

ATLAS OF ORAL  
& MAXILLOFACIAL  
SURGERY DEEPAK KADEMANI & PAUL TIWANA



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ATLAS OF ORAL  
& MAXILLOFACIAL  
SURGERY

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# ATLAS OF ORAL & MAXILLOFACIAL SURGERY

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*This book is dedicated to the following individuals:*

*Most importantly, to my wife, Rupam, who above all has made the greatest sacrifices in sharing my life as an academic surgeon. Thank you for raising our beautiful children, Jai (13), and Radha (11). For all your understanding, patience, and unconditional love, I am eternally grateful.*

*My parents, Yeshwant and Lakshmi, for their love and for the sacrifices they made to allow me every opportunity to pursue my education. My sister, Preet, for her love and support.*

*To all those who have invested in my education and career. My academic and surgical mentors, Peter Quinn, David Stanton, Lawrence Levin, Raymond Fonesca, John Mooney, Joseph Foote, Barry Hendler, Leon Assael, Eric Dierks, and Bryce Potter—thank you for being so generous.*

*I am deeply indebted to my great friend and co-editor, Paul Tiwana, for his hard work and dedication in meeting the greatest challenge of developing this book. To our section editors, authors, and artists, without whom this book would not have been possible.*

*To all my former, current, and future residents and fellows—thank you for inspiring me. I hope you will use this Atlas to establish the foundation of your operative knowledge.*

**Deepak Kademani**

*This book is dedicated to the following individuals:*

*To the surgeons who mentored and trained me:*

*Mark F. Erickson, Gene Sbalchiero, Timothy A. Turvey, John R. Zuniga, Raymond P. White, George H. Blakey III, Dennis G. Hillenbrand, Ramon L. Ruiz, Jeffrey C. Posnick, Gerald D. Verdi, Brian Alpert, Douglas P. Sinn, and Robert V. Walker.*

*They have given so much of themselves to my education and my professional life. Thank you.*

*To my great friend and colleague, Deepak Kademani, who enthusiastically embarked with me on this journey with vision and perseverance.*

*To our section editors, authors, and medical illustrators, without whom this text would not have been possible. Thank you for your hard work and dedication.*

*To my current and former residents, who inspire me every day to be the best surgeon I can be and remind me of my true calling: to be a teacher of surgeons.*

*To my father, Gurdev, and my mother, Balbir. They sacrificed so much to put the education of their children first. Teachers themselves, they fostered in me a passion for my education, the self-discipline needed for achievement, and the courage to follow my dreams. Also to my brother and sister, Dave and Karen. Thank you all for your understanding, support, encouragement, and love.*

*Most important, to my wife, Karen, and our two beautiful daughters, Jespreet (10) and Simran (8). They, above all, have borne the cost of an academic surgeon's life. Thank you for sharing me with both my patients and my specialty. Your constant support and unconditional love forms my bedrock, gives the compass of my life direction, and is a beacon that draws me home wherever in the world I happen to be.*

**Paul Tiwana**

*The diagnosis and management of benign pathology of the oral/head and neck region is a thought-provoking and formidable discipline in our specialty. In many respects, these exercises remain at the core of oral and maxillofacial surgery practice. I thank the authors of the chapters contained within, therefore, for their contributions on the scientific background and techniques associated with the extirpation of benign entities of the jaws, neck, salivary glands, thyroid, and parathyroid glands. With the direction provided by Deepak Kademani and Paul Tiwana, the development of this project has been a very gratifying experience.*

**Eric R. Carlson**

*Human anatomy does not change over time, but surgical approaches and techniques certainly do. The Kademani-Tiwana “K-T” Atlas will quickly become a classic and will be regarded by future generations of surgeons of multiple disciplines as a cornerstone of their learning. The scope of this Atlas is reflective of the scope of modern American oral and maxillofacial surgery, which has evolved into better alignment with that of the rest of the world.*

*I would like to dedicate my modest contribution to this noble effort to my wife, Barbara; our son, Gregor; and my daughter, Louise. Each has sacrificed, either knowingly or not, and their forbearance over the years regarding the time consumed by my academic endeavors is deeply appreciated and can never be adequately compensated.*

**Eric Dierks**

*I would like to thank Elsevier and Deepak Kademani and Paul Tiwana for allowing me to participate in this wonderful project as a section editor. I also would like to thank the authors who have contributed to the cosmetic surgery section of this great Atlas, which will be a tremendous edition to our specialty. Students, residents, and faculty will be able to benefit from it for many years to come. Congratulations to everyone involved in this project.*

**Tirbod Fattahi**

*I would like to dedicate my small portion of this text to my mentors, Dr. Robert V. Walker, Dr. William H. Bell, and Dr. Douglas P. Sinn—they opened all the doors! Personally, I dedicate this to the loves of my life, Judy and Richard II.*

**Richard Finn**

*The depth and completeness of this Atlas provides the reader a contemporary guide to the procedures undertaken in any leading-edge oral and maxillofacial surgery training program. I would like to extend my appreciation to the authors and section editors for their invaluable contributions to this work. In particular, I commend Drs. Kademani and Tiwana for this ambitious and monumental project that will most definitely appeal to a wide readership, in multiple surgical specialties, which will forever be captivated by this surgical Atlas. Finally and most importantly, I wish to extend my thanks and love to my wife Hope and our wonderful children, Gregor, Gracie, Gabrielle, and Garrisyn for their understanding and eternal support.*

**G.E. Ghali**

*I would like to thank all of the authors for their tireless effort in contributing to the creation of this important work. They have shared their expertise and dedicated their effort to produce a reconstructive oral and maxillofacial surgery Atlas that is current and will be a great resource for years to come. Their contributions will help improve the life of others by their skills and their dedication to surgery. I would also like to thank Dr. Deepak Kademani and Dr. Paul Tiwana for their vision for this challenging yet rewarding endeavor.*

*My wife, Kiralina, deserves special thanks for her endless support and encouragement for me to pursue my dreams in Oral and Maxillofacial Surgery while raising our four beautiful children. Thanks to my amazing children, Gavin, Zoe, Sadie, and Austin, for their love which provides the balance that allows me to have a wonderful life.*

**Alan Herford**



*To all of the OMS residents who inspire and challenge me every day.*

**Pamela Hughes**

*It has been an honor to oversee and edit this section on orthognathic and craniofacial surgery. Just when we think we have matured in this arena of surgery, we continue to see exciting developments—from planning our surgery with the use of virtual technology, to a more clear understanding of outcomes and the stability of our results. Most surgical procedures have changed little, but planning, execution, and stabilization have advanced to a higher level of predictability. This section incorporates all the changes in this surgical arena as well as providing the insight of experienced surgeons in diagnosis, timing of intervention, procedural technique, stabilization, and projected outcomes and expectations. The readers' take-away information will guide their thoughts and surgical outcomes. This is a win/win for both patients and their surgeons.*

