# Brainstem Safe Entry Zones

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## ABSTRACT

**BACKGROUND**: There have been no studies of the structure and safe surgical entry zones of the brainstem based on fiber dissection studies combined with 3-dimensional (3-D) photography.

**OBJECTIVE**: To examine the 3-D internal architecture and relationships of the proposed safe entry zones into the midbrain, pons, and medulla.

**METHODS**: Fifteen formalin and alcohol-fixed human brainstems were dissected by using fiber dissection techniques, ×6 to ×40 magnification, and 3-D photography to define the anatomy and the safe entry zones. The entry zones evaluated were the perioculomotor, lateral mesencephalic sulcus, and supra- and infracollicular areas in the midbrain; the peritrigeminal zone, supra- and infrafacial approaches, acoustic area, and median sulcus above the facial colliculus in the pons; and the anterolateral, postolivary, and dorsal medullary sulci in the medulla.

**RESULTS**: The safest approach for lesions located below the surface is usually the shortest and most direct route. Previous studies have often focused on surface structures. In this study, the deeper structures that may be at risk in each of the proposed safe entry zones plus the borders of each entry zone were defined. This study includes an examination of the relationships of the cerebellar peduncles, long tracts, intra-axial segments of the cranial nerves, and important nuclei of the brainstem to the proposed safe entry zones.

**CONCLUSION**: Fiber dissection technique in combination with the 3-D photography is a useful addition to the goal of making entry into the brainstem more accurate and safe.

## INTRODUCTION

Improved imaging techniques and electrophysiological monitoring along with more precise microsurgical techniques have increased the number of surgeries for brainstem lesions such as cavernous malformations and gliomas, and led to the definition of several proposed safe entry zones.[1-4] The relationships between these safe entry zones and internal brainstem structures have been explored by using predominately histological and neurophysiological studies.[5-8] The 1 study using fiber dissection techniques to examine safe entry zones has focused on the anterolateral brainstem, and most studies have focused on surface rather than internal anatomy.[9-12] This is the first study in which the complex internal architecture of the brainstem was examined using a combination of fiber tract dissections and 3-dimensional (3-D) photography to define the structures in and along the borders of the proposed safe entry zones of the midbrain, pons, and medulla. The microsurgical dissections were supplemented with selective diffusion tensor imaging (DTI) studies.

## METHODS

Fifteen formalin-fixed cadaveric brainstems with attached cerebellums were dissected after being preserved in 5% alcohol solution for 1 week. The arachnoid and surface vessels were removed and the fiber tracts were then dissected by using microdissectors with 1- to 3-mm tips under ×6 to ×40 magnifications provided by a Zeiss Surgical Microscope (Carl Zeiss AG, Oberkochen, Germany). After exposing the fiber tracts and cranial nerves and their nuclei, measurements were taken from 10 brainstems (20 sides) by using electronic scales (Table). Each stage of the dissections was recorded in 3-D photography to prepare 3-D anaglyph images as reported in a previous article from this laboratory.[13] Each 3-D illustration is displayed beside or above the same labeled 2-D illustration. The anaglyph images were assembled by using Adobe Photoshop CS5, Version 12.0X 64 (Adobe, San Jose, California).

**TABLE. Measurements From 10 Brainstems Bilaterally (n = 20)[a]**

| | Mean (Range), mm | SD, mm |
|---|---|---|
| Midbrain | | |
| Rostrocaudal length of the oculomotor nucleus | 5.2 (4.0-5.7) | 0.49 |
| Oculomotor and trochlear nuclei to lateral mesencephalic sulcus | 9.5 (8.8-11.1) | 0.80 |
| Surface of the superior colliculus to red nucleus | 5.5 (5.0-6.0) | 0.34 |
| Red nucleus to lateral mesencephalic sulcus | 4.3 (3.7-5.5) | 0.65 |
| Pons | | |
| Width of medial longitudinal fasciculus | 1.0 (0.7-2.0) | 0.43 |
| Trigeminal mesencephalic tract to the median sulcus at the level of | | |
| *Trochlear nerve* | 3.7 (3.0-4.4) | 0.55 |
| *Midpoint of length of upper half of fourth ventricular floor* | 5.4 (5.0-5.8) | 0.34 |
| *Trigeminal main sensory nucleus* | 5.9 (5.6-6.1) | 0.15 |
| Median sulcus to trigeminal motor nucleus | 6.0 (5.8-6.3) | 0.16 |
| Brainstem junction of the trigeminal nerve to the trigeminal motor nucleus | 10.1 (9.0-11.6) | 0.87 |
| Brainstem junction of the trigeminal nerve to the corticospinal tract | 9.2 (7.0-11.6) | 1.19 |
| Brainstem junction of the facial nerve to the corticospinal tract | 8.0 (5.6-9.6) | 1.04 |
| Rostrocaudal length of the suprafacial entry zone | 12.7 (12.0-14.6) | 0.80 |
| Facial colliculus to trochlear nucleus | 15.0 (13.9-15.8) | 0.78 |
| Fourth ventricular floor to the medial lemniscus at midlevel of suprafacial entry zone | 4.5 (3.6-5.5) | 0.78 |
| Fourth ventricular floor to the corticospinal tract at midpons | 20.0 (16.0-23.6) | 2.23 |
| Fourth ventricular floor to facial nucleus | 5.5 (5.0-6.0) | 0.36 |
| Rostrocaudal length of the facial | 4.5 (3.6-5.5) | 0.78 |

| | | |
|---|---|---|
| colliculus | | |
| Width of the facial colliculus | 3.5 (3.0-4.5) | 0.46 |
| Median sulcus to dorsal cochlear nucleus | 9.0 (8.0-10.6) | 0.81 |
| Sulcus limitans to dorsal cochlear nucleus | 6.0 (5.4-7.0) | 0.45 |
| Medulla | | |
| Length of infrafacial entry zone | 6.0 (5.0-8.6) | 0.99 |
| Fourth ventricular floor to the central tegmental tract at pontomedullary junction | 4.9 (4.0-5.4) | 0.39 |
| Retro-olivary sulcus to nucleus ambiguus | 4.0 (3.6-4.5) | 0.29 |
| Obex to upper margin of hypoglossal triangle | 10.6 (8.5-12.7) | 1.43 |

[a]SD, standard deviation.

## RESULTS

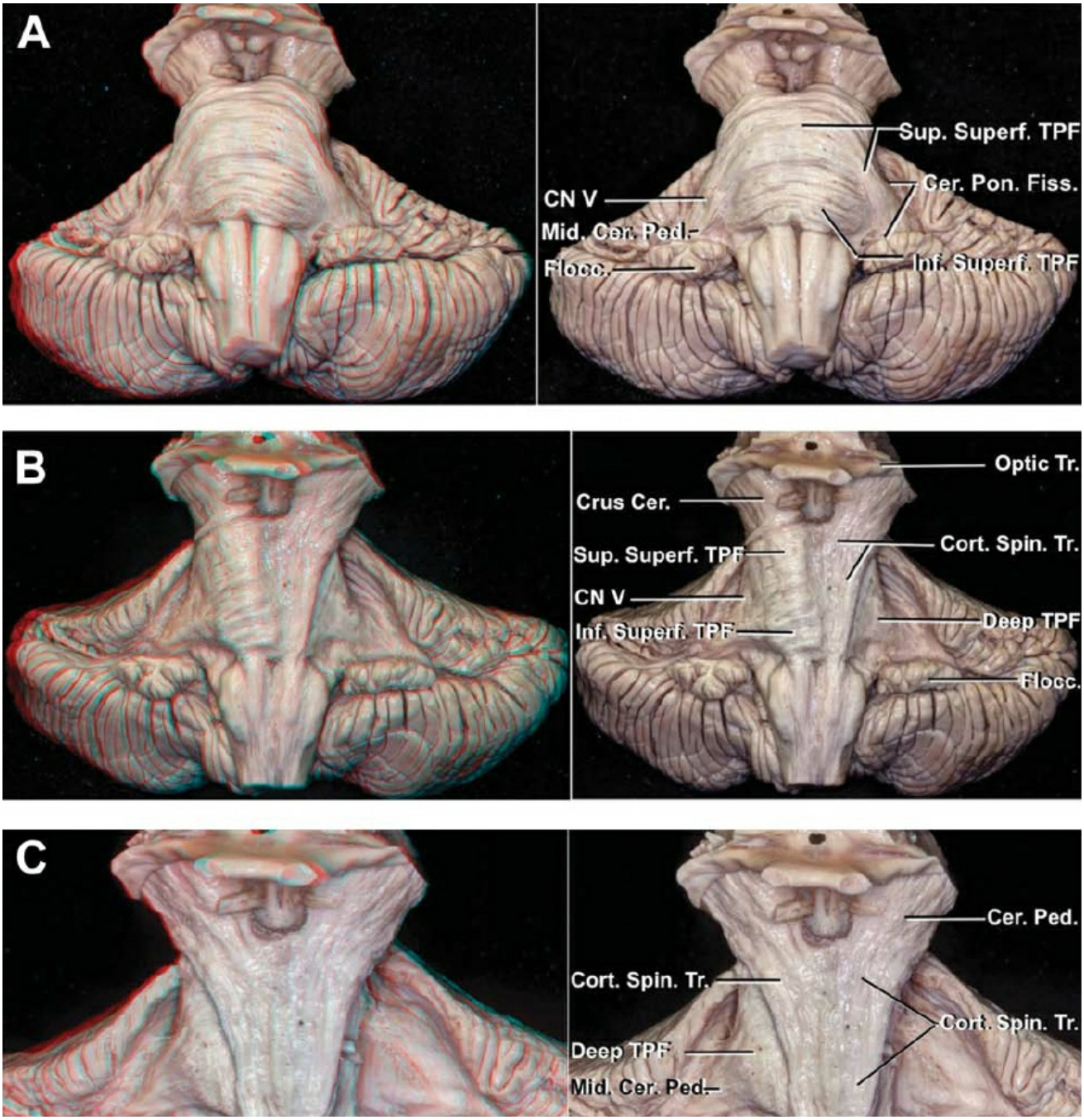
The fiber tract anatomy of the cerebellar peduncles, which wrap around and pass through the brainstem, the long brainstem tracts, and the intra-axial segment of the cranial nerves, are reviewed before considering the relationships of the safe entry zones of the midbrain, pons, and medulla.

### Cerebellar Peduncles

#### Middle Cerebellar Peduncle

This is the largest cerebellar peduncle. It is situated lateral to the superior and inferior cerebellar peduncles within the pons and cerebellum (Figure 1). The transverse pontine fibers arising from the scattered nuclei in the ventral pons reach the cerebellar cortex by way of the middle cerebellar peduncle. The transverse pontine fibers collect together to form the middle cerebellar peduncle at the level that the trigeminal nerve exits the pons. The fibers of the middle cerebellar peduncle are distributed to all of the cerebellar neocortex.[14] From their origin in the pontine nuclei, the fibers of the middle cerebellar peduncle travel obliquely lateral and caudally to form the floor of the cerebellopontine angle before entering

the cerebellum. The transverse pontine fibers of the middle cerebellar peduncle are divided into superficial and deep groups based on their location relative to the corticospinal tract and their distribution into the cerebellum. The deep transverse pontine fibers are located dorsal to and the superficial transverse pontine fibers ventral to the corticospinal tract. The superficial transverse pontine fibers are classified as superior or inferior based on their position relative to the brainstem entry site of the trigeminal nerve (Figure 1A and B).[14] Deep transverse pontine fibers are located immediately lateral to the inferior cerebellar peduncle and cover it (Figure 1C). The lateral surface of the middle cerebellar peduncle faces the cerebellopontine angle cistern, but does not reach or course along the fourth ventricular surface.



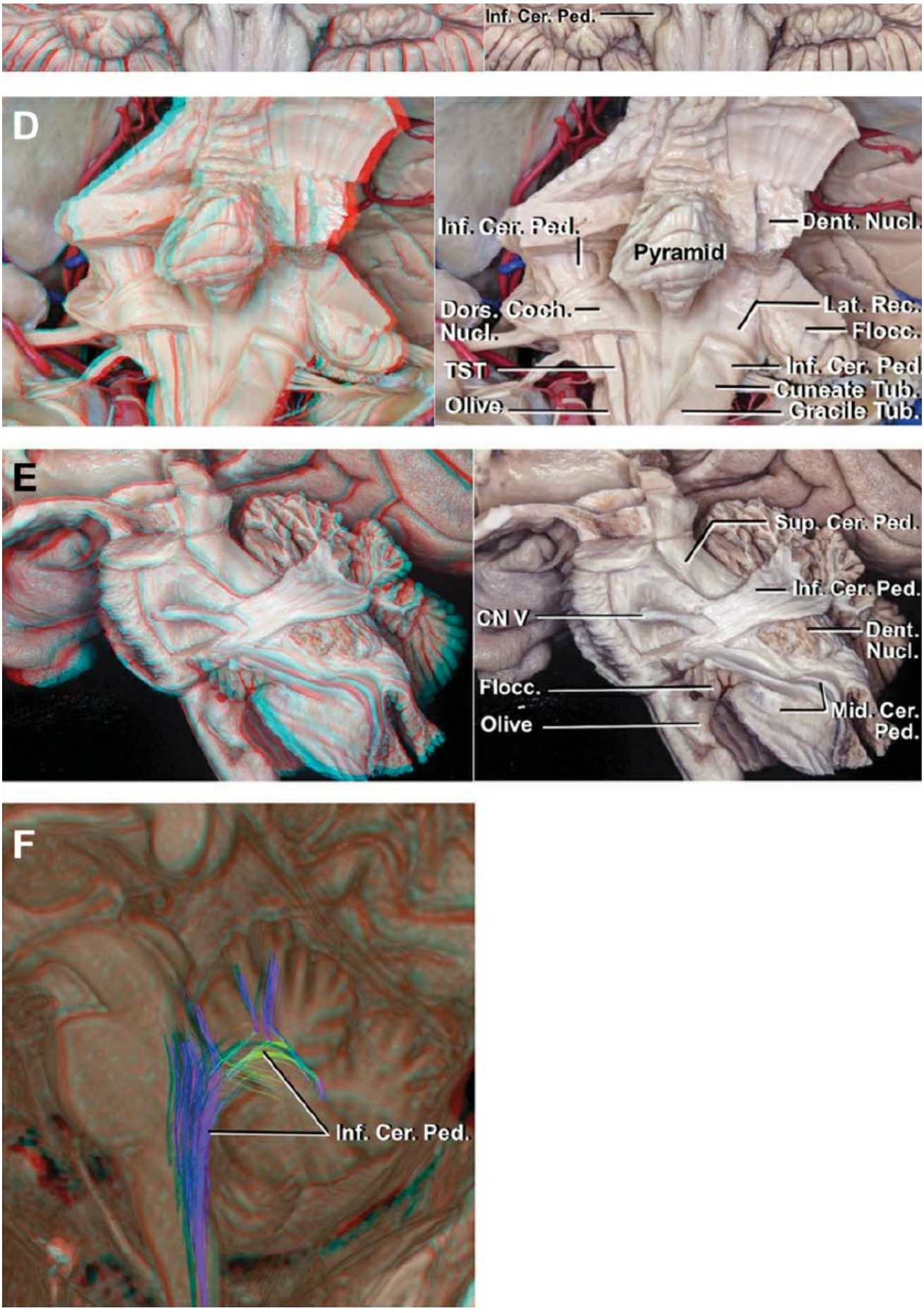
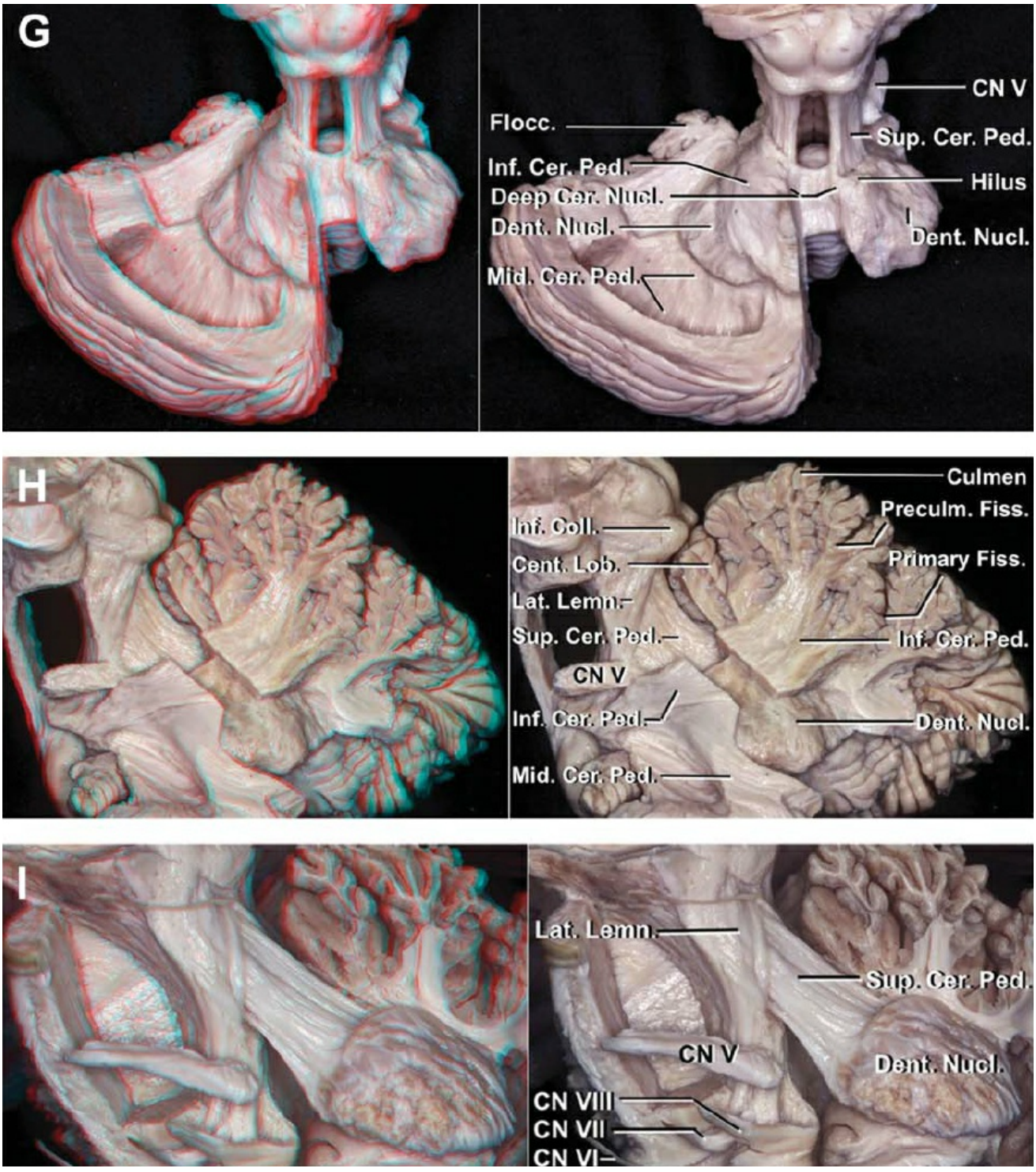



