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 sinus 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). Aydınıoğlu 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 sutureal 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 ectometopic 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

Figure 1.1 Severe case of hyperostosis frontalis interna with typical midline sparing along the frontal crest. Notice the tortuous pathway of the middle meningeal artery. FC: frontal crest; GMMA: groove for middle meningeal artery.


Figure 1.2 Picture shows the measurement of a large nodule (2.08 cm) located adjacent to the frontal crest at the juncture of the frontal and parietal bones.


Figure 1.3 Notice the significant compression of the frontal lobes.

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 vertebrae”). 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).

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 1.7** (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).

**Source:** Chauhan et al. (2010). Reproduced with permission from International Journal of Anatomical Variations.

![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.

**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.

**Source:** Rastogi and Budhiraja (2010). Reproduced with permission from International Journal of Anatomical Variations.
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 lambdoidal 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, notochordal remnants, and intrasynchondrosal 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 occipitojugal 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** Photograph showing Inca (interparietal) 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.

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 interclinoïd 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 interclinoïd tenia, sella bridge, or interclinoïd 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 ligmament 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 pterygoaral (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 pterygospinous 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 pterygospinous 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 (Chaisukunt 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. 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. 1996). The venous segment can 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 types of shape 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 (1994) 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 superolateral 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

![Figure 1.13 Variations in the shapes of the superior orbital fissure.](source: Sharma et al. (1988).)
cess. In 60% of the cases, the vomerovaginal canal originates on the upper surface of the vaginal process of the pterygoid process. The palatovaginal canal lies on the inferior surface of the vaginal process of the pterygopalatine fossa. The posterior opening of the palatovaginal canal is bounded by the inferior surface of the palatine bone. Its anterior opening lies in the posterior wall of the greater wing of the sphenoid bone. The upper slightly concave border of the roof had a small notch on 66 sides (17.7%).

16.9±2.9 mm on the left side, the distance from the superolateral to the inferior edge to be 20.8±3.9 mm on the right and 20.1±3.8 mm on the left side, and the distance from the superomedial to the inferior edge to be 9.5±2.2 mm on the right and 9.0±2.4 mm on the left side. Another study by Raymond et al. (2008) classified the morphology of the superior orbital fissure into nine types. Fissures A–E were grouped into one type and named type “a”; fissures F–I were grouped as morphological types “b.” Type a occurred in 63% and type b in the remaining 37%. Type a had a mean length of 17.47 mm (SD=2.26) and a mean width of 7.31 mm (SD=2.34). Type b had a mean length of 12.48 mm (SD=3.15) and mean width of 7.86 mm (SD=2.45).

The inferior orbital fissure is medially narrower and laterally wider. Its anterolateral border in about 50% of individuals is formed by the zygomatic bone, while in the remaining 50% it is formed by the sphenoid and maxillary bones (Lang 2001). In rare cases, mainly in the older population, this part of the fissure may be thinned and orbital fat may protrude into the temporal fossa. Its length is approximately 20 mm long (Lang 2001). According to De Battista et al. (2012), the inferior orbital fissure length ranges from 25 to 35 mm (mean 29 mm). The length/width of the individual anterolateral, middle, and posteromedial segments averaged 6.46/5, 4.95/3.2, and 17.6/2.4 mm, respectively.

A study by Xu et al. (2004) classified the morphology of the inferior orbital fissure as either: (1) baseball bat shaped; or (2) V shaped.

The vomerobasilar canal lies between the sphenoid bone and the wings of the vomer. It is present in the majority of the cases. The palatovaginal canal is also present in the majority of the cases. The palatovaginal canal is formed by a longitudinal groove on the inferior surface of the vaginal process, which is converted into a canal anteriorly by the sphenoidal process of the palatine bone. Its anterior opening lies in the posterior wall of the pterygopalatine fossa. The posterior opening of the palatovaginal canal lies on the inferior surface of the vaginal process of the sphenoid bone. On that surface and posterior to the opening, a small groove is present in most cases. The vomerovaginal canal is bounded by the inferior surface of the sphenoid bone, the upper surface of the vaginal process of the pterygoid process. In 60% of the cases, the vomerovaginal canal originates posterior to the anterior opening of the pterygoid canal, with an average distance of 4.4 mm (Lang 1995). In the remaining 40%, the vomerovaginal canal originates within the pterygopalatine fossa medial to the anterior opening of the pterygoid canal. Tanaka (1932) found it arising from the anterior part of the pterygoid canal in 18.3% of his Japanese specimens. The overall mean length of the vomerovaginal canal was 7 mm.

