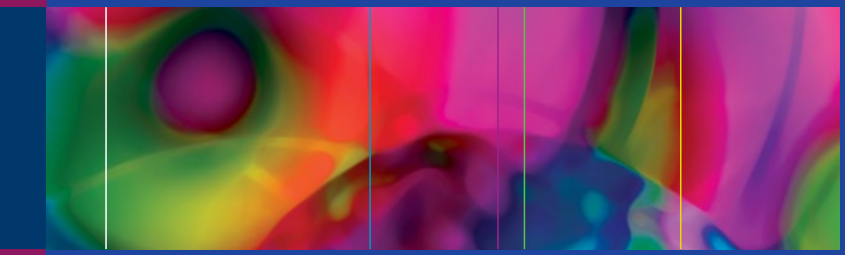
Jessica L. White
Kevin N. Sheth *Editors*



Neurocritical Care for the Advanced Practice Clinician

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Dedicated to our colleagues in the Neuro ICU – the nurses, physicians, and advanced practice clinicians who commit themselves to providing compassionate care for the neurologically ill.

And to our patients and their families – the practice and art of critical care neurology is our service to them.

Acknowledgment

This project strives to highlight the professional collaboration between advanced practice clinicians and physicians as part of a multidisciplinary team. We are grateful to our contributors for exemplifying this collaboration by generously sharing their expertise and experience in the field of neurocritical care.

We would like to thank the Yale University Neurocritical Care faculty and APC staff for their encouragement and feedback through this process. And special thanks to Guido Falcone for his editorial assistance. We are privileged to work everyday with such a phenomenal team.

Contents

Chapter 1
The Role of Advanced Practice Clinicians in the Neuroscience ICU

Jessica L. White and Kevin N. Sheth

The field of neurocritical care encompasses a broad range of neurological pathology and requires a multidisciplinary approach to provide best patient care. At institutions across the country, physicians work alongside physician assistants and nurse practitioners to care for neurologically ill patients. This collaborative relationship serves to provide an ideal complement of specialized medical knowledge and experienced bedside care. Stemming from a historical genesis in primary care practice, the fundamental education of nurse practitioners and physician assistants is general by design, including basic principles of medical science and clinical management. This educational foundation offers the benefit of professional flexibility and the ability to adapt to a myriad of subspecialties; however, such adaptation requires continued focused learning when entering a subspecialty to acquire advanced understanding of patient care. Recognizing this challenge, we embarked on a

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project to meet the knowledge needs of physician assistants and nurse practitioners that have selected neurocritical care as their field of practice.

Many terms have been used to describe the collective role of physician assistants and nurse practitioners—midlevel provider, nonphysician provider, and advanced practice provider among them. For the purposes of this project, the term advanced practice clinician (APC) is used to encompass both professions. The role of APCs has evolved considerably over the past several decades. Both professions were developed in the 1960s to adjunct a shortage of primary care providers in the United States. The implementation of restrictions on house staff work hours in the 1990s set the stage for the rapid expansion of the APC role into the hospital setting [1, 2]. This role of APCs working in inpatient medicine has grown substantially since that shift. In 1995 the acute care nurse practitioner certification was developed for the purpose of focusing training on caring for critically ill patients. This certification now represents the fifth most common area of practice for nurse practitioners [3]. Similarly, a hospital medicine specialty certification is available for physician assistants and ~25% of these professionals now work in hospital settings [4]. As the medical community is faced with continued projections of physician shortages across the board, the role of APCs in the inpatient realm is projected to increase [1, 2, 5]. The field of neurocritical care has experienced significant growth in recent years, outpacing the growth of residency and fellowship training programs. Across the country, this rapid expansion has provided a considerable opportunity for APCs to enter the field of neurocritical care and work in a dynamically evolving area.