*As this effort concludes on the Atlas by Paul Tiwana and Deepak Kademani, I feel it will be a valuable contribution to our specialty, to the volume of knowledge of our surgeons, and ultimately to patients. For more than 40 years, it has been personally rewarding to be involved in the development of surgical technique, and this effort was completed with affection for my patients and my dedication to OMS. I am, as always, grateful for the guidance of my mentor, Dr. Robert V. Walker, the support of my family, and the loving encouragement of my wife, Diane.*

**Douglas P. Sinn**

*I would like to offer my sincere thanks to Deepak Kademani and Paul Tiwana for the opportunity to contribute to their seminal Atlas. The content is sophisticated, yet it is presented clearly through an incredible number of meticulously rendered brand-new medical illustrations. I appreciate the effort each of my section authors put in to produce their high-quality chapters, presenting the boundaries we push at in the arena of dental implants. Personally, I would like to thank my wife, Michelle, for her insight, patience with my schedule, and her unending support of our endeavors.*

**Martin B. Steed**

*Reconstructive oral and maxillofacial surgery has experienced significant advances in the recent past, particularly with the addition of microvascular surgical techniques. I would like to thank all the authors for the comprehensive nature of their chapters in grafting techniques, axial flaps, and free tissue transfer, which I expect to be utilized by residents, fellows, and practicing surgeons in the years and decades to come. My thanks to Deepak Kademani and Paul Tiwana for inspiring and seeing this project through. Nothing I do in life comes without my heartfelt thanks to my wife, Jana, and our children, McKinlee, Tanner, Connor, Whitney, Parker, and Carter for their never-ending support.*

**Brent Ward**

*Surgery for temporomandibular joint disorders has been, and always should be, within the confines of oral and maxillofacial surgery. It has been an honor and a privilege to have learned from some of the best surgeons as a young resident, and it continues to be an honor and a privilege to work with the authors in the section on TMJ surgery, who continue to teach and evolve the field of TMJ surgery. Together, we hope to pass on our experiences to the next generation of TMJ surgeons. It is our patients and the future generation of patients who will benefit by the efforts and skills illustrated by the authors. Oral and maxillofacial surgeons should look to no one but themselves to provide the treatment and care for TMJ disorders now and in the future. My thanks to Deepak Kademani and Paul Tiwana for providing us the opportunity to make these contributions and their hard work to complete the task of organizing and producing a great Atlas.*

**John Zuniga**



# Preface

The first printed atlases were editions of the text of Claudius Ptolemy, an Alexandrian geographer working circa 150 AD. These were illustrated with a set of 27 maps constructed from Ptolemy's calculations. From this first collection, the concept of the atlas was developed: a bound collection of maps covering the current knowledge of a specific geographic region or world. We initially developed this atlas independently with Elsevier. The similarities in our individual concepts led us to combine our efforts in producing this book. Like Ptolemy, we have aimed our collaborative efforts to produce a landmark publication to define the world of our specialty.

Significant geographic differences in the scope of surgical practice from one country to another continue to exist in oral and maxillofacial surgery. These differences often are based on local educational requirements and training standards. Much of the evolution of our specialty is also balanced with the development of complementary specialties in otorhinolaryngology, head and neck surgery, and plastic and reconstructive surgery. Although our foundations are intimately associated with a comprehensive understanding of oral and craniomaxillofacial disease and function and are based in dentistry, the specialty of oral and maxillofacial surgery has evolved to include both a medical and a dental basis of training. This early and comprehensive focus on oral and craniomaxillofacial disease and function creates several distinct advantages: first, a body of knowledge for dealing with the structural anatomy and function of the oral and craniomaxillofacial complex; second, an in-depth familiarity with histopathology and the progression of diseases of the head and neck; and third, an emphasis on the importance of precise surgical reconstruction to ensure that the demands of oral and facial function are met. This atlas was written to take advantage of these unifying strengths of our specialty. It provides a navigational aid that can guide both experienced

surgeons and surgeons in training through new operations and provide a basis for refinements of already established operations in their repertoire. Each chapter is organized in a similar fashion, guiding surgeons through the complex anatomy, instrumentation, technical operative surgery, and modifications. Our aim is that this Atlas will define and capture the global perspective of oral and maxillofacial surgery.

Within the past few decades, we have seen the specialty of oral and maxillofacial surgery grow and expand. Although many books cover this expanded practice of the discipline, we observed that a comprehensive and detailed atlas covering operative technique was absent in the literature. This book is written to provide practicing surgeons, residents, and students the most up-to-date reference for the technical performance and reasoning behind the many types of operations used in our specialty. From the basic to the most complex, readers will find that each chapter is sequentially organized to provide a comprehensive, concise, and practical description of the operative details needed for contemporary surgical delivery of oral and maxillofacial surgery. A formal section on relevant surgical anatomy has been incorporated to further assist the reader. This section is a new idea in a surgical text, and we believe it will enhance the value of this Atlas. Each chapter has been written by an expert surgeon and author who has a specific area of expertise. We would like to express our gratitude to all the section editors and authors for lending their time and expertise to the development of this Atlas.

It is our hope that the information presented here will form the basis of defining the scope of practice of oral and maxillofacial surgery and will provide a basis for education and training for surgeons in the future, with the ultimate goal of improving the quality of patient care across the world.

# Foreword

When Paul Tiwana requested a foreword to accompany the *Atlas of Oral and Maxillofacial Surgery*, I was glad to accommodate him. Paul is not just a dedicated and skilled surgeon, but also an educator who has made research contributions to the field. Early on, Paul developed an interest in the surgical management of cleft and craniofacial malformations. His residency training was followed by a formal fellowship in pediatric craniofacial surgery under my direction in Washington, DC, and he now serves as graduate program director, Division of Oral and Maxillofacial Surgery, at the University of Texas Southwestern Medical Center in Dallas. His clinical practice includes the management of cleft and craniofacial anomalies.

Tiwana's and Kademani's intention in the writing and editing of this atlas is to define and capture the global perspective of oral and maxillofacial surgery. Although the education, training, and scope of practice of the specialty vary widely from country to country, the future direction of oral and maxillofacial surgery should be clear. This atlas serves as a beacon by which the specialty can navigate as it continues to define itself.

