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Computed Tomography of the Brain Stem with Intrathecal Metrizamide.
Part I: The Normal Brain Stem

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Detailed anatomy of the brain stem and cervicomedullary junction can be accurately demonstrated with metrizamide computed tomographic cisternography. Specifically, surface anatomy is unusually well outlined. Nine distinct and easily recognizable levels of section are described: four levels in the medulla, three in the pons, and two in the mesencephalon. Surface features of the brain stem, fine details in the floor of the fourth ventricle, cranial nerves, and vascular structures are shown and discussed.

Reliably accurate imaging of the brain stem and cervicomedullary junction has now become available using high-resolution computed tomographic (CT) scanning following intrathecal administration of metrizamide [1–6]. The demonstration of surface features of the brain stem such as the ventral fissure, ventrolateral sulcus, pyramids, and olivary protuberance has become commonplace; such details have not been routinely demonstrable in the past.

Many authors [1, 2] have already emphasized the value of metrizamide CT cisternography and its superiority to both angiography and pneumoencephalography. These latter procedures rely on subtle displacement of vessels or distortion of the air-filled fourth ventricle and posterior fossa cisterns. Compared with air, metrizamide spreads much more readily in the *entire* subarachnoid space without the problem of meniscus formation or "air lock." CT permits the separation of the various collections of contrast agent and avoids the superimposition of features encountered in nontomographic contrast studies.

Improved visualization of the details of the brain stem by metrizamide CT has allowed the detection of subtle morphologic changes in the brain stem and subarachnoid space not previously appreciated. Distortion of the brain stem by tortuous vessels, focal atrophic changes, and early changes of mass lesions are good examples of the value of this method. A detailed familiarity with the normal anatomy of the brain stem, cerebellum, and fourth ventricle on CT cisternography is essential in order to fully utilize the diagnostic capability of metrizamide CT.

Materials and Methods

From those patients who had a metrizamide CT cisternogram at the New York Neurological Institute in an 18 month period for a variety of indications, we analyze the morphology of the brain stem in 30 who had no clinical signs or symptoms of brain stem involvement.

Metrizamide was introduced in the subarachnoid space through a lumbar puncture or more often through a C1–C2 puncture, which allowed us to use a lesser amount of contrast medium. The average amount used was 8 ml of contrast material at 170 mg/ml, except in children. The use of metrizamide in children is not recommended by the manufacturer, however, in our experience, the diagnostic value of this method may outweigh the potential risks of the contrast agent in difficult cases. Scanning was performed in the supine position in the hour after injection. All patients were scanned on an 0450 Pfizer high-resolution scanner using primary reconstruction of an area of interest measuring about 10 cm in diameter on a 512 × 512 matrix. The usual slice thickness was 5 mm, but we often used

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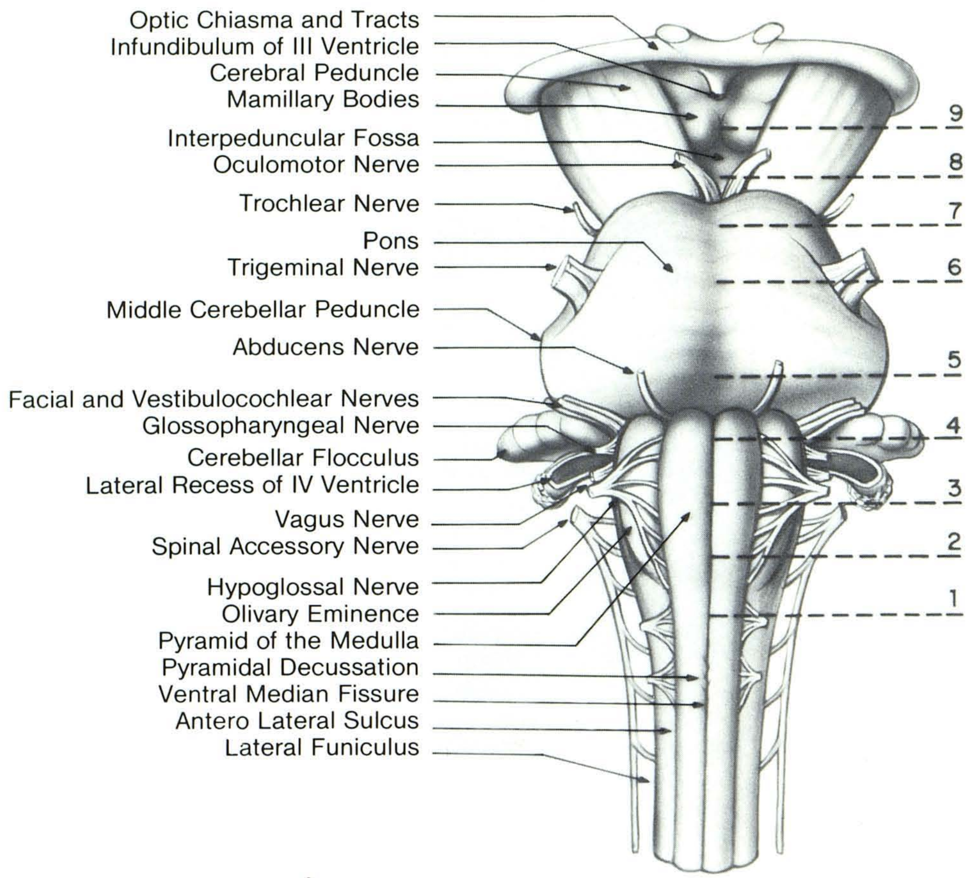


Fig. 1.—Anterior (**A**) and posterior (**B**) views of brain stem show the nine levels of section. The plane of section is usually higher anteriorly than posteriorly.

thinner slices of 2–4 mm; the average increment between two consecutive slices was 5 mm. The angle of section was that used for the standard examination of the brain, about 10°–15° inclination above the canthomeatal line. The anatomic description in this work refers to characteristic sections most commonly encountered. Often, however, because of difference in skull configuration or degree of angulation, the plane of section is not precisely reproduced, and one may obtain an image combining the anterior aspect of one standard level of the brain stem with the posterior aspect of an adjacent one. The description of coronal sections will be the subject of a future report.