Given this shift in scope of practice, it has been imperative to provide APCs with the training and experience necessary to provide exemplary care to the critically ill. In intensive care units across the country, it has been shown that nurse practitioners and physician assistants provide appropriate medical care to ICU patients, as measured in rates of morbidity and mortality [6, 7]. Beyond these measurements, there are also established

benefits of integrating APCs into intensive care units. APCs offer a unique level of experience and continuity of care that can result in improved compliance with clinical guidelines [8], decreased length of stay, and overall cost savings [9–11].

Intensive care units have integrated APCs in a variety of ways—some by developing units staffed by APCs alone, others by creating multidisciplinary teams of APCs and physicians. Regardless of the chosen structure, APC staffing can aid in providing sustained clinical expertise to bedside care, particularly in settings where house staff work on rotating schedules. In the challenging environment of the intensive care unit, the presence of seasoned clinicians to give support to physicians-in-training provides significant benefits. Survey data from academic institutions indicate that APCs are perceived as an effective complement to physicians-in-training, enhancing patient care through improved communication and continuity of care [12]. Furthermore, APCs contribute to the training of residents by reducing their workload, reducing patient-to-provider ratios, and increasing didactic educational time [13].

The neurocritical care community has experienced this shift in staffing along with the rest of the critical care realm. In keeping with broader trends, APCs working in neurocritical care are seen as promoting effective communication, a team environment, and, most importantly, timely identification of patients with neurological deterioration [14]. However, this impact does not come without dedicated learning and experience. The field of neurocritical care includes a unique spectrum of neurological disease and much of the expertise required to skillfully care for neuroscience ICU patients is not addressed in the general education of the APCs. The purpose of this book is to bridge the gap between the foundational medical education of APCs and the fundamentals of the neurocritical care subspecialty. By discussing common neurocritical topics as presented by a multidisciplinary collection of leaders in the field, we hope to engage and empower the continued expansion of the role of advanced practice clinicians in neurocritical care.

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Chapter 2
Neuroanatomy

Laura A. Lambiase, Elizabeth M. DiBella, and Bradford B. Thompson

2.1 Skull, Fossae, and Meninges

The cranium is composed of multiple bones that act as a protective container for the brain (Figs. 2.1 and 2.2). It is composed of the *frontal bone*, which articulates with the two *parietal bones* at the coronal suture. The parietal bones meet at the midline and are joined by the sagittal suture. The *temporal bones* lie inferior to the parietal bones and posterior to the greater wing of the *sphenoid bone*. The *occipital bone* meets the parietal bones at the lambdoid suture and protects the posterior surface of the brain. At the base of the occipital bone, there is a large opening, the *foramen magnum*, through which the spinal cord connects to the brainstem. A series of smaller bones including the *zygomatic, ethmoid, maxilla, mandible, nasal, vomer* and *lacrimal bones* comprise the complex facial surface of the skull [6, 7].

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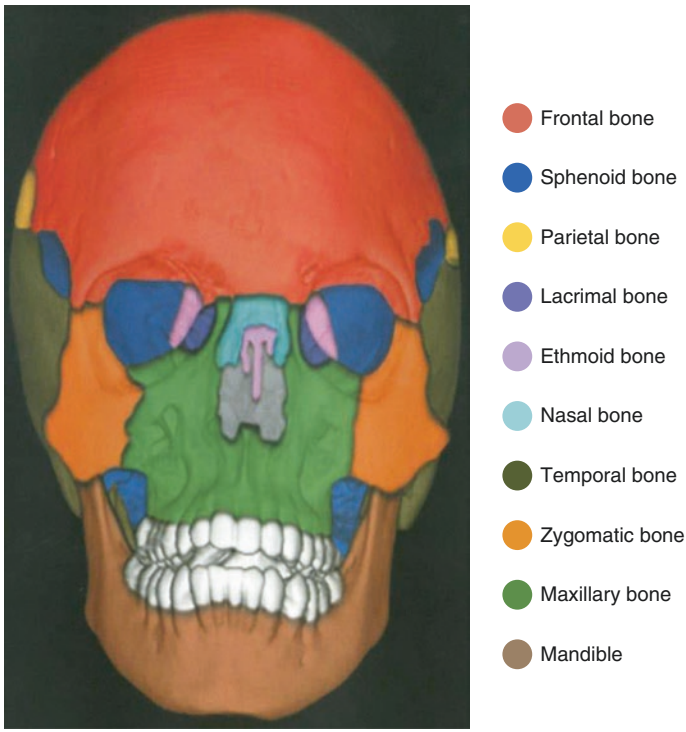