The atlas is divided into 11 sections with specific surgical procedures. Dividing the atlas into these 11 sections makes sense, based on surgical anatomy and disease considerations. Each section editor was well selected by Paul and Deepak for his or her expertise and past scientific contributions. The detailed surgical procedures covered in the atlas are relevant and, as a group, are comprehensive for the practice of oral and maxillofacial surgery.

An atlas of this depth and breadth rightfully requires the contributions of many authors from around the world. The task of the editors and publisher is to establish and then demand a consistent, readable format; high-quality contributions by each author; and then meticulous editing to avoid the repetition so commonly seen in texts with multiple authors. By definition, an atlas also must have consistently high-quality and accurate illustrations. This atlas achieves all of these objectives, which is a tribute to the joint efforts of each and every author, the illustrator, the editors, and the publisher.

Through the *Atlas of Oral and Maxillofacial Surgery*, Paul and Deepak have made a significant contribution to the specialty and, more important, to the care of children and adults with craniofacial and maxillofacial deformities of all kinds.

**Jeffrey C. Posnick, DMD, MD, FRCS, (C), FACS**  
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# Foreword

Two widely recognized, midcareer, academic oral and maxillofacial surgeons independently approached Elsevier several years ago with remarkably similar proposals for book projects. Each of these well-established leaders was the product of a contemporary advanced training pathway that was not available in the specialty of oral and maxillofacial surgery during the era of Fred Henny and R.V. Walker—*fellowships*. These aspiring authors had each completed fellowships with different foci: Paul Tiwana in craniofacial surgery and Deepak Kademani in head and neck oncologic surgery. The directors of each of their fellowships were themselves the products of dual training: Posnick in oral and maxillofacial surgery (OMFS) in addition to plastic surgery, and myself in oral and maxillofacial surgery as well as otolaryngology. Kathy Falk and John Dolan at Elsevier quickly saw the wisdom of combining the talents of Tiwana and Kademani. Once united, the co-editors assembled a core group of 11 section editors, who represent acknowledged subspecialty experts in American OMFS. They reviewed multiple proposals from medical illustrators and immediately grasped the talent of Joe Chovan as the artist to uniquely convey the visual message that defines an outstanding surgical atlas and that differentiates the best

from the rest. The result—this book—will come to be recognized as the definitive surgical atlas of the OMFS specialty and will have broad appeal to other specialties.

This Atlas represents the contributions of many thought leaders of our specialty, often in collaboration with younger, rising academic stars. This work will serve as a resource to many and at multiple levels. To OMFS residents in training, it will provide a fecund seed for the development of their surgical fund of knowledge. To fellows in OMFS and other related disciplines, this atlas will help refine their skills and perhaps stimulate their own future contributions. Contemporary broad-scope practitioners will readily find a place on their shelves for this thorough reference. It is a distinct pleasure to have been involved in the creation of this atlas.

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We are deeply grateful to our many friends and colleagues who have supported us and contributed to this book. In particular we wish to thank our section editors—Eric Carlson, Eric Dierks, Alan Herford, Tirbod Fattahi, Ghali Ghali, Martin Steed, Douglas Sinn, Richard Finn, Pamela Hughes, Brent Ward, and John Zuniga—who worked tirelessly to complete their editorial efforts. We thank them immensely for their confidence and support in bringing this project to fruition.

We are also indebted to the many authors who gave their time and expertise in contributing to this book to make it a reality. The editorial process was far easier because of the high-quality, timely submissions by all the authors. We owe a particular debt of gratitude to our primary artist on this

project, Joe Chovan. His artistic interpretation of surgical procedures was simply breathtaking. We also would like to acknowledge the artistic contributions of Devon Stuart and Mary Kate Wright.

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*Deepak Kademani*  
*Paul Tiwana*

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# The Neurocranium

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## The Neurocranium<sup>1</sup>

The oft-heard maxim “anatomy is destiny” was coined by Sigmund Freud in summary of his assertion that gender is the primary determinant of personality traits. For surgeons, the same quote may be applied to the importance of mastering the intricate construction of the portion of the human body for which they are responsible. Thorough comprehension of anatomy allows the surgeon to work safely and precisely, thereby optimizing restoration of health and minimizing morbidity. In this chapter, the structure of the neurocranium and how it relates to oral and maxillofacial surgery are examined.

The skull consists of the cranium (Figure 1-1) and the mandible (Figure 1-2). The cranium is divisible into the neurocranium and the splanchnocranium (see Figure 1-1). The neurocranium encases the brain and is found above the orbits. Below the orbits, the viscerocranium, alternately called the *splanchnocranium* or midface, supports the nasal passages and the oral cavity and makes up the face.

The neurocranium may be considered in two parts: the roof, or cranial vault (also called by its Latin name, the *calvaria*), and the floor, or cranial base. The space within the neurocranium occupied by the brain is the cranial cavity. The calvaria is formed anteriorly by the frontal bone, posteriorly by part of the occipital bone, and laterally by the paired parietal bones and squamous portions of the temporal bones (Figure 1-3). Although most bones develop by endochondral ossification, which involves formation of a cartilaginous template that is gradually replaced by bone, the bones of the calvaria develop through intramembranous ossification, whereby mesenchymal cells forming a membrane over the brain condense into a collection of nodes and differentiate directly into osteoblasts. The osteoblasts secrete a matrix that becomes calcified, resulting in the formation of flattened bone within the membrane. The nodes or islands of bone enlarge radially, but at birth the bones of the calvaria are still separated from each other by the mesenchymal membrane.<sup>2-4</sup> The largest areas of noncalcified membrane, which are called *fontanelles*, are found where the frontal and occipital bones meet the parietal bones on the superior aspect of the calvaria (see Figure 1-3). The failure of the calvarial bones to fuse prior to infancy allows the cranium to deform during passage through the birth canal and also allows the volume of the neurocranium to continue to expand after birth

to accommodate enlargement of the brain. Intramembranous ossification continues through infancy until the bones of the calvaria meet and form fibrous suture joints, which usually fuse during adulthood.