Within the vomerovaginal canal there are on average three nerve fiber bundles with a thickness of 136 μm (55–370 μm) and also 1–3 arteries with an average lumen of 38 μm (74–814 μm). The median craniohypophyseal canal is present in 0.5% of the adult population. The lateral craniohypophyseal canal lies between the medial border of the superior orbital fissure and the vomerovaginal canal. It is usually seen in children of 6 years in age or less (Lang 2001).

The pterygoid canal travels below the level of the floor of the sphenoidal sinus in 38% of individuals (Lang 1989). The roof of the canal is dehiscent in 10% and the nerve runs at the same level in 18% (Lang 1989). The pterygoid canal (Vidian canal) is 11.5–23 mm long and, in 44% of cases, runs anteromedially. The posterior opening of the canal is 12.4–19.2 mm from the midline and the anterior opening is 5.5–17.5 mm from the midline (Lang 1989). In about one-third of skulls, the canal protrudes into the floor of the sphenoid sinus. In about 3% it is entirely within this sinus, and in 6% the roof of the canal is dehiscent (Sondheimer 1971).

The carotid canal is in the inferior aspect of the petrous part of the temporal bone; and is 5–6.5 mm wide and 3–4 cm long. It can be absent with associated agenesis of the internal carotid artery.

The basi-sphenoid can have a retro-orbital pseudoforamen.

The optic canal has variable dimensions as described by Mancalco and Haba (1978) in their study of 83 cadavers, with a mean length of 9.22 mm (5.5–11.5 mm), mean horizontal canal width 7.18 mm (5–9.5 mm), mean medial canal wall proximal thickness 0.21 mm (0.1–0.31 mm), and mean optic ring thickness 0.57 mm (0.4–0.74 mm). In a study by Choudhry et al. (2005), the cranial openings of the optic canal viewed from the cranial aspect revealed a large number of recesses, fissures, and notches. In 229 sides (61.5%) of the 372 examined, the cranial opening of the optic canal was found to be associated with recesses on its lateral wall. These were bilateral in 224 sides (112 skulls) and unilateral in 7 sides. The recess was mostly accompanied by a fissure (42.4%) in the superior root of the lesser wing of the sphenoid bone. The upper slightly concave border of the roof had a small notch on 66 sides (17.7%).

A duplicated optic canal is a rare variation. Typically, the larger canal contains the optic nerve and the meninges and the smaller canal transmits the ophthalmic artery (Choudhry et al. 1988). Duplicated optic canals are separated by a septum of variable thickness dividing the posterior part of the canal into a large canal in the usual position and a smaller canal inferior to it or a bar forming the caroticocclinoid canal. Other duplicated canals may be divided by thin septae having a small slit (Choudhry et al. 1999). White (1923), Whitnall (1932),

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### Table 1.1 Comparative study of the types of shapes of the superior orbital fissure (percent).

<table>
<thead>
<tr>
<th>Type</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>Other</th>
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</thead>
<tbody>
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<td>Shapiro</td>
<td>40</td>
<td>16</td>
<td>12</td>
<td>12</td>
<td>9</td>
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<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Sharma</td>
<td>14</td>
<td>13</td>
<td>6.65</td>
<td>2.8</td>
<td>1.86</td>
<td>48.6</td>
<td>7.47</td>
<td>3.73</td>
<td>1.86</td>
<td>—</td>
</tr>
<tr>
<td>Magden</td>
<td>1.5</td>
<td>2.4</td>
<td>9.9</td>
<td>3.4</td>
<td>0.7</td>
<td>4.6</td>
<td>6</td>
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<td>38.8</td>
<td>15.2</td>
</tr>
<tr>
<td>Govsa</td>
<td>12.1</td>
<td>4.8</td>
<td>12.6</td>
<td>9.8</td>
<td>1.4</td>
<td>35.4</td>
<td>10.7</td>
<td>10.7</td>
<td>2.5</td>
<td>—</td>
</tr>
</tbody>
</table>

Keyes (1935), and Choudhry et al. (1988, 1999) have reported duplicated optic canals. Bilaterally duplicated canals are very rare variations and are seldom reported in the literature (Zoja 1885; Le Double 1903; Warwick 1951; Choudhry et al. 1988; Magden and Kaynak 1996; Singh 2005).

Temporal bone

The styloid processes vary markedly in length and can comprise two–five osselets, articulating by synchondroses (Bergman et al. 1996); the stylohyoid ligament can calcify to make a rigid connection with the hyoid bone. A 75-mm-long styloid process has been reported but the usual length is 2–3 cm. When it is more than 3 cm it is called an elongated styloid process; and can cause pain in the throat, difficulty in swallowing, foreign body sensation, carotid artery compression syndrome, etc. This elongation was first described in 1652 by the Italian surgeon Pietro Marchetti. In 1937, Watt W. Eagle coined the term “stylalgia” to describe the pain associated with elongation of the styloid process. Kolagi et al. (2010) reported a case of bilaterally elongated styloid process with ossified stylohyoid ligament. The total length of the process was 8 cm and it was 1 cm thick at the base which is extremely rare. The styloid process proper was 5 cm long and the remaining 3 cm was ossified stylohyoid ligament, the junction between the two being marked by a bulge of bony mass (Fig. 1.14).