Fig. 2.1 Bones of the cranium (Used with permissions from Gallici et al. [2])

The bones of the skull articulate to form three distinct fossae: anterior, middle, and posterior (Fig. 2.3). The *anterior fossa* is formed by the frontal, ethmoid, and sphenoid bones and contains the anterior and inferior aspects of the frontal lobes. The *middle fossa* is formed by the sphenoid and temporal bones and contains the temporal lobes. Additionally, the *sella turcica* of the sphenoid bone provides a protective seat for the pituitary gland within the hypophysial fossa. The *posterior fossa* is

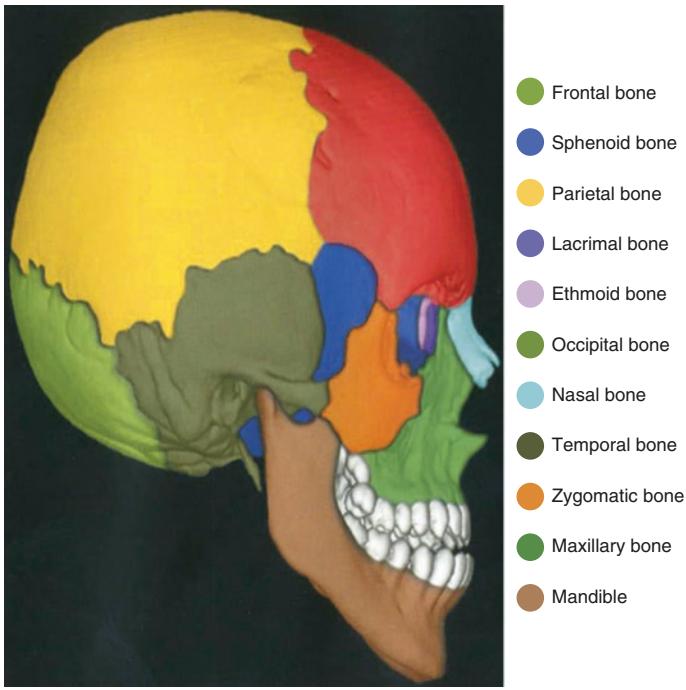

Fig. 2.2 Bones of the cranium (Used with permissions from Gallici et al. [2])

predominantly formed by the occipital bone with small contributions from the sphenoid and temporal bones—it contains the brainstem and the cerebellum.

The brain is covered in three layers of protective meninges, which work with the skull and cerebrospinal fluid (CSF) to blunt the effects of insults to the brain. The *dura mater* is the thickest fibrous external layer, which adheres to the internal surface of the cranium. The dura can be dissected into two distinct layers: the periosteal layer, which connects the dura to the skull, and the meningeal layer, which lies more medially. The