**Figure 1 (A–F). Cerebellar peduncles. A, anterior view of the brainstem. A labeled 2-D illustration accompanies each 3-D illustration. The transverse pontine fibers collect near the junction of the trigeminal nerve with the**

anterolateral pons to form the middle cerebellar peduncle. The middle cerebellar peduncle passes dorsally and slightly caudally to enter the cerebellum at the level of the angular cleft between the cerebellum and pons called the cerebellopontine fissure. The transverse pontine fibers located anterior to the corticospinal tract, referred to as superficial transverse pontine fibers, divide into 2 parts: those situated rostral to the trigeminal nerve are the superior superficial transverse pontine fibers and those situated caudal to the trigeminal nerve are the inferior superficial transverse pontine fibers. B, the left superficial transverse pontine fibers have been removed to expose the deep transverse pontine fibers. The superficial superior and inferior transverse pontine fibers are exposed anterior to the corticospinal tract in the right half of the pons and the deep transverse pontine fibers are exposed posterior to the corticospinal tract in the left half of the pons. C, all the superficial transverse pontine fibers on both sides have been removed. The middle cerebellar peduncle is situated lateral to the inferior cerebellar peduncle. D, posterior view of the inferior cerebellar peduncle in another specimen. Part of the cerebellum and the cuneate and gracile fasciculi in the left dorsal medulla have been removed. The inferior cerebellar peduncle ascends in the dorsolateral medulla, dorsal to the olive, lateral to the gracile and cuneate tubercles, and dorsolateral to the trigeminal spinal tract. At the level of the lateral recess, the inferior cerebellar peduncle ascends deep to the stria medullaris and dorsal cochlear nucleus and turns dorsally to reach the cerebellum. It is crossed ventromedially by the intrapontine segment of the facial nerve and dorsolaterally by the vestibulocochlear nerve. E, lateral view of the left inferior cerebellar peduncle in another specimen. Some left transverse pontine and middle cerebellar peduncle fibers have been removed to expose the inferior cerebellar peduncle. The inferior cerebellar peduncle passes dorsal to the olive and medial to the flocculus to reach the cerebellum. It surrounds the trigeminal nerve within the pons and mixes with fibers of the middle cerebellar peduncle. The inferior cerebellar peduncle within the cerebellum courses in a dorsomedial direction and passes dorsal to the upper two-thirds of the dentate nucleus and its hilus to reach the cerebellar vermis. F, left lateral view of a DTI showing the inferior cerebellar peduncle connecting the

spinal cord and cerebellum. Cent., central; Cer., cerebellar; Cer. Pont., cerebellopontine; Coch., cochlear; Coll., colliculus; Cort., cortico; Decuss., decussation; Dent., dentate; Dors., dorsal; DTI, diffusion tensor imaging; Fiss., fissure; Flocc., flocculus; Gl., gland; Inf., inferior; Junc., junction; Lat., lateral; Lemn., lemniscus; Lob., lobule; Med., medial; Mid., middle; Nucl., nucleus; Ped., peduncle; Pon. Mes., pontomesencephalic; Preculm., preculminate; Rec., recess; Spin., spinal; STN, subthalamic nucleus; Sup., superior; Superf., superficial; TPF, transpontine fibers; Tr., tract; TST, trigeminal spinal tract; Tub., tubercle; Vent., ventral. (Images courtesy of AL Rhoton, Jr.)



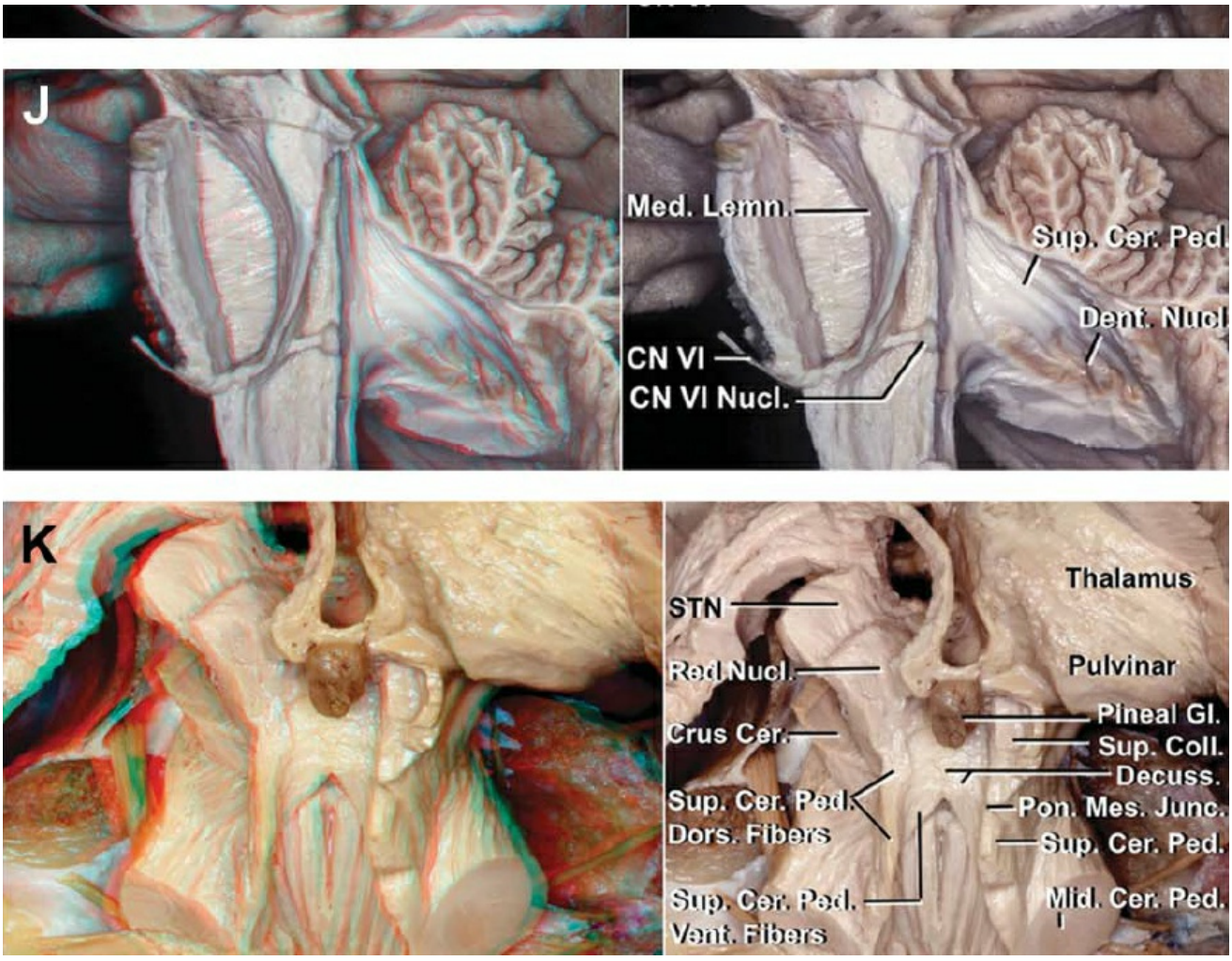



Figure 1 (G–K). Cerebellar peduncles. G, posterior view of another specimen. The right cerebellum has been removed, leaving only the dentate nucleus. The left inferior cerebellar peduncle passes just lateral to the left dentate nucleus. The hilus of the dentate nucleus and other deep cerebellar nuclei are positioned medial to and below the inferior cerebellar peduncle. H, left lateral view of another specimen. Part of the inferior cerebellar peduncle has been removed to expose the relationship of the superior cerebellar peduncle and dentate nucleus. The rostral border of the inferior cerebellar peduncle extends to the deepest point of the preculminate fissure of the cerebellum and the lower border extends to the deepest point of the primary fissure. The culmen and central lobule are positioned dorsal to the superior cerebellar peduncle. The superior cerebellar peduncle is located medial to the middle and inferior cerebellar peduncles. The lateral lemniscus, which ascends lateral to the superior cerebellar peduncle, is exposed above the trigeminal nerve. I, left lateral view of another dissection. The inferior cerebellar peduncle has been removed to expose the superior cerebellar peduncle, which connects the dentate nucleus to the red nucleus and thalamus. J, the left

**superior cerebellar peduncle and dentate nucleus have been removed to expose the medial surface of the superior cerebellar peduncle and dentate nucleus in the right lateral wall of the fourth ventricle. The superior cerebellar peduncle forms the lateral wall of the superior half of the fourth ventricle. K, posterior surface of another specimen showing the decussation of the superior cerebellar peduncle. The superior and inferior colliculi, cerebral aqueduct, and left thalamus have been removed to expose the decussation of the superior cerebellar peduncle and the left subthalamic and red nuclei. The decussation of the superior cerebellar peduncle is located at the level of the inferior colliculus. The ventral fibers of the superior cerebellar peduncle cross first and are located in the caudal part in the decussation. The dorsal fibers cross last and are located in the rostral part of the decussation. The most dorsal fibers continue without crossing. The most ventral fibers of the superior cerebellar peduncle are located at the caudal-most point of the decussation. After decussating, the superior cerebellar peduncle fibers turn laterally to reach the red nucleus, where they form the dorsal capsule of the red nucleus before reaching the thalamus. Cent., central; Cer., cerebellar; Cer. Pont., cerebellopontine; Coch., cochlear; Coll., colliculus; Cort., cortico; Decuss., decussation; Dent., dentate; Dors., dorsal; DTI, diffusion tensor imaging; Fiss., fissure; Flocc., flocculus; Gl., gland; Inf., inferior; Junc., junction; Lat., lateral; Lemn., lemniscus; Lob., lobule; Med., medial; Mid., middle; Nucl., nucleus; Ped., peduncle; Pon. Mes., pontomesencephalic; Preculm., preculminate; Rec., recess; Spin., spinal; STN, subthalamic nucleus; Sup., superior; Superf., superficial; TPF, transpontine fibers; Tr., tract; TST, trigeminal spinal tract; Tub., tubercle; Vent., ventral. (Images courtesy of AL Rhoton, Jr.)**

## Inferior Cerebellar Peduncle

This peduncle connects the spinal cord and medulla to the cerebellum and is formed predominantly by spinocerebellar fibers (Figure 1). The inferior cerebellar peduncle ascends in the dorsolateral medulla, dorsal to the olive, lateral to the cuneate and gracile tubercles, and dorsolateral to the trigeminal spinal tract which is oriented in the same rostrocaudal direction as the inferior cerebellar peduncle. It ascends deep to the stria medullaris

and the dorsal cochlear nucleus at the level of the lateral recess. It is covered laterally by the flocculus, ventrally by the inferior olivary nucleus, ventromedially by the intrapontine segment of the facial nerve, and dorsolaterally by the vestibulocochlear nerve. It ascends dorsally around the intrapontine segment of the trigeminal nerve and mixes with the pontine fibers forming the middle cerebellar peduncle. The inferior and middle cerebellar peduncles are recognizable based on their course. The inferior cerebellar peduncle passes dorsomedial around the upper two-thirds and hilus of the dentate nucleus to reach the cerebellar vermis. The hilus of the dentate nucleus and other deep cerebellar nuclei are positioned immediately medial to and below the inferior cerebellar peduncle (Figure 1E-H). The rostral border of the inferior cerebellar peduncle passes dorsally at the level of the junction of the superior cerebellar peduncle and the dentate nucleus and from lateral to medial in the area deep to the quadrangular lobule on the tentorial surface of the cerebellum. The upper border of the inferior cerebellar peduncle extends to the deepest point of the preculminate fissure, and the lower border extends to the deepest point of the primary fissure (Figure 1H).

## Superior Cerebellar Peduncle

This main efferent pathway of the cerebellum arises from the dentate nucleus and courses to the red nucleus and thalamus (Figure 1G-J).[15] The superior cerebellar peduncle is covered by the culmen and central lobule of the cerebellum in the midline and by the quadrangular lobule and wing of the central lobule laterally. The superior cerebellar peduncle originates from the dentate nucleus, is located medial to the middle and inferior cerebellar peduncles, and forms the lateral wall of the superior half of the fourth ventricle. It ascends to the midbrain and decussates at the level of the inferior colliculus. The decussation is similar to that of the optic chiasm in which the most lateral fibers at the midbrain level, which are also the most dorsal fibers, ascend on the ipsilateral side without crossing, while the medial fibers in the midbrain, which are ventral fibers in the peduncle, cross to the opposite side (Figure 1K). The ventral fibers cross first and are located in the caudal part of the decussation. The dorsal fibers cross last and are located in the rostral part of the decussation.

After decussating, some fibers enter the red nucleus but the majority turn laterally around the red nucleus to form the dorsal capsule of the red nucleus. They then course laterally adjacent to the medial lemniscus to end at the ventrolateral part of thalamus.[16]

## Fiber Tracts of the Brainstem

The medial lemniscus divides the brainstem and safe entry zones into ventral and dorsal parts.

### Medial and Lateral Lemniscus

The medial lemniscus ascends from the gracile and cuneate tubercles to the thalamus and divides the brainstem into ventral and dorsal parts (Figure 2).[16] In the medulla, after arising in the cuneate and gracile tubercles, it curves ventrally. The medial lemniscus, when viewed from lateral, ascends through the pons forming a concave shape facing ventrally. In the midbrain, it ascends dorsal to the cerebral peduncle and substantia nigra, ventrolateral to the red nucleus, and lateral to the subthalamic nucleus to terminate in the thalamus (Figures 2B-G and 3Q). The lateral lemniscus travels from the cochlear nuclei to the inferior colliculus.[15] It ascends lateral to the medial lemniscus and superior cerebellar peduncle (Figures 1H and 2A).

