# ACADEMIC DISCUSSIONS IN THE FIELD OF ANATOMY

Editor: Assist. Prof. Dr. Mehmet SELÇUK

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# DEVELOPMENTAL, MORPHOLOGICAL AND CLINICAL ANATOMY OF THE TEMPORAL BONE

**Ömer Can KIZILAY**[1]

## 1. INTRODUCTION

The temporal bone is one of the most complex bones of the human skull because it contributes simultaneously to the cranial vault, the cranial base, the external acoustic region, the middle ear, the inner ear, and the temporomandibular joint. It forms part of the lateral wall and base of the cranium and participates in the boundaries of the middle and posterior cranial fossae. Unlike many cranial bones that can be described mainly in terms of external morphology, the temporal bone must be understood as a three dimensional anatomical region containing sensory organs, neurovascular canals, air cell systems, and surgically important landmarks. This complexity explains why the temporal bone is of central importance not only in gross anatomy, but also in otology, neurotology, radiology, neurosurgery, maxillofacial surgery, and skull base surgery (Isaacson, 2018; Juliano, Ginat & Moonis, 2013).

Classically, the temporal bone is described in relation to its squamous, petrous, tympanic, mastoid, and styloid components. These parts differ not only in morphology and anatomical relationships, but also in their developmental origins and clinical relevance. During prenatal development, the temporal bone is composed of five main parts: squamous, styloid,

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mastoid, tympanic, and petrous. The squamous part and a portion of the mastoid region are associated primarily with intramembranous ossification, whereas the petrous and mastoid components related to the cranial base develop largely through endochondral ossification. This mixed developmental pattern contributes to the complex architecture of the mature temporal bone and has implications for congenital anomalies, fetal imaging, and the interpretation of developmental defects involving the external, middle, or inner ear (Grzonkowska, Baumgart, Kułakowski & Szpinda, 2023).

From a morphological perspective, the temporal bone provides protection for the organs of hearing and balance, including the cochlea, vestibule, and semicircular canals. It also contains or transmits several important structures, such as the facial nerve, vestibulocochlear nerve, internal carotid artery, sigmoid sinus, jugular bulb, chorda tympani, greater petrosal nerve, and tympanic branch of the glossopharyngeal nerve. Therefore, small anatomical variations or pathological changes within this bone may produce clinically significant symptoms, including conductive or sensorineural hearing loss, vertigo, tinnitus, facial nerve paralysis, otalgia, cerebrospinal fluid leakage, or vascular complications. For this reason, the temporal bone is frequently evaluated with high resolution computed tomography and magnetic resonance imaging in inflammatory, traumatic, congenital, vascular, and neoplastic conditions (Juliano et al., 2013).

The clinical anatomy of the temporal bone is particularly important because many of its structures are arranged in close proximity within a relatively small osseous space. The mastoid air cell system communicates with the middle ear cavity through the aditus ad antrum, making the mastoid region relevant in acute mastoiditis, chronic otitis media, and cholesteatoma. Mastoidectomy, one of the fundamental procedures in otologic surgery, requires detailed knowledge of the mastoid cortex, mastoid antrum, tegmen, sigmoid sinus, lateral semicircular canal, facial canal, and posterior wall of the external acoustic meatus. The variability of mastoid pneumatization further increases the importance of individualized anatomical evaluation before and during surgery (Kennedy & Lin, 2023).

Traumatic lesions of the temporal bone also demonstrate the clinical importance of its anatomy. Temporal bone fractures may involve the external acoustic canal, middle ear, otic capsule, facial canal, carotid canal, or jugular foramen. Depending on the fracture pattern and the structures involved, patients may present with hearing loss, vertigo, facial nerve dysfunction, cerebrospinal fluid otorrhea, vascular injury, or intracranial complications (Johnson, Semaan & Megerian, 2008). Thus, the temporal bone is not merely a passive skeletal element of the skull, but a clinically active anatomical region in which osseous, neural, vascular, and sensory structures are functionally integrated.

The aim of this chapter is to present the temporal bone from developmental, morphological, and clinical perspectives. First, the embryological development and ossification pattern of the temporal bone will be summarized. Then, its major anatomical parts and surface landmarks will be described. Particular attention will be given to the canals, foramina, neurovascular relationships, and air cell systems that make the temporal bone clinically significant. Finally, selected pathological and surgical correlations, including temporal bone fractures, otitis media, mastoiditis, cholesteatoma, mastoidectomy, temporomandibular joint relations, and Eagle syndrome, will be discussed in relation to anatomical landmarks. In this way, the chapter aims to integrate classical anatomical knowledge with clinically relevant interpretation.