Mukherjee et al. (2011) reported a 24-year-old female who presented with a two-year history of foreign body sensation in her throat, more to the left side, along with dysphagia, excessive salivation, and vague pharyngeal pain radiating to the mastoid region aggravated by rotation of the head. Palpation of the tonsillar fossa revealed elongated styloid processes on both sides. Digital X-ray of the skull revealed asymmetrical ossification of bilateral stylohyoid chains. On the left side it comprised two components, with the long styloid process as proximal and calcified stylohyoid ligament as distal part, total length (approximately) 4.7 cm with prominent “pseudoarticulation.” On the right side it was (approximately) 4.5 cm long, the distal portion being calcified stylohyoid ligament, but the proximal elongated styloid process was again divided into two parts representing its tympanohyal and stylohyal components (Fig. 1.15).

About 4% of the population has styloid processes more than 3 cm long; however, only 4.0–10.3% of these are symptomatic. Sasani et al. (2013) reported a case of bilateral elongated styloid processes that extended to the C3 vertebral level on the right side (78 mm) and C2 on the left (50 mm) (Fig. 1.16).

Embryologically, four different segments are present in the stylohyoid apparatus: the tympanohyal, stylohyal, ceratohyal, and hypohyal segments. The ligamentous part has its origin from the ceratohyal cartilage and extends from the stylohyal segment to the lesser horn of hyoid bone. There is a potential for ossification of the ligament, and when it is ossified there can be segmentation and pseudoarticulation (Sasani et al. 2013).

A canal or foramen (foramen of Hüschke) is found in the floor of the bony part of the external auditory meatus, near...
Chapter 1: Skull

Figure 1.15  Photograph shows the bilateral asymmetrical ossification of the stylohyoid chain (white arrowheads).

Figure 1.16  Bilateral elongated styloid processes are more prominent on the right side (red arrows) than the left side (yellow arrows), and extended to C3 vertebral level.
Source: Sasani et al. (2013). Reproduced with permission from International Journal of Anatomical Variations.

Figure 1.17  Figure showing a single oval-shaped foramen (red arrow) having transverse diameter of 0.2 cm and longitudinal diameter of 0.1 cm was noted on the left tympanic plate, and a single rounded foramen (white arrow) of 0.1 cm in diameter is present on the right side.

the tympanic ring, during the first five years of life. It can persist throughout life (Bergman et al. 1996). The German anatomist Hüschke (1797–1858) first described the probability of a deficiency in the development of the tympanic plate of the temporal bone, named the “foramen of Hüschke” or foramen tympanicum, which usually becomes apposed in adulthood. If it persists in adult life, complications can ensue such as herniation of the temporomandibular joint (TMJ), formation of salivary otorrhea, and spread of infection or tumor from the external acoustic meatus to the infratemporal fossa and vice versa. Srimani et al. (2013) identified seven cases of foramen of Hüschke among 53 skulls studied. The diameter of the foramen was 1–3 mm (Srimani et al. 2013) (Fig. 1.17). The external auditory meatus is sometimes duplicated (Vokurka 1989). The mastoid process can have a doubled apex, the medial portion being divided from the lateral by a fissure. Usually, the medial lip of the groove forms a distinct ridge and provides the point of attachment of the digastric muscle; an enlarged paramastoid process can result from the development of air cells within the medial portion of the process. Air cells, usually confined to the mastoid process, can invade the horizontal or vertical part of the squama or even the pars petrosa (Bergman et al. 1996). In a study of 298 temporal bones, 6% of the mastoid processes exhibited variations. There was no statistically significant difference between genders (Manolis et al. 2008).

The petrosphenoid ligament may be ossified and result in a bony foramen for the abducens nerve to travel through. Accessory ossicles can be present in the foramen lacerum and are known as ossicles of Cortese and Riolan. An accessory tubercle
of the supramastoid crest is known as the tubercle of Waldeyer. The internal acoustic meatus can be narrowed, dehiscent, doubled, or tripled.

**Ethmoid bone**

The crista galli can be pneumatized (Bergman et al. 1996). Hajiioannou et al. (2010) reviewed computed tomography findings of the morphology of the crista galli in 99 patients. Pneumatization of the crista galli was noticed in 14.1% of the scans.

The superior nasal conchae can also be pneumatized. Ari-yürek et al. (1996) evaluated CT scans of 52 patients who underwent CT examination prior to endoscopic sinus surgery and had normally aerated posterior ethmoidal cells and an unobscured nasal cavity. Pneumatization was evident in 48% of these patients. The superior turbinates seemed to be aerated through the posterior ethmoidal cells.

