Imaging of the Central Skull Base; Technique, Embryology and Microsurgical Anatomy

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Authors: D. Eriksen, P. Eriksen, S. Bhuta; Southport/AU
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Learning Objectives

1) To illustrate the complexity of the central skull base, various foramina and fissures and how these structures are best identified on multiplanar CT and MRI.

2) To understand microsurgical anatomy which helps in accurate localisation of pathology. This information is vital to guide the radiologist and surgeon for planning image guided intervention and complex skull base surgery.
Background

The central skull base is the region from the lesser wing of the sphenoid and planum sphenoidale to the level of the petrous ridge of the temporal bone and the dorsum sellae. The majority of this region is formed by the sphenoid bone with a small a small part of the temporal bone also considered part of the central skull base. (Figure 1) The sphenoid bone acts as a platform for the brain above while providing contributions to the orbit, nasal cavity and sinuses anteriorly and inferiorly. It acts as an interface between the brain and the facial structures and has multiple foramina and fissures that allow passage of nerves and vessels from one to the other and also houses the pituitary gland.

The central skull base has a very intricate anatomy due to the complex shape of the sphenoid bone and the multiple projections it produces anteriorly, posteriorly, laterally, inferior and superior. To add to this many of the projections are thin and fragile, the bony structures have an intimate relationship with important nerves and vessels and there is a reasonable amount of variability in the anatomical structure of the central skull base from one individual to the next. This has made this region challenging for the surgeons to operate in the past despite the fact that it is not infrequently the site of small lesions of endocrine or neurological origin that can have profound effects on the patient or that are life threatening. The advent of CT and MRI has meant that much better anatomical differentiation can now be made within the central skull base. The radiologist, in conjunction with surgeon, can use the precise imaging provided by CT and MRI as a map to plan the approach and can more accurately predict the morbidity of a certain surgery by defining the exact relationship between a lesion and the surrounding structures. This same approach also allows the physician to treat tumors with radiotherapy while avoiding important structures in close proximity. (1)

Due to the central location of the sphenoid, CR’s gives very little information, however CT and MRI can be used to effectively to visualise the central skull base as well as the associated neurological, vascular and soft tissue structures.
**Fig. 1**: Defines the region of the central skull base in the axial plane in relation the various bones forming the base of the cranium

Embryology

The skull base is important during embryonic development due to its relative stability, it provides a platform for the developing brain and acts as a keel for the development of surrounding structures.(2,3) The developing skull can be divided into the neurocranium, the protective case around brain and the viscerocranium, which forms the facial structures.(4) The neurocranium can be further subdivided into the membranous precursors that form the flat bones and the cartilaginous precursors or chondocranium that form into the bones of the skull base. The skull base is formed mainly from cartilaginous precursors, but does have small contribution from membranous bone. (2,5,6)