## 2. EMBRYOLOGICAL DEVELOPMENT OF THE TEMPORAL BONE

The temporal bone is not a single developmental unit, but a composite cranial bone formed by the integration of squamous, petrous, tympanic, mastoid, and styloid components. This developmental complexity explains why congenital anomalies of the temporal bone may involve the external ear, middle ear, ossicles, facial nerve canal, otic capsule, mastoid air cell system, or inner ear structures in different combinations. From an anatomical perspective, embryological development is therefore important not only for understanding the mature morphology of the temporal bone, but also for interpreting congenital hearing loss, external auditory canal atresia, ossicular malformations, facial nerve variations, inner ear anomalies, and differences in mastoid pneumatization (Nada, Agunbiade, Whitehead, Cousins, Ahsan & Mahdi, 2021).

The squamous part of the temporal bone develops primarily by intramembranous ossification and contributes to the lateral cranial wall, the temporal fossa, and the root of the zygomatic process. Its early ossification is important for the formation of the lateral skull contour and for the relationship of the temporal region to the developing cranial vault. Fetal morphometric data show progressive growth of the primary ossification center of the squamous part during prenatal life, emphasizing its role in cranial vault development (Grzonkowska, Baumgart, Kułakowski & Szpinda, 2023). If development of this region is deficient or altered, the resulting morphology may contribute to cranial wall defects, abnormal contour of the temporal region, or altered relationships around the temporal fossa and zygomatic arch. Although isolated squamous developmental defects are less frequently discussed than ear canal or inner ear anomalies, the squamous part remains important as the superficial cranial component of the temporal bone.

The petrous part develops in close relationship with the otic capsule and is mainly associated with endochondral ossification. The otic placode appears during the fourth week and gives rise to the otic pit and otocyst. The otocyst subsequently differentiates into the membranous labyrinth, including the cochlear duct, vestibular structures, and semicircular canals. The cartilaginous otic capsule forms around these structures and later ossifies, creating the dense petrous portion that protects the inner ear. Nada et al. (2021) reported that the otic capsule ossifies between the 15th and 23rd weeks, while the major membranous labyrinth structures reach near adult configuration relatively early in fetal life. Developmental arrest or abnormal differentiation in this region may result in inner ear malformations such as labyrinthine aplasia, cochlear aplasia or hypoplasia, common cavity malformation, incomplete partition anomalies, semicircular canal dysplasia, or internal auditory canal hypoplasia. Clinically, these anomalies are commonly associated with sensorineural or mixed hearing loss and may affect cochlear implantation planning.

The tympanic part is closely related to the formation of the external acoustic meatus and tympanic membrane. The cartilaginous portion of the external auditory canal develops from the first pharyngeal groove and pouch between the fourth and eighth weeks, while the bony portion develops from the canalized meatal plug. Except for the tympanic ring, ossification is largely completed by approximately two years of age, and the external auditory canal approaches adult size around nine years of age (Nada et al., 2021). Incomplete development of this region may result in congenital external auditory canal stenosis or atresia. Such defects may be membranous or bony and may coexist with auricular deformity, ossicular hypoplasia or aplasia, abnormal facial nerve course, oval or round window anomalies, and mastoid abnormalities. Therefore, developmental failure of the tympanic component has direct clinical relevance for conductive hearing loss and surgical planning in congenital aural atresia.

The mastoid part has a particularly important postnatal developmental pattern. The mastoid antrum forms during fetal life, whereas pneumatization begins later and continues after birth. Nada et al. (2021) stated that the mastoid antrum forms around the 18th week, pneumatization begins around the 34th week, most mastoid air cells develop by approximately two years of age, and the mastoid process becomes evident after birth. However, the final extent of mastoid pneumatization varies considerably among individuals. A recent scoping review also emphasized that mastoid air cell size changes with age and that growth of the mastoid air cell system may continue beyond puberty, depending on the method of measurement and population characteristics (Aladeyelu et al., 2022). Reduced or abnormal mastoid pneumatization may influence the spread of middle ear infection, the radiological appearance of the mastoid region, and the surgical anatomy encountered during mastoidectomy.

The styloid process differs developmentally from the squamous, petrous, tympanic, and mastoid components. It is associated with Reichert's cartilage of the second pharyngeal arch and forms part of the stylohyoid complex together with the stylohyoid ligament and the lesser horn of the hyoid bone. Variations in the length, angulation, or ossification pattern of this complex may persist into adulthood. When the styloid process is elongated or when the stylohyoid ligament is ossified, patients may develop symptoms related to Eagle syndrome, including cervicofacial pain, dysphagia, otalgia, foreign body sensation in the throat, or vascular symptoms due to close relationships with the carotid arteries and adjacent cranial nerves (Czako, Simko, Thurzo, Galis & Varga, 2020).