There are sometimes accessory ethmoidal foramina. Takahashi et al. (2011) studied 54 orbits from 27 Japanese cadavers. Accessory ethmoidal foramina were detected in 18 orbits (33.3%) from 11 cadavers; one accessory foramen (middle ethmoidal foramen) was identified in 17 orbits, and two foramina (additional deep middle ethmoidal foramina) in one orbit (Takahashi et al. 2011). The textbook number of ethmoid foramina is two; Lang (1983) found them on the left side in 68.3% of skulls and on the right side in 67.4%. In the remainder there were three–five; there were three foramina in about 40% of skulls (Bergman et al. 1996).

The perpendicular plate may protrude outward between the nasal bones (Lang 1989).

**Lacrimal bone**

The lacrimal bone can be divided into two or more parts or fused with neighboring bones. This bone sometimes exhibits so many minute foramina that it takes the appearance of a bony net (Bergman et al. 1996). Its thickness is variable. Hartikainen et al. (1996) reported the mean thickness of the bone as 106 μm. In 67% of patients the mean thickness of individual lacrimal bones was less than 100 μm and in 4% it was more than 300 μm. The thinnest measured cross-section of the lacrimal bone sample was 11 μm and the thickest was 722 μm. The lacrimal bone is composed of a thin plate of lamellar bone. An accessory osssicle located deep to the lacrimal bone has been termed the ossicle of the lacrimal canal or the ossicle of Gruber.

**Vomer**

Isolated vomer aplasia is rarely reported in the literature. It is a genetic variant presenting with no significant medical problems (Verim et al. 2012). Recently, absence of the vomer during the first two trimesters of pregnancy was identified as a marker of trisomy 21 and trisomy 13. There was no single case of trisomy in which the vomer could be identified during the first or early second trimester. The diagnostic accuracy of the vomer as a marker for trisomy was 0.985 (Mihailovic et al. 2012).

The vomer can be separated from the perpendicular plate of the ethmoid by a strip of cartilage from the nasal septum (Bergman et al. 1996). Rarely, a recess of the sphenoid sinus can extend into the vomer (Lang 1989).

**Inferior nasal concha**

Lang and Kley (1981) reported absence of the conchae, the vomer, and perpendicular plate. Bony bridges may exist between the inferior and middle nasal conchae. The inferior concha may be notched or have a curved convex surface.

**Maxilla**

Two or more infraorbital foramina have been described. Gruber reported that the number can range from one to five. In 1970, Kadanooff, Mutafov and Jordanov tabulated and illustrated the variety of infraorbital foramina found in over 1400 skulls; they found it doubled in 9%, tripled in 0.5%, and more than tripled in 0.3% (Bergman et al. 1996). Boopathi et al. (2010) examined 80 dry adult South Indian human skulls of unknown age and gender. Accessory infraorbital foramina were found in 16.25%. Saylam et al. (1999) examined 119 crania and 229 maxillae (a total of 467 infraorbital foramina); they found a single accessory foramen in 11.5% of specimens and double accessory foramina in 1.28%. In 79.6% of those with a single accessory foramen, the accessory foramen was superior and medial to the main opening.

The infraorbital canal issues a small branch on its lateral face close to its midpoint to allow the anterior superior alveolar nerve to pass. This small canal, sometimes called the canalis sinuosus, runs forward and downward to the inferior wall of the orbit, lateral to the infraorbital canal and bent medially to the anterior wall of the maxillary sinus, passing below the infraorbital foramen (Neves et al. 2012).

Maxillary sinus hypoplasia is an uncommon condition. It can be misdiagnosed as an infection or a neoplasm of the maxillary sinuses. Variations of the other paranasal structures, especially the uncinate process associated with maxillary sinus hypoplasia, have been defined. Maxillary sinus hypoplasia shows three distinct patterns: type I, mild hypoplasia of the maxillary sinus, normal uncinate process and a well-developed infundibular passage; type II, significant hypoplasia of the maxillary sinus, hypoplastic or absent uncinate process and absent or pathological infundibular passage; and type III, absence of an uncinate process and cleft-like maxillary sinus hypoplasia (Erdem et al. 2002).
Bilateral maxillary sinus aplasia or severe hypoplasia with associated paranasal sinus variations is extremely rare. Tasar et al. (2007) reported two cases with severe maxillary sinus hypoplasia/aplasia, one of them associated with other paranasal sinus variants. Aydinioglu and Erdem (2004) examined CT scans in the axial and coronal planes of the paranasal sinuses of 1526 patients. They reported only one case of bilateral and only one case of unilateral maxillary sinus aplasia.