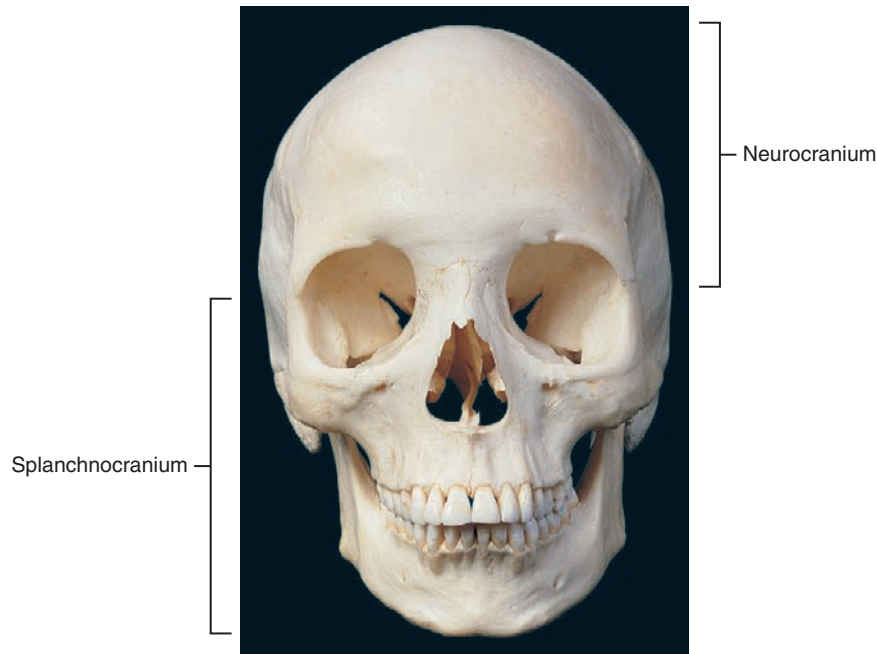
One or more of the sutures between the bones of the calvaria may prematurely fuse during fetal development. Virchow's Law states that this event, which is called *craniosynostosis*, results in imbalanced development of the skull; enlargement perpendicular to the fused suture is limited, and enlargement of the area where the sutures remain open is correspondingly increased. The resulting malformation has the potential to cause compression of a portion of the brain, which may result in neurologic abnormalities.<sup>5</sup>

After fusion, the sutures remain visible on the external and internal surfaces of the calvaria (see Figure 1-3). Along the midline, the sagittal suture is located between the left and right parietal bones. The vertex, a conceptual point indicating the apex of the skull, would be located on the sagittal suture on a perfect skull. On the internal surface of the calvaria, an indentation is normally visible along the midline that corresponds to the superior sagittal sinus, a venous sinus within the dura mater (this is discussed in more detail with the cranial base). The coronal suture runs between the frontal bone and parietal bones, and the lambdoid suture is found between the occipital bone and the parietal bones. The sagittal suture intersects the coronal suture at the bregma and the lambdoid suture at the lambda (Figure 1-4).

Bilaterally on the calvaria, the squamosal suture is visible between the parietal bone and the squamous portion of the temporal bone. The area where the parietal, temporal, and occipital bones meet is called the *asterion*, which serves as a neurosurgical landmark. More anteriorly, the frontal, parietal, and temporal bones intersect with a bone involved in the formation of the cranial base, the sphenoid bone, to form an H-shaped suture called the *pterion* (Figure 1-5). The middle meningeal artery, which arises from a branch of the external carotid artery called the *maxillary artery*, runs along the inside of the neurocranium and crosses the pterion. Trauma to the skull at the pterion can rupture the underlying middle meningeal artery, leading to a potentially fatal epidural hematoma.

The floor of the neurocranium is formed by the occipital, temporal, sphenoid, ethmoid, and frontal bones. The internal surface of the floor of the neurocranium, upon which the brain rests, may be divided into the anterior, middle, and posterior cranial fossae (Figure 1-6).





**Figure 1-1** The cranium and its divisions. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)



**Figure 1-2** The mandible. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)

The majority of the anterior cranial fossa consists of the orbital plates of the frontal bone, which form the roofs of the orbits. The orbital roofs bear impressions that mirror the undulating sulci and gyri of the overlying cerebrum. An explanation of how the gelatinous brain might influence the structure of rigid bone is found in Melvin Moss's functional matrix hypothesis, which states that development of bone sequentially follows, and is thus dependent on, structural changes in collections of developing soft tissues called functional matrices. The cerebrum would thus be a component of the functional matrix for which the associated bone is the frontal bone, or more specifically, the orbital plates of the

frontal bone. Likewise, the superior sagittal sinus is a component of the functional matrix associated with the parietal bones; hence, the impression along the internal surface of the sagittal suture described earlier.

Part of the ethmoid bone is found between the orbital plates of the frontal bone (Figure 1-7). The vertical ridge at the midline is the crista galli, named for its resemblance to a rooster's crest. The cerebral falx, a vertical sheet of dura mater separating the cerebral hemispheres, attaches to the crista galli. On either side of the crista galli are the cribriform plates, which have numerous perforations. Branches of the first cranial nerve, the olfactory nerve, pass through these perforations to reach the nasal cavity.

Posterior to the frontal and ethmoid bones are the lesser wings of the sphenoid bone, which form the posterior edge of the anterior cranial fossa. Extending posteriorly from the medial ends of the lesser wings are the anterior clinoid processes, to which attaches the cerebellar tentorium, a horizontal sheet of dura mater that separates the cerebrum from the cerebellum. The jugum, which is the flattened area between the anterior clinoid processes, supports the olfactory tracts.

The middle cranial fossa is formed by the greater wings and body of the sphenoid bone anteriorly and by the temporal bone posteriorly. The temporal lobes of the brain rest in the lateral recesses of this fossa. At the center of the middle cranial fossa is a part of the body of the sphenoid bone called the *sella turcica*, which is named for its resemblance to a Turkish saddle. The pituitary gland hangs down from the brain and "sits" in this "saddle." The depression for the gland in the center of the sella turcica is the hypophyseal fossa. On either side of the hypophyseal fossa is a concavity occupied by the cavernous sinus, another venous sinus in the dura

