Bergman’s Comprehensive Encyclopedia of Human Anatomic Variation
As the reader sees from the title of this textbook, it is dedicated to Dr. Ronald Bergman. Dr. Bergman was not the first to collect and publish on the variations of the human anatomy (e.g. Henle, Macalister, Adachi). However, he was the first to publish on this topic at such an in-depth and comprehensive scale. My first introduction to Dr. Bergman’s *Compendium of Human Anatomic Variation* was as a graduate student. As any dissector will eventually do, I came across something unusual in one of our cadavers during a routine dissection. I asked by my mentor, Dr. George Salter, about this who said, “You know there used to be a book in the lab office that focused on the anatomic variations of the body.” After some digging, I was delighted to find this book, which I set out to memorize as best as I could. From that day on, Dr. Bergman’s book and *Gray’s Anatomy* were my main resources for studying anatomy. Therefore, this current text is not only an updated resource but also a tribute to the pioneering efforts of Dr. Ronald Bergman who reminded us that no two bodies are the same!

R. Shane Tubbs
I would like to dedicate my work on this enormous project to my son, Isaiah. Isaiah you are the light of my life! To my wife, Susan, you are the best. Many thanks to Drs. Rod Oskouian and Johnny Delashaw for their encouragement. Also, Dr. W. Jerry Oakes has supported this project and my other academic endeavors and I sincerely thank him. Lastly, I thank Dr. E. George Salter for persuading me to take on a career in anatomy and for first introducing me to the *Compendium of Human Anatomic Variation*!

R. Shane Tubbs

To Susan and Shane Tubbs, a very beautiful couple.

Mohammadali M. Shoja

To the love of my life, my wife Joanna Loukas

Marios Loukas
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Since the beginning of time, differences between humans have made us identifiable to those around us. Some extreme forms of morphological variation have even resulted in individuals being either unique or outcasts. For example, dwarfs have been revered in various cultures and even represented in royal courts and some cultures have bestowed a god status on children born with multiple limbs. Other variations, however, have been viewed as “different” enough to warrant being ostracized. Children being born with a caudal appendage (tail) who were considered offspring of Satan exemplify this.

Human anatomic variation can be defined as human form that is outside of the normal. However, what is normal? This question is often very difficult to answer. For example, most would agree that having two breasts is normal but what about a woman with accessory breasts? Is this normal, abnormal or even pathologic? Is it a variant or an anomaly? Sometimes, the answer to these questions is based on cultural norms or societal acceptance.

Obviously, hair color is certainly varied among individuals with many having a color that doesn’t fit into the classic brown, black, red, or blonde categories. But are various hair colors that one of these terms does not apply to have a variation or is this simply an issue of definition e.g. red in the broader sense would include auburn, strawberry, etc.? In other words, our definition of normal is the gauge by which an anatomic trait is considered a variation or not. Some have tried to shed light on this by using such words as “borderlands.” Beyond the “border” a trait is thereby considered a variation. To confuse these issues, the term anomaly is and has been used interchangeably in regard to both variation and pathology. Herein, we have attempted to avoid pathologic anatomy but often, the line between an anatomic variation that is pathologic or predisposes one to pathology and one that is just a trait that is outside of what is considered normal is very gray. Moreover, as the term “anomaly” is often used to denote a variation that results in dysfunction or disease, we have tried to avoid this term when possible. However, the form of a structure may cause dysfunction in one person and not another. Therefore, “anomalies” do not always result in dysfunction or disease. The terms “abnormal” and “aberrant” have each been used loosely in the medical literature to describe anatomy that is non-pathologic or results in dysfunction.

Confoundedly, there are variations within variations. Where does one draw the line between a variation that is accepted as “normal” (the so-called normal variant) and a variation that is considered “abnormal”? In this text, we have attempted to be more inclusive than not. If the majority of individuals do not have an anatomic trait, then we have considered it a variation. With this however, the definition of majority has to be defined.

A quarter of a century ago, Dr. Ronald Bergman set forth to collect and publish a compendium of human variation. His textbook soon became the gold standard in human anatomic variation. As anatomists, we consulted this text almost daily. However, in the interim since its publication, radiologic technology and improved optics such as the surgical microscope have allowed us to see into the body with better accuracy than ever before. As a result, many more variations have come to the anatomist’s and clinician’s attention. Therefore, an updated textbook devoted to human anatomic variation seemed timely. However, as no single text on human anatomy can include all of the intricate details and structures of the body, so too can no single text on human anatomic variation capture all known or reported variants of the body, although we have tried. This tome will attempt to capture many of the known variants of the human form.