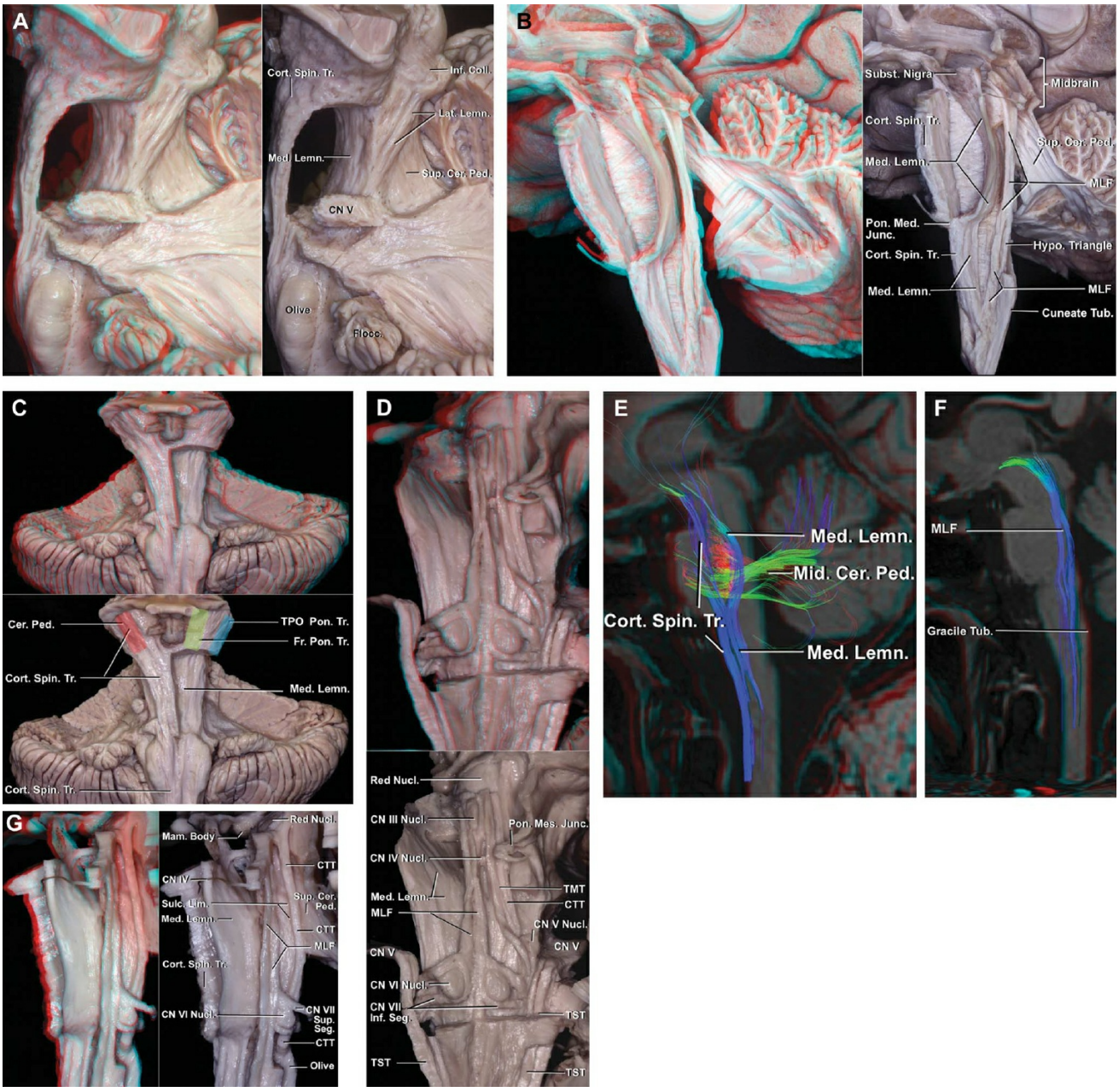
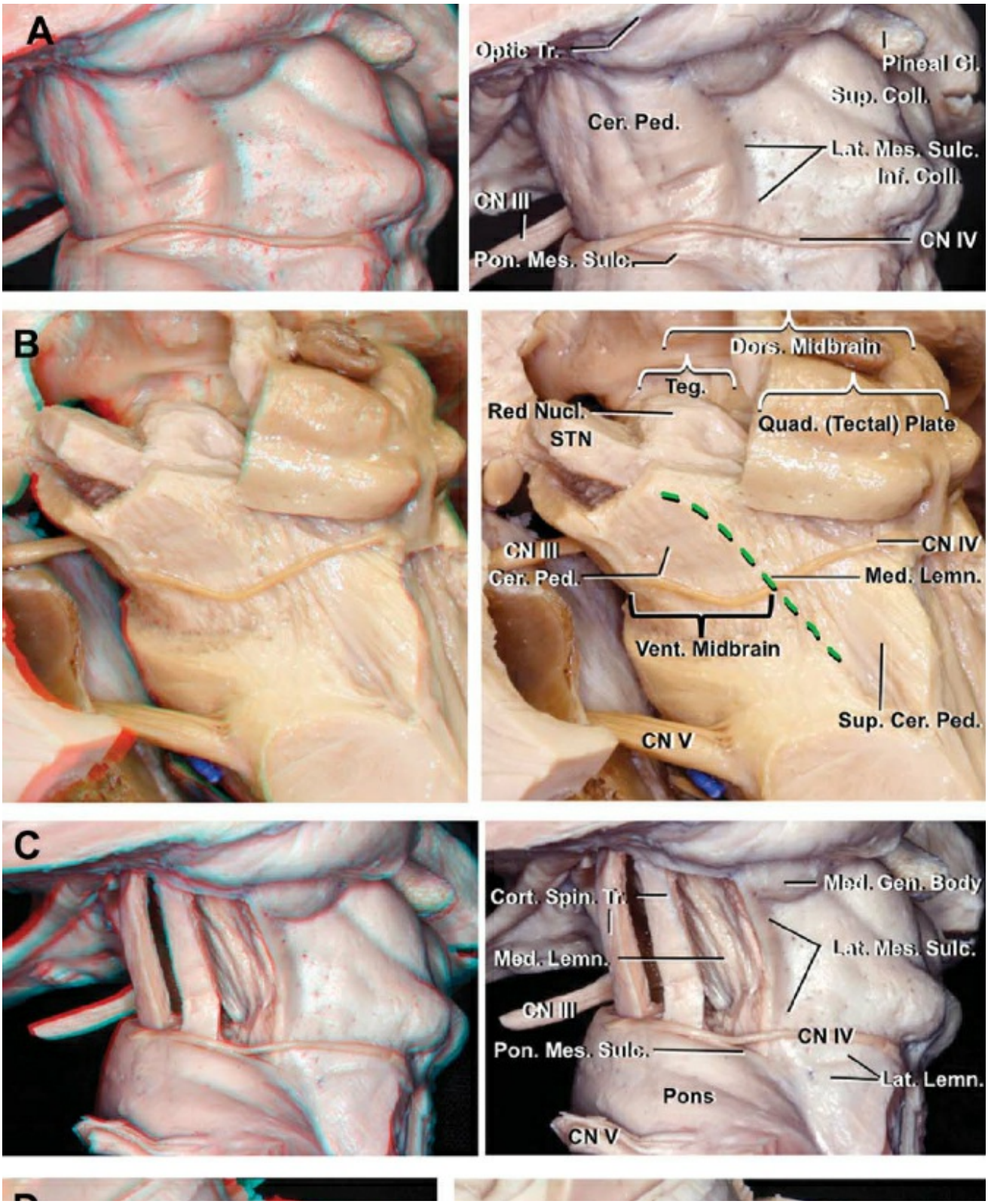



Figure 2. Fiber tracts of the brainstem. A, left lateral view. The transverse pontine fibers and some of the corticopontine tracts have been removed to expose the medial and lateral lemnisci. The lateral lemniscus is located lateral to the medial lemniscus and superior cerebellar peduncle. B, lateral view in another specimen. The medial lemniscus and medial longitudinal fasciculus have been exposed. The medial lemniscus arises in the gracile and cuneate tubercles and ascends to divide the brainstem into ventral and dorsal parts and to relay in the thalamus. In the medulla, the medial lemniscus is located just behind the pyramids formed by the corticospinal tracts that descend in the ventral medulla. The olive is located lateral to the medial lemniscus. In the pons, the medial lemniscus in the lateral view is concave ventrally. In the midbrain, it ascends dorsal to the cerebral peduncle where its fibers intermingle with the substantia

nigra. The medial longitudinal fasciculus curves ventrally at the lower edge of the facial colliculus and passes ventral to the hypoglossal triangle. It crosses the medial lemniscus at the level of the gracile and cuneate tubercles and descends in the ventral funiculus of the spinal cord. C, anterior view showing the relationships of the cerebral peduncle, medial lemniscus, and corticospinal tract in the pons. The ventral fiber tracts in the left half of the pons have been removed to expose the medial lemniscus. In the midbrain, the frontopontine fibers (green) are in the medial one-third, the temporoparieto-occipitopontine fibers (blue) are in the lateral one-third, and the corticospinal and corticobulbar tracts (red) are in the middle one-third of the cerebral peduncle. D, posterior view of the medial longitudinal fasciculus and the trigeminal mesencephalic and spinal tracts. Part of the dorsal pons and midbrain have been removed to expose the left medial lemniscus. The medial longitudinal fasciculus courses adjacent the midline near the floor of the fourth ventricle and connects to the trochlear nucleus at the level of the lower half of the inferior colliculus. The medial longitudinal fasciculus passes medial to the abducens nucleus and intrapontine segment of the facial nerve. The trigeminal nerve, after reaching its motor and main sensory nuclei, divides into the rostrally directed trigeminal mesencephalic tract and the caudally directed spinal tract. E, DTI, lateral view, showing the corticospinal tract, middle cerebellar peduncle, and medial lemniscus. F, DTI, lateral view of the medial longitudinal fasciculus. G, posterior view of the central tegmental tract, medial lemniscus, and medial longitudinal fasciculus. Parts of the dorsal pons and midbrain have been removed leaving the right central tegmental tract that connects the red nucleus and the olive. In the midbrain, the central tegmental tract originates from the dorsomedial part of the red nucleus and descends ipsilaterally between the superior cerebellar peduncle laterally, medial longitudinal fasciculus medially, and medial lemniscus ventrally. At the level of the facial colliculus, the central tegmental tract courses medial to the intrapontine segment of the facial nerve and lateral to the intrapontine segment of the abducens nerve to terminate in the olive. Cer., cerebellar, cerebral; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; DTI, diffusion tensor imaging;

Flocc., flocculus; Fr. Pon., frontopontine; Hypo., hypoglossal; Inf., inferior; Junc., junction; Lat., lateral; Lemn., lemniscus; Lim., limitans; Mam., mammillary; Med., medial; Mid., middle; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Pon. Med., pontomedullary; Pon. Mes., pontomesencephalic; Seg., segment; Spin., spinal; Subst., substantia; Sulc., sulcus; Sup., superior; TMT, trigeminal mesencephalic tract; TPO Pon., temporoparieto-occipitopontine; Tr., tract; TST, trigeminal spinal tract; Tub., tubercle. (Images courtesy of AL Rhoton, Jr.)



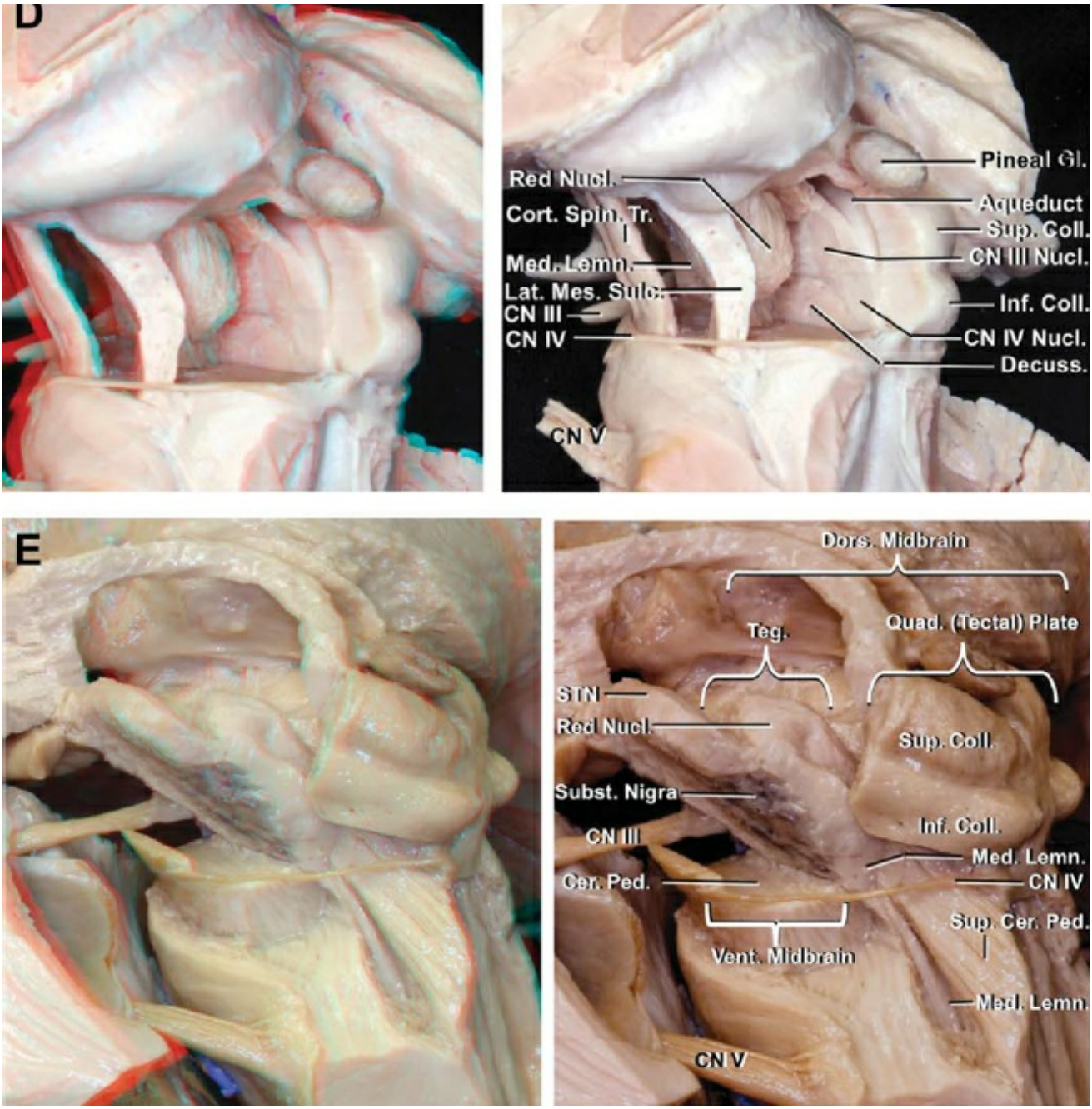
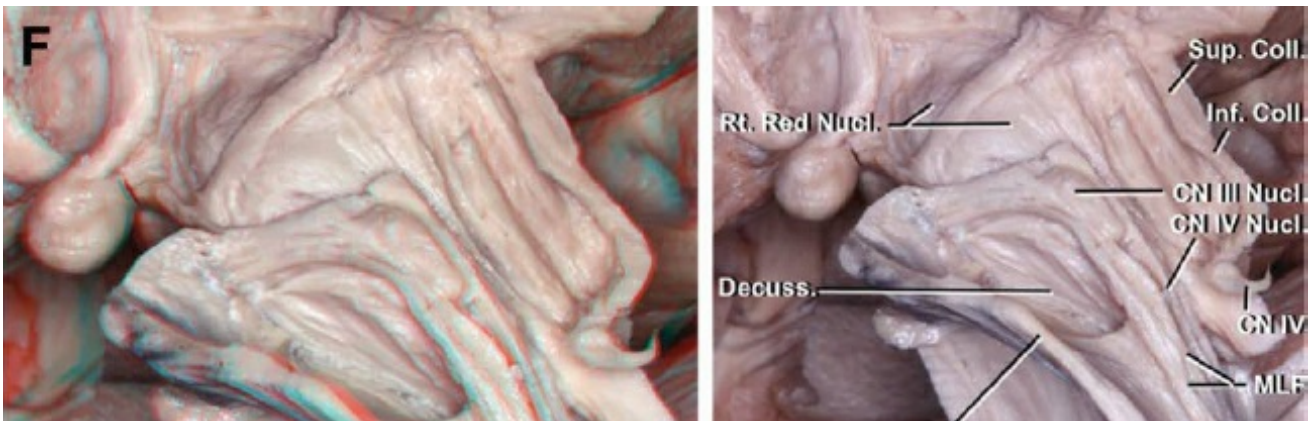
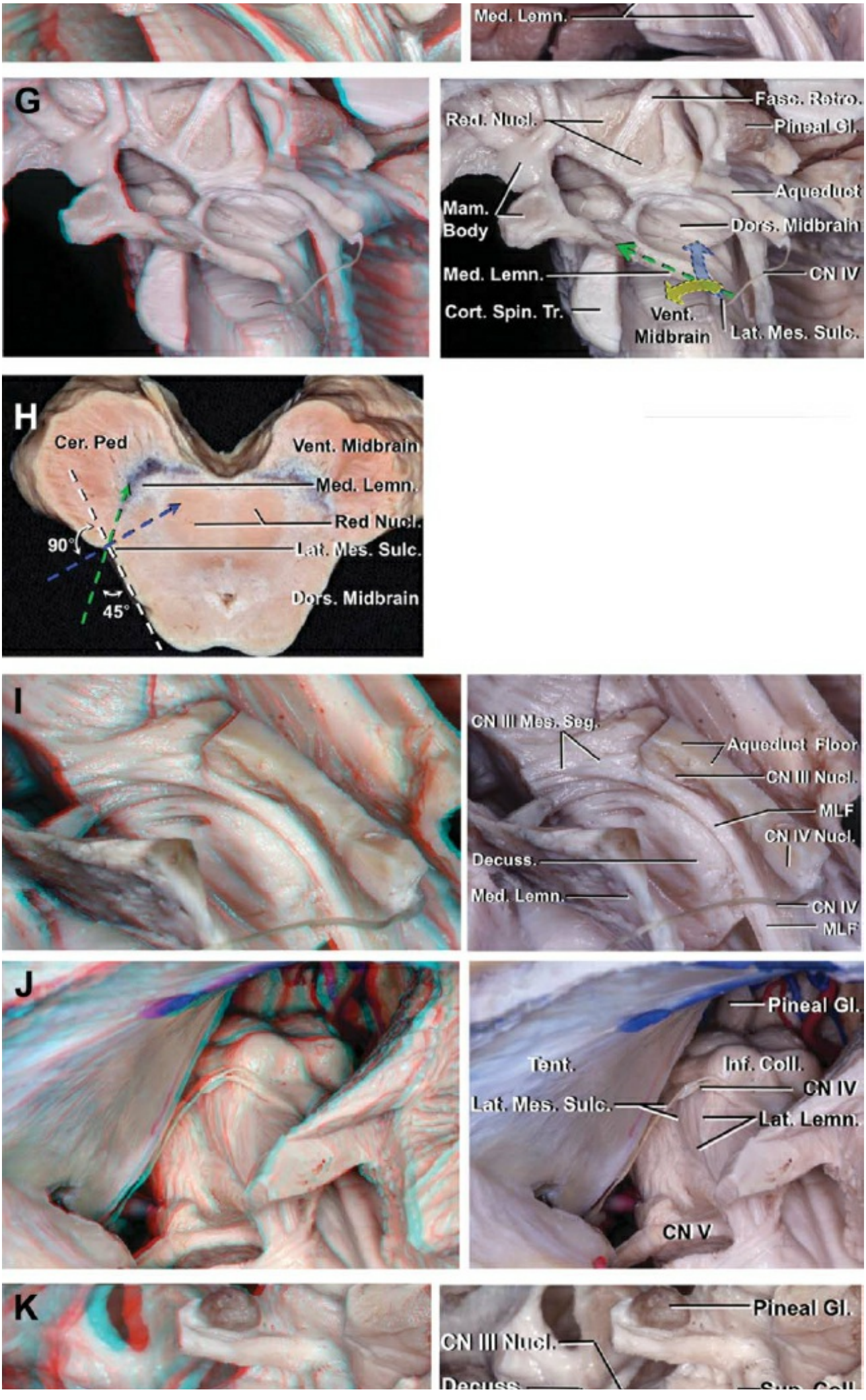