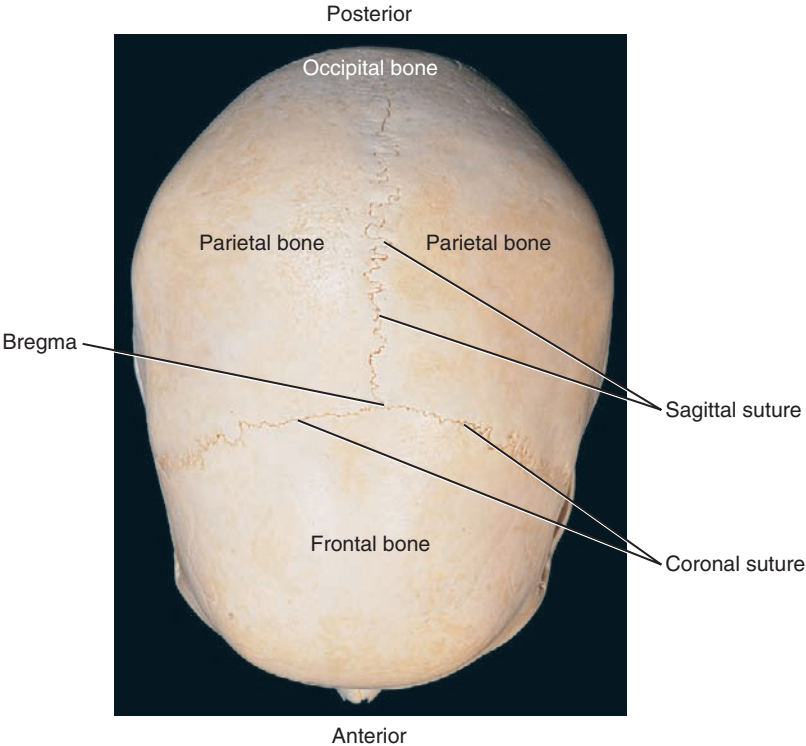


Figure 1-3 Superior view of the skull. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)

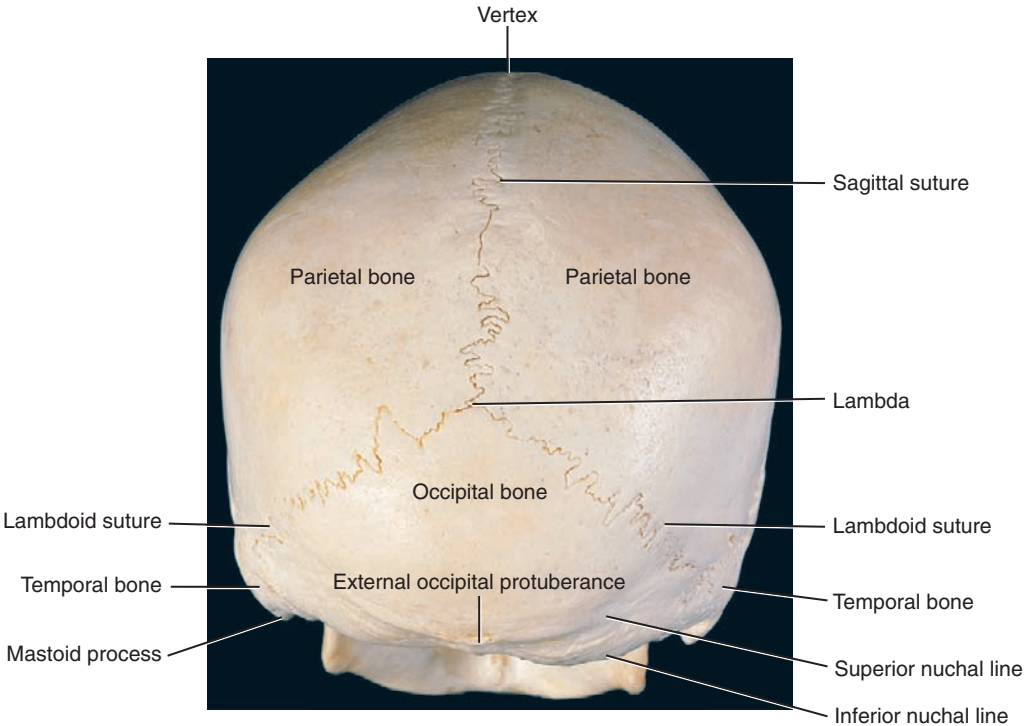
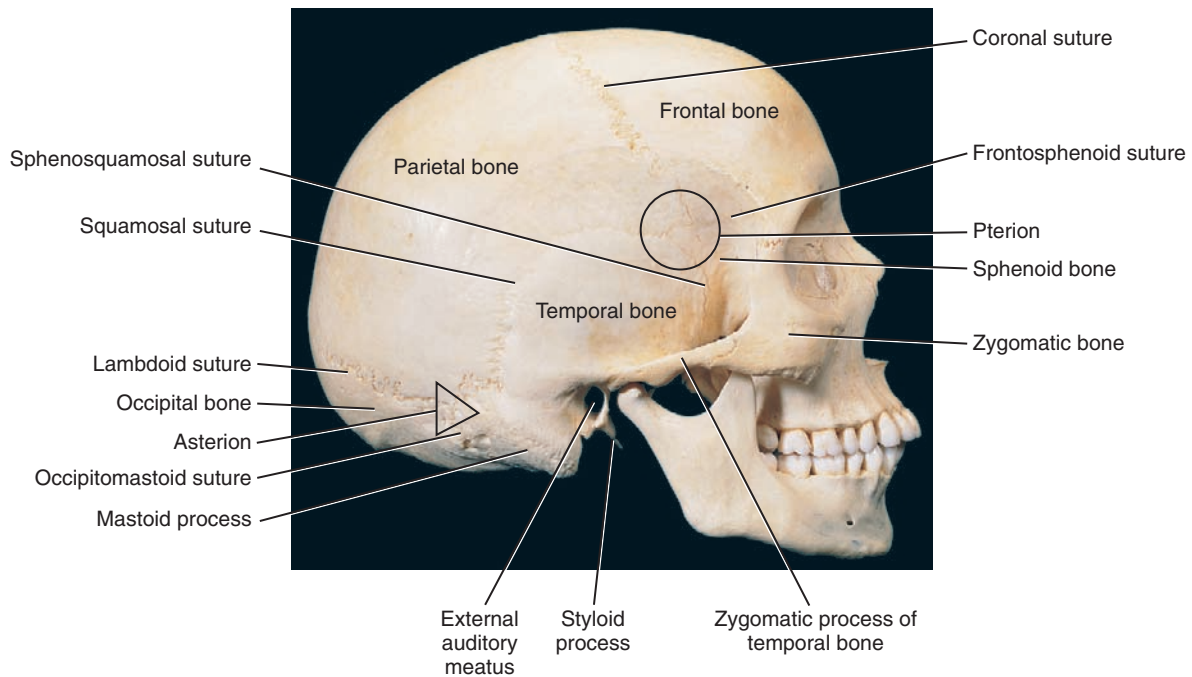
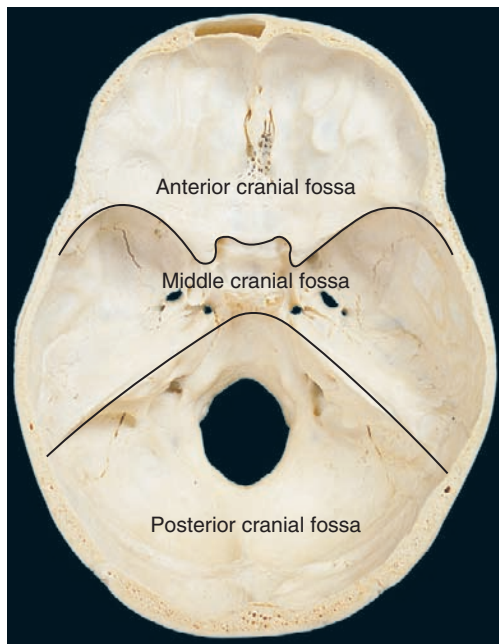