Nothing is pleasant that is not spiced with variety.

Francis Bacon

Through every rift of discovery some seeming anomaly drops out of the darkness, and falls, as a golden link into the great chain of order.

Edwin Hubbel Chapin

Variety’s the very spice of life that gives it all its flavor.

William Cowper

The essence of the beautiful is unity in variety.

W. Somerset Maugham

I have called this principle, by which each slight variation, if useful, is preserved, by the term of Natural Selection.

Charles Darwin

Variety of mere nothings gives more pleasure than uniformity of something.

Jean Paul

The gifts of nature are infinite in their variety, and mind differs from mind almost as much as body from body.

Quintilian
To such an extent does nature delight and abound in variety that among her trees there is not one plant to be found which is exactly like another; and not only among the plants, but among the boughs, the leaves and the fruits, you will not find one which is exactly similar to another.

Leonardo DaVinci

The catalogue of forms is endless: until every shape has found its city, new cities will continue to be born. When the forms exhaust their variety and come apart, the end of cities begins.

Italo Calvino

R. Shane Tubbs
With the possible exception of a few pairs of identical twins, the anatomy of every human being on this planet is unique. That means that there are as many anatomical variations as there are people! Obviously, only a small percentage of these variations are of clinical significance. There are subtle variations in facial anatomy that will allow a clinical anatomist to tell one person from another, but that is not the type of variation that this textbook is about. Instead, this textbook is a resource for the clinical anatomist who needs a single comprehensive source for all the variations that have been published in peer-reviewed journals or web sites.

This new text is the first of its kind since Compendium of Human Anatomic Variation: Text, Atlas, and World Literature by Ronald A. Bergman, Sue Ann Thompson, and Adel K. Afifi published in 1988. There have been many published accounts of variations since that time. In fact, this text contains thousands of published variations. This update is clinically important in view of recent advances in surgery and radiologic imaging. For a surgical example, endoscopic surgery makes what was previously an insignificant variation now necessary for the surgeon to recognize in order to perform a procedure safely. Improved resolution of radiologic images in all modalities makes it more important to be able to recognize what is pathologic and what is a normal variation.

Bergman’s “Compendium” was the “gold standard” of its day. This text will soon become the new gold standard. Even Dr. Bergman would agree with that!

Respectfully submitted,
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Professor Emeritus of Anatomy and Orthopedic Surgery,
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This book, with great personal pride for me, provides elegant confirmation of the proven fact that the human body (as well as every living thing) is not created without variability. To paraphrase a profound statement by Sir William Osler, “variability is the rule of life”! The present book complements and extends a previous compendium, and an internet edition of human anatomic variation. Dr. Shane Tubbs conceived and developed this revision. He and his co-editors expand our knowledge and are to be very highly commended for keeping the concepts fresh in the minds of all who are interested in the structure and function of the human body.

Ronald A. Bergman, PhD
Emeritus Professor of Anatomy
The University of Iowa
Frontal bone

The frontal sinus ostium is sometimes absent. In a cadaveric study, Ozgursoy et al. (2010) reported absence of right frontal sinus ostium in 3.6% of cases when there was a connection between the right and left frontal sinuses. They also noted that if one of the frontal sinus ostia cannot be found during sinus surgery, although this sinus and its recess can be seen on thick-sliced coronal computed tomographic scans, there could be an agenetic frontal sinus hidden by the extensive pneumatization of the contralateral sinus that crosses the midline (3.6%).

The frontal sinus itself can be absent. Computed tomographic scans in the axial and coronal planes of the frontal sinuses of 565 patients were examined. There was bilateral agenesis of the frontal sinuses in 8.32% of these cases and unilateral absence of the frontal sinus in 5.66% (Danesh-Sani et al. 2011).

Another study investigated the prevalence of agenesis of the frontal sinuses using dental volumetric tomography (DVT) in Turkish individuals. The frontal sinuses of 410 patients were examined by DVT scans in the coronal plane. There was bilateral and unilateral absence of the frontal sinuses in 0.73% and 1.22% of cases, respectively (Çakur et al. 2011a). Aydiniöglü et al. (2003) studied computed tomography (CT) scans of the paranasal sinuses in the axial and coronal planes from a series of 1200 cases. Bilateral and unilateral absences of the frontal sinuses were noted in 3.8% and 4.8%, respectively.