In summary, the embryological development of the temporal bone provides a structural explanation for many adult anatomical features and congenital anomalies. The squamous part reflects cranial vault development; the petrous part reflects otic capsule and inner ear development; the tympanic part is linked to the external auditory canal and tympanic membrane; the mastoid part is shaped by fetal formation and postnatal pneumatization; and the styloid process is related to the second pharyngeal arch. This developmental framework is clinically useful because defects in each component tend to produce different anatomical and functional consequences.

## 3. MORPHOLOGICAL ANATOMY OF THE TEMPORAL BONE

The temporal bone is a paired, irregular cranial bone located on the lateral aspect and base of the skull. It contributes to the lateral cranial wall, middle cranial fossa, posterior cranial fossa, external acoustic region, temporomandibular joint, and cranial base. In addition to its skeletal role, it contains the organs of hearing and balance, transmits important neurovascular structures, and provides attachment for several muscles and ligaments. Therefore, the temporal bone should be evaluated not only as a component of the skull, but also as a compact anatomical region in which cranial, auditory, vestibular, vascular, and neural structures are closely integrated (Dalley & Agur, 2023).

Classically, the temporal bone is divided into five main parts: the squamous part, petrous part, tympanic part, mastoid part, and styloid process. These components differ in shape, density, topographic relationships, and clinical significance. The squamous part forms a thin plate contributing to the lateral cranial wall; the petrous part is a dense pyramidal structure containing the inner ear; the tympanic part contributes to the external acoustic meatus; the mastoid part contains the mastoid process and mastoid air cell system; and the styloid process forms the superior component of the stylohyoid complex. Although these parts are described separately for anatomical clarity, they are continuous in the intact skull and are often involved together in traumatic, inflammatory, congenital, and surgical conditions (Juliano et al., 2013).

### 3.1. Squamous Part

The squamous part is the thin and plate like superior portion of the temporal bone. It forms part of the lateral wall of the cranium and contributes to the temporal fossa. Its external surface provides attachment for the temporalis muscle, while its internal surface is related to the temporal lobe of the cerebral hemisphere and meningeal vessels. Inferiorly, the squamous part gives rise to the zygomatic process, which extends anteriorly to articulate with the temporal process of the zygomatic bone and forms the zygomatic arch. The zygomatic arch is an important surface landmark because it separates the temporal fossa superiorly from the infratemporal region inferiorly and provides attachment for the masseter muscle (Standring, 2020).

The inferior aspect of the squamous part participates in the formation of the mandibular fossa, which receives the head of the mandible and forms the superior articular component of the temporomandibular joint. Anterior to the mandibular fossa is the articular tubercle, a bony prominence that contributes to the mechanics of mandibular movement. The temporomandibular joint is anatomically adjacent to the external acoustic meatus, with the thin tympanic plate separating the joint region from the external auditory canal. In addition, shared sensory innervation through the auriculotemporal nerve provides an anatomical basis for referred otalgia. Although otologic symptoms have been reported in patients with temporomandibular disorders, current evidence supports an association rather than a proven causal relationship (Hernández-Nuño de la Rosa, Keith, Siegel & Moreno-Hay, 2022). The petrotympanic fissure lies in this region and transmits the chorda tympani nerve from the middle ear toward the infratemporal fossa.

### 3.2. Petrous Part

The petrous part is the densest and most complex portion of the temporal bone. It has a pyramidal shape and is positioned obliquely between the sphenoid and occipital bones at the cranial base. Its apex is directed anteromedially, while its base is continuous laterally with the squamous and mastoid parts. The petrous part contributes to both the middle and posterior cranial fossae and forms a protective osseous capsule around the structures of the inner ear. It contains the cochlea, vestibule, and semicircular canals and is closely related to the internal acoustic meatus, facial canal, carotid canal, jugular fossa, and petrosal nerve pathways (Standring, 2020).

The anterior surface of the petrous part faces the middle cranial fossa. Important landmarks on this surface include the arcuate eminence, tegmen tympani, trigeminal impression, and hiatuses for the greater and lesser petrosal nerves. The tegmen tympani forms the thin bony roof of the tympanic cavity and mastoid antrum. Because of this relationship, disease processes involving the middle ear or mastoid region may extend superiorly when the tegmen is dehiscent, eroded, or surgically exposed. The posterior surface of the petrous part faces the posterior cranial fossa and contains the internal acoustic meatus, which transmits the facial nerve, vestibulocochlear nerve, and labyrinthine vessels. The inferior surface is irregular and includes the carotid canal, jugular fossa, and structures related to the styloid and mastoid regions (Isaacson, 2018; Juliano et al., 2013).