Figure 3 (A–E). Midbrain. A, left lateral view. The midbrain is separated from the diencephalon above by the sulcus between the optic tracts and the cerebral peduncles, and from the pons below by the pontomesencephalic sulcus. B, the medial lemniscus divides the midbrain into ventral and dorsal parts. The tegmentum (red nucleus) and tectum (quadrigeminal plate) are situated in the dorsal midbrain and the cerebral peduncle is situated in the ventral midbrain. The lateral mesencephalic sulcus extends along the lateral edge of the medial lemniscus (interrupted green line). C, the lateral mesencephalic sulcus runs on the surface of the midbrain between the cerebral peduncle and the lateral lemniscus extending from the medial geniculate body above to the pontomesencephalic sulcus below. The lateral mesencephalic sulcus

extends along the lateral edge of the medial lemniscus. D, when entering into the lateral mesencephalic sulcus at a right angle to the surface, the structures encountered are the trigeminal mesencephalic and central tegmental tracts, red nucleus, decussation of the superior cerebellar peduncle, and the oculomotor and trochlear nuclei in the midline. The red nucleus extends upward from the midlevel of the inferior colliculus to the level of the lateral wall of the third ventricle. The superior cerebellar peduncle decussates caudal to the red nucleus. E, left lateral view of the ventral and dorsal midbrain. Part of the cerebral peduncle and the left thalamus have been removed to expose the subthalamic nucleus and substantia nigra. The cerebral peduncle is in the ventral midbrain and the tegmentum (red nucleus) and tectum (quadrigeminal plate) are in the dorsal midbrain. The substantia nigra is located just dorsal the cerebral peduncle and along the ventral surface of the medial lemniscus. The medial lemniscus passes ventrolateral to the red nucleus to reach the thalamus. Ant., anterior; Cap., capsule; Cer., cerebellar, cerebral; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Decuss., decussation; Dors., dorsal; Fac., facial; Fasc., fasciculus; Fr. Pon., frontopontine; Gen., geniculate; Gl., gland; Inf., inferior; Int., internal; Interped., interpeduncular; Lat., lateral; Lemn., lemniscus; Mam., mammillary; Med., medial, medullaris; Mes., mesencephalic; Mid., middle; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Perioc., perioculomotor; Pon., ponto; Quad., quadrigeminal; Retro., retroflexus; Rt., right; Seg., segment; Spin., spinal; STN, subthalamic nucleus; Str., stria; Subst., substantia; Sulc., sulcus; Sup., superior; Teg., tegmentum; Tent., tentorium; Thal., thalami, thalamic; TMT, trigeminal mesencephalic tract; Tr., tract; Vent., ventral. (Images courtesy of AL Rhoton, Jr.)




Med. Lemn.
G
Fasc. Retro.
Red. Nucl.
Pineal Gl.
Aqueduct
Mam. Body
Dors. Midbrain
Med. Lemn.
CN IV
Cort. Spin. Tr.
Vent. Midbrain
Lat. Mes. Sulc.
H
Cer. Ped
Vent. Midbrain
Med. Lemn.
Red Nucl.
90°
Lat. Mes. Sulc.
Dors. Midbrain
45°
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CN III Mes. Seg.
Aqueduct Floor
CN III Nucl.
MLF
CN IV Nucl.
Decuss.
Med. Lemn.
CN IV
MLF
J
Pineal Gl.
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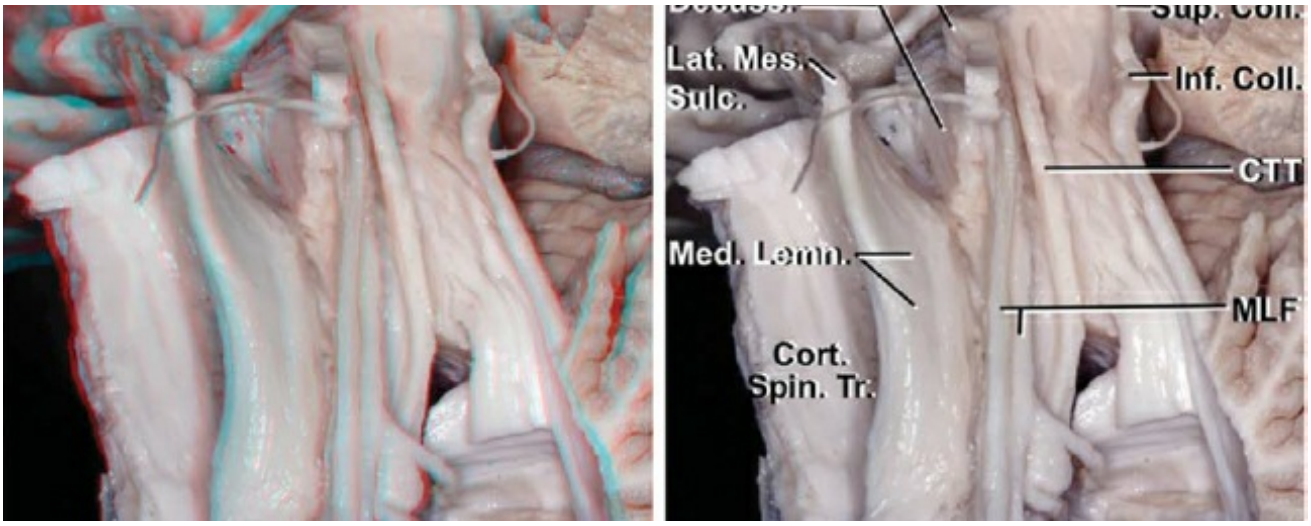
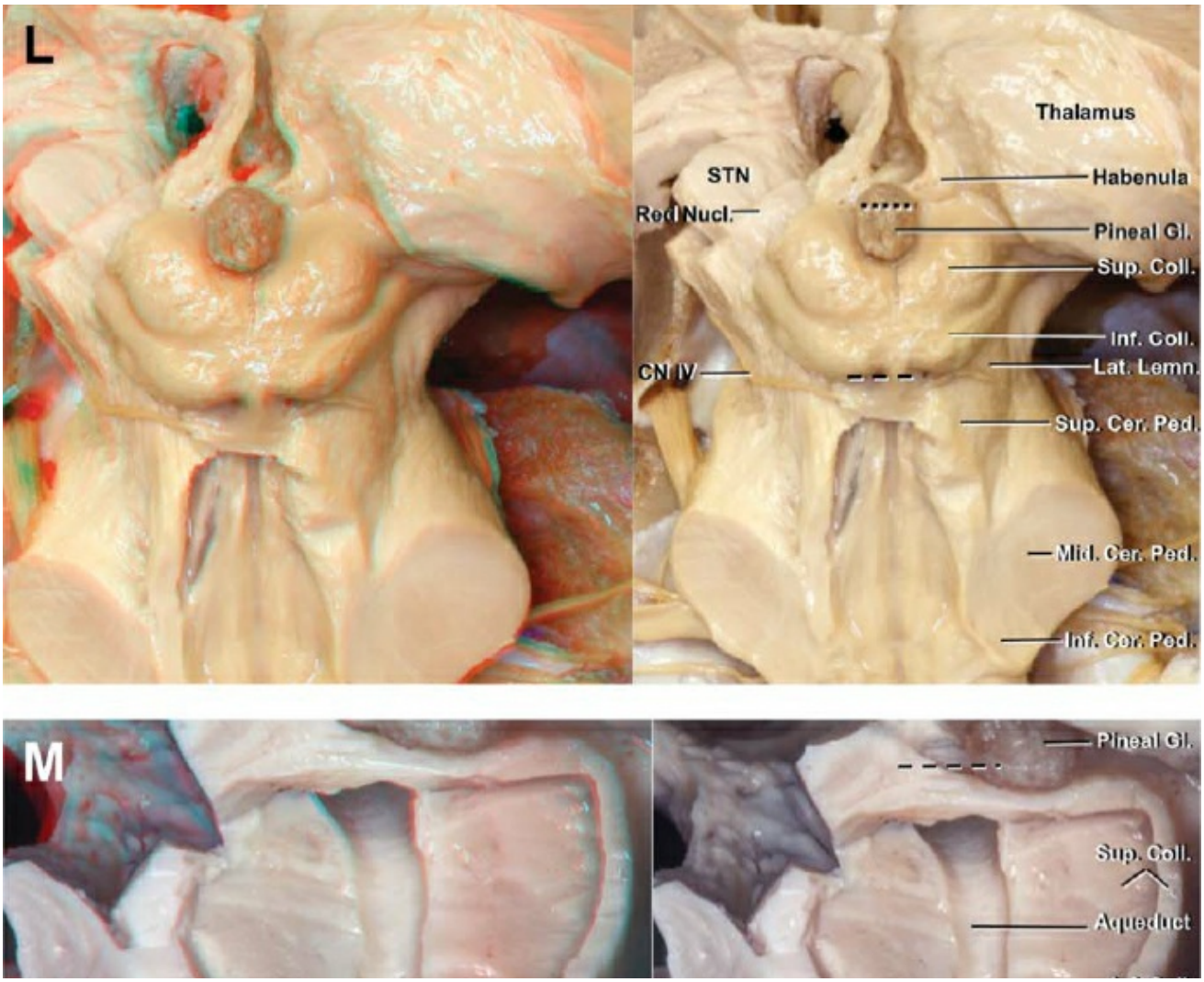



Figure 3 (F–K). Midbrain. F, left lateral view of the midbrain tegmentum. The left dorsal midbrain structures have been removed to expose the right tegmental midbrain. The oculomotor nucleus is located adjacent the midline at the level of the lower half of the superior colliculus and the upper half of the inferior colliculus, and the trochlear nucleus is located at the level of the lower half of the inferior colliculus. The red nucleus extends from the midlevel of the inferior colliculus to the lateral wall of the third ventricle. The decussation of the superior cerebellar peduncle is positioned caudal to the red nucleus and at the level of the inferior colliculus. G, lateral view. The lateral mesencephalic sulcus is located lateral to the lateral edge of the medial lemniscus (interrupted green line). The approaches to the dorsal (blue arrow) and ventral midbrain (yellow arrow) are shown. H, midbrain axial section. The lateral mesencephalic sulcus is located lateral to the lateral edge of the medial lemniscus, the border between the ventral and dorsal midbrain. Entry into the lateral mesencephalic sulcus at a right angle (blue interrupted line) to the tectal surface (white interrupted line) reaches the dorsal midbrain. Angling 45° forward (green interrupted line) will reach the medial lemniscus. The substantia nigra is located along the anterior surface of the medial lemniscus. I, enlarged view of the midbrain. The medial longitudinal fasciculus located ventrolateral to the oculomotor nucleus ascends to mix with the intramesencephalic segment of the oculomotor nerve, and ends in the interstitial nucleus located rostral to the cerebral aqueduct. The oculomotor and trochlear nuclei in the midbrain are located between the cerebral aqueduct dorsally and the decussation of the superior cerebellar peduncle ventrally. The trochlear nerve is the only cranial nerve

originating from the dorsal surface of the brainstem. J, left retrosigmoid surgical view of the brainstem. The lateral mesencephalic sulcus is located between the cerebral peduncle and lateral lemniscus. K, the same brainstem shown in J. The lateral mesencephalic sulcus has been preserved. The long tracts in the midbrain have been exposed. Ant., anterior; Cap., capsule; Cer., cerebellar, cerebral; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Decuss., decussation; Dors., dorsal; Fac., facial; Fasc., fasciculus; Fr. Pon., frontopontine; Gen., geniculate; Gl., gland; Inf., inferior; Int., internal; Interped., interpeduncular; Lat., lateral; Lemn., lemniscus; Mam., mammillary; Med., medial, medullaris; Mes., mesencephalic; Mid., middle; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Perioc., perioculomotor; Pon., ponto; Quad., quadrigeminal; Retro., retroflexus; Rt., right; Seg., segment; Spin., spinal; STN, subthalamic nucleus; Str., stria; Subst., substantia; Sulc., sulcus; Sup., superior; Teg., tegmentum; Tent., tentorium; Thal., thalami, thalamic; TMT, trigeminal mesencephalic tract; Tr., tract; Vent., ventral. (Images courtesy of AL Rhoton, Jr.)



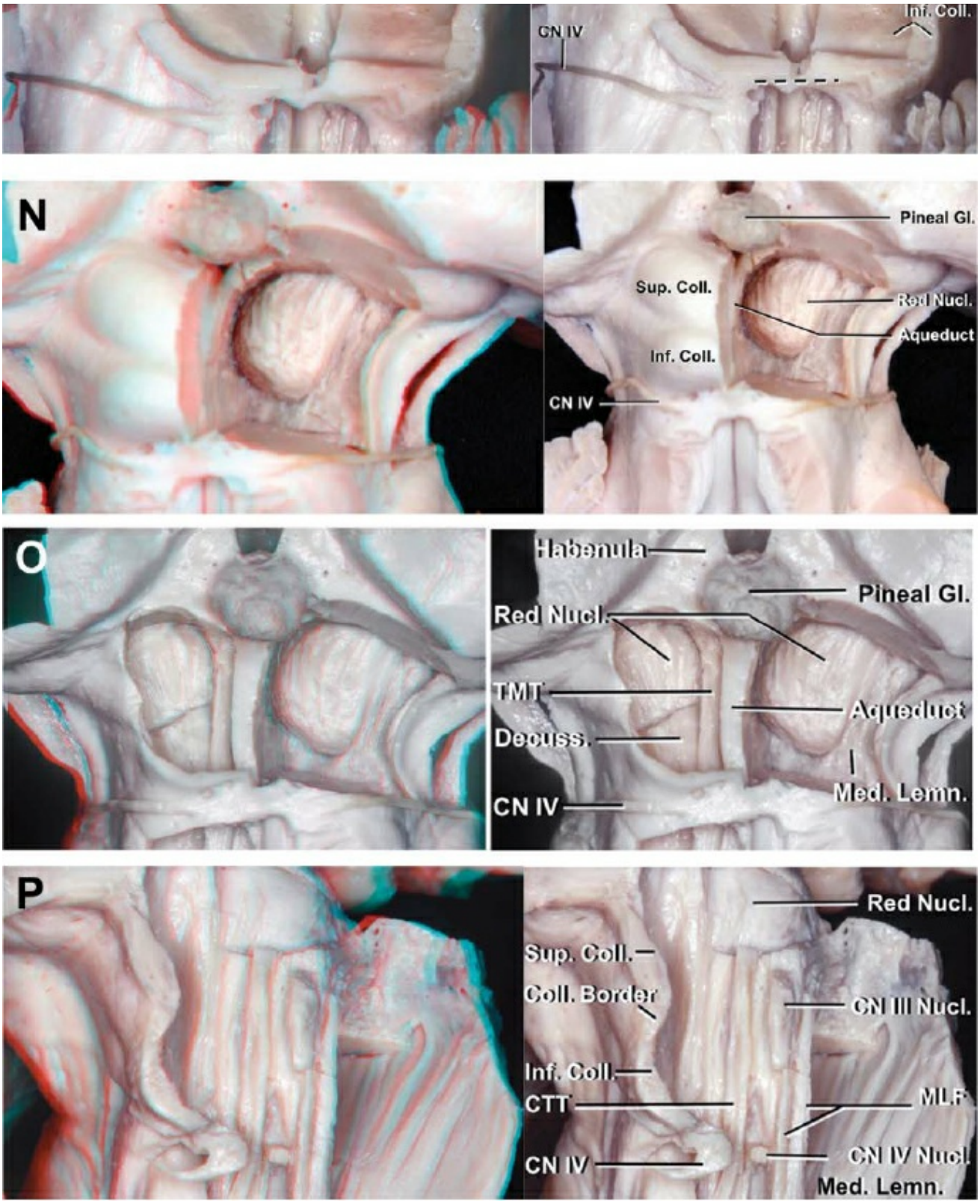



Figure 3 (L–P). Midbrain. L, posterior view of the tectal plate, and the supra- and infracollicular safe entry zones (interrupted lines). The cerebellum and left thalamus have been removed. The transverse supracollicular incision is made just above the upper edge of the superior colliculus. The infracollicullar incision is directed transversely between the trochlear nerve and the lower edge of the inferior colliculus. The superior cerebellar peduncle and lateral lemniscus will be divided if the transverse incision extends too far laterally. M, posterior view, further

dissection of the tectal plate. Some of the superior and inferior colliculi have been removed to expose the aqueduct, an important landmark at the ventral limit of the supra- and infracollicular approaches. N, further dissection of the tectal plate. The right red nucleus is exposed while preserving the superior and inferior colliculi on the left side. O, posterior view. The red nucleus extends from the midlevel of the inferior colliculus to the lateral wall of the third ventricle. An incision extending laterally from the midline encounters the habenula, trigeminal mesencephalic tract, central tegmental tract, and red nucleus as the incision is extended from dorsal to ventral. The decussation of the superior cerebellar peduncle is positioned caudal to the red nucleus and at the level of the inferior colliculus. P, posterior view of the midbrain tegmentum on the left side. The oculomotor nucleus is located at the level of the lower half of the superior colliculus and the upper half of the inferior colliculus. The trochlear nucleus is located caudal to the oculomotor nucleus at the level of the lower half of the inferior colliculus. The medial longitudinal fasciculus connects these cranial nuclei. Extending the infracollicular incision deeper than the aqueduct from dorsal to ventral will cross the trochlear nuclei, medial longitudinal fasciculus, and decussation of the superior cerebellar peduncle. Ant., anterior; Cap., capsule; Cer., cerebellar, cerebral; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Decuss., decussation; Dors., dorsal; Fac., facial; Fasc., fasciculus; Fr. Pon., frontopontine; Gen., geniculate; Gl., gland; Inf., inferior; Int., internal; Interped., interpeduncular; Lat., lateral; Lemn., lemniscus; Mam., mammillary; Med., medial, medullaris; Mes., mesencephalic; Mid., middle; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Perioc., perioculomotor; Pon., ponto; Quad., quadrigeminal; Retro., retroflexus; Rt., right; Seg., segment; Spin., spinal; STN, subthalamic nucleus; Str., stria; Subst., substantia; Sulc., sulcus; Sup., superior; Teg., tegmentum; Tent., tentorium; Thal., thalami, thalamic; TMT, trigeminal mesencephalic tract; Tr., tract; Vent., ventral. (Images courtesy of AL Rhoton, Jr.)