The maxillary sinus can be septated. These septa are barriers of cortical bone that arise from the floor or the walls of the sinus, and can even divide the sinus into two or more cavities. They can originate during maxillary development and tooth growth, in which case they are known as primary septa, or can be acquired structures resulting from the pneumatization of the maxillary sinus after tooth loss, in which case they are called secondary septa. Between 13% and 35.3% of maxillary sinuses have septa (Maestre-Ferrín et al. 2010).

Accessory ostia of the maxillary sinus are found in about 30% of skulls; as many as three in one skull have been reported (Bergman et al. 1996).

The incisive part of the alveolar process can be an independent bone, the os incisivum (Bergman et al. 1996). The discovery of the premaxillary bone (os incisivum, os intermaxillare, or premaxilla) in humans has been attributed to Goethe, so it has also been named “os Goethei”. However, Broussonet and Vicq d’Azyr obtained the same result in 1779 and 1780, respectively, using different methods. Early anatomists described this medial part of the upper jaw as a separate bone in the vertebrate skull; Coiter was the first in 1573 to present an illustration of the sutura incisiva in the human (Barteczko and Jacob 2004). Sutural bones can sometimes be seen in the sutures of the hard palate.

**Palatine bone**

One study demonstrated that the sphenopalatine foramen can be single (61.5–87%), double (11.1–32.5%), triple (1.9–5.5%), or quadrupled (0.05%) (Lang 1995). It is located at the superior nasal meatus in 81.5% of cases, between the middle and superior nasal meatus in 14.8%, and in the middle nasal meatus in 1.9% (Scanavine et al. 2009).

The lesser palatine canal is frequently absent. It can also be located between the palatine bone and maxilla (Bergman et al. 1996).

The torus palatinus is an overgrowth of bone in the palatal region and represents an anatomical variation. Its prevalence varies with the population studied and its etiology is still unclear; however, it seems to be a multifactorial disorder with genetic and environmental involvement. Surgical removal of the torus palatinus is indicated under the following circumstances: (1) deglutition and speech impairment; (2) cancer phobia; (3) traumatized mucosa over the torus; and (4) prosthetic reasons (Nogueira et al. 2013). Palatal tori are seen in approximately 20–30% of the population and are more common in females than in males. Frequently, these bony outgrowths are incidental findings on routine oral examinations, and there is often considerable variation in clinical appearance (Bennet 2013).

Simunković et al. (2011) studied 1679 subjects, 985 females and 694 males in the age range 9–99 years, who were subjected to clinical examination and analysis of plaster casts. The torus palatinus was found in 42.9%, 40.1% of females and 46.8% of males, indicating a significantly higher prevalence in the male population ($P=0.006$). Interestingly, Sisman et al. (2008) studied 2660 patients and reported the prevalence of the torus palatinus as low as 4.1%. Yildiz et al. (2005) examined a total of 1943 schoolchildren, 1056 males and 887 females ranging in age from 5 to 15 years. The prevalence of the torus palatinus in the study population was 30.9%, and was significantly more frequent in females than males (34.3 vs 28.1%, $P<0.005$). Most of the palatine tori were smaller than 2 cm (91.5%) and in molar location (62.9%).

The hard palate has been reported to be duplicated by Bruns (1947) and can have a cleft. Wormian bones can be seen in between the palatine bones or between this bone and the maxillary part of the hard palate.

**Zygomatic bone**

The zygomatic bone is sometimes divided into two parts by either a horizontal or a vertical suture. Such a bipartite bone has been called os Japonicum (os Ainoicum) as it has mostly been observed in Japanese subjects. A sutural bone may be seen between the zygomatic bone and temporal bones where they join to form the zygomatic arch. Anil et al. (2000) studied 1266 zygomatic bones in 633 dry Anatolian skulls and 1348 zygomatic bones in 674 plain cranium radiographs of adult patients. The os Japonicum was present in 2.2% of female and 1.7% of male specimens. All 24 multipartite bones observed in the study were bipartite except for one. In addition, 15 of 690 female (2.2%) and 12 of 658 male (1.8%) zygomatic bones examined radiologically were bipartite or tripartite; there was a total of 674 plain cranium radiographs. Jayasingh et al. (1982) studied 500 crania in Uttar Pradesh and found the prevalence of os Japonicum to be 4%. Typical bipartite zygomatic bone was present in 40 instances. In only 6 bones, a horizontal groove was seen on the temporal surface. In one skull the zygomatic process of the maxilla and the zygomatic process of the temporal bone articulated directly on the temporal surface of the zygomatic bone. In another skull the maxilla and the temporal bone articulated with each other along the lower border of the zygomatic bone, giving the appearance of a tripartite condition.