### 3.3. Tympanic Part

The tympanic part is a curved plate of bone that forms much of the anterior, inferior, and posterior walls of the bony external acoustic meatus. It surrounds the medial bony portion of the external auditory canal and contributes to the tympanic sulcus, which provides attachment for the tympanic membrane. The external acoustic meatus extends medially to the tympanic membrane, which separates the external ear from the middle ear cavity. In normal anatomy, the lateral third of the external auditory canal is fibrocartilaginous, whereas the medial two thirds are bony and are surrounded mainly by the tympanic part of the temporal bone (Dalley & Agur, 2023).

As discussed in the embryological section, congenital abnormalities of this region may be associated with external auditory canal stenosis or atresia. In the adult skull, however, the tympanic part is primarily important because of its relationships with the external acoustic canal, tympanic membrane, temporomandibular joint, and middle ear. Its anterior relationship with the mandibular fossa and posterior relationship with the mastoid region make it an important anatomical transition zone between otologic and maxillofacial structures.

### 3.4. Mastoid Part

The mastoid part is located posteroinferior to the squamous part and posterior to the external acoustic meatus. Its most prominent external feature is the mastoid process, a conical projection that provides attachment for several muscles, including the sternocleidomastoid, splenius capitis, and longissimus capitis muscles. Medial to the mastoid process is the mastoid notch, which gives attachment to the posterior belly of the digastric muscle. The occipital groove, located medial to the mastoid notch, transmits the occipital artery. These surface features make the mastoid region an important anatomical landmark in the posterolateral skull base (Dalley & Agur, 2023; Standring, 2020).

Internally, the mastoid part contains the mastoid air cell system, which communicates with the middle ear cavity through the mastoid antrum and the aditus ad antrum. The mastoid antrum is a constant air containing space located posterior to the epitympanic recess and superior to the mastoid air cells. Its roof is formed by the tegmen mastoideum, which separates the mastoid region from the middle cranial fossa. Posteriorly, the mastoid region is related to the sigmoid sinus, and medially it is close to the labyrinthine structures, particularly the lateral semicircular canal. These relationships are essential for understanding the spread of middle ear disease and the anatomical basis of mastoid surgery (Isaacson, 2018).

The degree of mastoid pneumatization is variable among individuals. A well pneumatized mastoid contains numerous air cells extending into the mastoid process and sometimes into adjacent parts of the temporal bone. In contrast, a poorly pneumatized or sclerotic mastoid has fewer air cells and more compact bone. This variation is important in radiological interpretation and surgical planning because the size and extent of mastoid air cells influence the operative corridor, the identification of the mastoid antrum, and the relationship of the surgical field to the sigmoid sinus, tegmen, facial canal, and semicircular canals. As discussed in the embryological section, mastoid pneumatization has a strong postnatal component and may show considerable individual variation (Aladeyelu et al., 2022).

The mastoid region is also closely related to the facial nerve. After passing through the labyrinthine and tympanic segments of the facial canal, the facial nerve turns inferiorly at the second genu and descends as the mastoid segment before exiting the skull through the stylomastoid foramen. This course explains why mastoid surgery requires precise anatomical orientation. The posterior wall of the external acoustic canal, the lateral semicircular canal, the short process of the incus, the digastric ridge, the sigmoid sinus, and the tegmen mastoideum are among the important landmarks used to navigate the mastoid region safely (Juliano et al., 2013).

In clinical anatomy, the mastoid part is particularly relevant in otitis media, mastoiditis, cholesteatoma, temporal bone trauma, and mastoidectomy. Infection or cholesteatoma may extend from the middle ear to the mastoid air cell system through the aditus ad antrum. Erosion of the tegmen may create a route toward the middle cranial fossa, while involvement of the sigmoid plate may create risk for venous sinus related complications. Therefore, the mastoid part should be understood not merely as a posterior projection of the temporal bone, but as a surgically important air containing region situated between the external ear, middle ear, labyrinth, facial nerve, middle cranial fossa, and posterior cranial fossa.

### 3.5. Styloid Process

The styloid process is a slender, pointed projection extending inferiorly from the inferior surface of the temporal bone. It is located anterior to the mastoid process and lateral to the jugular fossa. Its base lies near the stylomastoid foramen, where the facial nerve exits the skull. Because of this close topographic relationship, the styloid process is an important landmark in the inferior aspect of the temporal bone and in the upper parapharyngeal region (Dalley & Agur, 2023).

The styloid process provides attachment for three muscles and two ligaments. The styloglossus, stylohyoid, and stylopharyngeus muscles arise from the styloid process and pass toward the tongue, hyoid bone, and pharyngeal wall, respectively.