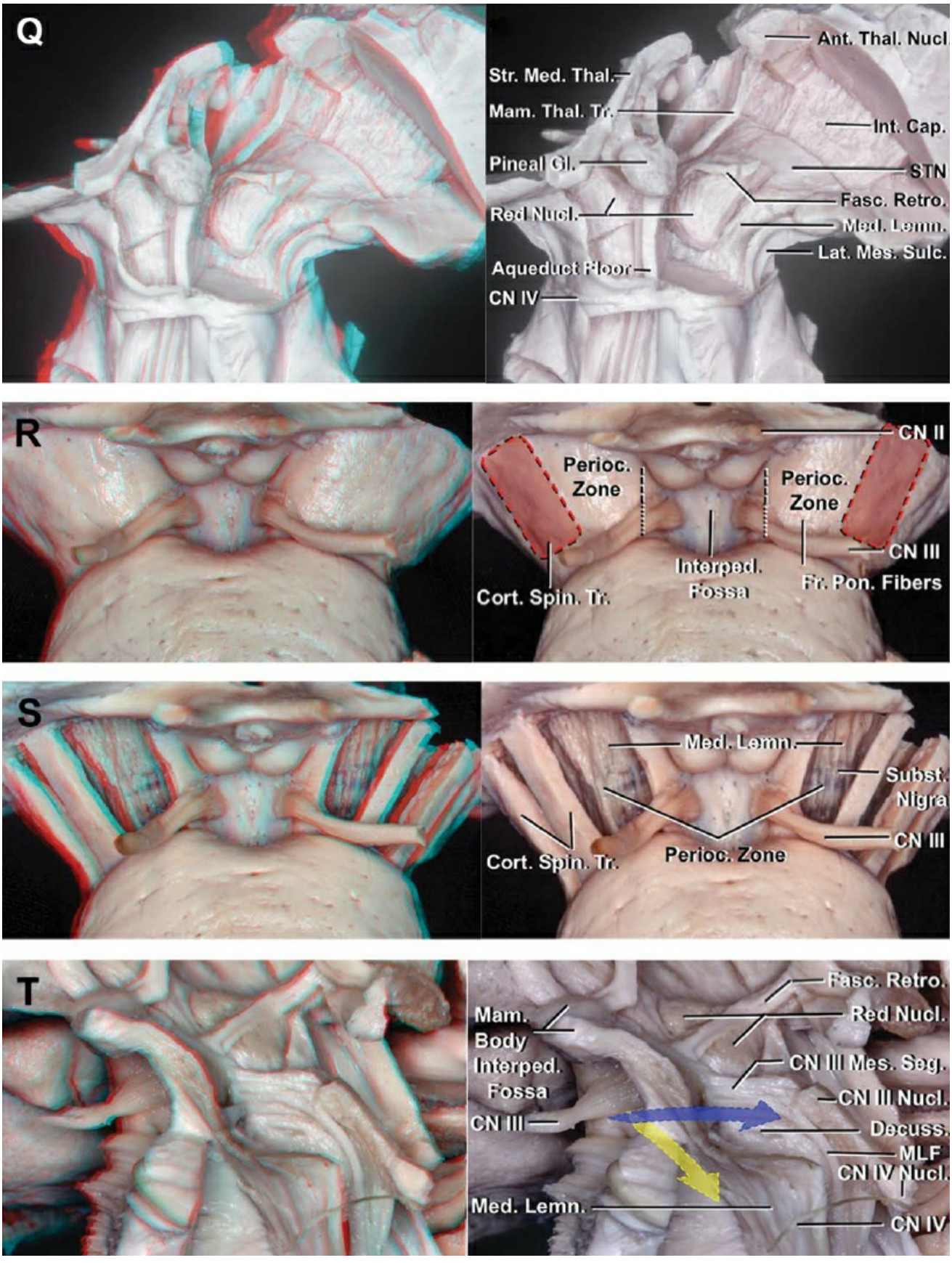



Figure 3 (Q–T). Midbrain. Q, posterior view, after removal of the thalami. In the midbrain, the medial lemniscus ascends ventrolateral to the red nucleus and lateral to the subthalamic nucleus to enter the thalamus. The red nucleus extends from midlevel of the inferior colliculus to the lateral wall of the third ventricle. The subthalamic nucleus is located just ventral to the red nucleus and dorsomedial to the internal capsule. Other

**structures labeled are the fasciculus retroflexus, which courses along the dorsomedial side of the red nucleus and connects the habenula to the interpeduncular nucleus, the mammillothalamic tract, which connects the mammillary body to the anterior thalamic nucleus, and the stria medullaris thalami connecting the habenula to the septal area. R, anterior view of the interpeduncular fossa. The perioculomotor safe entry zone is located between the medial edge of the corticospinal tract laterally and the exit point of the oculomotor nerve medially. Angling the incision too far medially may damage the intramesencephalic segment of the oculomotor nerve and too far laterally may enter the corticospinal tract. S, further dissection. The perioculomotor entry will encounter the red nucleus just behind the medial lemniscus. T, left lateral view. The intramesencephalic segment of the oculomotor nerve passes medial to the red nucleus and exits the interpeduncular fossa. The red nucleus is located dorsal to the exit point of the oculomotor nerve from the brainstem. The surgical routes through the perioculomotor zone to the ventral (yellow arrow) and dorsal (blue arrow) midbrain are shown. Ant., anterior; Cap., capsule; Cer., cerebellar, cerebral; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Decuss., decussation; Dors., dorsal; Fac., facial; Fasc., fasciculus; Fr. Pon., frontopontine; Gen., geniculate; Gl., gland; Inf., inferior; Int., internal; Interped., interpeduncular; Lat., lateral; Lemn., lemniscus; Mam., mammillary; Med., medial, medullaris; Mes., mesencephalic; Mid., middle; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Perioc., perioculomotor; Pon., ponto; Quad., quadrigeminal; Retro., retroflexus; Rt., right; Seg., segment; Spin., spinal; STN, subthalamic nucleus; Str., stria; Subst., substantia; Sulc., sulcus; Sup., superior; Teg., tegmentum; Tent., tentorium; Thal., thalami, thalamic; TMT, trigeminal mesencephalic tract; Tr., tract; Vent., ventral. (Images courtesy of AL Rhoton, Jr.)**

## Ventral Fiber Tracts

The ventral midbrain and pons contain the corticospinal, corticobulbar, and corticopontine tracts (Figure 2). The caudal medulla contains only the corticospinal tract. In the midbrain, the frontopontine fibers lie in the medial part, the corticospinal and corticobulbar tracts in the middle part,

and the temporoparieto-occipitopontine tract in the lateral part of the cerebral peduncle (Figure 2C).[1,17-19] It was difficult to define the corticospinal tract in the pons with dissection starting in the midbrain, but when dissected from below at the medullary pyramid, it could be followed into the middle third of the cerebral peduncle in agreement with other anatomic and clinical studies.[1,15,17-19] In the pons, the corticospinal tract courses anteromedially. The corticobulbar tract descends immediately dorsal to the corticospinal tract to connect with the related cranial nerve nuclei. The corticopontine fibers end at the pontine nuclei that are scattered anterior and posterior to the corticospinal and corticobulbar tracts.[14]

## Dorsal Fiber Tracts

The dorsal tracts examined include the medial longitudinal fasciculus, and the central tegmental, trigeminal mesencephalic, and trigeminal spinal tracts.

**Medial Longitudinal Fasciculus.** This myelinated tract extends from the midbrain to the upper thoracic spinal cord and interconnects the visual and vestibular centers with the nuclei controlling movement of the eyes and the head and neck (Figure 2B and 2D-G). At the level of the midbrain, it is found adjacent to the midline between the cerebral aqueduct dorsally and the decussation of the superior cerebellar peduncle ventrally. The medial longitudinal fasciculus passes lateral and ventral to the oculomotor nuclei where it mixes with the intramesencephalic segment of the oculomotor nerve and ends in the interstitial nucleus located rostral to the cerebral aqueduct (Figures 2F and 3I).[15] At the level of the lower half of the inferior colliculus, the medial longitudinal fasciculus connects to the trochlear nucleus and travels near the floor of the fourth ventricle and adjacent to the midline of the pons. Its width on each side of the median sulcus is 1 mm (Figure 2D). It curves ventrally at the lower edge of the facial colliculus, approaches the medial lemniscus, and passes ventral to the hypoglossal triangle. It crosses the medial lemniscus at the level of the gracile and cuneate tubercles and continues in the ventral funiculus of the spinal cord (Figure 2B).

**Trigeminal Mesencephalic and Spinal Tracts.** The trigeminal nerve enters the brainstem at the midpons. It courses through the middle cerebellar peduncle toward the fourth ventricle to reach the trigeminal motor and main sensory nuclei, where it divides into the trigeminal mesencephalic and spinal tracts (Figure 2D). The trigeminal mesencephalic tract ascends deep to the superior half of the floor of the fourth ventricle between the superior cerebellar peduncle laterally, the sulcus limitans medially, the central tegmental tract ventrally, and the locus coeruleus dorsally. The distances between the trigeminal mesencephalic tract and the median sulcus are variable because of the curved course of the mesencephalic tract. The distance between the trigeminal mesencephalic tract and the median sulcus averaged 5.9 mm at the level of the trigeminal motor and main sensory nuclei, which are located rostrolateral to the facial colliculus. At the midlevel of the upper floor, this distance averaged 5.4 mm, and at the level of the trochlear nerve it averaged 3.7 mm (Figure 4I).

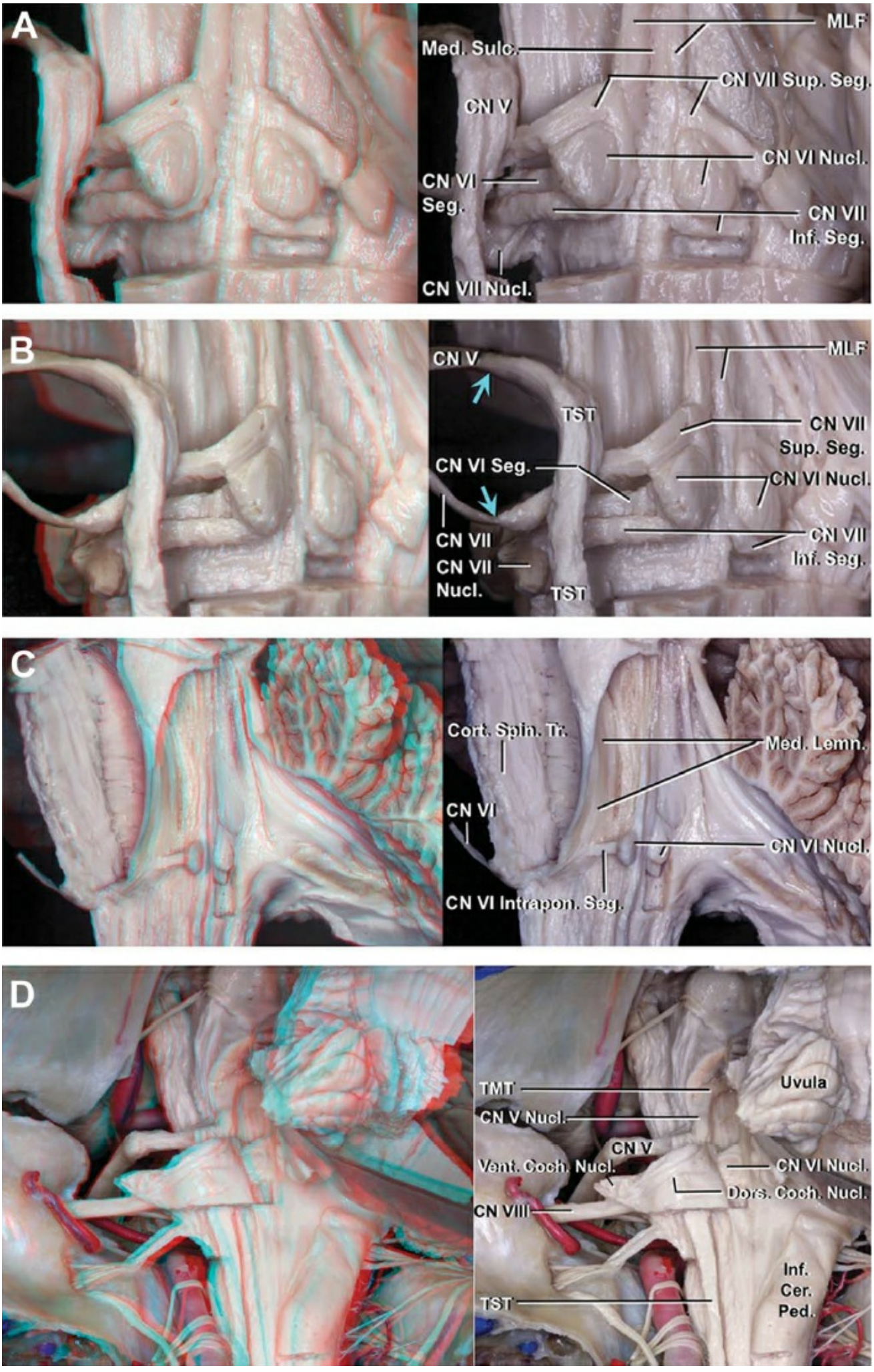

A
MLF
Med. Sulc.
CN VII Sup. Seg.
CN V
CN VI Nucl.
CN VI Seg.
CN VII Inf. Seg.
CN VII Nucl.
B
CN V
MLF
TST
CN VII Sup. Seg.
CN VI Seg.
CN VI Nucl.
CN VII
CN VII Inf. Seg.
CN VII Nucl.
TST
C
Cort. Spin. Tr.
Med. Lemn.
CN VI
CN VI Nucl.
CN VI Intrapon. Seg.
D
TMT
Uvula
CN V Nucl.
CN V
Vent. Coch. Nucl.
CN VI Nucl.
Dors. Coch. Nucl.
CN VIII
Inf. Cer. Ped.
TST

Figure 4 (A–D). Pons. A, posterior view of the facial colliculus. The ependyma of the fourth ventricle and white matter around the facial colliculus have been removed. The facial colliculus overlies the abducens nucleus and intrapontine segment of the facial nerve. The abducens nucleus is located in a paramedian position just ventral to the surface of the floor. The medial longitudinal fasciculus and intrapontine segment of the facial nerve course between the median sulcus and abducens nucleus. B, posterolateral view of the facial colliculi. The blue arrows show the point where the facial and trigeminal nerves become intrapontine. The facial nucleus is located ventrolateral to the abducens nucleus and ventromedial to the trigeminal spinal tract. The initial intrapontine segment of the facial nerve extends dorsomedially toward the floor of the fourth ventricle, curves around the lower, medial, and upper edges of the abducens nucleus, and continues ventrolaterally along the medial side of the trigeminal spinal tract to exit the pons. C, left posterolateral view of another specimen after removing the left facial nerve. The intrapontine segment of the abducens nerve originates from the ventral face of its nucleus and proceeds anteriorly through the medial lemniscus and lateral to the corticospinal tract to exit the ventral pons. D, posterior view of another specimen. The dorsal cochlear nucleus sits on the dorsal surface of the inferior cerebellar peduncle, where it forms a smooth prominence called the auditory tubercle. The ventral cochlear nucleus is located on the lateral surface of the inferior cerebellar peduncle. The intrapontine segment of the vestibulocochlear nerve passes dorsal to the trigeminal spinal tract. Amb., ambiguus; Attach., attachment; Cer., cerebellar; CN, cranial nerve; Coch., cochlear; Coe., coeruleus; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Cun., cuneate; Dors., dorsal; Fac., facial; Flocc., flocculus; Fren., frenulum; Hypo., hypoglossal; Inf., inferior; Intrapon., intrapontine; Junct., junction; Lat., lateral; Lemn., lemniscus; Limit., limitans; Med., medial, median; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Pon., pontine; Post., postrema; Rec., recess; Seg., segment; Spin., spinal; Sulc., sulcus; Sup., superior; Tent., tentorium; TMT, trigeminal mesencephalic tract; Tr., tract; Triang., triangle; TST, trigeminal spinal tract; Tub., tubercle; Vent., ventral; Vest., vestibular. (Images courtesy of AL Rhoton,

Jr.)