Multiple zygomaticofacial and zygomaticotemporal canals can be observed; their detailed intrabony courses are unknown. Kim et al. (2013) scanned 14 sides of the zygomatic bones with micro-computed tomography, with 32 μm slice thickness. They
found that some zygomaticotemporal canals originated from the zygomaticofacial canal. In 71.4% of specimens the zygomaticotemporal canals divided from the intrabony canal along the course of the zygomaticofacial canals; 28.6% of zygomaticotemporal canals were opened through each corresponding zygomaticotemporal foramen. The zygomaticofacial canal originated from the zygomaticoorbital foramen, divided into some of the zygomaticotemporal canals, and finally opened as the zygomaticofacial foramen. Aksu et al. (2009) evaluated the number of foramina on the facial aspects of zygomatic bones. There were none in 15.6%, one in 44.4%, two in 28.1%, three in 6.3%, four in 4.4%, and five in 1.3% of sides. Loukas et al. (2008) studied 200 dry human skulls for zygomaticofacial (ZF), zygomaticoorbital (ZO) and zygomaticotemporal (ZT) foramina. All three foramina varied from absence to as many as four small openings. The authors classified each of these foramina as types I–V for single, double, triple, quadruple, and absent foramina, respectively. The relative frequencies were as follows: type I, ZO 50%, ZF 40%, ZT 30%; type II, ZO 20%, ZF 15%, ZT 15%; type III, ZO 10%, ZF 5%, ZT 5%; type IV, ZO 3%, ZF 1%, ZT 0%; and type V, ZO 17%, ZF 39%, ZT 50%.

Similarly, Mangal et al. (2004) studied these foramina in 165 dry human skulls. A single ZF foramen was seen in 148 (44.9%) sides. Two ZF foramina were found in 92 (27.9%) sides, out of which 29 (8.8%) sides had one ZO foramen, while 63 (19.1%) sides had two ZO foramina. Three ZF foramina, a relatively uncommon occurrence, were found in 17 (5.1%) sides, which included eight (2.4%) sides with one less and nine (2.7%) sides with the same number of ZO foramina. Four ZF foramina were seen in one (0.3%) side with three on the orbital aspect, a feature not reported before.

Govsa et al. (2009) reported that the angle between the ZT nerve and the ZF nerve within the orbit was approximately 42.21 degrees. The mean (SD) distance between the orbital opening of the ZT nerve and the meeting point of the ZT nerve was measured as 9.21 (5.18) mm. The mean (SD) distance between the orbital opening of the ZF nerve and the meeting point of the ZF nerve was calculated as 11.22 (4.25) mm. The mean (SD) distance between the orbital opening of the ZFN and the infraorbital margin of the orbit was 13.04 (3.21) mm. According to Tubbs et al. (2012), the zygomaticotemporal nerve penetrated the facial muscles at a mean of 2.3 cm superior to the zygomatic arch.

The orbital eminence (eminentia orbitalis) or marginal tubercle (of Whitnall) is located on the orbital surface of the frontal process of the zygomatic bone just within the orbital margin and about 1 cm inferior to the frontozygomatic suture (Didio 1962). The marginal tubercle serves as an attachment point for the lateral check ligament. According to Lang (1989), the marginal tubercle is present in 20% of the cases before puberty and in 95% of adults. The marginal process was present in 4% of the cases.

Other authors have also studied the incidence of the marginal tubercle and are presented in Table 1.2.

### Table 1.2 Incidence of marginal tubercle.

<table>
<thead>
<tr>
<th>Reference</th>
<th>No. samples</th>
<th>Incidence (%)</th>
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<tbody>
<tr>
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<td>2000 skulls</td>
<td>&gt;95</td>
</tr>
<tr>
<td>Buschkowitsch (1927)</td>
<td>419 skulls</td>
<td>63</td>
</tr>
<tr>
<td>Kangas (1928)</td>
<td>1,350 skulls</td>
<td>80.1</td>
</tr>
<tr>
<td>Ono (1928)</td>
<td>164 skulls</td>
<td>80</td>
</tr>
<tr>
<td>Tomita (1935)</td>
<td>476 skulls</td>
<td>49.15</td>
</tr>
<tr>
<td>Didio (1942)</td>
<td>285 skulls and 100 living</td>
<td>89.56</td>
</tr>
<tr>
<td>Didio (1962)</td>
<td>163 skulls</td>
<td>96.3</td>
</tr>
</tbody>
</table>

### Mandible

The mandible varies extensively in size and weight during an individual’s lifetime. The chin can protrude or recede, and there can be one rather than two mental tubercles (Bergman et al. 1996). A torus mandibularis can be present on one or both sides of the lingual aspect of the mandible.