The stylohyoid ligament extends from the styloid process to the lesser horn of the hyoid bone, while the stylomandibular ligament extends toward the angle of the mandible. These structures collectively connect the temporal bone to the tongue, pharynx, hyoid apparatus, and mandible, giving the styloid process functional relevance in swallowing, speech, and movements of the hyoid laryngeal complex.

The anatomical relations of the styloid process are clinically important. Medially, it is related to the pharyngeal wall and tonsillar region. Posteromedially and deeply, it lies near the internal carotid artery, internal jugular vein, and lower cranial nerves. Laterally and anteriorly, it is related to the parotid region and mandibular ramus. These relationships explain why abnormalities of the styloid process or stylohyoid complex may produce symptoms that are not limited to the bone itself, but may be perceived as throat pain, otalgia, dysphagia, facial pain, or vascular discomfort (Czako et al., 2020).

As discussed in the embryological section, variation in the length, angulation, or ossification of the stylohyoid complex may persist into adulthood. An elongated styloid process or ossified stylohyoid ligament may be associated with Eagle syndrome. However, radiological elongation alone does not necessarily indicate symptomatic disease. Clinical significance depends on the presence of compatible symptoms and the relationship of the styloid process to adjacent neurovascular structures. Therefore, the styloid process should be evaluated as part of a regional anatomical complex rather than as an isolated bony projection.

## 4. CANALS, FORAMINA AND NEUROVASCULAR RELATIONS

The temporal bone contains a complex network of canals, foramina, fissures, aqueducts, clefts, and grooves that transmit or accommodate important neurovascular structures. These small anatomical pathways connect the cranial cavity, middle ear, inner ear, mastoid region, infratemporal fossa, carotid canal, jugular region, and posterior cranial fossa. Although some of these structures are minute and may be difficult to identify even on thin section computed tomography, they have considerable anatomical and clinical importance. They may be overlooked, mistaken for fracture lines or pathological lesions, or involved by developmental, inflammatory, infectious, traumatic, or neoplastic processes (Benson et al., 2020). Therefore, understanding these structures as part of an integrated three dimensional anatomical system is essential for temporal bone imaging, otologic surgery, skull base surgery, and the interpretation of neurovascular complications.

The internal acoustic meatus is located on the posterior surface of the petrous part and transmits the facial nerve, vestibulocochlear nerve, and labyrinthine vessels toward the inner ear. At its lateral end, the fundus of the internal acoustic meatus is divided into compartments for the facial, cochlear, superior vestibular, and inferior vestibular nerves. This arrangement is clinically important in vestibular schwannoma, facial nerve pathology, congenital nerve deficiency, and cochlear implantation planning (Nada et al., 2021).

The facial canal is one of the most clinically important canals of the temporal bone. It begins at the fundus of the internal acoustic meatus and carries the facial nerve through labyrinthine, tympanic, and mastoid segments before the nerve exits the skull through the stylomastoid foramen. Along this course, the facial nerve is closely related to the cochlea, geniculate ganglion, oval window, lateral semicircular canal, pyramidal eminence, mastoid antrum, and posterior wall of the tympanic cavity. These relationships explain the vulnerability of the facial nerve in temporal bone fractures, middle ear disease, cholesteatoma, congenital anomalies, and mastoid surgery (Gupta, Mends, Hagiwara, Fatterpekar & Roehm, 2013).

The carotid canal begins on the inferior surface of the petrous part and transmits the internal carotid artery and its sympathetic plexus into the cranial cavity. The artery first ascends vertically and then turns anteromedially within the petrous temporal bone. Its proximity to the middle ear, cochlea, Eustachian tube, and petrous apex is clinically relevant because congenital or acquired dehiscence, aberrant vascular anatomy, trauma, infection, or surgical drilling in this region may place the internal carotid artery at risk (Juliano et al., 2013). Similarly, the jugular fossa accommodates the superior bulb of the internal jugular vein and lies near the jugular foramen, through which the glossopharyngeal, vagus, and accessory nerves pass. Variations such as a high riding or dehiscent jugular bulb may alter the anatomy of the hypotympanum and increase the risk of vascular injury in middle ear or cochlear implant surgery (Ueda, Yamazaki, Michida, Shinohara & Naito, 2024).

Smaller canals and fissures of the temporal bone also have important functional and clinical implications. The petrotympanic fissure transmits the chorda tympani nerve from the tympanic cavity to the infratemporal fossa. The canaliculus tympanicus transmits the tympanic branch of the glossopharyngeal nerve, which contributes to the tympanic plexus on the promontory. The canaliculus mastoideus transmits the auricular branch of the vagus nerve and is related to sensory innervation of the external acoustic region. The hiatus for the greater petrosal nerve transmits the greater petrosal nerve from the facial canal region toward the middle cranial fossa. The vestibular aqueduct contains the endolymphatic duct and is clinically important in enlarged vestibular aqueduct and other congenital inner ear disorders. The cochlear aqueduct connects the perilymphatic space near the basal turn of the cochlea with the subarachnoid space and may be relevant in inner ear fluid dynamics and skull base pathways (Benson et al., 2020).