Results: Normal Brain Stem and Surrounding Spaces

We subdivide the brain stem into the following nine distinct and recognizable levels (fig. 1):

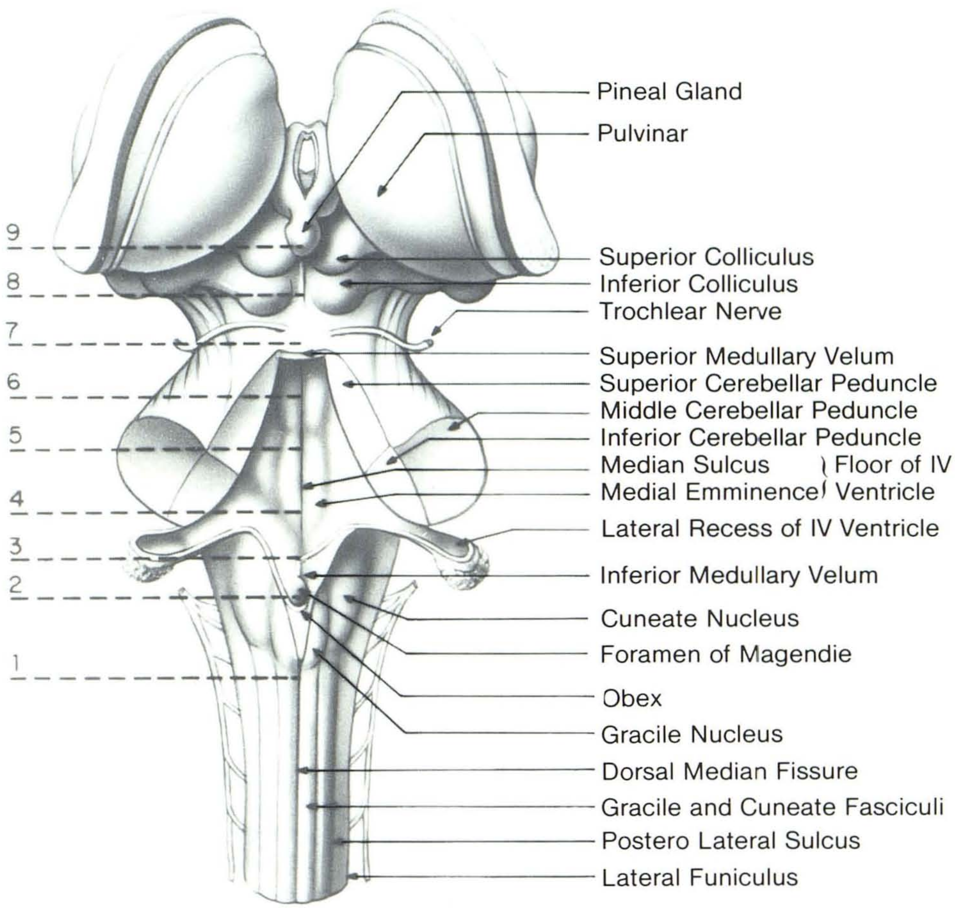
Medulla:
1. closed medulla (C1 roots to obex)
2. transition from closed to open medulla (obex; foramen of Magendie)
3. open medulla (olivary nucleus; floor of fourth ventricle)
4. medullary pontine junction

Pons:
5. lower pons (seventh and eighth nerves)
6. mid pons (fifth nerve)
7. isthmus of the pons

Mesencephalon:
8. inferior colliculus
9. superior colliculus (third nerve)

1. *Closed Medulla* (fig. 2)

This extends from the first cervical roots, which are usually slightly below the foramen magnum, to the obex. In



B

cross section, the closed medulla has a pear-shaped appearance with a narrow ventral surface featuring a short, often oblique, median fissure and a broader, dorsal surface with a less pronounced dorsal median fissure. Anteriorly, on either side of the ventral fissure are two eminences that correspond to the pyramids of the medulla (largely formed by the corticospinal tracts). The ventrolateral sulcus is a very shallow groove posterior and lateral to the pyramidal eminence. The vertebral arteries usually lie close to this ventrolateral sulcus. The lateral and posterior medullary segments of the posterior inferior cerebellar artery are often seen lateral and posterior to the medulla within the medullary cistern. The hypoglossal and accessory nerves arise respectively from the ventrolateral sulcus and the lateral surface of the medulla, but they are very rarely seen on metrizamide CT scanning.

On several occasions, we have found an axial rotation of the medulla in a well positioned scan; we consider this to be a normal variant as it does not correlate with any underlying pathology.

