drains into the left limb, whereas the superior sagittal sinus more frequently joins the transverse sinus on the right side. The reason for the more frequent drainage of the superior sagittal sinus into the right transverse sinus may be related to the relatively linear courses of the transverse sinus, the sigmoid sinus, the internal jugular vein, the superior vena cava, and the atrium on the right side (10). On the left side, the internal jugular vein has to take an extra-long inferomedial bend through the left brachiocephalic vein before joining the superior vena cava located on the right. Thus drainage of cranial venous blood is more circuitous on the left than on the right (Fig 11).

The asymmetry of the heights of the medial portions of the transverse sinuses is clearly related to the asymmetric heights of the tentorial leaves. Frequently, the plexiform torcular

makes it difficult to evaluate the exact location of the torcular in fetus on external inspection. The difference between the relatively straight connection from the transverse sinus through the sigmoid sinus down to the internal jugular vein seen in the fetus and the more sinuous course of the same segments seen in adults is in most part caused by the development of the telencephalon and secondary posterior and inferior displacement of the transverse sinuses (14).

Morphological Changes of the Sigmoid, Occipital, and Marginal Sinuses with Emissary Veins and Jugular Bulb

Although a drainage mode from the primitive transverse sinuses through the primitive sigmoid sinuses to the primitive internal jugular veins is already detectable at the 30-mm stage (9, 10), the sigmoid sinuses are easily identifiable after the 80-mm stage (9, 10). Our studies, however, indicate that the sinuses are poorly developed at this stage and maintain their tiny inner calibers until after birth. On the other hand, the change in the volume of the posterior fossa, influenced greatly by the development of the cerebellum, is most marked between the ages of 30 and 40 weeks in fetus (16). Alterations in the course of the sigmoid sinuses appear to occur during this period.

Reports on the occipital and the marginal sinuses along the foramen magnum have been scanty. Even a classical monograph by Padget (8, 9) failed to include any description until the fetus reaches the 80-mm stage. Our cases (65-mm stage, 3 months of gestation) and Masaki's cases (4) (4 months of gestation) show the plexiform occipital and marginal sinuses extending from the region of the tentorial attachment down to the foramen magnum. The transient enlargement followed by diminution in number and size of the occipital sinuses similarly is related to the physiologic hemodynamic response to the increased venous drainage from the intracranial to the extracranial spaces.

Each internal jugular vein of the adult has an enlargement in two places (4). The superior jugular bulb is located in the jugular foramen and forms the origin of the internal jugular vein. Inferiorly, there is dilatation in the course of the vein located a short distance above the junction with the brachiocephalic vein. The latter corresponds to the site of the two-leaf valves. These
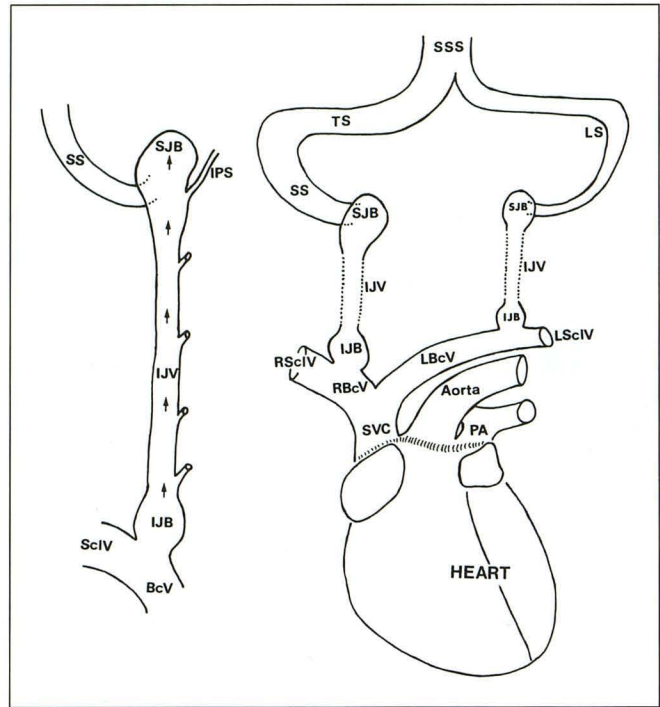

Fig 11. Schematic diagram showing (in adult) the relatively linear course of the superior jugular bulb, the internal jugular vein, the inferior jugular bulb, and the brachiocephalic (also called innominate) vein on the right side before opening into the superior vena cava and the right atrium. Labeled are the pounding effects of ascending negative pulse waves (*arrow*), the inferior jugular bulb (*IJB*), internal jugular vein (*IJV*), left brachiocephalic vein (*LBcV*), lateral sinus (*LS*), which includes the transverse and sigmoid sinuses, left subclavian vein (*LSclV*), pulmonary artery (*PA*), right brachiocephalic vein (*RBcV*), right subclavian vein (*RSclV*), superior jugular bulb (*SJB*), sigmoid sinus (*SS*), superior sagittal sinus (*SSS*), superior vena cava (*SVC*), and transverse sinus (*TS*). In the fetus, the superior sagittal sinus splits posteriorly into two posterior limbs. The posterior limbs of the superior sagittal sinus and the transverse, sigmoid, and jugular sinuses on the right therefore take a much less laterally curved (more linear) course (convex laterally). The fetal jugular sinus is also much less tortuous than the adult jugular bulb.