The following table summarizes the principal canals, foramina, fissures, and aqueducts of the temporal bone and their major transmitted or related structures (Table 1).

In anatomical and clinical practice, these structures should be interpreted together rather than memorized as isolated openings. The temporal bone is a compact region in which the facial nerve, vestibulocochlear nerve, internal carotid artery, jugular bulb, sigmoid sinus, middle ear cavity, inner ear, and mastoid air cells are separated by thin bony partitions. This explains why small congenital variations, inflammatory erosion, traumatic fracture lines, or surgical drilling may produce significant neurological, vascular, auditory, or vestibular consequences.

## 5. CLINICAL AND SURGICAL ANATOMY OF THE TEMPORAL BONE

The clinical importance of the temporal bone arises from the close spatial relationship between its osseous structures, the external and middle ear, the inner ear, the facial nerve, the vestibulocochlear nerve, the internal carotid artery, the jugular bulb, the sigmoid sinus, and the dura of the middle and posterior cranial fossae. Because many of these structures are separated only by thin bony partitions, relatively small pathological processes may cause significant auditory, vestibular, neural, vascular, or intracranial complications. Therefore, the temporal bone is a central region in otology, neurotology, radiology, skull base surgery, maxillofacial surgery, and clinical anatomy.

### 5.1. Temporal Bone Fractures

Temporal bone fractures are clinically important because fracture lines may involve the external acoustic canal, ossicular chain, otic capsule, facial canal, carotid canal, jugular foramen, or mastoid air cell system. Traditionally, these fractures were classified as longitudinal or transverse according to their orientation relative to the long axis of the petrous temporal bone. However, from a clinical perspective, the distinction between otic capsule sparing and otic capsule violating fractures is particularly useful because otic capsule involvement is more strongly associated with sensorineural hearing loss, vestibular dysfunction, cerebrospinal fluid leakage, and facial nerve injury (Johnson et al., 2008).

The clinical presentation depends on the structures involved. Conductive hearing loss may result from hemotympanum, tympanic membrane injury, external acoustic canal disruption, or ossicular chain dislocation. Sensorineural hearing loss and vertigo are more suggestive of labyrinthine or otic capsule involvement. Facial nerve dysfunction may occur when the fracture line crosses the facial canal, especially near the geniculate ganglion or tympanic and mastoid segments. Fractures extending toward the carotid canal or jugular foramen may also create risk for vascular injury or lower cranial nerve involvement. Thus, temporal bone trauma should be evaluated as a regional injury involving osseous, neural, vascular, and sensory structures rather than as an isolated skull fracture (Kennedy, Avey & Gentry, 2014).

### 5.2. Otitis Media, Mastoiditis and Cholesteatoma

The temporal bone is also clinically important in inflammatory and infectious diseases of the middle ear and mastoid region. The middle ear cavity communicates with the mastoid antrum and mastoid air cells through the aditus ad antrum. This anatomical continuity explains why middle ear infection may extend into the mastoid air cell system and cause mastoiditis. In uncomplicated cases, the disease may remain limited to the mucosa of the tympanic cavity and mastoid cells. However, progression may result in bony erosion, subperiosteal abscess, facial canal involvement, labyrinthine complications, sigmoid sinus thrombosis, or intracranial spread through the tegmen tympani or tegmen mastoideum (Cassano, Ciprandi, & Passali, 2020).

Cholesteatoma is another important condition in which anatomy directly determines clinical behavior. Although it is histologically benign, cholesteatoma may enlarge and erode adjacent bony structures. The ossicles, scutum, tegmen tympani, lateral semicircular canal, facial canal, and mastoid air cells may be affected. Erosion of the ossicles may produce conductive hearing loss, while involvement of the lateral semicircular canal may cause vertigo or labyrinthine fistula. Facial canal dehiscence or erosion increases the risk of facial nerve dysfunction, especially during surgery. Therefore, detailed knowledge of the epitympanum, aditus ad antrum, mastoid antrum, facial recess, sinus tympani, and lateral semicircular canal is essential in both diagnosis and surgical management (Rosito, Canali, Teixeira, Silva, Selaimen, & Costa, 2019).