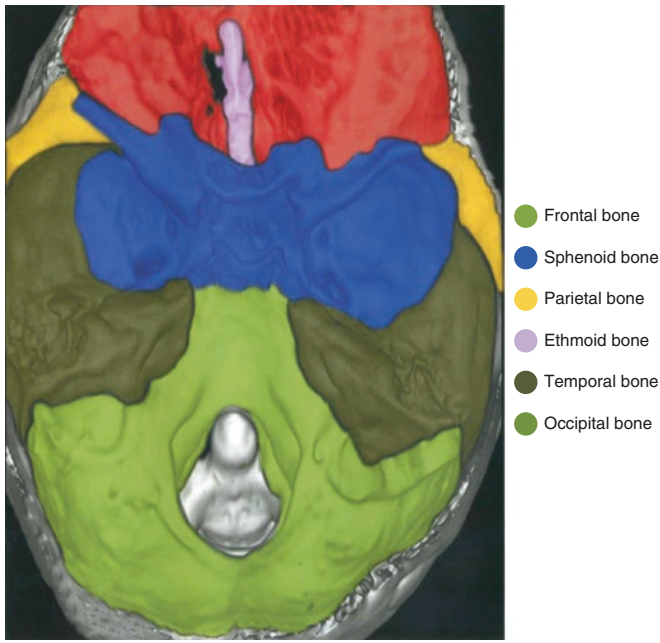

Fig. 2.3 Cranial fossa (Used with permissions from Gallici et al. [3])

dura mater folds in on itself in the interhemispheric fissure to create the *falx cerebri*. An additional dural fold creates the *tentorium cerebelli*, separating the cerebral hemispheres from the cerebellum. While these dural folds provide structure to the brain, they constitute sites of potential herniation in the setting of space occupying lesions or cerebral edema.

The *arachnoid mater* lies medial to the dura mater. The subarachnoid space separates the arachnoid and pia mater. Small fibrous strands called trabeculae tether the arachnoid and pia to one another. The CSF in this space serves as another protective buffer for the brain. The *pia mater* is the thinnest meningeal

layer and is adherent to the brain. This layer is highly vascular and provides oxygen and nutrients to the brain [6, 7, 15].

Clinical Correlate

- With traumatic injury, there is potential for bleeding between the skull and dura (epidural hematoma), between the dura and arachnoid meninges (subdural hematoma), or within the subarachnoid space (subarachnoid hemorrhage). (See Chap. 10 for further clinical information).
- An epidural hematoma occurs most commonly when a temporal bone fracture severs the middle meningeal artery, although venous bleeding can also be a cause.
- A subdural hematoma is most often caused by tearing of the bridging veins in the subdural space.
- Subarachnoid hemorrhage can occur in a number of conditions, including rupture of a cerebral aneurysm and trauma.

2.2 Cerebrum

The *cerebrum* constitutes the bulk of the brain and is the area responsible for intellectual thought and function. The *cerebral cortex* is the circumferential gray matter on the surface of the brain that covers the white matter and the deeper gray matter structures. The cortex folds to create raised *gyri* and sunken grooves called *sulci*.

The cerebrum is separated into two hemispheres by the interhemispheric fissure and connected by a bundle of nerves called the *corpus callosum*. Each hemisphere contains a frontal, parietal, temporal, and occipital lobe (Fig. 2.4). The *frontal lobe*

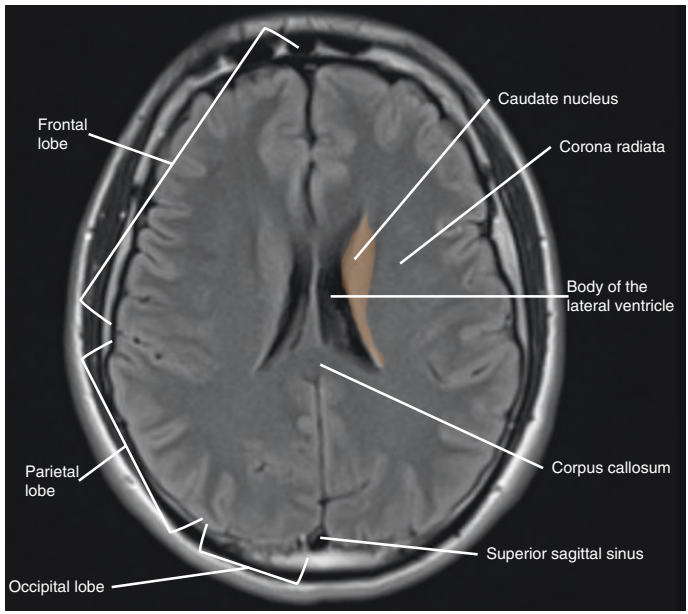

Fig. 2.4 Cerebrum (Flair sequence MRI brain)