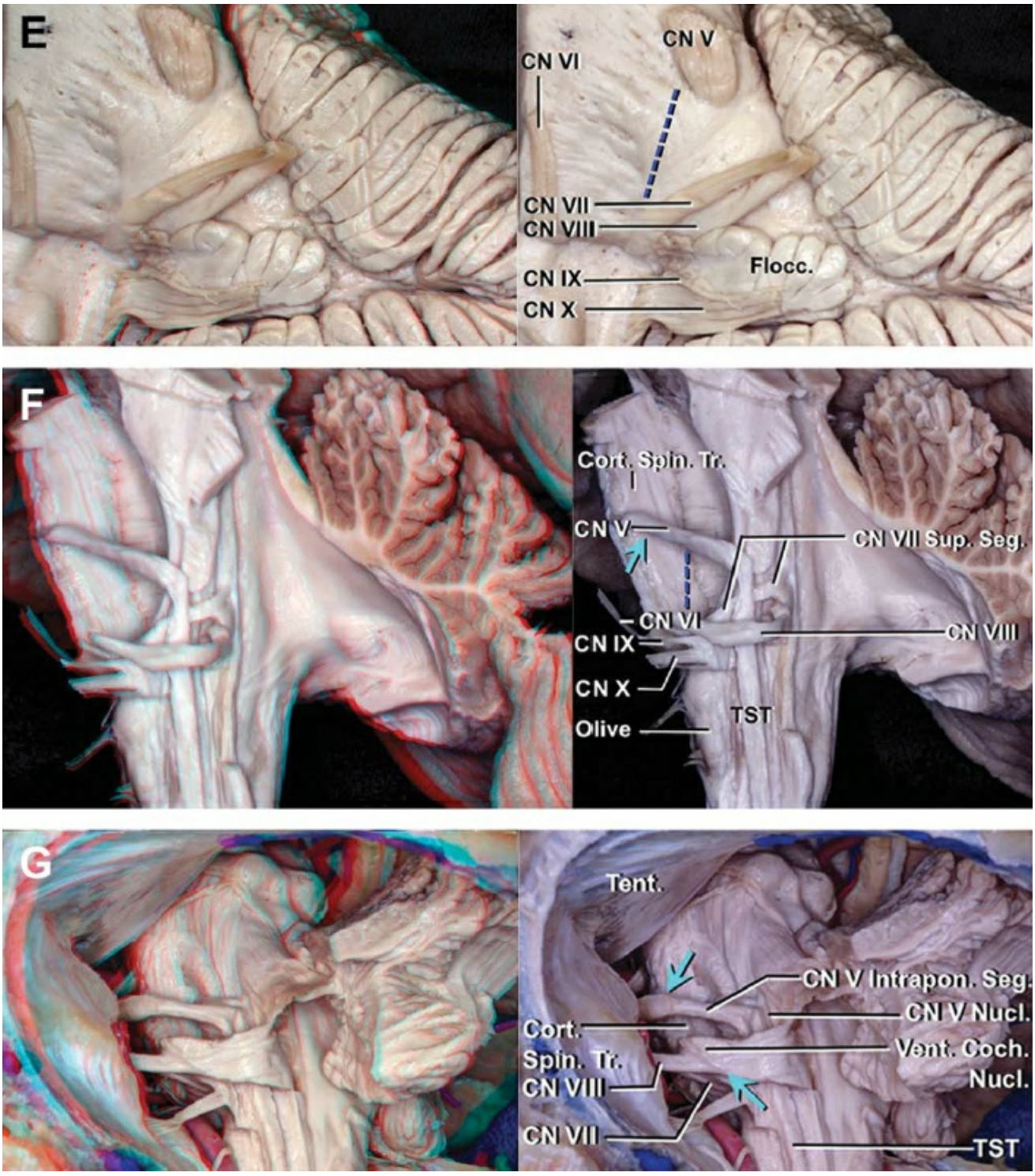



Figure 4 (E–G). Pons. E, anterolateral view of another specimen. The peritrigeminal entry zone (interrupted line) is located between the trigeminal and facial nerves. F, oblique view of the peritrigeminal zone in another specimen. The left cerebellum and part of the brainstem have been removed to show the relationship between the trigeminal spinal tract and cranial nerves. The blue arrow shows the point that the trigeminal nerve exits the brainstem, and the blue interrupted line shows the vertical peritrigeminal incision. The trigeminal spinal tract turns

caudally at the midpons level and descends to the spinal cord. The trigeminal spinal tract descends dorsal to the intrapontine segments of CNs 7, 9, 10, 11, and 12, and ventral to CN 8. G, left retrosigmoid view of a similar dissection in another specimen. The blue arrow shows the point where the facial and trigeminal nerves become intrapontine. The important structures in the peritrigeminal zone are the corticospinal tract anteromedially, the intrapontine segment of the posterior trigeminal root superiorly, the trigeminal motor and main sensory nuclei, intrapontine segment of the facial nerve, and trigeminal spinal tract posteromedially, and the ventral cochlear nucleus, and intrapontine segment of the abducens nerve inferiorly. Amb., ambiguus; Attach., attachment; Cer., cerebellar; CN, cranial nerve; Coch., cochlear; Coe., coeruleus; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Cun., cuneate; Dors., dorsal; Fac., facial; Flocc., flocculus; Fren., frenulum; Hypo., hypoglossal; Inf., inferior; Intrapon., intrapontine; Junct., junction; Lat., lateral; Lemn., lemniscus; Limit., limitans; Med., medial, median; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Pon., pontine; Post., postrema; Rec., recess; Seg., segment; Spin., spinal; Sulc., sulcus; Sup., superior; Tent., tentorium; TMT, trigeminal mesencephalic tract; Tr., tract; Triang., triangle; TST, trigeminal spinal tract; Tub., tubercle; Vent., ventral; Vest., vestibular. (Images courtesy of AL Rhoton, Jr.)

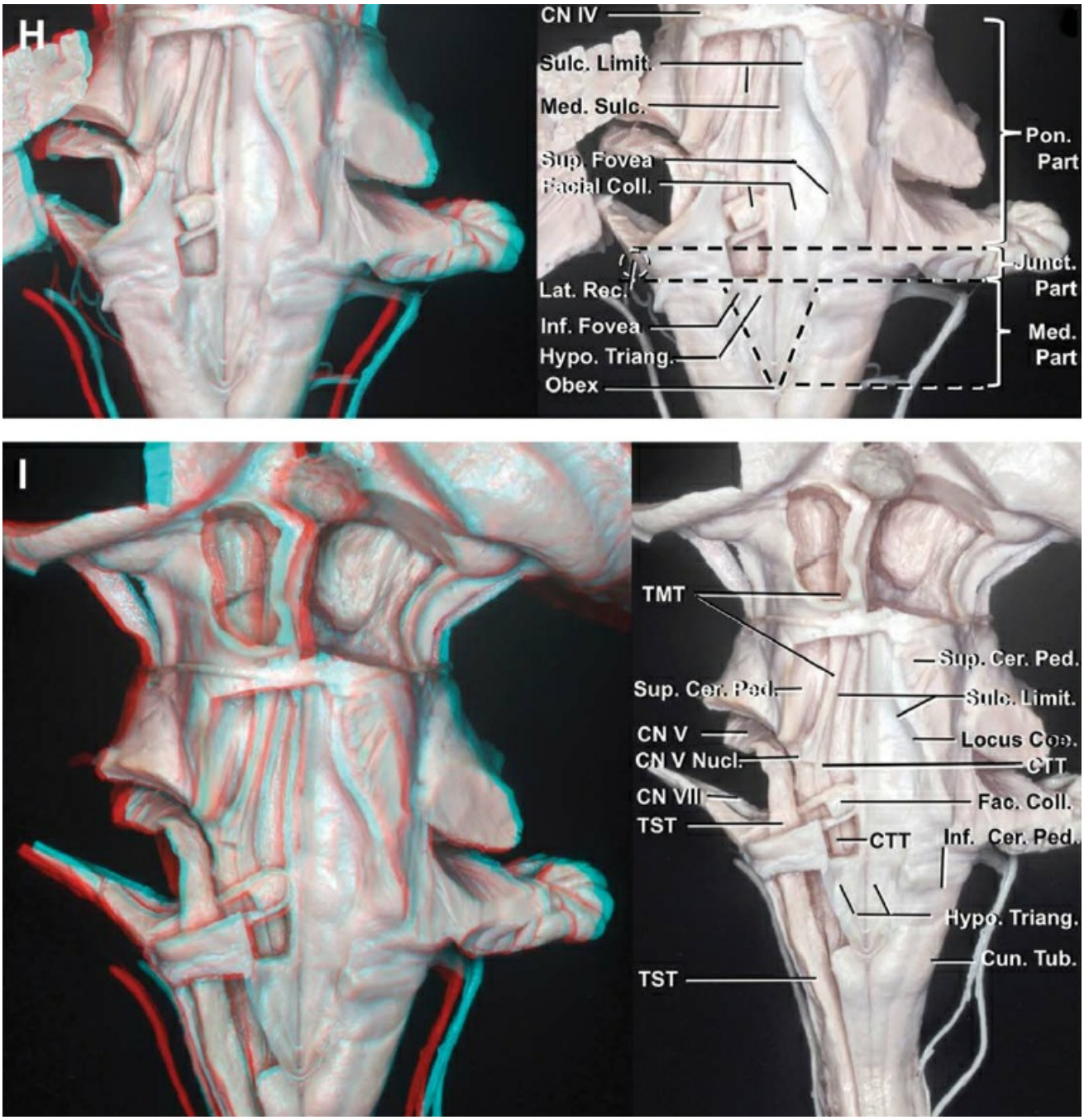



**Figure 4 (H–I). Pons. H, posterior surface of the brainstem and fourth ventricular floor. The floor of the fourth ventricle is divided in the midline by the median sulcus. The sulcus limitans, another longitudinal sulcus, extends along the floor lateral to the median sulcus. The floor is divided into 3 parts: a superior or pontine part, an intermediate or junctional part, and an inferior or medullary part. The superior fovea is positioned lateral to the facial colliculus, and the inferior fovea is lateral to the hypoglossal triangle. I, posterior view of midbrain, pons, and medulla. The trigeminal nerve has 3 sensory nuclei: the chief sensory nucleus that is located immediately lateral to the motor nucleus, the trigeminal mesencephalic nucleus that ascends to the midbrain with its tract, and the trigeminal spinal nucleus that descends with its tract to the upper spinal cord. The**

**trigeminal mesencephalic tract ascends between the superior cerebellar peduncle laterally and the sulcus limitans medially and curves toward the midline in the upper pons and midbrain. The central tegmental descends deep to the trigeminal mesencephalic tract. The trigeminal mesencephalic and central tegmental tracts are located deep to the locus coeruleus. The inferior cerebellar peduncle ascends just lateral to the cuneate fasciculus. Amb., ambiguus; Attach., attachment; Cer., cerebellar; CN, cranial nerve; Coch., cochlear; Coe., coeruleus; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Cun., cuneate; Dors., dorsal; Fac., facial; Flocc., flocculus; Fren., frenulum; Hypo., hypoglossal; Inf., inferior; Intrapon., intrapontine; Junct., junction; Lat., lateral; Lemn., lemniscus; Limit., limitans; Med., medial, median; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Pon., pontine; Post., postrema; Rec., recess; Seg., segment; Spin., spinal; Sulc., sulcus; Sup., superior; Tent., tentorium; TMT, trigeminal mesencephalic tract; Tr., tract; Triang., triangle; TST, trigeminal spinal tract; Tub., tubercle; Vent., ventral; Vest., vestibular. (Images courtesy of AL Rhoton, Jr.)**

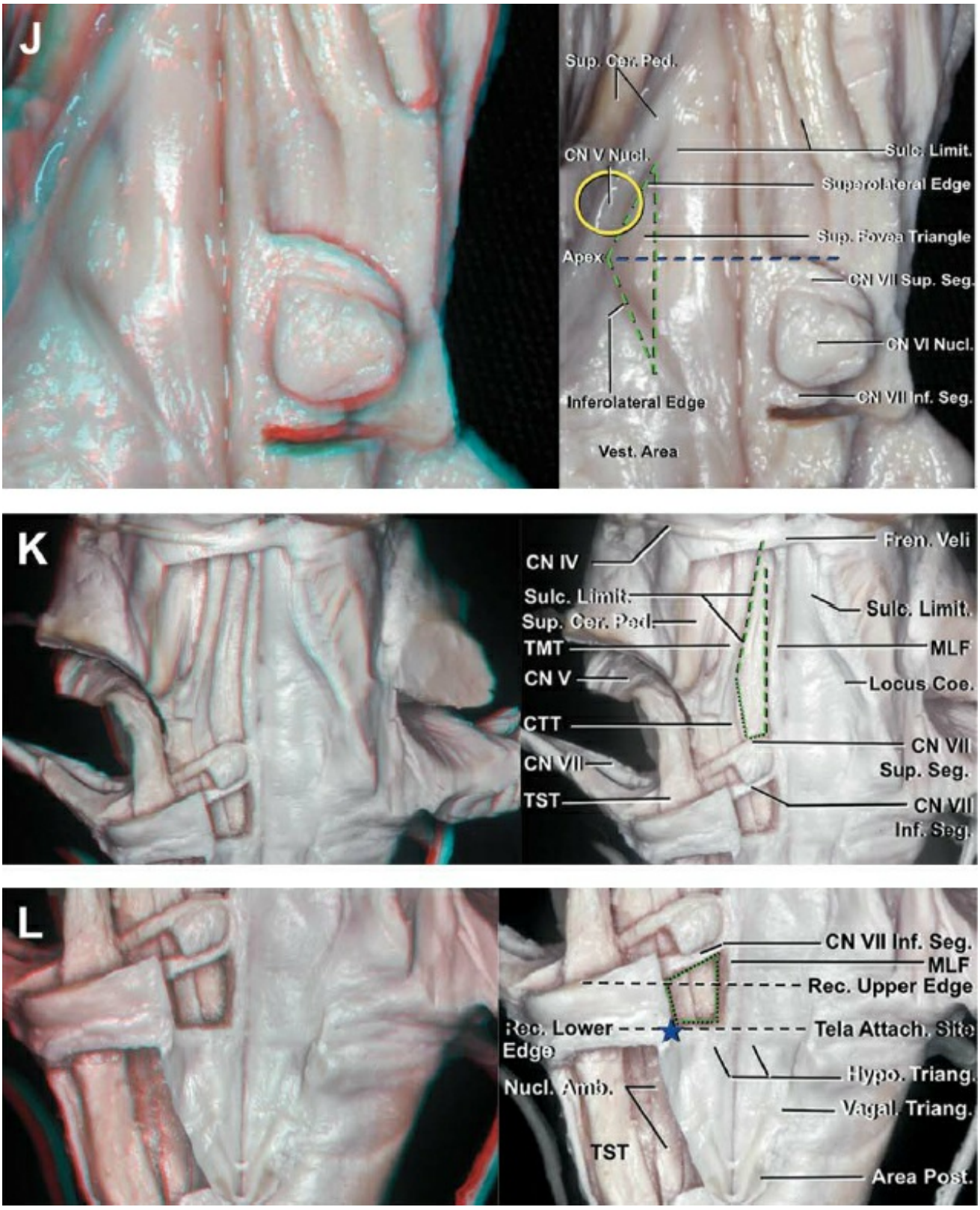



Figure 4 (J–L). Pons. J, posterior view. The superior fovea has a triangular shape. The apex of the triangle is at the most lateral point of the upper part of the floor. Its superolateral edge is formed by the superior cerebellar peduncle, the inferolateral edge by the vestibular area, and its medial base by the sulcus limitans. The superolateral edge of the superior fovea triangle is a landmark for the deep location of the trigeminal motor and main sensory nuclei (yellow circle). The apex of the superior fovea triangle is located at the same transverse level as the rostral edge of the

**facial colliculus. The lateral border of the facial colliculus is formed by the sulcus limitans, and its medial border is formed by the medial longitudinal fasciculus. K, posterior view of the suprafacial area (green interrupted lines). The suprafacial approach is limited rostrally by the frenulum veli through which the trochlear nerve passes, caudally by the superior intrapontine segment of the facial nerve forming the upper edge of the facial colliculus, medially by the medial longitudinal fasciculus, and laterally by the sulcus limitans. L, enlarged posterior view of the infrafacial approach. The rostral border of this approach is the inferior intrapontine segment of the facial nerve forming the lower edge of the facial colliculus and corresponding to the level of a transverse line crossing the upper edges of the lateral recesses. The caudal border of the infrafacial approach, which is the site of horizontal attachment of the tela choroidea along the lower margin of the lateral recess, is positioned at the same transverse level as the upper margin of the hypoglossal triangle. The lateral edge of the ipsilateral medial longitudinal fasciculus forms the medial border and the facial nucleus and nucleus ambiguus are positioned below the surface of the floor at the lateral border of the infrafacial approach. The facial nucleus and nucleus ambiguus are found deep and just lateral to the most medial point of the attachment of the tela along the lower edge of the lateral recess (blue star). The facial nucleus is located at the level of the pontomedullary junction. Amb., ambiguus; Attach., attachment; Cer., cerebellar; CN, cranial nerve; Coch., cochlear; Coe., coeruleus; Coll., colliculus; Cort., cortico; CTT, central tegmental tract; Cun., cuneate; Dors., dorsal; Fac., facial; Flocc., flocculus; Fren., frenulum; Hypo., hypoglossal; Inf., inferior; Intrapon., intrapontine; Junct., junction; Lat., lateral; Lemn., lemniscus; Limit., limitans; Med., medial, median; MLF, medial longitudinal fasciculus; Nucl., nucleus; Ped., peduncle; Pon., pontine; Post., postrema; Rec., recess; Seg., segment; Spin., spinal; Sulc., sulcus; Sup., superior; Tent., tentorium; TMT, trigeminal mesencephalic tract; Tr., tract; Triang., triangle; TST, trigeminal spinal tract; Tub., tubercle; Vent., ventral; Vest., vestibular. (Images courtesy of AL Rhoton, Jr.)**

The trigeminal spinal tract turns caudally at the level of the trigeminal motor and sensory nuclei and descends between the intrapontine

segment of the vestibulocochlear nerve dorsally and the intrapontine segments of the facial, glossopharyngeal, vagus, accessory, and hypoglossal nerves ventrally to reach the spinal cord (Figure 4F).