In a study on the septation of the frontal sinuses, Comer et al. (2013) concluded that frontal sinus septations appear to be significantly associated with and predictive of the presence of supraorbital ethmoid cells. Identifying frontal sinus septations on sinus CT could therefore imply a more complex anatomy of the frontal recess.

In a study by Bajwa et al. (2013), all patients older than 15 months and 23 days had completely fused metopic sutures. The estimated median age for the start of the fusion process was 4.96 months (95% confidence interval, 3.54–6.76 months), and the estimated median age for completion of fusion was 8.24 months (95% confidence interval, 7.37–9.22 months). The fusion process was complete between 2.05 and 14.43 months of age in 95% of the normal population. There was no significant difference between sexes. This study demonstrated wide variation in the timing of normal fusion, which can complete as early as two months of age (Bajwa et al. 2013).

Persistent metopic sutures can be misdiagnosed as vertical traumatic skull fractures extending down the midline in head trauma patients. The surgeon should therefore be aware of this anatomical variant during primary and secondary surveillance of the traumatized patient and during surgical intervention, especially including frontal craniotomy. A reconstructed tomography scan demonstrating sutural closing status could provide useful additional information in the diagnostic sequence, superior to a plain X-ray in the emergency setting (Bademci et al. 2007). Nakatani et al. (1998) encountered a complete eumontopic suture in a 91-year-old Japanese male cadaver during a gross anatomy course. It was observed in 1 of 26 skulls aged 62–92 years and was about 13 cm long from the bregma to the nasion. A metopic suture is rare in a person of advanced age, as in their case.

In another study, 1276 adult Indian skulls were examined for the incidence of metopic sutures. There was metopism in 2.66% of the skulls and metopic sutures were present in 38.17% (35.27% in the lower part of the frontal bone in various shapes); the incidences in the upper, upper middle and lower middle parts of the frontal bone were 0.8% in each location. As well as the abovementioned findings, a peculiar shape (inverted Y) was seen in 0.63% and a radiating type in 0.31% of the skulls (Agarwal et al. 1979).

Hyperostosis frontalis interna is a condition of bony overgrowth of the frontal region of the endocranial surface, appearing in the scientific literature as early as 1719. During routine dissection of a donor’s calvaria it was noted that she had significant bony overgrowth of the endocranium. Such overgrowth was diffuse throughout the frontal bone, extending slightly into the parietal region with midline sparing (Fig. 1.1). It ranged from 1.0 cm thickness in the temporal region to 1.3 cm adjacent to the midline in the frontal region. Large individual nodules were located along either side of the frontal crest at the intersection of the frontal and parietal bones. The largest nodules measured 2.08 cm in thickness on the right and 1.81 cm on the left (Fig. 1.2). As a result, the pathway of the middle meningeal artery was tortuous. In addition there was significant bilateral depression of the frontal lobes and surrounding neural tissues (Fig. 1.3) (Champion and Cope 2012).
Nikolić et al. (2010) determined the rate of occurrence and appearance of hyperostosis frontalis interna (HFI) in females and correlated this phenomenon with aging. The sample included 248 deceased females, 45 with different types of HFI and 203 without HFI, average ages 68.3±15.4 (range 19–93) and 58.2±20.2 years (range 10–101), respectively. The rate of HFI was 18.14%. The older the woman, the higher the possibility of HFI (Pearson correlation 0.211, \( N=248, P=0.001 \)), but the type of HFI did not correlate with age (Pearson correlation 0.229, \( N=45, P=0.131 \)). The frontal and temporal bones were significantly thicker in women with HFI than in women without it (\( t=-10.490, DF=246, P=0.000 \), and \( t=-5.658, DF=246, P=0.000 \), respectively). These bones became thicker with aging (Pearson correlation 0.178, \( N=248, P=0.005 \) and 0.303, \( N=248, P=0.000 \), respectively). The best predictors of HFI were frontal bone thickness, temporal bone thickness, and age (respectively: Wald coefficient=35.487, \( P=0.000 \); Wald coefficient=3.288, \( P=0.070 \), and Wald coefficient=2.727, \( P=0.099 \)). Diagnosis of HFI depends not only on frontal bone thickness but also on the waviness of the internal plate of the frontal bone and the involvement of the inner bone surface (Nikolić et al. 2010). May et al. (2011) studied two female populations separated by a period of 100 years: 992 historical and 568 present-day females. HFI was detected by direct observation or CT images. HFI was significantly more prevalent in the present-day than the historical females (\( P<0.05 \)). The risk of developing it was approximately 2.5 times greater in present-day females than in those who lived 100 years ago (\( P<0.05 \)). HFI tended to appear at a younger age in the present-day population. The last two decades have witnessed an increase in prevalence (from 55.6% to 75%); prevalence has also increased during the past century, especially among
young individuals, possibly indicating a profound change in human fertility patterns together with the introduction of various hormonal treatments and new dietary habits (May et al. 2011).