### 5.3. Mastoidectomy and Surgical Landmarks

Mastoidectomy is one of the most important surgical procedures demonstrating the applied anatomy of the temporal bone. The procedure requires orientation within a compact region bordered by the tegmen superiorly, sigmoid sinus posteriorly, external acoustic canal anteriorly and laterally, middle ear anteriorly, labyrinthine structures medially, and digastric ridge inferiorly. Important landmarks include the mastoid cortex, spine of Henle, posterior wall of the external acoustic canal, mastoid antrum, tegmen mastoideum, sigmoid sinus, lateral semicircular canal, short process of the incus, facial canal, facial recess, chorda tympani, and digastric ridge (Isaacson, 2018; Kennedy & Lin, 2023).

The degree of mastoid pneumatization may significantly affect the operative field. A well pneumatized mastoid usually provides a wider air cell system and more recognizable landmarks, whereas a sclerotic mastoid may make surgical dissection more difficult. As discussed previously, mastoid pneumatization shows considerable individual variation and age related growth patterns (Aladeyelu et al., 2022). The facial nerve is particularly important because its mastoid segment descends within the facial canal and exits through the stylomastoid foramen. Injury to the facial nerve may cause significant functional and cosmetic morbidity. Similarly, the sigmoid sinus and tegmen are relevant because excessive drilling or disease related erosion may lead to venous injury, dural exposure, cerebrospinal fluid leakage, or intracranial complications. For this reason, mastoid surgery depends not only on knowledge of named anatomical structures, but also on the ability to interpret their three dimensional relationships during dissection (Isaacson, 2018; Kennedy & Lin, 2023).

### 5.4. Temporomandibular Joint Relations and Eagle Syndrome

The temporal bone is also relevant to clinical conditions outside the classical field of otology. The mandibular fossa and articular tubercle of the squamous part form the temporal component of the temporomandibular joint. Because the joint is located close to the external acoustic meatus and shares regional sensory innervation through the auriculotemporal nerve, patients with temporomandibular disorders may report otalgia, ear fullness, tinnitus, or other otologic complaints. However, the available evidence supports an association rather than a clearly proven causal relationship. Therefore, otologic symptoms in patients with temporomandibular disorders should not automatically be attributed to the joint; appropriate otolaryngological evaluation and differential diagnosis remain necessary (Hernández-Nuño de la Rosa et al., 2022).

The styloid process and stylohyoid complex represent another clinically relevant region of the temporal bone. Elongation of the styloid process or ossification of the stylohyoid ligament may be associated with Eagle syndrome. Depending on the direction and length of the styloid process and its relationship with adjacent neurovascular structures, patients may present with throat pain, dysphagia, otalgia, foreign body sensation in the pharynx, cervicofacial pain, or vascular symptoms. However, radiological elongation alone is not sufficient for diagnosis, because asymptomatic elongation may also occur. Clinical correlation is therefore essential when interpreting styloid process morphology (Czako et al., 2020).

### 5.5. Vascular Variations and Surgical Risk

Vascular relationships are among the most critical aspects of temporal bone anatomy. The internal carotid artery passes through the carotid canal within the petrous temporal bone, while the jugular bulb occupies the jugular fossa inferiorly (Standring, 2020). Variations such as aberrant internal carotid artery, dehiscent carotid canal, high-riding jugular bulb, dehiscent jugular bulb, or jugular bulb diverticulum may alter the expected surgical anatomy of the middle ear and skull base. These variations are important because they may mimic middle ear masses, produce pulsatile tinnitus or conductive symptoms, and create risk for severe bleeding during otologic procedures (Nada et al., 2021; Ueda et al., 2024).

High resolution computed tomography is particularly valuable for defining these bony and vascular relationships before surgery. For example, a high riding or dehiscent jugular bulb may protrude into the tympanic cavity and obscure surgical access to the round window or hypotympanum. In cochlear implantation or middle ear surgery, failure to recognize such a variation may result in hemorrhagic complications or alteration of the surgical plan. Therefore, preoperative imaging should be evaluated systematically with attention to the carotid canal, jugular bulb, sigmoid sinus, facial canal, round window niche, mastoid pneumatization, and middle ear cavity (Ueda et al., 2024).

## 6. CONCLUSION

The temporal bone is a highly complex cranial bone in which developmental, morphological, neurovascular, and clinical features are closely integrated. Its squamous, petrous, tympanic, mastoid, and styloid components differ in origin, structure, density, anatomical relationships, and clinical relevance. This composite organization explains why temporal bone anatomy cannot be fully understood by surface morphology alone.

From a developmental perspective, the temporal bone reflects the interaction of the cranial vault, cranial base, otic capsule, external auditory canal, middle ear cavity, mastoid air cell system, and pharyngeal arch derivatives. From a morphological perspective, it contains and protects the organs of hearing and balance, forms part of the temporomandibular joint, and transmits several critical neurovascular structures. Its canals, foramina, fissures, and aqueducts provide pathways for the facial nerve, vestibulocochlear nerve, internal carotid artery, jugular bulb, petrosal nerves, chorda tympani, and other small but clinically important structures.