Figure 1-4 Posterior view of the skull. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)





**Figure 1-5** Lateral view of the skull. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)



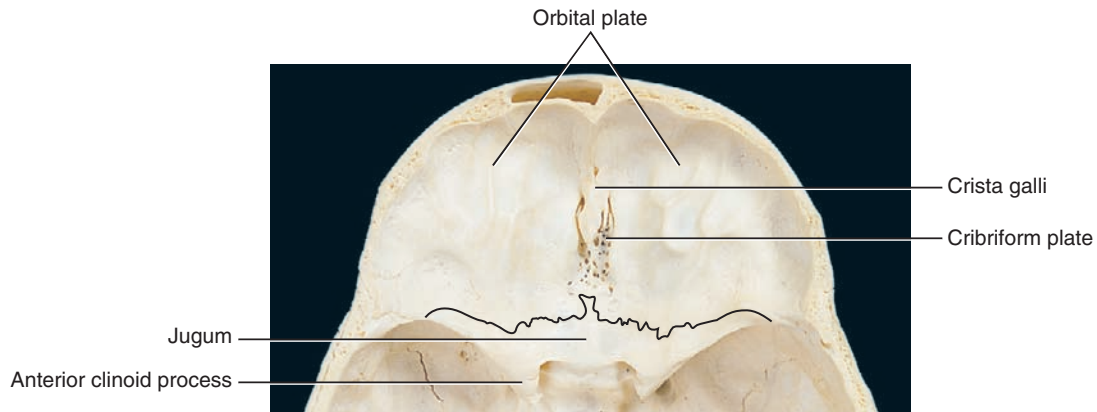
**Figure 1-6** Divisions of the neurocranium. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)

mater. The internal carotid artery and the abducens nerve (cranial nerve VI) pass through this sinus, and the oculomotor nerve (cranial nerve III), the trochlear nerve (cranial nerve IV), and the first and second divisions of the trigeminal nerve (cranial nerve V) are embedded in the dura mater, forming the lateral wall of this sinus. The posterior portion of the sella

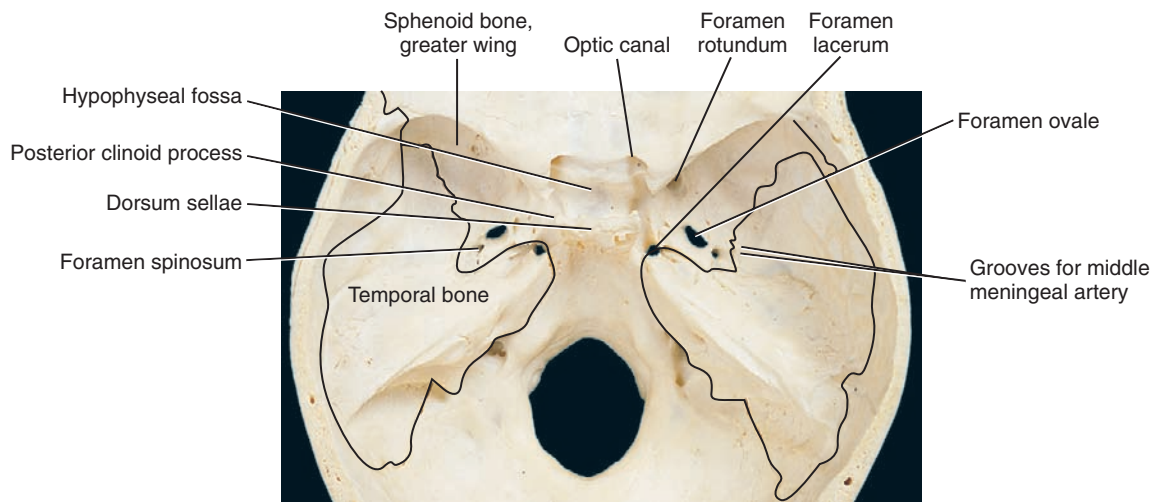
turcica is the dorsum sellae, from which extend the posterior clinoid processes. These processes are another site of attachment for the cerebellar tentorium ([Figure 1-8](#)).

There are several paired openings in the middle cranial fossa that allow passage of structures into and out of the cranial cavity. Just inferior to the overhanging portion of the lesser wing of the sphenoid are the optic canal and the superior orbital fissure. The optic canal passes through the lesser wing of the sphenoid bone and allows passage of the optic nerve (cranial nerve II), which is responsible for vision, and the ophthalmic artery, a branch of the internal carotid artery. The superior orbital fissure is a gap between the greater and lesser wings of the sphenoid. Three nerves supplying motor innervation to the extraocular muscles, the oculomotor nerve (cranial nerve III), the trochlear nerve (cranial nerve IV), and the abducens nerve (cranial nerve VI), and one sensory nerve, the ophthalmic division of the trigeminal nerve (cranial nerve V), pass through the superior orbital fissure to reach the orbit. The superior ophthalmic vein also passes through this fissure to drain blood from the orbit into the cavernous sinus.

Three pairs of foramina in the middle cranial fossa pass through the greater wing of the sphenoid bone. From anterior to posterior, they are the foramen rotundum, foramen ovale, and foramen spinosum. The second division, or maxillary division, of the trigeminal nerve passes through the foramen rotundum to reach the pterygopalatine fossa. The foramen ovale serves as the passageway that the third division, or mandibular division, of the trigeminal nerve, and often the lesser petrosal nerve, a branch of the glossopharyngeal nerve (cranial nerve IX), use to reach the infratemporal fossa. The middle meningeal artery travels from the infratemporal fossa