2. *Transitional Medulla* (fig. 3)

Starting at the obex, the posterior aspect of the medulla is cleft by a narrow midline groove that corresponds to the most caudal part of the fourth ventricle and gives to the medulla the posteriorly open appearance on cross section. The obex is the point of transition from the closed medulla to what we choose to call the open medulla. The lower, open medulla is a short segment, only a few millimeters thick, extending from the obex to the upper margin of the foramen Magendie. The latter foramen is sometimes seen in the midline bounded on both sides by a thin membrane that comprises the ependyma and the choroid. Lateral to this membrane are the eminences of the gracile and cuneate nuclei. Anteriorly, the cross section at this level features the

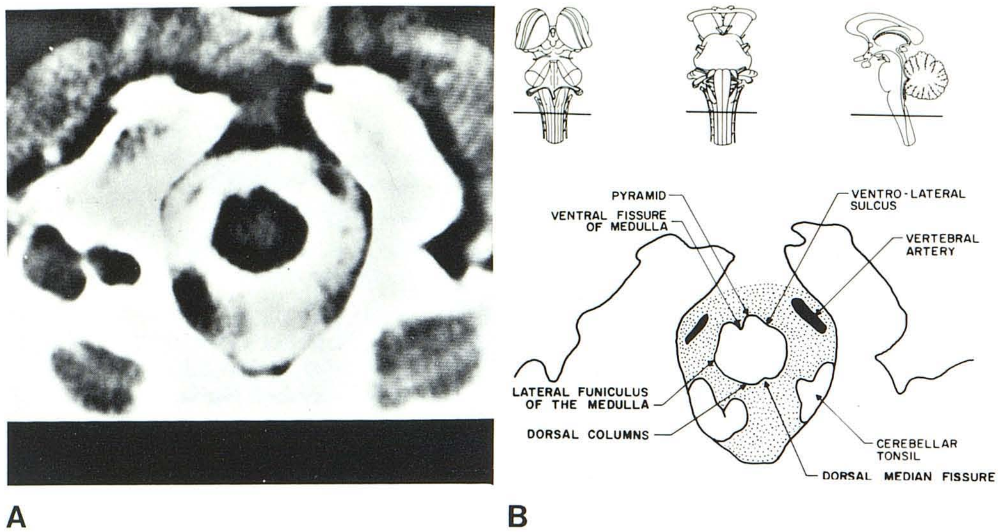


Fig. 2.—Level 1. Closed medulla at level of foramen magnum is pear-shaped and usually somewhat rotated.

olivary eminence, which is lateral to the pyramid and corresponds to a large underlying cellular structure called the inferior olivary nucleus. The anterior surface characteristics of the medulla are better discussed on the following higher section where the olivary nucleus is somewhat more prominent.

3. *Open Medulla* (fig. 4)

Above the foramen of Magendie, the medulla (which is now *open* posteriorly) has, on cross section, a characteristic laterally biconcave appearance due to the shallow postolivary sulcus. While the closed medulla has only one anterior protuberance (medullary pyramid) on either side of the ventral fissure, the open medulla has two: the medullary pyramid medially and the olivary eminence laterally. The preolivary sulcus separates the olivary eminence from the pyramid. Lateral to the olive is the shallow postolivary sulcus, which gives to the open medulla its laterally biconcave symmetry. The dorsal aspect of the medulla is now formed by the floor of the fourth ventricle where one can sometimes recognize the eminences of the nuclei of the twelfth, tenth, and eighth nerves located on either side of the median sulcus in this order from medial to lateral. The roof of the fourth ventricle is formed by the inferior medullary velum, which can be identified on CT. These fine structures are almost impossible to visualize with any other imaging method. Figure 5 shows the details in the floor of the fourth

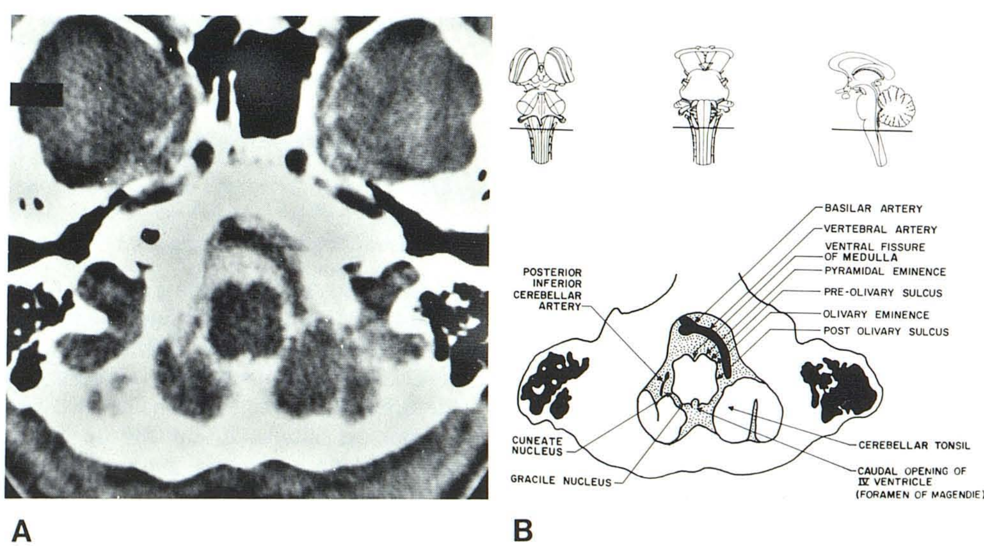
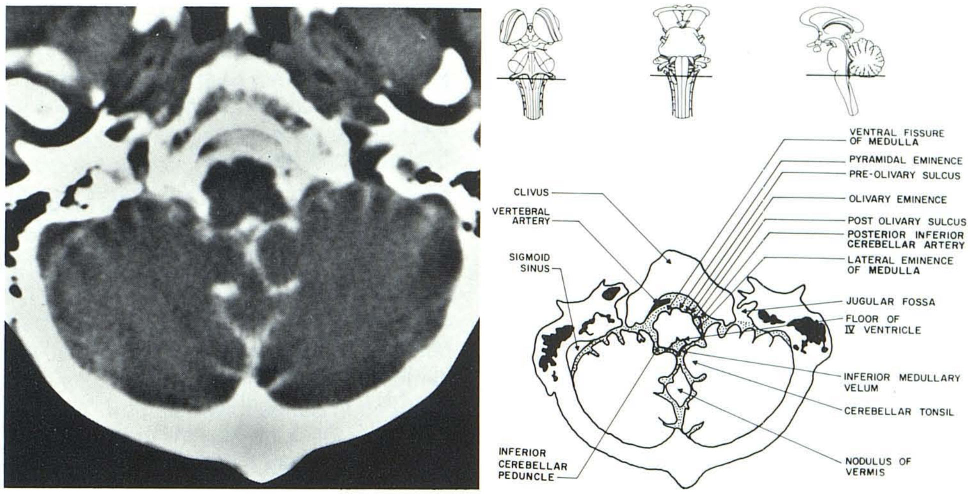