is anterior to the central sulcus that separates the frontal and parietal lobes. The frontal lobe is the site of abstract reasoning, judgment, behavior, creativity, and initiative. The *parietal lobe* is involved in language, maintaining attention, memory, spatial awareness, and integrating sensory information including tactile, visual, and auditory senses [8]. The lateral (or Sylvian) fissure separates the parietal and frontal lobes from the temporal lobe. The *temporal lobe* processes sensory input such as language, visual input, and emotions. Tucked deep within the lateral fissure lays the *insula*, which is involved with emotion and consciousness. The *occipital lobe* is the most posterior lobe of the cerebrum and is separated from the parietal and temporal lobes by the parieto-occipital fissure. The occipital lobe con-

tains the primary visual cortex and is involved in sight and interpretation of visual stimuli. On the medial surface of each cerebral hemisphere, the *limbic cortex* modulates emotion, behavior, and long-term memory [5].

Clinical Correlate

- In a majority of people, the left hemisphere is dominant, being responsible for language production and comprehension. This is true for both right-handed (90% left dominance) and left-handed individuals (70% left dominance).
- In the dominant hemisphere, Broca's area in the frontal lobe is responsible for fluent speech. Damage to this region causes expressive aphasia. Wernicke's area, located in the temporal lobe of the dominant hemisphere, is responsible for comprehension. Damage to Wernicke's area causes receptive aphasia.
- Damage to the nondominant hemisphere can cause unilateral neglect of the contralateral side and apraxia, which can impact activities of daily living and lead to spatial disorientation.

2.3 Diencephalon

The diencephalon is composed of the thalamus and hypothalamus. The *thalami* are bilateral relay stations for sensory information located medial to the internal capsule and lateral to the third ventricle. They initiate reflexes in response to visual and auditory stimuli. Sensory fibers ascend from the brainstem to the thalamus and then their signals are relayed to the cortex.

The *hypothalamus* is connected inferiorly to the *pituitary gland*; together, these structures regulate many hormonal activities within the body. The anterior lobe of the pituitary gland (adenohypophysis) secretes hormones including adrenocorticotrophic hormone, thyroid-stimulating hormone, luteinizing hormone, follicle-stimulating hormone, prolactin, and melanocyte-stimulating hormone in response to signals from the hypothalamus. The posterior lobe (neurohypophysis) contains axons extending from the hypothalamus that secrete oxytocin and vasopressin [11].

Clinical Correlate

- After pituitary surgery, central diabetes insipidus can develop due to reduced secretion of antidiuretic hormone (vasopressin). Patients develop excessive urine output with resultant hypovolemia and hypernatremia.

2.4 Basal Ganglia

The *basal ganglia* are the deep gray matter structures consisting of the caudate nucleus, globus pallidus, and putamen (Fig. 2.5). The basal ganglia relay information from the cortex and work with the cerebellum to coordinate movement. They are responsible for the initiation and termination of movements, prevention of unnecessary movement, and modulation of muscle tone.

2.5 Brainstem

The *brainstem* consists of three components: midbrain, pons, and medulla. It contains critical structures, such as the cranial nerve nuclei, regulates several autonomic functions and basic reflexes, and determines the level of consciousness (Figs. 2.6–2.9).