At the 4th week of gestation a cluster of cells derived from the neural crest and paraxial mesoderm congregate between the embryonic brain and foregut and form the desmocranium, the earliest precursor of the skull base.(2,7,8) By the 8th week of gestation the desmocranium has become the chondrocranium, an irregularly shaped cartilaginous structure that lies ventral to the embryonic brain.(3) At the 8th week of gestation differentiation begins to occur within various parts of the chondrocranium to form 9 cartilaginous precursors.(2,3) Precursors 5-9 lie anterior to the notochord (presphenoid centres) and are derived from neuroderm whilst precursors 1-4 lie posterior to the notochord (postsphenoid centres) and are derived from paraxial mesoderm. (Figure 2) The pre and postsphenoid centres fuse around the early pituitary gland meaning the pituitary marks the division between them in the AP plane. This in turn means that the anterior and posterior aspects of the sphenoid body are embryologically distinct. (3,8) The body of the sphenoid is formed from the fusion of the pre and postsphenoid with basisphenoid cartilage around the pituitary gland and forms the sellae turcica. The orbitosphenoid and alisphenoid (lateral cartilaginous centres) complete the sphenoid bone and provide contributions to the ethmoid and temporal bones. The orbitosphenoid forms the anterior clinoid and lesser wings of the sphenoid and encloses the optic nerve forming the optic canal while the alisphenoid contributes to the greater wing and is the site of formation of the foramen rotundum, ovale and spinosum.(2,5) The various foramina are formed by the cartilage forming and fusing around the already present nerves and vessels.(5) The space between the alisphenoid and orbitosphenoid creates the superior orbital fissure for passage of CN's III, IV, VI and V1 (ophthalmic division of trigeminal nerve).(2) The medial and lateral pterygoid plates are formed at a later stage through intramembranous ossification.
In all 41 ossification centres have been identified in the chondrocranium and form at about the 8th week of gestation. Cartilage is converted to bone between the 8th and 12th week of gestation and the chondrocranium becomes the basicranium. Once formed, growth takes place through anterior-posterior, lateral-medial and superior-inferior expansion as well as through angulation (flexion and extension of the pre and post chondral parts of the basicranium). Development continues into adult life and is completed with the fusion of the sphenoorccipital synchondrosis.

**Imaging Technique**

CT and MRI have a complimentary role in the evaluation of skull base anatomy, pathology and are often used together to determine the full extent of a lesion. CT scans of the skull base must always include sections in at least two different planes, axial and coronal are the best and slices thickness of less than 3mm. CT is particularly well suited to define the bony anatomy of the skull base. High-resolution bone algorithms depict the thin cortical margins of neurovascular foramina. MR imaging is preferred to assess the soft tissue component and to determine its relations with adjacent structures. It is the modality with the highest accuracy to depict intracranial extent (dural, leptomeningeal, and brain parenchyma invasion), perineural and perivasular spread and bone marrow involvement. A conventional spin echo or fast spin echo T1-weighted sequence is the single best sequence to understand the anatomy as fat provides the natural contrast and hence is useful to depict bone marrow invasion.

**Anatomy**

The sphenoid is the major contributing bone to the central skull base and will be the focus of the anatomical discussion. The word sphenoid is a Greek derivative with "sphen" meaning "wedgelike," however the anatomy is much more complex than this and a more accurate description is that of a bat with outstretched wings when viewed from above. The sphenoid is anatomically the most complex bone of the skull and consists of a central body, 2 greater and 2 lesser wings laterally and 2 pterygoid processes that are directed downward from the region where the greater wings adjoin to the body. The body is the central part of the sphenoid and is roughly cuboidal in shape. It contains within it the sphenoidal sinuses, 2 large air spaces that have considerable variability in size from side to side and person to person and are separated by a thin septum. The structures of the superior aspect of the body going anteriorly to posterior begin with the planum sphenoid. This is a flat region of bone that articulates with cribiform plate of the ethmoid bone anteriorly and supports a small part of the frontal lobes endocranially.
This can best be appreciated on CT and MRI in the coronal views. (Figures 14 and 25) Laterally the flat surface is continuous with the flat surfaces of the lesser wings. Posterior to the planum sphenoid is the tuberculum sellae, an oval shaped elevation that forms the anterior border of the sellae turcica. The sellae turcica ("Turkish saddle") is a saddle shaped depression that at its deepest part houses the hypophyseal fossa that in turn houses the pituitary gland. (Figure 3, 19 and 25) The sellae turcica is bordered by the middle clinoid processes laterally ("clinoid" meaning "bedpost") and the dorsum sellae posteriorly. (11) The dorsum sellae is a rectangular plate of bone that has 2 elevations laterally known as the posterior clinoid processes that can be identified on CT in the axial plane. (Figure 9) The slopping posterior surface of the dorsum sellae is the clivus and it articulates with the basiocciput forming the foramen magnum as well as supporting a small area of the pons. (Figure 3) The anterior portion of the sphenoid body is divided by the sphenoid crest, a bony projection running superior-inferiorly that articulates with the nasal septum. The ostia of the sphenoid sinuses lie laterally to the sphenoid crest and communicate with the spheno-ethmoidal recess of the nasal cavity. The upper and lateral region of the anterior sphenoid body articulates with ethmoid bone and completes the ethmoid sinus while the lower and medial aspect forms the posterior aspect of the roof of the nose.