**Central Tegmental Tract**. This tract, which is a part of the extrapyramidal system, connects the red and inferior olivary nuclei (Figures 2D, E, G, 3K, and 4I). At the level of the midbrain, the central tegmental tract originates from the dorsomedial part of the red nucleus and descends ipsilaterally, passing dorsally through the decussation of the superior cerebellar peduncle and lateral to the medial longitudinal fasciculus.[16] The central tegmental tract courses deep to the superior half of the floor of the fourth ventricle between the sulcus limitans laterally and superior cerebellar peduncle medially. The central tegmental tract is located deep to the locus coeruleus and trigeminal mesencephalic tract and dorsal to the medial lemniscus. At the level of the facial colliculus, the central tegmental tract courses between the intrapontine segment of the facial nerve laterally and intrapontine segment of the abducens nerve medially to end in the dorsomedial part of the inferior olivary nucleus.

## The Midbrain and Safe Entry Zones

### Internal Anatomy of the Midbrain

The midbrain is separated from the diencephalon above by the sulcus between the optic tracts and the cerebral peduncles, and from the pons below by the pontomesencephalic sulcus (Figure 3). The medial lemniscus divides the midbrain into ventral and dorsal parts. The tegmentum (red nucleus) and tectum (quadrigeminal plate) are situated in the dorsal midbrain and the cerebral peduncle is situated in the ventral midbrain (Figure 3B and E). The midbrain contains the intramesencephalic segments of the oculomotor and trochlear nerves and their nuclei.

**Oculomotor Nerve and Nucleus**. This nucleus is located next to the midline at the level of the lower half of the superior colliculus and the upper half of the inferior colliculus, and between the cerebral aqueduct dorsally and the decussation of the superior cerebellar peduncle ventrally (Figure 3D, F, I, and T). The rostrocaudal length of the oculomotor nucleus

averaged 5.3 mm. The intramesencephalic segment of the oculomotor nerve passes inside and along the medial side of the red nucleus to exit the midbrain in the lateral wall of the interpeduncular fossa (Figure 3T).

**Trochlear Nerve and Nucleus**. The trochlear nucleus is located adjacent to the midline in the midbrain at the level of the lower half of the inferior colliculi (Figure 3D, F, I, and P). Like the oculomotor nuclei, it is positioned between the cerebral aqueduct dorsally and the decussation of the superior cerebellar peduncle ventrally. The trochlear fibers turn dorsally after they exit the nucleus, curve around the aqueduct to exit the dorsal surface of the brainstem at the lower side of the inferior colliculus, and cross in the cerebellomesencephalic fissure to the contralateral side (Figure 3I).

## Safe Entry Zones of the Midbrain

The proposed safe entry zones of the midbrain are along the lateral mesencephalic sulcus, supra- and infracollicular areas, and perioculomotor zone (Figure 3).

**Lateral Mesencephalic Sulcus.** This groove runs on the surface of the midbrain between the cerebral peduncle and the lateral lemniscus and extends from the pontomesencephalic sulcus inferiorly to the medial geniculate body superiorly (Figure 3A-D).[17] It is positioned immediately lateral to the ventral surface of the medial lemniscus and the substantia nigra at the border between the ventral and dorsal midbrain. Angling an incision into the lateral mesencephalic sulcus 45° forward will reach the medial lemniscus at the border between the ventral and dorsal midbrain (Figure 3H). Angling the incisions through the sulcus further forward will encounter the cerebral peduncle. An incision entering at a right angle to the tectal surface will be directed further posterior to enter the dorsal midbrain (Figure 3H). This incision, based on the level of the entry point, may encounter in order from lateral to medial: the trigeminal mesencephalic and central tegmental tracts located dorsal to the decussation of the superior cerebellar peduncle, the red nucleus located at the level of the upper half of the inferior colliculus near the midline and extending upward along the lateral wall of the third ventricle, the

decussation of the superior cerebellar peduncle located just caudal to the red nucleus at the level of the inferior colliculus, the oculomotor nucleus at the level of the lower half of the superior colliculus and upper half of the inferior colliculus, and the trochlear nucleus at the level of the lower half of the inferior colliculus. The red nucleus is located an average of 4.3 mm deep to the lateral mesencephalic sulcus, and the oculomotor and trochlear nuclei are positioned adjacent to the midline an average of 9.5 mm medial to the surface of the lateral mesencephalic sulcus (Figure 3D-G).

**Supracollicular and Infracollicular Areas**. These are the proposed safe entry zones for lesions in the tectum (quadrigeminal plate) dorsal to the aqueduct.[1] The aqueduct is an important midline landmark for determining the depth of the approach (Figure 3L and M).

For the supracollicular approach, a transverse incision is made just above the upper edge of the superior colliculus. An incision deeper than the aqueduct will damage the intramesencephalic segment of the oculomotor nerve and medial longitudinal fasciculus, both of which sit ventral to the aqueduct in the midline. As the supracollicular incision extends lateral from the midline, it will encounter, in order, the habenula, trigeminal mesencephalic tract, central tegmental tract, and red nucleus. The depth from the surface of the superior colliculus to the red nucleus averaged 5.5 mm (Figure 3N and O).

For the infracollicular approach, a transverse incision is made between the trochlear nerve and the lower edge of the inferior colliculus. An incision deeper than the aqueduct will encounter, from superficial to deep, the trochlear nucleus, medial longitudinal fasciculus, and decussation of the superior cerebellar peduncle. Transverse infracollicular incisions extending laterally will first incise the superior cerebellar peduncle, and then the lateral lemniscus. As the lateral incision deepens from dorsal to ventral, it will encounter the trigeminal mesencephalic tract, central tegmental tract, and decussation of the superior cerebellar peduncle (Figure 3P and T).

**Perioculomotor Zone**. Ventromedian lesions of the midbrain can be

reached via the perioculomotor zone that is directed through the cerebral peduncle between the corticospinal and corticobulbar tracts laterally and the exit point of the oculomotor nerve medially (Figure 3R-T).[1,14,18] The width of the perioculomotor zone, the distance between the exit point of the oculomotor nerve medially, and the medial edge of the corticospinal and corticobulbar tracts laterally is a narrow zone adjacent the oculomotor nerve approximating the medial one-third to one-fourth of the cerebral peduncle.[1,15,17-19] However, it is best to restrict the approach to the medial one-fourth of the peduncle. The fibers in the cerebral peduncle immediately lateral to the oculomotor nerve are frontopontine fibers. The first structures to be encountered in the dorsal midbrain are the red nucleus and the intramesencephalic segment of the oculomotor nerve passing through it. The red nucleus is located dorsal to the medial lemniscus and the exit point of the oculomotor nerve from the midbrain. Care must be taken to avoid the red nucleus, intramesencephalic segment of the oculomotor nerve, and corticospinal and corticobulbar tracts in the middle third of the cerebral peduncle (Figure 3S and T).

## The Pons and Safe Entry Zones

### Internal Anatomy of the Pons

The pons is located between the pontomesencephalic sulcus superiorly and the pontomedullary sulcus inferiorly. The pons is divided into ventral (basilar) and dorsal (tegmentum) parts by the medial lemniscus (Figures 2B and 4). It contains the intrapontine segments of the trigeminal, abducens, facial, and vestibulocochlear nerves and their individual nuclei.

**Trigeminal Nerve and Its Nuclei**. The trigeminal motor and main sensory nuclei are located at the level of the midpons and deep to the lateral edge of the floor of the fourth ventricle (Figure 4). The trigeminal motor and main sensory nuclei are located 6 mm lateral to the median sulcus just rostral, lateral, and deep to the level of the upper edge of the facial colliculus. The trigeminal nuclei sit deep to the superolateral edge of the superior fovea triangle and the medial edge of the superior cerebellar peduncle (Figure 4J). The trigeminal nerve has 3 sensory nuclei: (1) the

main sensory nucleus, which is located immediately lateral to the motor nucleus, (2) the trigeminal mesencephalic nucleus, which ascends to the midbrain with its tract, and (3) the trigeminal spinal nucleus, which descends with its tract to the upper spinal cord (Figure 4I).

**Abducens Nerve and Its Nucleus**. The abducens nucleus is located paramedian immediately ventral to the floor of the fourth ventricle (Figure 4A-C, J, and K). The medial longitudinal fasciculus and intrapontine segment of the facial nerve course between the median sulcus and the abducens nucleus (Figure 4A). The intrapontine segment of the abducens nerve originates from the ventral face of the abducens nucleus and proceeds ventrally through the medial lemniscus and lateral to the corticospinal tract to exit the pons at the lateral edge of the corticospinal tract (Figure 4C).

**Facial Nerve and Its Nucleus**. The facial nucleus is located at the level of the pontomedullary junction, dorsal to the medial lemniscus, rostral to the nucleus ambiguus, ventrolateral to the abducens nucleus, ventromedial to the trigeminal spinal tract, and immediately dorsomedial to the uppermost edge of the inferior olivary nucleus (Figure 4A, B, and J-L). The depth from surface of the floor to the facial nucleus averaged 5.5 mm. The intrapontine segment of the facial nerve after originating from the facial nucleus passes dorsomedial toward the floor of the fourth ventricle and around, in order, the lower, medial, and upper edge of the abducens nucleus, and just lateral to the medial longitudinal fasciculus to exit the pons in the cerebellopontine angle by passing medial to the trigeminal spinal tract.

**Vestibulocochlear Nerve and Its Nuclei**. The vestibulocochlear nerve enters the brainstem at the lateral end of the pontomedullary sulcus (Figure 4D). The vestibular component is positioned anterosuperior and the cochlear component posteroinferior. The dorsal cochlear nucleus sits on the dorsal surface of the inferior cerebellar peduncle in the lateral recess where it forms a smooth prominence called the auditory tubercle. The ventral cochlear nucleus is located on the lateral surface of the inferior cerebellar peduncle. The distances from the medial edge of the

dorsal cochlear nucleus to the median sulcus and to the ipsilateral sulcus limitans are 9 and 6 mm, respectively.

## Safe Entry Zones of the Ventral Pons

The safe entry zone in the ventral pons is the peritrigeminal zone.

**The Peritrigeminal Zone.** The approach through the peritrigeminal entry zone for lesions in the ventral pons is usually directed through a longitudinal incision between the trigeminal and facial nerves (Figure 4E and F).[20] The incision crosses the superficial transverse pontine fibers. As the incision deepens it reaches the pontine nuclei and crosses the deep transverse pontine fibers. The corticospinal tract courses through the ventromedial pons. The distances between the posterolateral edge of the corticospinal tract and the brainstem junction of the trigeminal and facial nerves averaged 9.2 mm and 8 mm, respectively. This incision should not extend caudal to the rostral edge of the facial nerve exit zone because of the risk of damaging the intrapontine segments of the abducens and facial nerves. Making an incision dorsal to the trigeminal nerve risks injuring the intrapontine segment of the trigeminal nerve and the ventral cochlear nucleus. Extending the incision rostral to the trigeminal and caudal to the facial nerve risks injuring the intrapontine segments of the trigeminal, abducens, and facial nerves. The trigeminal motor nucleus is located an average of 10.1 mm dorsomedial to the junction of the trigeminal nerve with the pons (Figure 4F and G).

## Internal Anatomy of the Dorsal Pons

The dorsal pons is located between the medial lemniscus ventrally and floor of the fourth ventricle dorsally.

**Floor of the Fourth Ventricle**. The floor of the fourth ventricle has a rhomboid shape (Figure 4H-L). The rostral two-thirds of the floor are on the posterior surface of the pons and the caudal one third is on the posterior surface of the medulla. The cerebral aqueduct opens into the apex and the caudal end is at the obex. A line connecting the rostral edges of the lateral recesses marks the junction of the pontine and medullary

parts of the floor of the fourth ventricle. The floor is divided into superior (pontine), intermediate (junctional), and inferior (medullary) parts. The superior part has a triangular shape: its apex is at the aqueduct and its base is created by a line crossing the rostral edges of the lateral recesses. The locus coeruleus is positioned lateral to the sulcus limitans at the edge of the rostral part of the floor. The intermediate part is formed by the strip between the upper and lower edges of the lateral recesses. The caudal part has a triangular shape limited laterally by the inferolateral margin of the floor along which the tela choroidea is attached, and caudally by the obex.

The floor from rostral apex to caudal tip is divided into 2 symmetric halves by the median sulcus. The sulcus limitans, another longitudinal sulcus, extends along the ventricular floor lateral to the median sulcus. The median eminence is the longitudinal prominence between the median sulcus and the sulcus limitans. It is the site of the facial colliculus, prominences overlying the hypoglossal and vagal nuclei, and the area postrema. These 3 paired triangular areas overlying the hypoglossal and vagal nuclei and area postrema in the medullary part of the floor give this area a pen-nib-shaped appearance, and consequently, the name calamus scriptorius. The sulcus limitans deepens at 2 points to form dimples called fovea. The superior fovea is lateral to the facial colliculus, and the inferior fovea is lateral to the hypoglossal triangle. The inferior fovea is located in the medullary part of the floor immediately lateral to the hypoglossal triangle between the vestibular area superiorly and the upper edge of the vagal triangle inferiorly. The striae medullaris cross the ventricular floor at the level of lateral recess.

**Superior Fovea**. The superior fovea has a triangle shape and is located lateral to the facial colliculus (Figure 4J). The superolateral edge of the triangle is formed by the superior cerebellar peduncle, the inferolateral edge by the vestibular area, and the medial base by the sulcus limitans. The apex of the triangle is located at the most lateral point of the rostral part of the fourth ventricle. The superior fovea is an important landmark for estimating the position of the facial colliculus and the deep location of the motor and main sensory nuclei of the trigeminal nerve. The apex of

the superior fovea triangle is located laterally at the same transverse level as the upper edge of the facial colliculus. The superolateral edge of the triangle is a landmark for estimating the deep position of the trigeminal motor and main sensory nuclei. If the prominence of the facial colliculus is not well defined, the level of the apex of the superior fovea triangle can be used as the transverse level of the upper edge of the facial colliculus.

**Facial Colliculus**. The facial colliculus is positioned near the midline between the medial longitudinal fasciculus and the sulcus limitans (Figure 4A, B, and H-L). The rostral edge of the facial colliculus is formed by the superior intrapontine segment of the facial nerve, located at the same transverse level as the lateral apex of the superior fovea triangle. Its caudal edge is formed by the inferior intrapontine segment of the facial nerve, located at the level of a transverse line crossing the upper edges of the lateral recess. The inferior intrapontine segment of the facial nerve is in the same transverse plane as the facial nucleus. The rostrocaudal length of the facial colliculus averaged 4.5 mm, and its width averaged 3.5 mm.

## Safe Entry Zones of the Dorsal Pons

The proposed safe entry zones in the dorsal pons are the suprafacial and infrafacial approaches directed superior and inferior to the facial colliculus, respectively (Figure 4).

**The Suprafacial Approach**. The suprafacial safe entry zone is limited rostrally by the frenulum veli through which the trochlear nerve passes, caudally by the superior intrapontine segment of the facial nerve at the upper margin of the facial colliculus, medially by the medial longitudinal fasciculus, and laterally by the sulcus limitans (Figure 4H-K). The incision for this approach should not extend medially into the medial longitudinal fasciculus or laterally to the sulcus limitans to avoid damaging the trigeminal mesencephalic and central tegmental tracts located deep to the locus coeruleus, or the trigeminal motor and main sensory nuclei deep to the superolateral edge of the superior fovea triangle. The trigeminal motor and main sensory nuclei are located deep to a point an average of 6 mm lateral to the median sulcus. The mean rostrocaudal length of the suprafacial entry zone averaged 12.7 mm. The width of the medial

longitudinal fasciculus is 1 mm. The depth from the surface of the floor to the medial lemniscus averaged 4.5 mm.