**Figure 1-7** The anterior cranial fossa. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)



Not shown: Superior orbital fissure

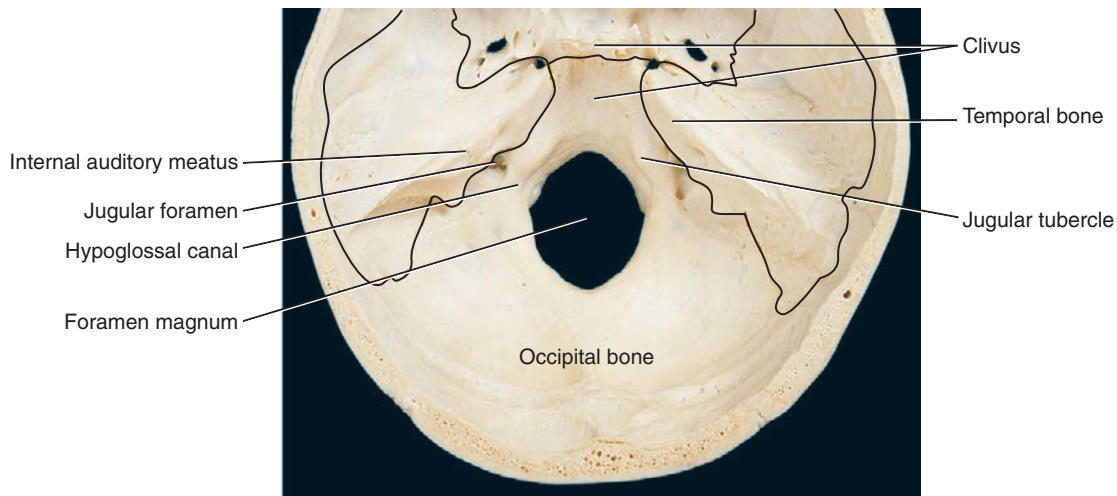
**Figure 1-8** The middle cranial fossa. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)

to the middle cranial fossa by passing through the foramen spinosum. A series of grooves representing the paths of the branches of the middle meningeal artery, which supply the bone and dura mater between which they run, radiate laterally from the foramen spinosum across the middle cranial fossa and superiorly along the lateral aspect of the calvaria. The foramen spinosum also transmits one or more of the meningeal branches of the trigeminal nerve, which provide sensory innervation to the dura mater lining the middle cranial fossa.

Medial to the foramen ovale and foramen spinosum lies the foramen lacerum, which is a gap between the temporal and sphenoid bones that may be thought of as a very short vertical tunnel. The inferior end of this tunnel is completely blocked off by cartilage, and the only structures traversing the entire length of the foramen lacerum from its inferior to its superior opening are a few small blood vessels. Two structures of note travel part of the way through the foramen lacerum,

however. The internal carotid artery enters the foramen lacerum from an opening in its wall that connects it to the carotid canal, which is described below. The artery then turns to access the cavernous sinus. A branch of the facial nerve (cranial nerve VII), the greater petrosal nerve, passes through the superior opening of the foramen lacerum, joins with the deep petrosal nerve, and leaves the foramen lacerum through an opening in its wall that leads to the pterygoid canal.

The occipital, sphenoid, and paired temporal and parietal bones contribute to the posterior cranial fossa, where the cerebellum and part of the brainstem are located. The foramen magnum is the large opening in the occipital bone that transmits the spinal cord and the vertebral arteries. The flat surface of the occipital and sphenoid bones anterior to the foramen magnum and posterior to the dorsum sellae is the clivus. The clivus is adjacent to the anterior surface of the pons, the middle portion of the brain stem. Superior to the foramen magnum and lateral to the clivus are the jugular tubercles,



**Figure 1-9** The posterior cranial fossa. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)

inferior to which are found the hypoglossal canals. In addition to the hypoglossal nerve (cranial nerve XII), the hypoglossal canal transmits branches of the upper cervical nerves that provide part of the sensory innervation to the dura mater lining the posterior cranial fossa (Figure 1-9).

The hypoglossal nerve supplies motor innervation to the muscles of the tongue. Damage to the hypoglossal may result in unilateral paralysis of the tongue. To test for hypoglossal nerve damage, the patient is asked to protrude (i.e., stick out) the tongue. Normally the tongue protrudes along the midline without deviating to either side; if motor innervation is lost to one side of the tongue, it deviates to the affected side.

Located superolateral to the jugular tubercle is a large gap between the temporal and occipital bones; this is the jugular foramen, which is named for the large vein it transmits, the internal jugular vein. The glossopharyngeal nerve (cranial nerve IX), the vagus nerve (cranial nerve X), and the accessory nerve (cranial nerve XI) pass through the jugular foramen. The glossopharyngeal nerve provides sensory and motor innervation to the pharynx and the tongue. The vagus nerve, in addition to carrying the majority of the body's parasympathetic innervation, sends motor and sensory branches to the pharynx and a branch to the posterior cranial fossa that is responsible for the remainder of the sensation to the dura mater in this area. The accessory nerve provides motor innervation to the sternocleidomastoid muscle of the neck and the trapezius muscle of the posterior neck and upper back.

Superior to the jugular foramen and inferior to the peak of the petrous portion of the temporal bone is the internal acoustic meatus, which is also called the *internal auditory meatus* or *canal*. The facial nerve (cranial nerve VII) and the vestibulocochlear nerve (cranial nerve VIII) enter this foramen. The facial nerve provides motor innervation to muscles that include those of facial expression; parasympathetic innervation to the lacrimal gland, glands of the nasal and oral mucosa, and two salivary glands; and the sensation

of taste to the front of the tongue. The vestibulocochlear nerve is responsible for the sensations of hearing and balance.

Impressions for two of the dural venous sinuses, the superior sagittal and cavernous sinuses, have already been noted. The posterior cranial fossa also bears impressions corresponding to some of the dural sinuses, notably the bilateral sigmoid and transverse sinuses, and the centrally located confluence of sinuses. The dura mater is a bilaminar membrane; it has an external periosteal layer adherent to the internal surface of the cranial cavity and an internal meningeal layer continuous with the dura mater of the spinal cord. The periosteal and meningeal layers of the dura mater are fused except at the dural infoldings and at the dural venous sinuses. The infoldings are extensions of the meningeal layer of the dura that pass between parts of the brain to lend it structural support. Examples of the dural infoldings are the cerebral falx and the cerebellar tentorium mentioned earlier. The dural sinuses are channels between the two dural layers through which venous blood flows. The veins of the brain drain into the dural sinuses, which in turn drain into the internal jugular vein via the jugular foramen in the posterior cranial fossa.

Most of the dural venous sinuses lie within the margins of the dural infoldings. Running through the superior and inferior margins of the cerebral falx are the superior and inferior sagittal sinuses. The superior sagittal sinus begins anteriorly near the crista galli at the foramen cecum, an opening in the anterior cranial fossa where the frontal bone and the ethmoid bone meet. A vein from the nasal cavity enters the sinus through this foramen. The superior sagittal sinus runs posteriorly along the midline of the calvaria to the confluence of sinuses, a dilation that leaves an impression in the midline of the occipital bone.