A accessory spine of the zygomatic process of the frontal bone is referred to as the spine of Broca.

**Occipital bone**

The occipital condyle can be oval, triangular, circular, or two-portioned in shape. Ozer et al. (2011) reported the most common type as oval or ovoid (59.67%), whereas the most unusual type was a two-portioned condyle (0.32%). In another study, occipital condyles were classified according to shape: type 1: oval-like; type 2: kidney-like; type 3: S-like; type 4: eight-like; type 5: triangular; type 6: ring-like; type 7: two-portioned; and type 8: deformed. The most common type was type 1 (50%) and the most unusual was type 7 (0.8%) (Naderi et al. 2005).

In some cases a median or third occipital condyle is present. This is occasionally located on the anterior margin of the foramen magnum. Some instances are expressed as a simple rounded tubercle, but in more developed cases an articular facet receives the tip of the odontoid process forming a true diarthrosis (Bergman et al. 1996; Figueiredo et al. 2008). The "condylus tertius" or "third occipital condyle" is an embryological remnant of the proatlas sclerotome. Anatomically, it is attached to the basion and often articulates with the anterior arch of the atlas and the odontoid apex; it is therefore also called the “median occipital condyle” (Udare et al. 2014). It varies in length (0.65 cm in this case); Hadley mentioned that a third condyle with a length of 13–14 mm had been reported in the literature (Rao 2002).

Various structures similar to parts of the atlas have been seen around the foramen magnum and have been described as occipital vertebrae (“manifestation of occipital vertebra”). The atlas can be fused in whole or in part with the occipital bone (“assimilation of the atlas”). This variation occurs in about 0.5–1% of skeletons and has been interpreted by some authors as a cranial shift in the regional grouping of vertebrae in the vertebral column. Signs believed to be associated with assimilated or occipital vertebrae around the foramen magnum include: (a) a massive paramastoid process; (b) an enlarged jugular process; (c) the anterior margin of the foramen magnum thickened and raised to form a bar of bone between the condyles; (d) the hypoglossal canal divided by a bony bridge; and (e) a tertiary condyle and a facet or other marking for the apex of the dens on the anterior margin of the foramen magnum (Bergman et al. 1996).

Bony elements extending towards the foramen magnum are partly attributable to occipital vertebrae. Prakash et al. (2011) reported a single median tubercle situated at the anterior margin of foramen magnum (basion), with the apex facing backwards into the foramen magnum. The tubercle measured 5 mm anteroposteriorly and 3 mm transversely (Fig. 1.4).

Occipitalization of the atlas can be detected incidentally at autopsies or during routine cadaveric dissections, or in dry skulls in osteology classes. Fusion of the atlas with the occipital bone can result in compression of the vertebral artery and first cervical nerve. Occipitalization of the atlas (atlanto-occipital fusion, assimilation of the atlas) is a congenital osseous variation found in the craniovertebral junction. It is caused by assimilation of the first cervical vertebra (the atlas) to the basicranium (Bose and Shrivastava 2013). Bose and Shrivastava (2013) reported a case where the atlas vertebra was almost completely fused with the occipital bone at the base of the skull, except at the transverse processes on both sides. The lateral masses had fused completely with the occipital condyles (Fig. 1.5).
If there is duplication of the atlas, the condyles are of the occipitoatlantal type. In a series of 1246 skeletons, 13 (1.04%) exhibited two or more characteristics of manifestations of an occipital vertebra; 2 (0.16%) revealed assimilation of the atlas and were among 10 (0.80%) that manifested definite cranial shifting of the intersegmental boundaries of the vertebral column (Bergman et al. 1996).

Occipitalization is a congenital synostosis of the atlas to the occiput, which is a result of failure of segmentation and separation of the most caudal occipital sclerotome and the first cervical sclerotome during the first few weeks of fetal life. The degree of bony fusion between the atlas and occiput can vary; complete and partial assimilation have been described. In most cases assimilation occurs between the anterior arch of the atlas and the anterior rim of the foramen magnum, and is associated with other skeletal malformations such as basilar invagination, occipital vertebra, spina bifida of the atlas, or fusion of the second and third cervical vertebrae (Klippel-Feil syndrome). The incidence of atlanto-occipital fusion ranges from 0.14% to 0.75% of the population, both sexes being equally affected (Saini et al. 2009) (Fig. 1.6).