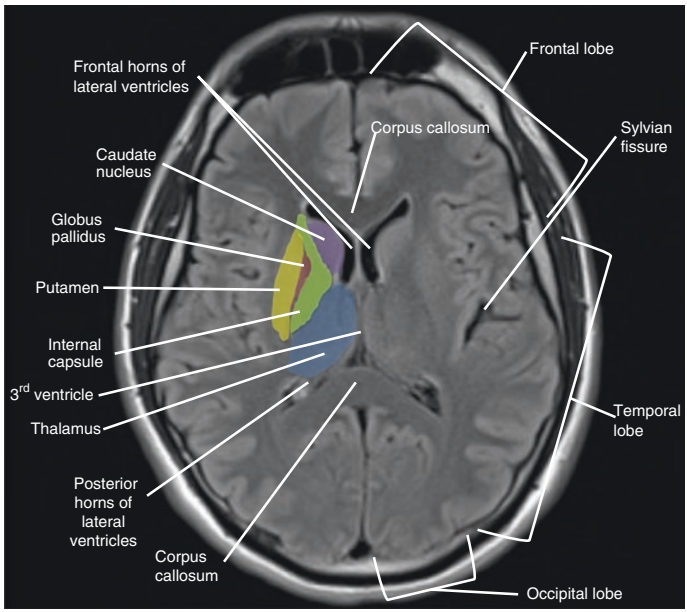

Fig. 2.5 Basal ganglia (Flair sequence MRI brain)

The descending motor and ascending sensory pathways pass through the brainstem. The reticular activating system resides in the rostral brainstem and projects to the thalami and then the cortex to maintain wakefulness. Damage to this structure results in decreased level of arousal or coma.

2.6 Cerebellum

The *cerebellum* is located posterior to the brainstem (Figs. 2.7, 2.8 and 2.9). The cerebellum works in tandem with the basal ganglia to provide smooth coordinated movement. Damage to the cerebellum causes limb ataxia, vertigo, and gait disturbances.

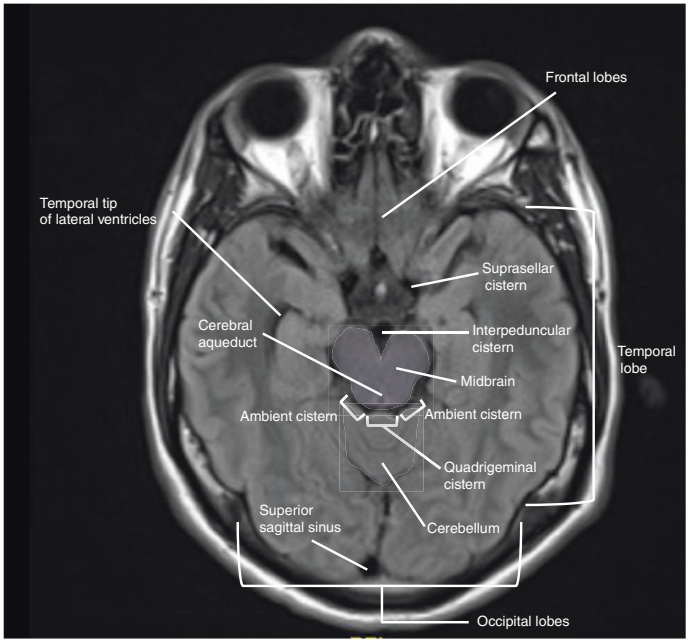

Fig. 2.6 Midbrain and cisterns (Flair sequence MRI brain)

2.7 Cerebral Vasculature

The arterial supply to the brain is divided into anterior and posterior circulations. The anterior circulation originates from bilateral *internal carotid arteries* (ICA). Each ICA travels superiorly through the neck and enters the cranium via the carotid canal within the temporal bone. The ICA then bifurcates into the *anterior cerebral artery* (ACA) and the *middle cerebral artery* (MCA). The ACA supplies the anterior medial surface of the brain, which includes the frontal and anterior parietal lobes. The