The greater wings are 2 strong processes that curve upward and laterally from the body. The posterior part of the greater wing is a triangular shape that fits into the angle between the petrous portion of the temporal bone and the squamous part forming the sphenosquamosal suture. The cerebral surface is a deep concave with depressions matching the convolutions of the temporal lobe of the brain and forms the floor of the middle cranial fossa. (12) The posteromedial margin of the greater wing forms the superior border of the greater orbital fissure that is best seen on axial and coronal CT. (Figure 10 and 14) The anterior portion has a quadrilateral shape facing forward and forms part of the posterior wall of the orbit. Superiorly it articulates with the orbital plate of the frontal bone, the zygomatic bone laterally and inferiorly forms the lateral boundary of the inferior orbital fissure.

There are 3 main foramina that pass through the greater wing, a table of the foramina, fissures and canals and their contents is present in figure 8. The foramen spinosum is located in the posterolateral corner of the greater wing and transmits the middle meningeal artery and the meningeal branch of the mandibular nerve. The foramen is best observed in axial CT while the artery is most readily seen in an axial T1 MRI. (Figures 24 and 25) It varies in size from side to side and person to person but should not exceed 5 mm in diameter and should not differ from side to side by more than 2 mm. (10) Just medial to the foramen spinosum is the foramen ovale. This connects the middle cranial fossa to the masticator space and transmits the mandibular nerve and the accessory meningeal artery, like the foramen spinosum it varies in size from side to side and person to person but also should not be greater than 5 mm in diameter and not differ from side to side by more than 4 mm. (10) This is a large foramen and nerve and the foramen is
easily seen in axial and coronal views on both CT and MRI while the mandibular nerve is readily seen in coronal and axial views on MRI. (Figures 13, 17, 22, 23, 26 and 27) The foramen rotundum lies at the anteromedial part of the greater wing and transmits the maxillary nerve. This can also be viewed in axial and coronal planes on both CT and MRI, however a very good visual can be obtained in the coronal plane due to it running in an AP direction. (Figures 11, 15, 21 and 25)

The lesser wings are 2 triangular structures that project laterally from the anterosuperior region of the sphenoid body and end in sharp points. It is attached to body by 2 roots that also form the lateral, superior and inferior wall of the optic canal with the sphenoid body forming the medial wall. The optic canal allows the passage of the optic nerve (Figure 18) and the ophthalmic artery and is separated from the superior orbital fissure by the inferior root. (Figure 9) The upper surface of the superior root is flat and continuous with planum sphenoidale and also supports a small part of the frontal lobe. The posterior border of the lesser wing is smooth and the medial region gives rise to anterior clinoid processes, visible on CT in the axial and coronal plane and on MRI in the coronal plane. (Figure 9, 14 and 25).

The pterygoid processes extend inferiorly and perpendicular to the greater wing where it joins the sphenoid body. Each pterygoid process consists of a medial and lateral plate that are separated distally by the pterygoid fissure and fuse superiorly at their anterior border. (Figure 16) The plates diverge from one another posteriorly forming a wedge like shape known as the pterygoid fossa that houses the medial pterygoid and tensor veli palatini muscles. (6) The anterior surface near the root of the pterygoid process is broad and forms the posterior wall of the pterygopalantine fossa and is also the site of the vidian canal that transmits the vidian nerve, artery and vein from the foramen lacerum to the pterygopalantine fossa and is seen on CT and MRI in the axial and coronal planes. (Figures 12, 16, 23 and 24) The pterygopalantine fossa connects with 5 different spaces; the middle cranial fossa, the nasal and oral cavity, the orbit and the infratemporal fossa making it important in the staging of head and neck tumours. It's best appreciated on both CT and MRI in the axial planes. (5,13) (Figure 11, 20 and 21) The lateral plate of the pterygoid is broad and thin and everted. The lateral side forms the medial wall of the infratemporal fossa while lateral side forms the medial wall of the pterygoid fossa. The medial plate is narrower and longer and has a hook distally that deviates laterally known as the pterygoid humulus. Its lateral surface forms the medial wall of the pterygoid fossa and its medial surface the lateral boundary of the nasal aperture. The upper surface of the medial pterygoid plate articulates with the vomer and together they form the platinovaginal canal that transmits the pharyngeal branch of the maxillary artery and the pharyngeal nerve.