Fig. 3.—Level 2. Transitional medulla at level of obex.



A B

Fig. 4.—Level 3. Biconcave open medulla above foramen of Magendie.

ventricle as well as the surface features of the anterior part of the open medulla. In this segment of the medulla, the twelfth nerve arises from the anterolateral sulcus while the ninth and tenth nerves arise posterolateral to the olivary eminence. These nerves are, however, very small and rarely seen radiographically. Only the twelfth nerve has been demonstrated in its cisternal course on rare occasions. The nodulus of the cerebellar vermis, surrounded with metrizamide, lies in the midline behind the inferior medullary velum and between the cerebellar tonsils.

Asymmetric flattening of the medullary pyramid and olivary protuberance are often observed as a result of an adjacent tortuous vertebral or basilar artery (fig. 6). While a mild asymmetry is very common and may even be the rule, a pronounced deformity can be associated with symptoms referable to this part of the medulla, as is discussed in part II (in this issue).

4. *Medullary-Pontine Junction* (fig. 7)

The tomographic cross section at this level has a characteristic mushroom-like appearance with the most caudal edge of the basis pontis forming a round anterior mass with a shallow midline groove for the basilar artery. This shallow groove is quite different in appearance from the deeper ventral fissure seen on the lower section. The overhanging

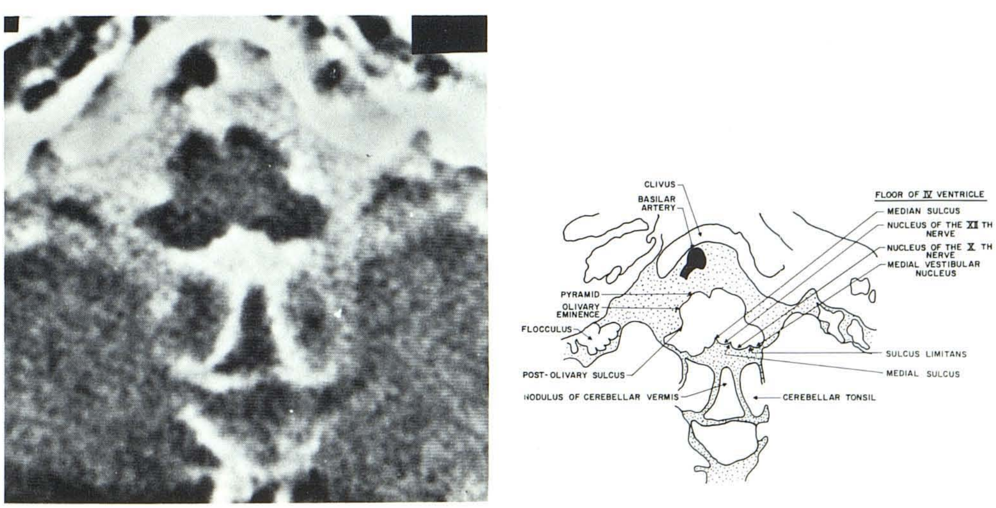


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Fig. 5.—Level 3. Open medulla: details of floor of fourth ventricle.

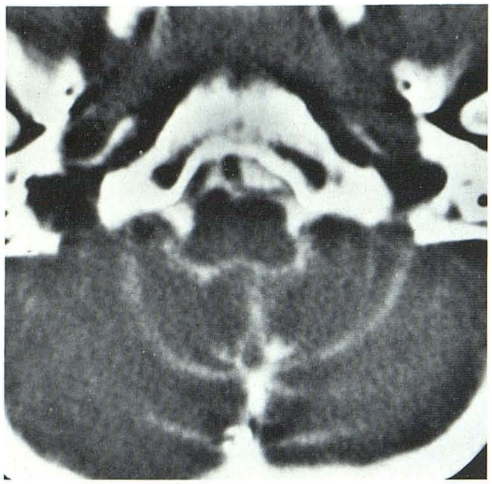

Fig. 6.—Level 3. Tortuous vertebral artery causes asymmetric deformity of medulla.

edge corresponds to the lowest part of the middle cerebellar peduncles; these are separated from the medulla by the pontomedullary sulcus. The inferior cerebellar peduncles (restiform bodies) that connect the medulla to the cerebellum appear as a posteriorly diverging biped structure in continuity with the floor of the fourth ventricle. At this level, the lateral recess of the fourth ventricle makes a characteristic obtuse angle with the body of the fourth ventricle; it extends anterolaterally and opens into the cerebellopontine angle cistern through the foramen of Luschka posterior and lateral to the inferior cerebellar peduncle. The seventh and eigth nerves arise from the brain stem at this level and are often seen bounded anteromedially by the lateral recess of the fourth ventricle and posterolaterally by the brachium of the flocculus. The latter two nerves may be seen in their entire course from the brain stem to the porus acousticus (fig. 8); as a rule, however, the internal auditory canal is better seen on the next higher section.