The mental foramen is sometimes doubled or tripled. It can be located as far forward as the first premolar or as far back as the second. In very rare cases a median mental foramen is present, comparable with an arterial canal normally found in certain apes (Bergman et al. 1996). Sahin et al. (2010) reported a case with double mental nerve and foramina in a 44-year-old trauma patient. On the left side, below the level of the premolar teeth, two mental nerves emerged from two different mental foramina. The nerves had almost the same diameter. One of the mental foramina was located more anterior and superiorly (Fig. 1.18).

In contrast to other primates the mental foramen is usually single in humans, but accessory foramina have been recorded. It has been suggested that separation of the mental nerve into several fasciculi earlier than the formation of the mental foramen up to the 12th gestational week could explain why accessory mental foramina are formed (Hasan et al. 2010). Naitoh et al. (2011) analyzed...
365 patients (130 males and 235 females). Para-panoramic images were reconstructed from cone-beam computed tomography (CBCT) images of the accessory mental foramen/foramina using 3D visualization and measurement software. A total of 37 accessory mental foramina were observed in 28 patients on CBCT images. Naitoh et al. (2009) studied CBCT images of 157 patients and found accessory mental foramina in 7%. The presence or absence of the accessory structure had no significant effect on the size of the mental foramen. The mean distance between the mental and accessory mental foramina was 6.3 mm (SD 1.5 mm). Toh et al. (1992) reported three cases with accessory mental foramina in which the distribution of the accessory mental nerve was different. These nerves communicated with the branches of the facial and buccal nerves.

In very rare cases the mental foramen is absent. The foramen was absent twice on the right side (0.06%) and once on the left side (0.03%) in a study of 1435 dry human mandibles (2870 sides) (de Freitas et al. 1979). The frequency of unilateral absence of the mental foramen ranges from less than 0.02% to 0.47%. No sexual or ethnic differences in absence of the mental foramen have been found (Hasan et al. 2010). Hasan et al. (2010) reported one case with bilateral absence of the mental foramina. The dry mandible (unspecified age and sex, and unknown ethnic background, average sized, and partially edentulous) was normal in all other aspects of gross morphology. The mandibular foramen was bilaterally symmetrical and the mandibular canal was patent to a distance of 3 cm on the right and 4.7 cm on the left side using a steel wire probe. Radiography established normal bone density with no evidence of age-related bone resorption or previous surgical or mechanical trauma, establishing that the case was one of congenital absence of the mental foramen (Fig. 1.19). An accessory foramen (of Dubreuil–Chambardel) has been described in the mandibular symphysis.

Chauhan and Dixit (2011) reported a mandible with unusually long coronoid processes on both sides. It proved to be that of male in late adulthood. The length of the coronoid was taken from the line tangent to the deepest part of the mandibular notch to the apex; it measured 2.4 cm on the right and 2.6 cm on the left side (Fig. 1.20).

Coronoid processes project above the level of the condyles at the time of birth. As the neck of the mandible grows, it comes to lie at a lower level in adults. Unusual elongation of the coronoid process, formed of histologically normal bone with no synovial tissue around it, suggests hyperplasia. Bilateral hyperplasia of the coronoid processes of the mandible is quite infrequent and affects mostly males (male to female ratio 5:1) between the ages of 14 and 16. It leads to restricted mouth opening caused by impingement of the process on the medial and anterior surfaces of the zygomatic arch (Chauhan and Dixit 2011). Huang et al. (2013) studied mandibular morphology and dental anomalies to propose a relationship between mandibular/dental phenotypes and deficiency of CCAAT/enhancer-binding protein beta in mice. They concluded that CCAAT/enhancer-binding protein beta deficiency was related to elongation of the coronoid process and formation of supernumerary teeth.

A small accessory tubercle on the posterior border of the coronoid process is known as Delachapelle’s tubercle. An accessory tubercle between the oblique line and anterior margin of the ramus of the mandible is termed the proeminentia lateralis of Rasche.

**Nasal bone**

There can be several nasal bones or only one (unpaired). Inter-nasal bones have been found at the edges of the nasal bones in the upper corner of the piriform aperture, lying on the anterior tip of the perpendicular plate of the ethmoid (Fig. 1.21) (Bergman et al. 1996).
Teeth

It is common to find fewer (partial anodontia) than the normal complement of teeth, although complete absence (true anodontia) of the teeth has been reported (Woelfel and Scheid 1997). The upper lateral incisors are most often absent, then the second lower premolars, the wisdom teeth, and the medial incisors, in that order. The upper canines are rarely missing, the upper premolars and second molars even more rarely, and most rarely the first permanent molars (Bergman et al. 1996). The mandibular canine tooth and root can divide into labial and lingual parts or its lingual surface can be shovel-shaped. This rarely occurs with the maxillary canine (Woelfel and Scheid 1997).