The superior orbital fissure connects the endocranial region to the orbit and is best viewed on CT in both the coronal and axial planes. (Figures 10 and 14) It's bordered by the lesser
wing superiorly, the greater wing inferiorly and the body medially. It transmits cranial nerves III, IV, VI and the ophthalmic division of V as well as the ophthalmic vein. The medial 1/3rd of the fissure contains the annulus of Zinn, the common tendinous origin of the extraocular muscles.(6,14)

The cavernous sinuses are situated on each side of the body of the sphenoid bone and extend from the superior orbital fissure anteriorly to the petrous apex posteriorly. The internal carotid artery, surrounded by a sympathetic plexus, courses through the sinus, while the abducens nerve (cranial nerve VI) lies inferolateral to the artery. Proceeding from superior to inferior, the oculomotor and trochlear nerves and the ophthalmic (V1) and maxillary (V2) divisions of the trigeminal nerve are each contained within separate fibrous sheaths within the lateral wall of the sinus. Endothelium separates these structures from the venous blood contained in the sinus. The pituitary and sphenoid sinuses are medial to the cavernous sinuses. The Meckel cave, enclosing the trigeminal ganglion, is situated at the posteroinferior aspect of the sinus. The uncus of the temporal lobe is related to the lateral wall as well. The cavernous sinus can be best evaluated with coronal or axial CT/MR images. (Figures 25 and 27)
Fig. 1: Defines the region of the central skull base in the axial plane in relation the various bones forming the base of the cranium.

Fig. 2: Demonstrates the site of formation of the various cartilaginous centres

Fig. 3: CT sagital view of a 14 yo demonstrates an unfused articulation between the sphenoid bone and basiocciput, this becomes fused by early adult life

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**Fig. 4:** Anterior view of sphenoid bone

Fig. 5: Posterior view of sphenoid bone

Fig. 6: Superior view of sphenoid bone

**Fig. 19:** Axial 3T MR imaging of the central skull base. Images moving from superior to inferior with increasing figure number.

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Fig. 20: Axial 3T MR imaging of the central skull base. Images moving from superior to inferior with increasing figure number.

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**Fig. 21:** Axial 3T MR imaging of the central skull base. Images moving from superior to inferior with increasing figure number.

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Fig. 22: Axial 3T MR imaging of the central skull base. Images moving from superior to inferior with increasing figure number.

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**Fig. 23:** Axial 3T MR imaging of the central skull base. Images moving from superior to inferior with increasing figure number.

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**Fig. 24:** Coronal 3T MR imaging of the central skull base. Images moving from anterior to posterior with increasing figure number.

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**Fig. 25:** Coronal 3T MR imaging of the central skull base. Images moving from anterior to posterior with increasing figure number.

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Fig. 26: Coronal 3T MR imaging of the central skull base. Images moving from anterior to posterior with increasing figure number.

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**Fig. 18:** Axial 3T MR imaging of the central skull base. Images moving from superior to inferior with increasing figure number.

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**Fig. 17:** High resolution 128 slice coronal CT of the central skull base. Images moving from anterior to posterior with increasing figure number.

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Fig. 16: High resolution 128 slice coronal CT of the central skull base. Images moving from anterior to posterior with increasing figure number.