5. *Low Pons* (fig. 9)

The low pons extends from the medullary-pontine junction upward to a level below and not including the origin of the fifth nerve. This part of the pons, largely formed by the pyramidal tracts and the pontine nuclei, is connected to the cerebellum by the middle cerebellar peduncle or brachium pontis. The cerebellar peduncles at this level are clearly demonstrated without the difficulty of the partial volume effect seen on the lower section. The pons shows a shallow anterior midline groove for the basilar artery, which may be tortuous and often lies on one side or the other of the midline. The space between the brachium pontis and the petrous bone constitutes the cerebellopontine angle cistern, which extends posteriorly and laterally from the pontine cistern. It is limited posterolaterally by the flocculus, which projects into the cistern. The internal auditory canal is visualized and can be clearly demonstrated with contrast medium extending into the canal if the sections are 3 mm thick or less and if they are taken at every millimeter. On this section, the anterior cerebellar artery is often seen in the cerebellopontine angle cistern, and its relation to the eighth nerve can often be demonstrated. It should be noted that while the eighth nerve emerges from the brain stem at the somewhat lower level of the medullary-pontine junction, its peripheral segment may be seen entering the internal auditory canal on this section.

At the level of the lower pons, the two posterior recesses of the fourth ventricle can be demonstrated. The floor of the fourth ventricle may show the median sulcus with the medial eminence on either side (best demonstrated in fig. 5C of

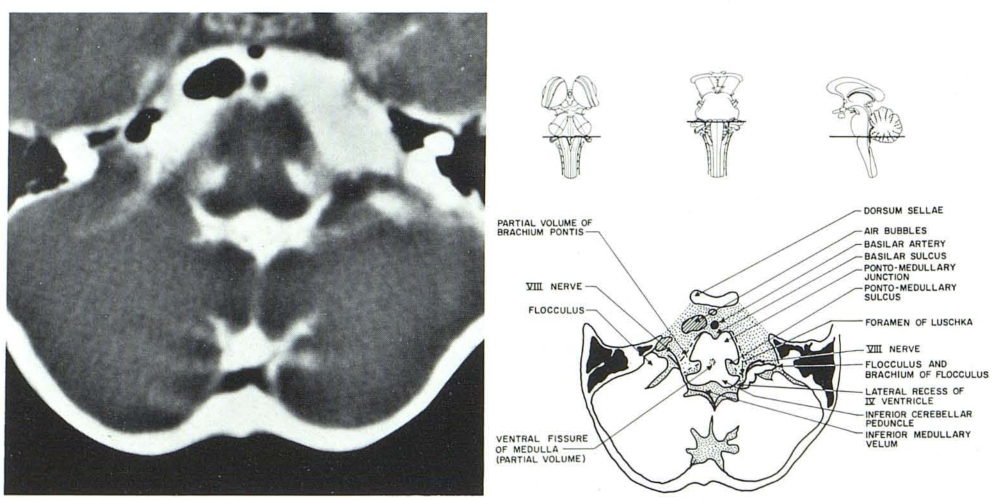

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Fig. 7.—Level 4. Medullary-pontine junction. Brain stem has characteristic mushroomlike appearance. Brachium pontis is often seen lateral to pontomedullary sulcus as less dense structure due to partial volume effect (**B**, dashed lines).

part II). Both features are important aspects of the anatomy of the floor of the fourth ventricle. The obliteration of these features is often the earliest indication of a swelling or mass in the brain stem, but incomplete filling of the floor of the fourth ventricle with metrizamide, due to the layering of the contrast agent, may leave a space (filled with partially opacified spinal fluid) that is indistinguishable from the rest of the brain stem, thus rendering the precise evaluation of the fourth ventricle difficult when CT is performed in the supine position. If partial filling is suspected, the scan may be repeated immediately after the patient has shaken his head or turned his face down briefly. If the patient is being evaluated for a mild swelling of the brain stem, the demonstration of the median sulcus in the floor of the fourth ventricle is crucial.

In the evaluation of the cerebellopontine angle with metrizamide for angle tumors, care should be exercised not to confuse the flocculus with a neoplasm. Overlapping thin slices no thicker than 3 mm should be used for the proper evaluation of the internal auditory canal and definition of the flocculus as it joins the cerebellar hemisphere posterolateral to the eighth nerve.

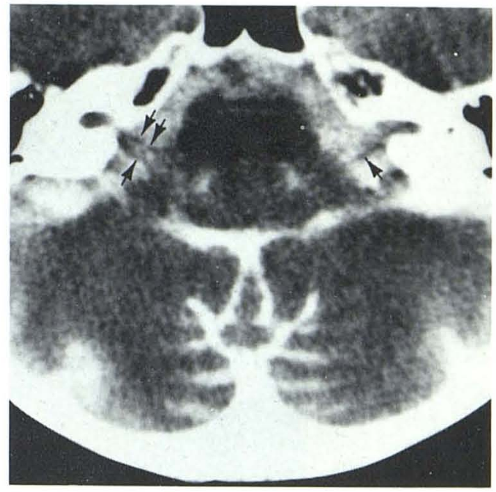

Fig. 8.—Level 4. Pontomedullary junction: seventh and eighth cranial nerves (*arrows*) from brain stem to porus acousticus.

6. *Mid Pons* (fig. 10)

The midpons represents the middle third of the pons, and is distinguished primarily by the easily recognizable origin of the trigeminal nerves. From the lateral aspect of the pons, and near the origin of the brachium pontis, the large trigeminal nerve crosses the cerebellopontine angle cistern heading toward Meckel cave. The cerebellopontine angle cistern does not, as a rule, extend posterolaterally as far as at the lower levels. A thin film of metrizamide may extend, on the posterior surface of the petrous bone, laterally beyond the flocculus to outline the surface of the sigmoid sinus.