![Figure 1.6 Total occipitalization of the atlas, with bifid posterior arch.](a) Incomplete foramen transversarium (black paper). (b) A foramen on the right side (arrowhead).


Rarely, there is a bony canal in the clivus. This canal probably represents a persisting remnant of the notochord. Chauhan et al. (2010) reported a bony canal in the clivus traversing through the basilar part of the occipital bone from its superior to inferior surface. Considering the direction and location of the canal, they suggested two explanations for its formation: a connecting vein between the basilar plexus and pharyngeal venous plexus could pass through it, or it could have contained the remnant of the notochord (Fig. 1.7).

The hypoglossal canal exhibits variations. Five types can be distinguished: type 1, no evidence of division (typical single canal) (65.4%); type 2, one osseous spur located at either the inner or the outer orifice of the canal or inside it (16.1%); type 3, two or more osseous spurs along the canal (2.3%); type 4, complete osseous bridging in either the internal or external portion of the canal (13.1%); and type 5, complete osseous bridging occupying the entire extent of the canal (3.1%). Berry and Berry (1967) examined 585 skulls and discovered a double hypoglossal canal in 14.6%. The hypoglossal canal has been described as triple or quadruple in rare cases (Bergman et al. 1996; Paraskevas et al. 2009).

The jugular foramen can be divided into parts by intrajugular processes (Bergman et al. 1996). Six processes, arising from the petrous and the occipital bones, were identified and demonstrated in a study by Athavale (2010). The most prominent and common was the posterior petrous process toward the endocranial side, which has been described in the literature as an intrajugular process of the occipital bone and has formed the basis of previous classifications of the compartments of the jugular foramen. The tendency towards septation was more common near the endocranial side (Athavale 2010). Unusual bony projections can narrow the jugular foramen. Rastogi and Budhiraja (2010) reported a case in which a bony growth had converted the jugular foramen into a slit (Fig. 1.8). Such a narrow jugular foramen could cause neurovascular symptoms. Involvement of the ninth, tenth, and eleventh cranial nerves at the jugular foramen is known as Vernet’s syndrome, and could occur in such foramina (Rastogi and Budhiraja 2010). The right jugular foramen is usually larger than the left jugular foramen.

The grooving on the inner surface of the occipital bone is variable. In about 17% of cases the sagittal sulcus turns to join the left transverse sulcus. The sagittal sulcus can bifurcate, the larger groove turning to join the right transverse sulcus and the smaller one joining the left transverse sulcus (about 15% of cases). In rare cases, the larger groove joins the left and the smaller the right. In very rare cases, the right and left grooves appear equal in size (Bergman et al. 1996).

The shape of the foramen magnum varies in both children and adults. Lang (1990) classified the shapes into five groups: two semicircles (adults in 41.2% and children in 18.4%); elongated circle (adults in 22.4% and children in 20.4%); egg-shaped (adults in 17.6% and children in 25.5%); rhomboidal (adults in 11.8% and in children 31.6%); and rounded (adults...
in 7% and in children in 4%) (Bergman et al. 1996). Göçmez et al. (2014) determined the morphology of the foramen magnum using three-dimensional (3D) computed tomography and distinguished eight types of shape. In order of frequency, these were: round (18.8%); two semicircles (17.8%); egg-shaped (14.9%); hexagonal (13.9%); tetragonal (10.9%); oval (10.9%); pentagonal (8.9%); and irregular (4%). Burdan et al. (2012) examined Eastern European individuals using computed tomography. They found all the cranial and foramen measurements were significantly higher in individuals with the round type of foramen magnum. There was sexual dimorphism, related mainly to the linear diameters and area (not to the shape). There was a greater correlation between the examined parameters of the foramen and proper external cranial measurements in females than in males, which indicates more homogeneous growth in girls. Chethan et al. (2012) reported that in 20.7% of skulls the occipital condyle protruded into the foramen.

A Kerckring ossicle or pseudoforamen is sometimes seen. An accessory fontanelle can also be seen behind the foramen magnum and is known as the fontanelle of Hamy. A notch of the anterior rim of the foramen magnum is termed a keyhole foramen magnum.