Supernumerary teeth can appear in both deciduous and permanent dentitions, but usually in the permanent dentition, and occur in 0.3–3.8% of the population (Woelfel and Scheid 1997). The most common supernumerary tooth is a mesiodens, which is usually small and conical, between the maxillary incisors. This is generally followed by maxillary lateral incisor, maxillary fourth molar, and mandibular third premolar supernumeraries. Supernumerary maxillary premolar, canine, and mandibular fourth molar are the least common. The incidence in the mandibular anterior tooth area is about 0.01% (Rossi et al. 2010). Rossi et al. (2010) reported a supernumerary permanent lower incisor in the dry mandible of an adult Brazilian male. Owing to its location and morphology, the supernumerary tooth presented as a lower lateral incisor joined to the lower lateral incisor normal in the mandibular arch through their distal and mesial contact faces, respectively (Figs 1.22, 1.23).

Ozgul et al. (2013) evaluated 7551 non-syndromic patients aged 3–16 years who applied for routine check-up. Supernumerary teeth were detected in 74 (0.98%). Of these, 48 were male and 26 were female (male-to-female ratio: 1.84:1). A total of 84 supernumerary teeth were detected, 80 (95.2%) permanent and four (4.8%) deciduous (n=4). Most supernumerary teeth (n=59, 70.2%) were located in the maxillary arch. The most common supernumerary teeth were mesiodens (36.9%), followed by those located in the maxillary incisor region (33.3%), the mandibular

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Figure 1.21 Variations in the sutures of the nasal bones. Redrawn after Krmpotić-Nemanić et al. (1988).
Mesiodentes were the most frequently diagnosed type of supernumerary teeth (48.52%), followed by supernumerary premolars (23.76%) and lateral incisors (18.81%). Supernumeraries were most commonly conical in shape (42.6%) with a normal or inclined vertical position (61.4%).

Other oddities of the teeth include variable sizes, crown shape, peg-shaped lateral incisor or notched incisor or maxillary central incisors, fused teeth, multiple roots, accessory cusps or tubercles (e.g., cusp of Carabelli of the mesiopalatal upper first molar), shovel-shaped maxillary incisors, angled root, root fusion, segmented root, dwarfed (short) roots, unerupted teeth, transposition of the teeth, rotation of a tooth, and ectopic teeth (e.g., nasal septum) (Woelfel and Scheid 1997).

### Middle ear bones

#### Stapes

The stapes exhibits marked variations. The head differs in the prominence of its margins, shape of the articular facet, and degree of inclination in relation to the crural arches. There is no correlation between the length of the stapes and its weight; the breadth and weight of the ossicle could be more closely related.

In most cases the posterior crus was found to be thicker, larger, and more curved than the anterior crus. The junction of the anterior crus with the base is usually thinner than the junction of the posterior crus (Bergman et al. 1996).

Van de Maele et al. (1989) reported a columellaform stapes in an 18-year-old male patient with a conductive hearing loss. SEM and light microscopy demonstrated that the ossicle was smaller than normal. The head was linked to the base by a crural plate, probably formed by fusion of the material of the two crura. Microscopy demonstrated a slightly less interwoven structure of the fibrillar bone, mainly at the cranial aspect of the crural plate. Honeycomb-like bone was confined to the caudal part of the crural plate. Microscopy revealed a cavity in the center of the stapes at the transition between the base and the plate. During surgery, a bony structure was found to link the posterior side of the head of the stapes to the pyramidal eminence. The authors concluded that a columellaform stapes can occur without forming part of a syndrome.

#### Malleus

Arviso and Todd (2010) studied a total of 41 adult crania without clinical otitis. They measured: (1) the distance from the lateral process of the malleus to the umbo and to the annulus; and (2) the angles formed anteriorly and posteriorly at the umbo.

The two metrics of malleus foreshortening did not correlate with one another; that is, the manubrium-length/tympanic-diameter ratio did not correlate with the posterior/anterior umbo angle ratio. Mastoid size did not correlate with either metric of malleus foreshortening. The authors concluded that a foreshortened malleus is an anatomical variant, not a sign of pathology.
Incus
Chien et al. (2009) studied the anatomy of the distal incus, including the lenticular process, in histological sections from 270 normal cadaveric human temporal bones covering an age range from less than 1 month to 100 years. All but nine of the sections exhibited signs of a bony connection between the long process of the incus and the flattened plate of the lenticular process, and in 108 specimens a complete bony attachment was observed in a single 20 μm section. In these 108 ears, the bony lenticular process consisted of a proximal narrow “pedicle” connected to a distal flattened “plate” that formed the incudal component of the incudo-stapedial joint. A fibrous joint capsule extended from the stapes head to the pedicle of the lenticular process on all sides, where it was considerably thickened.

References


Further reading