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Fig. 7: Inferior view of sphenoid bone

**Fig. 11:** High resolution 128 slice axial CT of the central skull base. Images moving from superior to inferior with increasing figure number.

© Dept of Medical Imaging, Gold Coast Hospital - Southport/AU
Fig. 10: High resolution 128 slice axial CT of the central skull base. Images moving from superior to inferior with increasing figure number.

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Fig. 9: High resolution 128 slice axial CT of the central skull base. Images moving from superior to inferior with increasing figure number.

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Fig. 12: High resolution 128 slice axial CT of the central skull base. Images moving from superior to inferior with increasing figure number.

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**Fig. 13:** High resolution 128 slice axial CT of the central skull base. Images moving from superior to inferior with increasing figure number.

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Fig. 14: High resolution 128 slice coronal CT of the central skull base. Images moving from anterior to posterior with increasing figure number.

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Fig. 15: High resolution 128 slice coronal CT of the central skull base. Images moving from anterior to posterior with increasing figure number.

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Fig. 27: Coronal 3T MR imaging of the central skull base. Images moving from anterior to posterior with increasing figure number.

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<table>
<thead>
<tr>
<th>Structure</th>
<th>Location</th>
<th>Spaces it connects</th>
<th>Contains</th>
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<tbody>
<tr>
<td>Foramen ovale</td>
<td>Posterolateral greater wing of sphenoid</td>
<td>Middle cranial fossa to the masticator space</td>
<td>Mandibular division of trigeminal nerve</td>
</tr>
<tr>
<td>Foramen spinosum</td>
<td>Posterolateral greater wing of sphenoid</td>
<td>Middle cranial fossa to infratemporal fossa</td>
<td>Middle meningeal artery, meningeal branch of the mandibular nerve</td>
</tr>
<tr>
<td>Foramen rotundum</td>
<td>Medial greater wing of sphenoid</td>
<td>Middle cranial fossa to the pterygopalantine fossa</td>
<td>Maxillary division of trigeminal nerve</td>
</tr>
<tr>
<td>Optic canal</td>
<td>Lesser wing of sphenoid sup, inf and laterally, sphenoid body medially</td>
<td>Middle cranial cavity to the orbit</td>
<td>Optic nerve (CN II)</td>
</tr>
<tr>
<td>Vidian canal</td>
<td>Junction of the pterygoid process and sphenoid body</td>
<td>Foramen lacerum to the pterygopalantine fossa</td>
<td>Vidian artery (branch of maxillary artery), nerve and vein</td>
</tr>
<tr>
<td>Superior orbital fissure</td>
<td>Greater wing superiorly, lesser wing inferiorly and</td>
<td>Middle cranial fossa to the orbit</td>
<td>CN’s III, IV, VI and ophthalmic division of V as well as the nerve and vein</td>
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**Fig. 8:** Table of foramina, fissures and canals passing through the sphenoid bone

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Conclusion

Central skull base has a very complex and intricate anatomy with many vital cranial nerves and vessels exiting from the brain to the face and neck. Knowledge of the embryology is useful in understanding the relationship it has to the structures around it, the origin of its various components and provides a better insight into why and how certain pathologies develop. Being familiar with microsurgical anatomy is essential for the radiologist in accurate diagnosis of pathologies and determining their relationship to the bone, neurological, vascular and soft tissue structures around them. Advances in CT and MRI technology provides very high-resolution images of this region and means that conditions that have previously been deemed inoperable can now be considered for surgery due to the ability of the radiologist and surgeon to work as a team and plan a safe surgical route with a much greater degree of certainty and least morbidity and mortality.
Personal Information

Corresponding Author

Dr Sandeep Bhuta
Staff Neuroradiologist and Associate Professor
Griffith University School of Medicine
Dept of Medical Imaging, Southport
Gold Coast Hospital
Gold Coast
Email- sandeepbhuta@gmail.com
References