Elevation of an area between the supreme and superior nuchal lines is termed a “torus occipitalis.” Other names include “occipital spur.” In these cases the inion can be greatly enlarged. It is the insertion site of the ligamentum nuchae (Bergman et al. 1996). The portion of the occipital bone between the superior and highest nuchal lines develops in membrane or in cartilage. This portion of the bone, which is denser, smoother, and

Figure 1.7 (a) Basis cranii interna showing inner opening of clival canal (wire in the canal). (b) Basis cranii externa showing outer opening of clival canal (wire in the canal).


Figure 1.8 Skull base showing slit-like jugular foramen and the abnormal bone growth in the jugular fossa. NJF: normal jugular foramen; SJF: slit-like jugular foramen; BG: bone growth in jugular fossa; BPO: basilar part of the occipital bone; PT: petrous part of the temporal bone; SP: styloid process.

sometimes prominently bulged, is known as the torus occipitalis transversus; it forms a distinct projection in anthropoids and to a lesser extent in earlier races of man (Srivastava 1992).

Sutural bones are usually small, irregularly shaped ossicles, often found in the sutures of the cranium, especially in the parietal bones. When the lateral portions of the transverse occipital sutures persist, the situation is termed sutura mendosa. This starts from both lambdoidal sutures and represents the remnant of a transverse occipital suture. This suture forms an interparietal bone (Inca bone or intercalary bone or sutural bone). As many as 172 sutural or Wormian bones have been found in one skull (e.g., Bonthier D’Andernach’s ossicle near the obelion). They are rarely found in the sutures of the face (Bergman et al. 1996). True interparietal bones or Inca bones are bounded by the lambdoid suture and sutura mendosa (transverse occipital suture). They were previously known as os Incae, os interparietale, or Goethe’s ossicles. An Inca bone resembles the triangular architectural monument design of the Inca tribe; it is rare, ranging between 0.8% and 2.5%. Inca bones occur due to non-fusion of the multiple ossification centers in the membranous portion of the squamous part of the occipital bone (Udupi and Srinivasan 2011) (Fig. 1.9).

Other variants of the basiocciput include clefts, fissures, noto-chordal remnants, and intrasynchondral ossified bodies. Near the basioccipital junction, accessory ossicles known as the basi-otic bone of Albrecht can sometimes be found. Accessory air cells of the jugular process of the occipital bone are known as the occipitojugular air cells of Mouret.

**Parietal bone**

Accessory intraparietal or subsagittal sutures are rare but can be seen dividing the parietal bone. They can be explained on the basis of incomplete union of the two separate ossification centers. These are usually bilateral and fairly symmetrical, but can occasionally be unilateral. The pattern of development can give rise to numerous accessory sutures that could be mistaken for fractures, especially with plain film evaluation alone. A CT scan with 3D reconstruction is vital for further characterization of a questionable fracture (Sanchez et al. 2010).

In the anterior between the paired frontal and parietal bones there is sometimes an accessory ossicle, os bregmaticum, either free or fused with one of the frontals or parietals (Bergman et al. 1996). The anterior fontanelle may remain open and the normal time to closure of this area is between 4 and 26 months of age (Tunnessen 1990).

A 14-week-old girl presented with characteristic signs of metopic craniosynostosis and frontal cranioplasty was recommended. Upon inspection of the cranium at the time of surgery, a large symmetrical bregmatic accessory bone (measuring 4.5 cm², pentagonal) was discovered. The cranium was broadly examined, including the area posterior to the region of the lambda and the area inferior to the squamosal sutures. No other unusual bones were present (Stotland et al. 2012).

Sutural or Wormian bones are small irregularly shaped bones found at the cranial sutures. Their size, shape, and number differ from skull to skull. A sutural bone is occasionally present at the pterion or junction of the parietal, frontal, greater wing of the sphenoid, and the squamous portion of the temporal bone. It is called “pterion ossicle,” “epipteric bone,” or Flower’s bone. Nayak and Soumya (2008) reported a case of three sutural bones at the pterion (Figs 1.10, 1.11).

![Figure 1.9](source_url) Photograph showing Inca (interparietal) bone.

**Figure 1.9** Photograph showing Inca (interparietal) bone.


![Figure 1.10](source_url) Lateral view of the skull showing sutural bones at the pterion. PB: parietal bone; FB: frontal bone; TB: temporal bone; GW: greater wing of sphenoid bone; SB: sutural bones; ZB: zygomatic bone.