"inferior jugular bulbs" (one on each side) are of incomplete spherical (or fusiform) shape during the fetal life (5th to 10th month). They appear to complete their morphologic appearance just after birth. The superior jugular bulb is not formed during fetal life (12). Although there are two jugular bulbs, the superior jugular bulb may simply be called the jugular bulb because the inferior jugular bulb is rarely discussed clinically and in the neuroradiologic literature. This superior bulbous enlargement, the (superior) jugular bulb, was not found in our fetal specimens (ranging from 3 to 7 months) nor observed in cerebral angiograms of our infants less than 2 years of age. Indeed, these (superior) jugular

bulbs are usually seen only in children aged 2 years or older. This appears to correspond to the period when a shift takes place from a "fetal" to a "postnatal" circulatory type (or from a "lying down" position to an erect posture). For this reason, it appears more appropriate for the portion of the sinus that later becomes the jugular bulb to be called the *jugular sinus* before it becomes the jugular bulb at age 2 years.

Because the jugular sinus is surrounded by cartilaginous and osseous structures, it is difficult to expand during fetal life. This needs the pounding effects of ascending negative pulse waves originating from the right atrium, traversing upward to strike the jugular sinus at near right angle at the base of the skull (jugular foramen). This takes place only after the infants assume erect posture. The hammering effects of the negative pulse waves hitting the roof of the jugular sinus eventually create the (superior) jugular bulb and enlarge the surrounding osseous structure, creating the osseous jugular fossa (6) (Fig 11). The reason for the frequently larger transverse sinus and sigmoid sinus on the right side is also explained. The dynamic change of the inner caliber of the sigmoid sinuses is similar to that of the superior jugular bulb. According to Hirakoh (2), the volume of each (superior) jugular bulb in adults far exceeds the total combined blood volume of the sigmoid and the inferior petrosal sinuses. In addition, there is a low pressure area (empty space) within the (superior) jugular bulb that acts as a reservoir for venous blood. This works as a suction pump, smoothly conveying the intracranial venous blood through the internal jugular vein into the heart. Occasionally there may be an excessive enlargement of the jugular bulb causing an upward arching of the internal auditory canal and the adjacent inner ear, which might be a cause of tinnitus, dizziness, or mild hearing impairment (ectasia of the jugular bulb) (3).

The present study focused mainly on the morphological development of the posterior fossa dural sinuses, emissary veins, and jugular bulb. On the other hand, recent functional anatomic studies, such as the higher hydrostatic pressure of the dural sinuses in children than in adults (13), the lack of autoregulation of blood pressure in premature infants (11), and the predilection to hemorrhage in the germinal matrix in premature neonates in cases of increased intracranial venous pressure (5, 15) await future deeper understanding of the correlation between the morphological and functional changes of the intracranial venous structures.

References

1. Böving BG. Anatomy of reproduction. In: Greenhill JP, ed. *Obstetrics*. Philadelphia: WB Saunders; 1965:3–101
2. Hirakoh G. On the fossa jugularis and outflow cranial venous blood through it [in Japanese]. *J Kurume Med Ass* 1962;25:965–971
3. Huang YP, Okudera T, Ohta T, Robbins A. The torcular, the straight, sagittal, lateral, occipital and tentorial sinuses: the variations and clinical significance. In: Kapp JP, Schmideck HH, eds. *The Cerebral Venous System and Its Disorders*. Orlando, Fla: Grune and Stratton; 1984:109–167
4. Masaki S. Studies on the development of the dural sinuses of the human fetus [in Japanese]. *Fukuoka Acta Medica* 1959;50:2769–2788
5. Nakamura Y, Okudera T, Hashimoto T. Germinal matrix hemorrhage of venous origin in preterm neonate. *Human Pathol* 1990;21:1059–1062
6. Noda R. Development of the cerebral vessels of the human fetus [in Japanese]. *Fukuoka Acta Medica* 1958;1057–1072
7. Okudera T, Ohta T, Huang YP. Development of the torcular, adjacent dural sinuses and related draining veins in human fetus. In: Kapp JB, Schmideck HH, eds. *The Cerebral Venous System and Its Disorders*. Orlando, Fla: Grune and Stratton; 1984:93–107
8. Okudera T, Ohta T, Huang YP, Yokota A. Development and radiological anatomy of the superficial cerebral convexity vessels in the human fetus. *J Neuroradiol* 1988;15:205–224
9. Padget DH. Cranial venous system in man in reference to development of adult configuration and relation to arteries. *Am J Anat* 1956;98:307–355
10. Padget DH. The development of the cranial venous system in man: from the viewpoint of comparative anatomy. *Contrib Embryol* 1957;247:81–138
11. Pape KE, Wigglesworth JS. Haemorrhage, ischemia and the perinatal brain. *Clinical Developmental Medicine*. London: Spastics International Medical Publications, 1979:69/70:1–185
12. Shinohara M. Morphological study on the bulbus venae jugularis internae of embryo [in Japanese]. *Acta Anat* 1957;32:41
13. Sobata E, Ebina K, Hikichi M, Iwabuchi T. Distinctiveness of children in terms of dural sinus pressure [in Japanese]. *Nervous System in Children* 1985;10:257–266
14. Streeter GL. The development of alterations in the vascular system of the brain of the human embryo. *Contrib Embryol* 1918;24:7–38
15. Takeshige Y. Bedeutung des Venensystems für die Häemodynamik des Hirnstammes. *Anat Anz* 1967;125:166–192
16. Yamaguchi K, Goto N, Nara T. Development of the human fetus cerebellum: a volumetric study of the cerebellar structures [in Japanese]. *No To Hattatsu* 1988;20:3–9