The fourth ventricle is a fairly symmetric structure in the midline of the posterior fossa; while some asymmetry in the sizes of its two halves can often be seen, it is one of the most sensitive indicators of displacement of the midline structures in the evaluation of the posterior fossa [7–9]. The dorsal aspect of the fourth ventricle is usually indented by the nodulus of the vermis and the fastigial nucleus.

The pontine and cerebellopontine angle cisterns contain a large number of vascular structures such as the basilar artery and its branches; these are usually tortuous and wavy compared with the course of the fifth nerve, which runs anteriorly and superiorly from the lateral aspect of the pons.

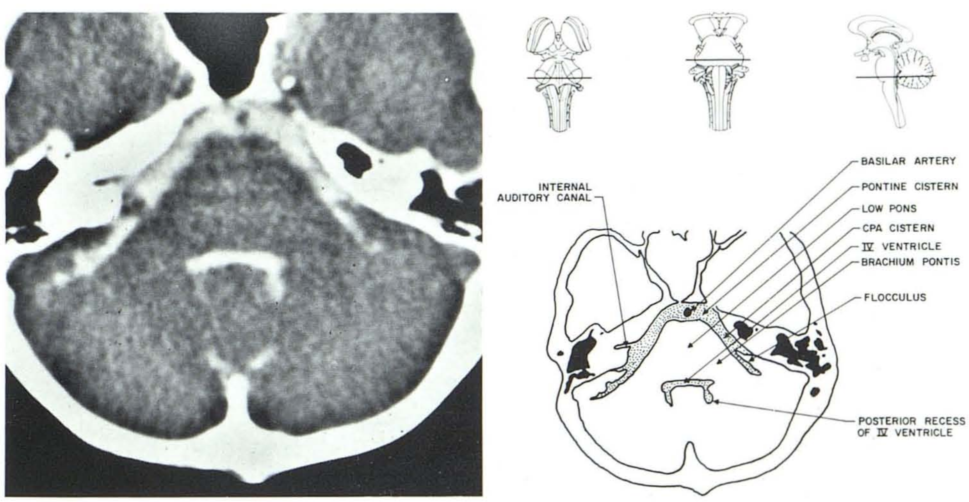

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Fig. 9.—Level 5. Low pons.

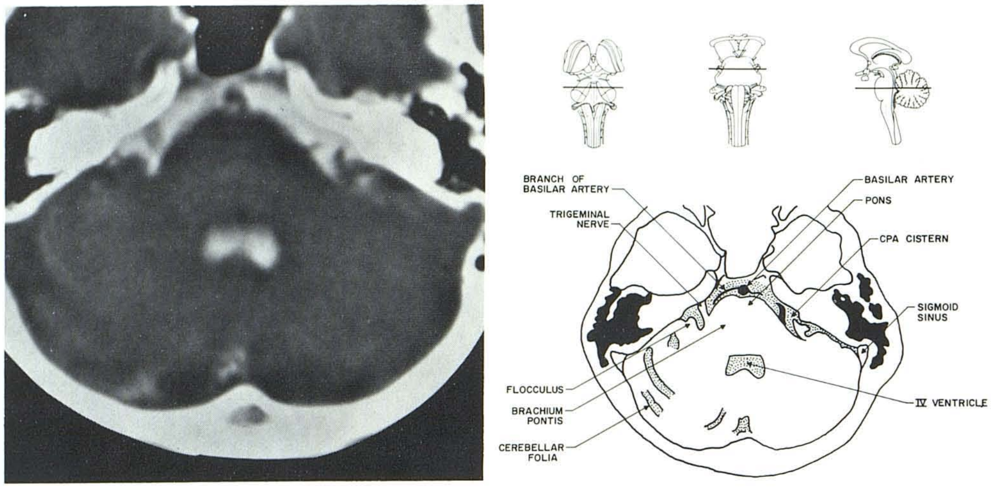

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Fig. 10.—Level 6. Midpons. Size, shape, and course of trigeminal nerve distinguish it from adjacent vascular structures.

7. *The Isthmus* (fig. 11)

This is the transition between the pons and the midbrain. It is only a few millimeters thick. The brain stem at this level is almost entirely surrounded by metrizamide. The continuity of the perimesencephalic cistern at this level is interrupted by the superior cerebellar peduncles (brachium conjunctivum) and the upper end of the fourth ventricle. Ventrally, the isthmus has the shallow basilar groove that characterizes the lower two levels of the pons. The section typically passes above the origin of the fifth nerve, which, at this level, has already entered Meckel cave. The upper end of the fourth ventricle is bounded on both sides by the superior cerebellar peduncles and posteriorly by the superior medullary velum. Its roof is usually flat at this level, but the floor of the fourth ventricle is indented by the median sulcus. This feature again is quite helpful in detecting or describing mild swelling of the brain stem. The CT section at this level usually passes above the petrous bone, and, while the central features are those of the cerebellum, the more anterior and lateral metrizamide-containing sulci are supratentorial. Anterior to the pons, the upper end of the basilar artery is usually recognizable, and some of its branches (e.g., the superior cerebellar artery) may be seen. The dorsum sella is anterior to the basilar artery, and occasionally one can see, on either or both sides of the dorsum,