**Figure 1.10** Lateral view of the skull showing sutural bones at the pterion. PB: parietal bone; FB: frontal bone; TB: temporal bone; GW: greater wing of sphenoid bone; SB: sutural bones; ZB: zygomatic bone.

Sphenoid bone

The sphenoidal sinus varies in size, septation, and extensions. The dimensions of the average sinus are 20 mm (height), 18 mm (width), and 12 mm (length). The capacity of the sphenoidal sinus varies from 0.5 to 30 mL, averaging about 7.5 mL. The bony plate separating the sphenoidal sinus from the optic nerve, maxillary division of the trigeminal nerve, the nerve of the pterygoid canal, the cavernous sinus, the carotid artery, and the hypophysis is sometimes very thin or absent, rendering these structures vulnerable in chronic sinus infections (Bergman et al. 1996). Idowu et al. (2009) reported a main single intersphenoid septum in 95% of patients. Poirier et al. (2011) studied high-resolution computed tomographic scans of patients undergoing endoscopic trans-sphenoidal pituitary tumor resection. They reported a mean of 1.57 septations for each sphenoid sinus. Çakur et al. (2011a, b) investigated the prevalence of sphenoid sinus hypoplasia and agenesis using dental volumetric computed tomography in an adult population. They reported no bilateral agenesis of the sphenoid sinus, though there was unilateral agenesis in 0.26% of the sample and sphenoid sinus hypoplasia was seen in 0.52% (unilateral in 0.26%, bilateral in 0.26%). A bony bridge sometimes connects the anterior and posterior clinoid processes, which are more usually connected by the fibrous interclinoid ligaments. If these ossify they give rise to the anatomical variation, which some authors consider rare. Its nomenclature in the literature is still vague; it has been variously named the interclinoid tenia, sella bridge, or interclinoid bony bridge. Its prevalence could be as high as 5% (Bergman et al. 1996; Aragão et al. 2013).

The sella turcica can be absent, hypoplastic, enlarged, and/or empty (i.e., empty sella syndrome). It has been reported to be duplicated or to have an intrasellar tubercle or spike.

The caroticoclinoid foramen is an inconstant structure located in the anterior cranial fossa. It is formed by the ossification of a fibrous ligament that begins on the anterior clinoid process and binds to the middle clinoid process. The caroticoclinoid foramen is a space through which the clinoidal segment of the internal carotid artery passes. It has an approximate diameter of 5.0–5.5 mm and causes morphological changes in the internal carotid artery in almost all cases, creating difficulty for neurosurgical techniques in the region (Freire et al. 2010) (Fig. 1.12).

Occasionally, ligaments near the foramen ovale – the pterygospinous (ligament of Civinini) and pterygoalar (ligament of Hyrtl) ligaments – ossify and form variant foramina. The pterygoalar bar is a bony bridge that stretches between the lateral pterygoid lamina and the greater wing of the sphenoid bone; the space under this bar is termed the pterygoalar foramen (Skrzat et al. 2005). Pterygospinous foramina occur in about 5% of cases. In another study, the pterygosphenoid foramen was found in 6.28% of 1544 skulls and in 5.46% of a second series of 2745 skulls in American whites and blacks; it was more frequent in the whites and in males (Bergman et al. 1996). Tubbs et al. (2009) analyzed 154 adult dry human skulls and reported one pterygosphenoid foramen (foramen of Civinini) and one pterygoalar foramen (foramen of Hyrtl). A study of 160 skulls revealed complete and incomplete pterygospinous foramina in 1.25% and 7.5%, respectively (Saran et al. 2013).

The foramen rotundum is 1–5 mm from the superior orbital fissure and has a lateral angulation of 3–20° (Sondheimer 1971).
Its length falls within the range 1–5 mm and average width is 1.5–4 mm. A small foramen within the foramen rotundum can sometimes be found in its inferomedial wall and might transmit an emissary vein (Sonheimer 1971). The foramen may be narrowed or missing.