Blood in the confluence of sinuses may drain laterally through the horizontally oriented left and right transverse sinuses, which run along the posterior and lateral margins of the cerebellar tentorium. At the base of the petrous portion of the temporal bones, the transverse sinuses are continuous

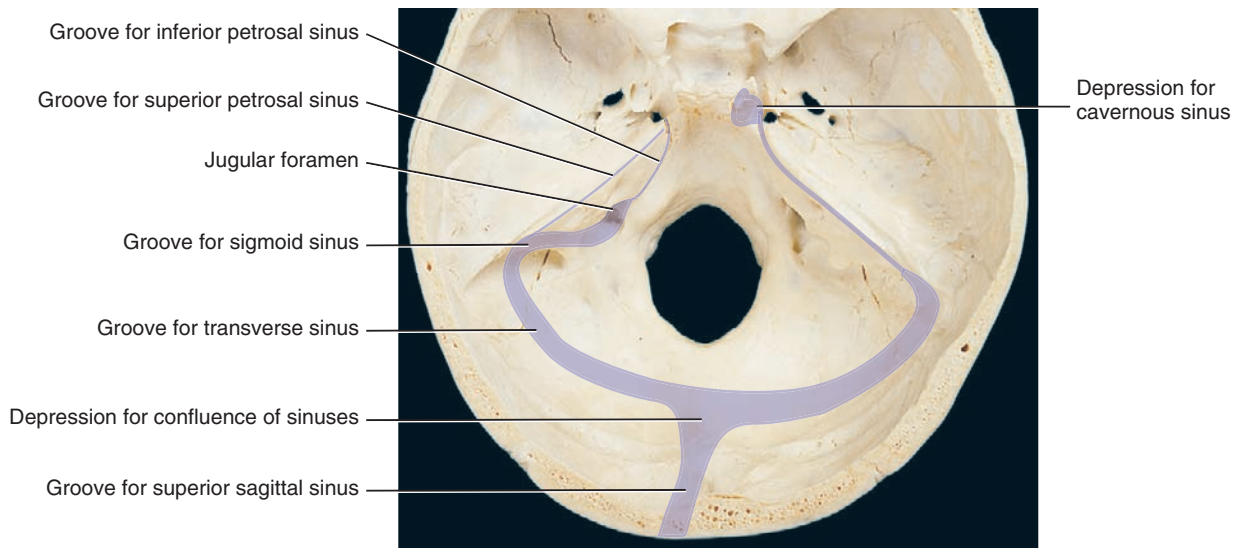


with the sigmoid sinuses. These S-shaped sinuses continue inferiorly as the internal jugular veins at the level of the jugular foramina.

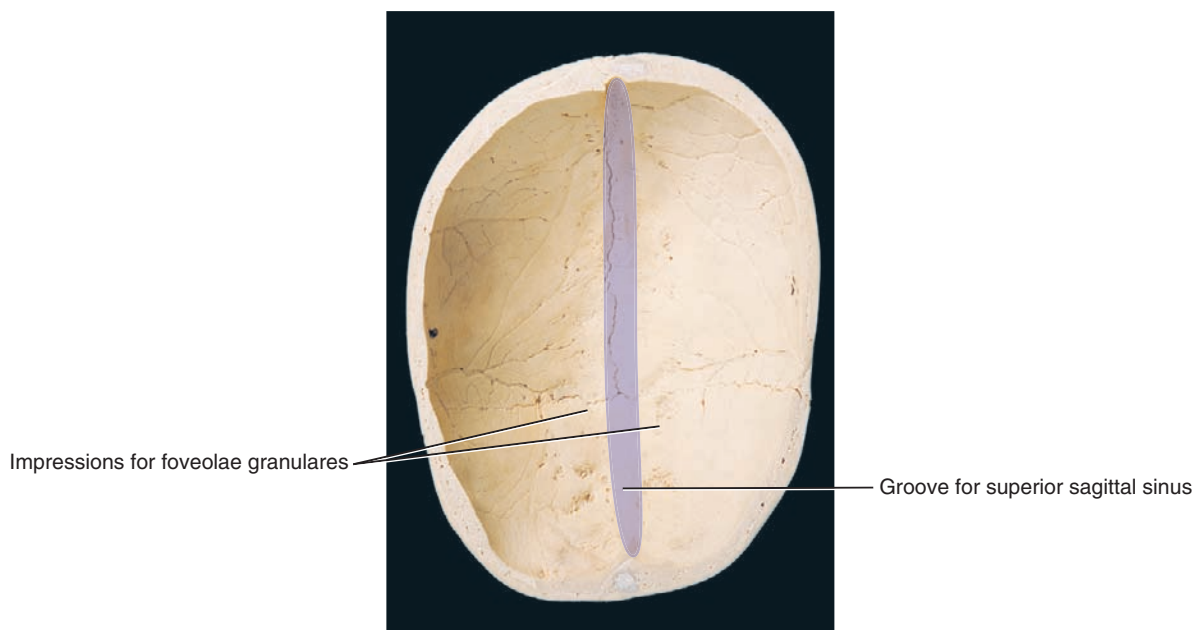
Blood from the orbit may pass through the superior orbital fissure via the superior ophthalmic vein and drain into the cavernous sinus. The cavernous sinus also receives blood from the brain via the superficial middle cerebral vein. Blood in the cavernous sinus may then pass posteriorly through the superior and inferior petrosal sinuses. The superior petrosal sinus runs along the margin of the cerebellar tentorium across the crest of the petrous portion of the temporal bone and empties into the junction of the transverse and sigmoid

sinuses. The inferior petrosal sinus runs posteriorly in a very subtle groove between the petrous portion of the temporal bone and the occipital bone and drains directly into the origin of the internal jugular vein at the jugular foramen (Figures 1-10 and 1-11).

Some of the foramina in the interior of the neurocranium lead directly to the viscerocranium and are not visible on the underside of an intact skull (Figure 1-12). These include the openings in the cribriform plate, which lead to the nasal cavity; the optic canal and orbital fissures, which lead to the orbit; and the foramen rotundum, which leads to the pterygopalatine fossa. All but one of the remaining openings in



**Figure 1-10** Grooves for the dural sinuses. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)



**Figure 1-11** Underside of the calvaria. (From Abrahams PH, Spratt JD, Loukas M, van Schoor AN: *McMinn and Abrahams' clinical atlas of human anatomy*, ed 7, St Louis, 2013, Mosby.)