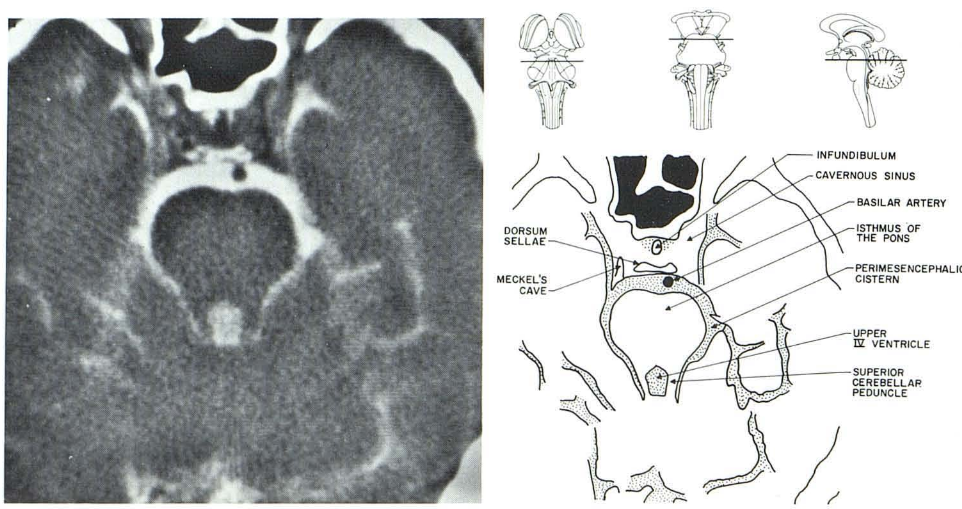

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Fig. 11.—Level 7. Isthmus of pons. Continuity of perimesencephalic cistern is interrupted by superior cerebellar peduncles.

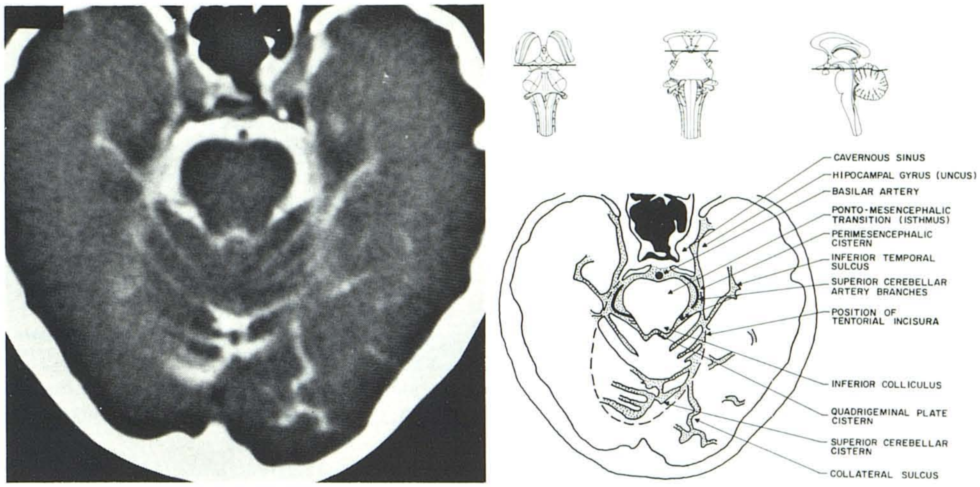

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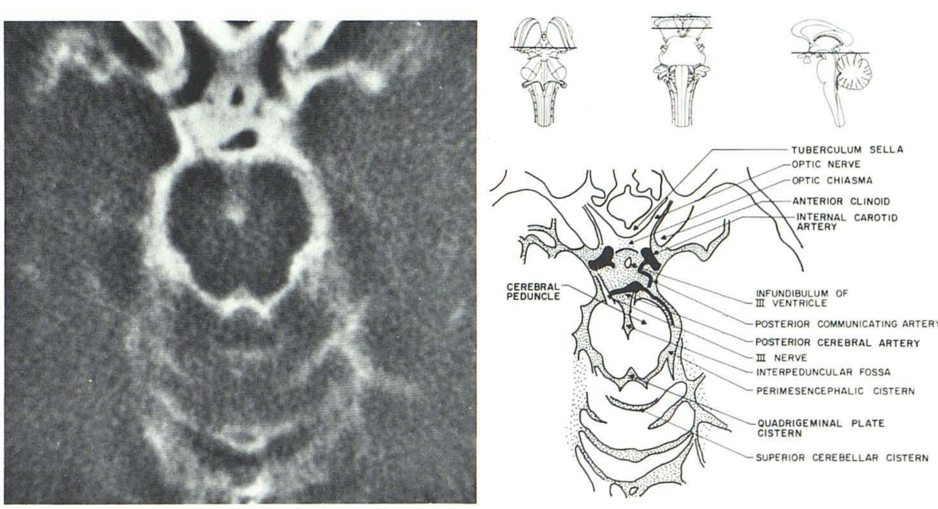
Fig. 12.—Level 8. Lower mesencephalon, inferior collicular level. Perimesencephalic cistern completely surrounds midbrain without interruption.

Meckel cave filled with metrizamide. Within the sella turcica, one can recognize the pituitary stalk surrounded by a small amount of metrizamide that may have passed through the diaphragma sellae; this amount increases in the case of an empty sella.