**The Infrafacial Approach**. The inferior intrapontine segment of the facial nerve that forms the lower edge of the facial colliculus also forms the rostral border of the infrafacial approach located at the level of a transverse line passing through the upper edges of the lateral recess (Figures 4L and 5B). The caudal border is positioned at the upper edge of the hypoglossal triangle, located at the level of the attachment of the tela choroidea to the lower edges of the lateral recess. The rostrocaudal length of the infrafacial safe entry zone is the same as the distance between the upper and lower borders of the lateral recess or intermediate (junctional) part of the floor. The medial longitudinal fasciculus forms the medial border, and the facial nucleus and nucleus ambiguus located in order from rostral to caudal deep to the floor form the lateral border. The facial nucleus and nucleus ambiguus are found deep and just lateral to the most medial point of attachment of the tela choroidea along the lower margin of the lateral recess.

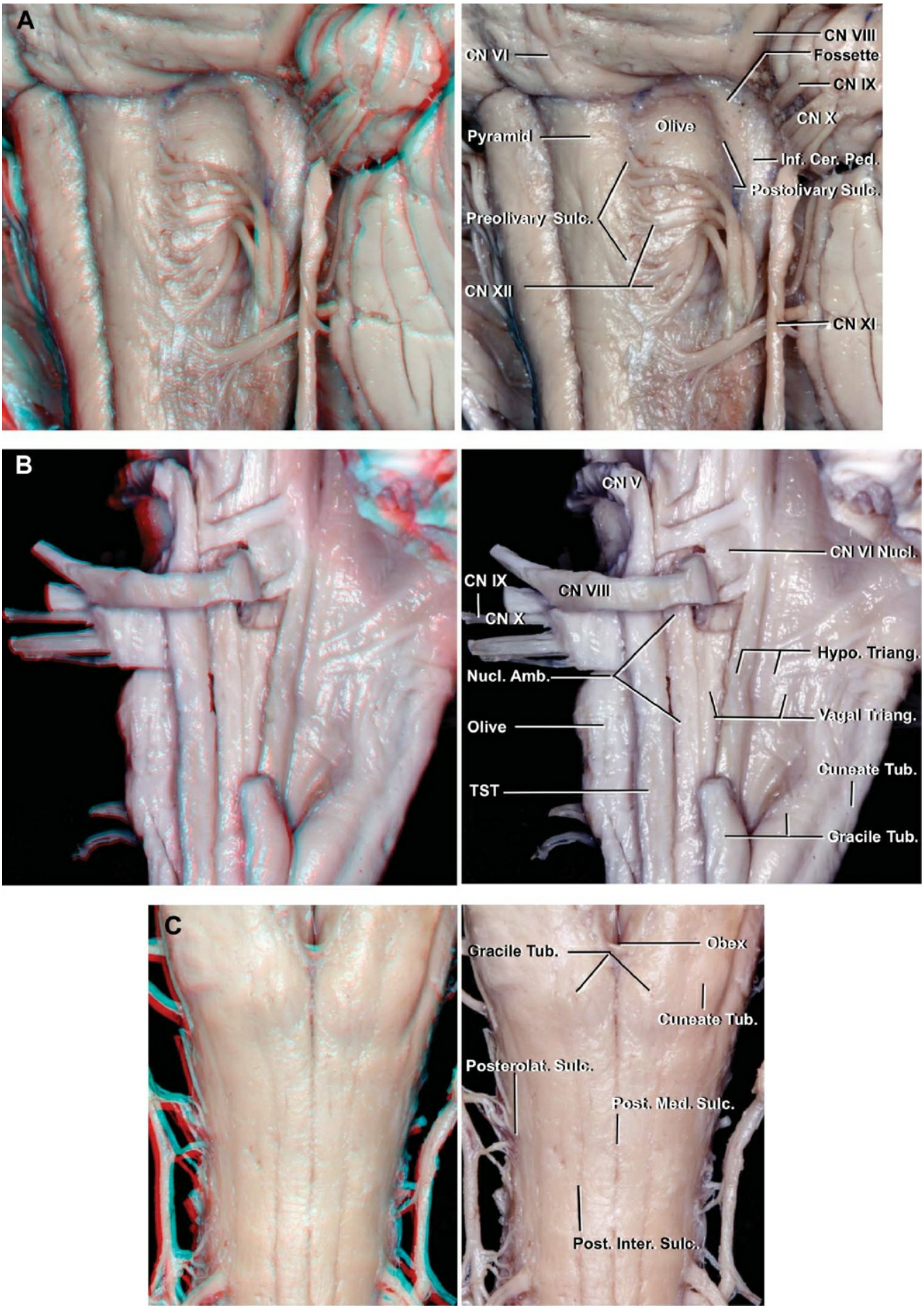



Figure 5. A, left anterolateral view. The preolivary sulcus is located between the olive and the pyramid. The depression rostral to the olive, the supraolivary fossette, is just below the junction of the facial and

**vestibulocochlear nerves with the brainstem. The glossopharyngeal, vagus, and accessory nerves exit the medulla just dorsal to the postolivary sulcus, which is located between the olive and inferior cerebellar peduncle. The hypoglossal rootlets exit the medulla along the preolivary sulcus. B, the medulla, posterior view. The nucleus ambiguus is located ventrolateral to the vagal triangle, ventromedial to the trigeminal spinal tract, ventral to the cuneate tubercle, dorsal to the olive, and caudal to the facial nucleus. The intramedullary segment of the glossopharyngeal, vagus, and accessory nerves after exiting the nucleus ambiguus travel laterally, ventral to the trigeminal spinal tract, to exit the medulla along the retro-olivary sulcus. C, the 3 dorsal medullary entry zones are located along the posterior median sulcus below the obex in the midline, the posterior intermediate sulcus between the gracile and cuneate fasciculi, and the posterolateral sulcus along the ventral margin of the cuneate fasciculus. Amb., ambiguus; Cer., cerebellar; Hypo., hypoglossal; Inf., inferior; Inter., intermediate; Med., median; Nucl., nucleus; Ped., peduncle; Post., posterior; Posterolat., posterolateral; Sulc., sulcus; Triang., triangle; TST, trigeminal spinal tract; Tub., tubercle. (Images courtesy of AL Rhoton, Jr.)**

## The Medulla and Safe Entry Zone

### Internal Anatomy of the Medulla

The medial lemniscus divides the medulla into ventral and dorsal parts (Figure 5). The ventral medulla is formed by the pyramids overlying the corticospinal tracts (Figure 2B). The olive is located lateral to the medial lemniscus. The preolivary sulcus extends longitudinally between the pyramid and the olive. The intramedullary segment of the hypoglossal nerve arises in the hypoglossal nucleus underlying the hypoglossal triangle, and extends ventrally between the medial longitudinal fasciculus medially and the olive laterally to exit the medulla along the caudal two-thirds of the preolivary sulcus. The supraolivary fossette, a depressed area rostral to the olive, is where the facial and vestibulocochlear nerves join the brainstem. The postolivary sulcus, the groove between the olive ventrally and the inferior cerebellar peduncle dorsally, is located just

ventral to where the glossopharyngeal, vagus, and accessory nerves exit the medulla. The trigeminal spinal tract descends ventromedial and the cuneate fasciculus ascends medial to the inferior cerebellar peduncle (Figure 4I).

**Nucleus Ambiguus**. It is located ventrolateral to the vagal triangle, ventromedial to the trigeminal spinal tract, dorsal to the olive, and caudal to the facial nucleus (Figure 5B). The glossopharyngeal, vagus, and accessory nerves pass laterally from the nucleus ambiguus and ventral to the trigeminal spinal tract to exit the medulla just dorsal to the postolivary sulcus. The glossopharyngeal and vagus nerves exit just dorsal to the upper part of the retro-olivary sulcus and the accessory rootlets exit along the caudal part of the retro-olivary sulcus.

## Safe Entry Zones

The proposed medullary safe entry zones are along the anterolateral (preolivary), postolivary, posterior median, posterior intermediate, and posterior lateral sulci (Figure 5).

**The Anterolateral (Preolivary) Sulcus**. This entry zone is located along the preolivary sulcus between the caudal roots of the hypoglossal and the rostral C1 rootlets. As it is very close to the pyramidal tract and its decussation, this entry is preferred for only exophytic lesions.[2]

**The Postolivary Sulcus**. This zone is entered through the postolivary sulcus located between the olive and inferior cerebellar peduncle and ventral to the glossopharyngeal and vagus rootlets.[9] The glossopharyngeal and vagal rootlets join the brainstem just dorsal to the upper part of this sulcus. As the incision deepens it encounters the nucleus ambiguus located an average of 4 mm deep to the surface of the sulcus.

**The Dorsal Medulla**. Three entry zones for dorsal medullary lesions have been defined. These are the posterior median sulcus located inferior to the obex in the midline, posterior intermediate sulcus located between the gracile and cuneate fasciculi, and the posterior lateral sulcus located lateral to the cuneate fasciculus.[1] The trigeminal spinal tract descends

ventral to the cuneate fasciculus into the upper spinal cord.

## DISCUSSION

Surgical entry into the brainstem, which may result in significant morbidity, requires an understanding of the brainstem's internal architecture and the relationships of borders of the safe entry zones to eloquent internal structures.[2,21] In this study, the white matter of the cerebellum and brainstem were examined by using fiber dissection techniques to evaluate the borders of safe entry zones into the midbrain, pons, and medulla, and their corresponding landmarks on the brainstem surface. The size and location of each safe entry zone was defined by using fiber tract dissections supported by selective 3T magnetic resonance (MR) tractography. Although there have been many histological and radiological studies of the internal structure of the brainstem, there has not been an examination of the safe entry zones based on fiber dissection techniques and 3-D photography. Applying these results is limited by 2 facts: first, there are individual variations in patients, and second, it is difficult to know the exact course of the pathways because the lesion distorts the anatomy so that normal anatomy is no longer an adequate guide to abnormal anatomy. Intraoperative stimulation is somewhat helpful, especially in the area of the facial nucleus or pyramidal tract, but it does not tell us about the course of other tracts inside the brainstem.

In surgical planning for the removal of brainstem lesions, the intent should be to proceed through as little normal tissue as possible and to abstain from disturbing critical nuclei and tracts.[22] The most important issue in these approaches is to determine the shortest distance from the surface to the lesion and the route that will cause the least neural damage. The safest approach for lesions located below the surface is usually the shortest and most direct one.[23] For lesions that reach the surface of the brainstem, the safest entry zone is obvious.[24] However, alternative approaches may be needed in order to protect critical neural tissues.[22] For deep lesions, some safe entry zones have been described.[1,3] In general, the entry zone through the closest surface to the lesion is preferred.

## Safe Entry Zones

### Peritrigeminal Approach

The peritrigeminal area between the trigeminal and facial nerves has been identified as a safe entry zone for lesions ventral to the medial lemniscus in the ventrolateral part of the pons.[20] Opinions differ about the need for vertical (longitudinal) or transverse incisions.[4,25,26] The aim of a transverse incision is to make it parallel to the transverse pontine fibers and thereby minimize damage to these fibers.[9] The distance from the exit zone of the trigeminal nerve to the corticospinal tract averaged 9 mm in this study. The critical neural structures that should be avoided during transverse incisions between the trigeminal and facial nerves are the corticospinal tract, trigeminal spinal tract, intrapontine segment of the facial nerve, and trigeminal motor and sensory nuclei. The structures to be avoided in the vertical incision between the trigeminal and facial nerves are the intrapontine segments of the facial and abducens nerves. When proceeding deeper anteriorly with a vertical incision, the corticospinal tract will be encountered.

### Perifacial Collicular Approaches

The areas superior and inferior to the facial colliculus in the floor of the fourth ventricle have been reported to be safe surgical entry zones.3 A significant problem in identifying the borders of safe entry zones in the floor of the fourth ventricle is recognition of the facial colliculus. There have been many studies about the position of the facial colliculus in the floor based on numerical measurements. Our study differs from others in that the facial nerve, nucleus, and intrapontine segments along with the abducens nucleus were exposed in the dissections. This allowed a more detailed description of the borders of supra- and infrafacial and other proposed safe entry zones. The most important structure to avoid in this area is the facial colliculus. Bogucki et al,[10] in a study of 40 specimens, found that 37% of facial colliculi did not form a distinctive prominence in the floor of the fourth ventricle. He tried to estimate its location based on other permanent landmarks like the obex and frenulum veli, and others

have based it on numerical measurements.[5,12] Our measurements agree with these other studies. In this study, the intrapontine segment of the facial nerve and the abducens nucleus that produces the facial colliculus were dissected, and the borders of supra- and infrafacial safe entry zones were described in detail in relation to landmarks in the ventricular floor.

## Suprafacial Approach

The borders of the suprafacial approach have been reported to be the medial longitudinal fasciculus medially, the facial colliculus caudally, and the medial edge of the superior cerebellar peduncle laterally.[3] The medial longitudinal fasciculus extends 1 mm laterally on both sides of the median sulcus. Bogucki et al10 suggested the frenulum veli containing the trochlear nerve to be the rostral limit. Our results agree with this rostral limit, but differ from previous reports in finding that the sulcus limitans is a safer lateral limit than the superior cerebellar peduncle. Using the sulcus limitans rather than the superior cerebellar peduncle as the lateral limit will avoid damaging the trigeminal motor nucleus, mesencephalic tract, and central tegmental tract found lateral to the sulcus limitans. Central tegmental tract damage may cause nystagmus and intention tremor.[17,27,28] The trigeminal motor nucleus is located slightly above the facial colliculus and lateral to the sulcus limitans. The apex of the superior fovea triangle, located at the same level as the upper edge of the facial colliculus, is a useful landmark if the facial colliculus cannot be seen on the floor. The medial lemniscus, found an average of 4.5 mm deep to the floor, is the anterior limit. If the lesion cannot be found in the depth of the suprafacial zone, it is likely in the ventral pons deeper than the medial lemniscus. The corticospinal tract is situated an average of 20 mm deep to the floor. The peritrigeminal approach should be considered for lesions located ventral to the medial lemniscus.

## Infrafacial Approach

This approach is directed between the facial colliculus formed by the inferior intrapontine segment of the facial nerve rostrally, the hypoglossal and vagal triangles caudally, the medial longitudinal fasciculus medially,

and the facial nucleus laterally.[10] In this study, the rostral and caudal borders of the infrafacial safe entry zone were found to be at the upper and lower edges of the lateral recesses, respectively. The average length of this entry zone was 6 mm, in this study, although other lengths have been reported.[5,10,12] The upper pole of the nucleus ambiguus, located just caudal to the facial nucleus, forms the lateral border of the infrafacial approach. The facial nucleus and nucleus ambiguus are located just lateral to the most medial point of attachment of the tela choroidea along the lower margin of the lateral recess. The incision should be kept medial to this point in order to avoid damage to the facial nucleus and nucleus ambiguus.

The striae medullaris have been suggested as the caudal border of the infrafacial triangle.[3] However, this finding has been challenged because of the many variations of the striae medullaris and because they cannot be seen in 30% of fourth ventricular floors.[10] Other more predictable landmarks have been explored.[5,6] We found the distance between the upper margin of the hypoglossal triangle and the obex averaged 10.6 mm. The upper edge of the hypoglossal triangle is always rostral to the vagal triangle and at the same transverse level as the horizontal attachment of the tela choroidea along the lower margin of the lateral recess.[5]

In conclusion, suggested landmarks for infrafacial triangle borders are: the transverse lines along the upper and lower edges of the lateral recess rostrally and caudally, the medial longitudinal fasciculus medially, and the rostrocaudal level of the most medial point of the attachment of the tela choroidea along the lower margin of the lateral recess laterally. The ventral limit is the central tegmental tract which sits an average of 4.9 mm deep to the floor.

## Median Sulcus Above the Facial Colliculus

This approach, proposed for central lesions in the superior half of the pons, is directed through a longitudinal incision along the median sulcus above the upper edge of the facial colliculus.[4,18] It carries some risk of damaging the medial longitudinal fasciculi, which course along the edges

of the median sulcus and the trochlear nuclei, located 15 mm superior to the facial colliculi and adjacent the midline. Alterations or loss of consciousness may be observed during the postoperative period if the reticular formation located close to the midline at this level is damaged bilaterally.[29]

### Acoustic Area

This area is proposed for lesions located further away along the midline.[1] Structures encountered in this approach include the dorsal cochlear nucleus, inferior cerebellar peduncle, trigeminal spinal tract, nucleus ambiguus, and facial nucleus, in order from superficial to deep.

## CONCLUSION

An important limitation is that the internal structures and borders of safe entry zones, as seen on preoperative computed tomography and MRI, may shift because of the distorting effects of the lesion after opening the skull and dura. As a result, the use of intraoperative neurophysiological monitoring and mapping is crucial.[6] Display of the brainstem structures with DTI is also useful in preoperative planning. It is likely that in this and other morphometric studies, measurements may be affected by shrinkage of specimens associated with fixation.[5,30] In order to minimize this shrinkage, we used only 5% alcohol for fixation, and did not freeze the specimens as in the Klingler technique.[31] We have not found any significant difference in the difficulty of fiber dissection between frozen and unfrozen brainstems. This may be because the compact tissue of the brainstem does not allow the diffusion of water to separate the fibers when frozen. We hope that the use of this knowledge will make surgical entry into the brainstem more accurate and safe.

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*The Neurosurgical Atlas* is honored to maintain the legacy of Albert L. Rhoton, Jr, MD.

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