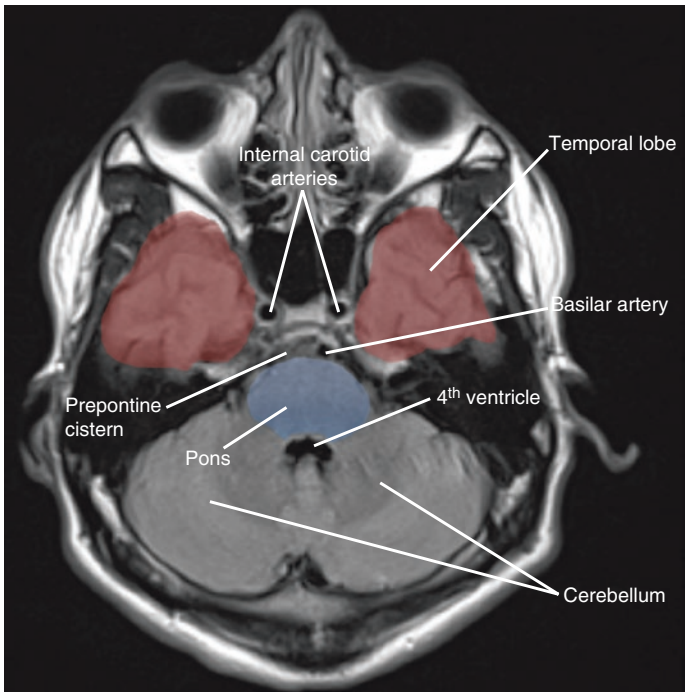

Fig. 2.7 Pons and posterior fossa (Flair sequence MRI brain)

MCA supplies the bulk of the cerebral hemisphere. It typically divides into *superior* and *inferior divisions* as it passes through the lateral fissure. These divisions supply the cortex superior and inferior to the lateral fissure, respectively. Prior to this bifurcation, several small vessels called the *lenticulostriate arteries* arise from the MCA. These vessels provide the blood supply for a majority of the basal ganglia and internal capsule.

The posterior circulation is supplied by bilateral *vertebral arteries* (VA). They travel superiorly through the transverse

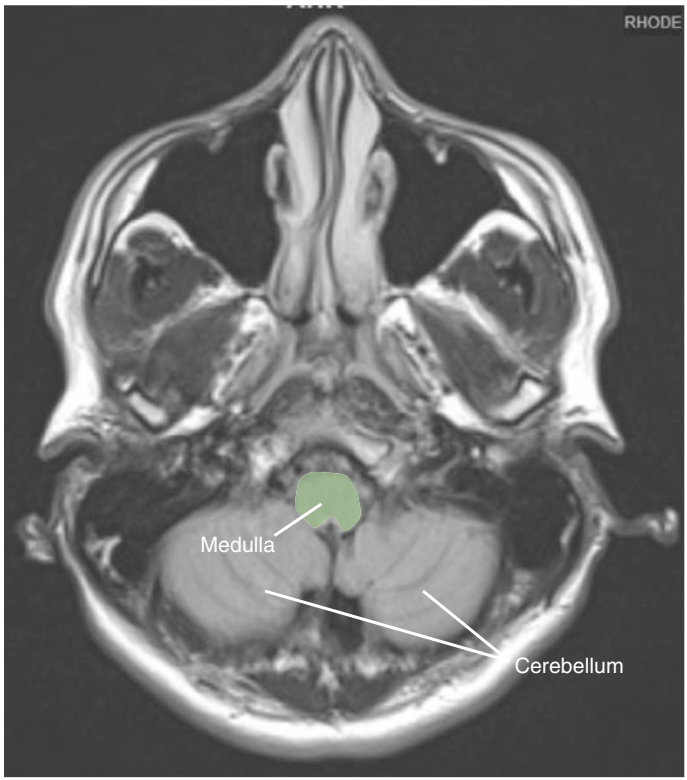

Fig. 2.8 Medulla and posterior fossa (Flair sequence MRI brain)

processes of the cervical vertebrae and then the foramen magnum to enter the skull. The VAs then merge to form the *basilar artery* (BA), which in turn branches into bilateral *posterior cerebral arteries* (PCA). The PCAs supply the inferior and medial temporal lobes as well as the occipital lobes. There are three major paired branches which arise from the posterior circulation to perfuse the brainstem and cerebellum. The *posterior inferior cerebellar artery* (PICA) arises from the VA and supplies the lateral medulla and