8. *Lower Mesencephalon* (fig. 12)

This is the level of the inferior colliculus. The midbrain is completely surrounded by metrizamide; the collicular plate is posterior, and the lower end of the cerebral peduncles is anterior. Occasionally, the lower part of the interpeduncular fossa may be seen as a result of a partial volume effect. The cross section shows the lateral mesencephalic sulcus, on the lateral aspect of midbrain, at the junction of the cerebral peduncle with the rest of the midbrain; often a vascular structure may be identified at this point. The fourth cranial nerve arises from the posterior aspect of the midbrain at this level, but we have not been able to identify it with certainty. The pontine and perimesencephalic cisterns contain the basilar artery ventrally and branches of the superior cerebellar artery and veins on both sides of the midbrain. These vessels are readily recognized by their characteristic wavy appearance. Posterior to the collicular plate is the quadriqeminal plate cistern, which is bounded posteriorly by the central lobule of the vermis. The cerebellar folia can be



A B

Fig. 13.—Level 9. Upper mesencephalon, superior collicular level. Supraclinoid internal carotid merges with optic nerve to form a single lucent structure on CT scan. On anterior view diagram, level of section is indicated as a wide shaded band that includes optic chiasm.

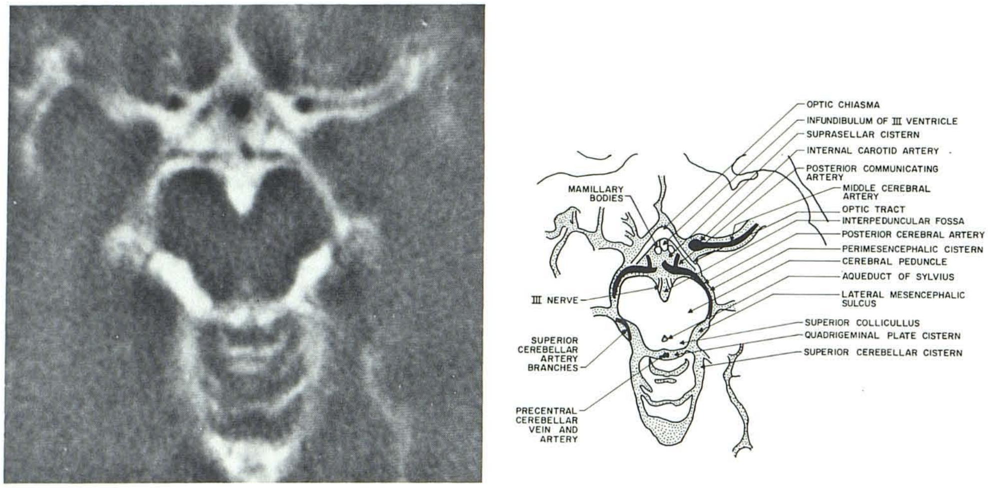


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Fig. 14.—Level 9. Upper mesencephalon. Details of suprasellar cistern.

identified in the central region of the section. The change from the metrizamide-filled transverse parallel cerebellar foliae to the sulci on the inferior surface of the temporal lobes represents the boundary of the tentorial incisura. The cerebral aqueduct, when filled with contrast material, is seen as a small slit just anterior to the collicular plate.

9. *The Upper Mesencephalon* (fig. 13)

This plane usually passes through the superior quadrigeminal plate posteriorly and delineates the deep interpeduncular fossa anteriorly. On the lateral aspect of the midbrain, the lateral mesencephalic sulcus indicates the posterior boundary of the cerebral peduncle. The oculomotor nerve arises from the medial aspect of the cerebral peduncle and crosses the interpeduncular fossa in an almost horizontal course lateral to the posterior communicating artery. Anterior to the interpeduncular fossa, the basilar artery divides into the two posterior cerebral arteries. More anterior is the suprasellar cistern, which may show the two mamillary bodies and the infundibulum of the third ventricle coursing inferiorly to form the pituitary stalk. Anterior to the infundibulum, the optic chiasm and tract are usually seen (fig. 14). In the perimesencephalic cistern, branches of the posterior cerebral artery and the basal vein of Rosenthal may be detected. Small veins like the posterior mesencephalic vein and the lateral mesencephalic veins are rarely discerned. The upper end of the vermis and the cerebellar folia can still be demonstrated at this level, posterior to the quadrigeminal plate cistern, in a small triangular cistern.

Summary

In summary, the anatomic details of the brain stem are exquisitely demonstrated with metrizamide CT. The obex is the zone of transition from the closed medulla, which has a conical pear-shaped appearance to the quadriconcave open medulla. The pyramids and inferior olivary nuclei characterize the anterior surface of the open medulla, whereas the median sulcus and the cranial nerve nuclei constitute the floor of the fourth ventricle at the same level. The mushroomlike appearance of the pontomedullary junction is easily reproducible with the restiform bodies forming the posteriorly diverging biped. The seventh and eighth nerves are usually seen at this level or on the adjacent higher section of the low pons. The brachia pontis are well delineated in almost their entire length at the level of the low pons as they bound the fourth ventricle laterally. The trigeminal nerves are seen at the level of the midpons, which is a few millimeters lower than the isthmus. The latter constitutes the junction of the pons with the mesencephalon. The colliculi divide the midbrain into two levels of axial cross section: the inferior collicular level, which may or may not show the trochlear nerve, and the superior collicular level, which features anteriorly the suprasellar cistern and its contents.

Air is an inadequate contrast agent for CT for the demonstration of the surface features of the brain stem because of partial filling of the cisterns and meniscus formation that precludes a detailed outline. Metrizamide, however, with careful technique, fills the fourth ventricle and subarachnoid space both infra- and supratentorially. High-resolution scanning using primary reconstruction, and thin tomographic sections of no more than 5 mm are a necessity for metrizamide CT. Consecutive scans should not be spaced more than 5 mm apart if all the features of the brain stem are to be evaluated. The demonstration of the various grooves and protuberances on the surface of the brain stem provides a unique opportunity for evaluating focal atrophy and focal swelling henceforth impossible to visualize consistently.

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