Among several foramina on the greater wing of the sphenoid bone, the inconstant foramen of Vesalius connects the pterygoid plexus with the cavernous sinus and transmits a small emissary vein that drains the cavernous sinus. The importance of this foramen is that it offers a pathway for the spread of infection from an extracranial source to the cavernous sinus. The small foramen of Vesalius, if present, is generally situated posteromedially from the foramen rotundum and anteromedially from the foramen ovale, foramen spinosum, and carotid canal. In a study of 377 dry skulls, the foramen of Vesalius was present in 11.9% unilaterally and 4.2% bilaterally (Chaisuksunt et al. 2012). Vesalius was the first to describe and illustrate the foramen that bears his name (foramen Vesalii), which is 1–4 mm in diameter. It is also known as the sphenoid emissary foramen, foramen venosum (of Vesalius) and canaliculus sphenoidalis. When present, it is located between the foramen rotundum and the foramen ovale on its medial side. It is traversed by a vein (vein of Vesalius), a small emissary from the cavernous sinus to the pterygoid plexus. It is not uncommon: in 157 skulls it was found 26 times bilaterally (17%) and 20 times unilaterally (13%). One report suggests a frequency as high as 40% (unilateral or bilateral) (Bergman et al. 1996). In another study of 400 skulls, the foramen of Vesalius was identified in 135 (33.75%) and absent on both sides in 265 (66.25%). It was present bilaterally in 15.5%. Its incidence was 18.25%, 7.75% on the right side and 10.5% on the left (Shinohara et al. 2010). It is also variable in size, shape, and position.

An innominate canal of Arnold is sometimes found a few millimeters posterior to the foramen ovale and medial to the foramen spinosum. It is seen in about 20% of skulls. When present, the lesser petrosal nerve travels through this defect.

The foramen ovale occasionally exhibits variations. Its length ranges from 1 to 10 mm and the width from 3 to 10 mm (Sondheimer 1971). Ray et al. (2005) observed variant foramina ovale in 24.2% of the skulls they studied. Its venous segment can be separated from the remainder of its contents by a bony spur, resulting in a so-called doubled foramen ovale. Such spurs are present in 0.5% of subjects studied (Bergman et al. 1996). Reymond et al. (2005) found that the foramen ovale is divided into two or three components in 4.5% of cases. Moreover, the borders of the foramen ovale in some skulls were irregular and rough. On radiological images this could suggest morbid changes, possibly the sole anatomical variation. An accessory process behind the foramen ovale is termed the process of Weber. When the innominate foramen is not present, the lesser petrosal nerve exits the skull through the foramen ovale. The foramen ovale can be confluent with the foramen lacerum and/or the foramina spinosum and Vesalius.

The foramen spinosum is 2–4 mm long and may communicate with the innominate foramen. Bergman et al. (1996) reported the absence of the foramen spinosum in 0.64–4.57% of cases. Nikolova et al. (2012) reported its absence as 0.72% on the right side and 2.13% on the left in medieval female skulls. The absence of the foramen spinosum involves an unusual development and course of the middle meningeal artery and is usually accompanied by replacement of the conventional middle meningeal artery with one arising from the ophthalmic artery system. In these cases, the middle meningeal artery most often enters the middle cranial fossa through the superior orbital fissure and rarely through the meningo-orbital foramen (Nikolova et al. 2012). If the middle meningeal artery has its usual origin, it enters the cranial cavity via the foramen ovale in the absence of a foramen spinosum (Bergman et al. 1996). When the lacrimal artery arises from the middle meningeal artery, it enters the middle fossa through an accessory foramen in the floor of the sphenoid bone known as the foramen of Hyrtl.

The superior orbital fissure can be divided into three anatomical regions by the annulus of Zinn: lateral, central, and inferior regions. The lateral wall of the superior orbital fissure can also be divided into upper and lower segments; and the angle between them was found to be 144.27±20.03° (Shi et al. 2007). According to Govsa et al. (1999), nine different shapes of the superior orbital fissure were observed based on the classification of Sharma et al. (1988) (Fig. 1.13, Table 1.1). The shape of the superior orbital fissure was first classified into six different types by Shapiro and Janzen (1960). Sharma et al. (1988) added three new types to this classification and Magden et al. (1995) added eight original types to Sharma’s classification. Natori and Rhoton (2007) measured the distance from the superomedial to the superolateral edges of the superior orbital fissure as 15.9 mm (7.7–22.1 mm), the distance from the superomedial to the inferior edge as 17.6 mm (10–24.3 mm), and the distance from the superomedial to the inferior edge as 7.0 mm (5.6–8.2 mm) (Natori and Rhoton 1995). Govsa et al. (1999) found the distance from the superomedial edge to the superolateral edge to be 17.3±3.4 mm on the right side and

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
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</tr>
<tr>
<td>II</td>
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<tr>
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</tr>
<tr>
<td>VIII</td>
<td>10.7%</td>
</tr>
<tr>
<td>IX</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

*Figure 1.13 Variations in the shapes of the superior orbital fissure.*

Source: Sharma et al. (1988).