Clinically, the temporal bone is involved in a wide range of conditions, including congenital anomalies, temporal bone fractures, otitis media, mastoiditis, cholesteatoma, facial nerve disorders, vascular variations, temporomandibular joint-related symptoms, and Eagle syndrome. Many of these conditions are explained by the close spatial relationships between the middle ear, inner ear, mastoid air cells, facial canal, carotid canal, jugular fossa, sigmoid sinus, and cranial fossae. Therefore, a detailed understanding of temporal bone anatomy is essential not only for anatomical education, but also for radiological interpretation, otologic surgery, neurotology, skull base surgery, and the prevention of neurovascular complications.

**Table 1. Principal Canals, Foramina, Fissures, and Aqueducts of the Temporal Bone**

| Canal / Foramen / Fissure | Main Location | Transmitted Or Related Structures | Clinical Relevance |
|---|---|---|---|
| Internal acoustic meatus | Posterior surface of the petrous part | Facial nerve, vestibulocochlear nerve, labyrinthine vessels | Vestibular schwannoma, facial nerve pathology, congenital nerve deficiency, cochlear implantation planning |
| Facial canal | Petrous and mastoid parts | Facial nerve, geniculate ganglion, greater petrosal nerve, nerve to stapedius, chorda tympani | Facial paralysis, temporal bone fracture, cholesteatoma, middle ear disease, mastoid surgery |
| Stylomastoid foramen | Between styloid and mastoid processes | Facial nerve exit, stylomastoid artery | Facial nerve block, parotid region surgery, facial nerve injury |
| Carotid canal | Inferior surface of petrous part to petrous apex | Internal carotid artery, sympathetic plexus | Vascular injury, aberrant internal carotid artery, skull base surgery |
| Jugular fossa / jugular foramen region | Inferior surface of petrous part | Superior bulb of internal jugular vein; cranial nerves IX, X, XI pass through jugular foramen | High riding or dehiscent jugular bulb, glomus jugulare tumors, lower cranial nerve deficits, vascular injury risk |
| Petrotympanic fissure | Between mandibular fossa and tympanic region | Chorda tympani, anterior tympanic vessels | Taste pathway, middle ear and infratemporal fossa connection |

| Canal / Foramen / Fissure | Main Location | Transmitted Or Related Structures | Clinical Relevance |
|---|---|---|---|
| Hiatus for greater petrosal nerve | Anterior surface of petrous part | Greater petrosal nerve | Lacrimal secretomotor pathway, facial nerve lesions, perineural tumor spread |
| Canaliculus tympanicus / inferior tympanic canaliculus | Inferior petrous surface / pars nervosa region of jugular foramen | Tympanic branch of glossopharyngeal nerve (Jacobson's nerve) | Tympanic plexus, glomus tympanicum, middle ear neurovascular anatomy |
| Canaliculus mastoideus / mastoid canaliculus | Jugular fossa and mastoid region | Auricular branch of vagus nerve (Arnold's nerve) | Arnold nerve reflex, cough reflex, referred otalgia from external ear stimulation |
| Vestibular aqueduct | Posterior surface of petrous part | Endolymphatic duct and endolymphatic sac | Enlarged vestibular aqueduct, sensorineural or mixed hearing loss, Pendred syndrome |
| Cochlear aqueduct | Inferior petrous region near round window and petrous apex | Perilymphatic duct; communication between scala tympani and subarachnoid space | Inner ear pressure regulation, labyrinthitis ossificans pathway, possible CSF related communication |
| Petromastoid canal / subarcuate canaliculus | From subarcuate fossa to medial mastoid antrum | Dura mater, subarcuate artery and vein | Potential route for infectious spread from mastoid air cells to cranial cavity; pediatric normal variant when prominent |
| Singular canal | From posterior margin of internal auditory canal to posterior semicircular canal | Posterior ampullary nerve / singular nerve | May mimic fracture on imaging; landmark in posterior fossa transmeatal approaches and singular neurectomy |
| Mastoid foramen | Mastoid or occipitomastoid region | Mastoid emissary vein, meningeal branch of occipital artery | Emissary venous communication, bleeding risk, potential route of infection spread |

**REFERENCES**

Aladeyelu, O. S., Olaniyi, K. S., Olojede, S. O., Mbatha, W. B. E., Sibiya, A. L., & Rennie, C. O. (2022). Temporal bone pneumatization: A scoping review on the growth and size of mastoid air cell system with age. *PLOS ONE, 17*(6), e0269360. https://doi.org/10.1371/journal.pone.0269360

Benson, J. C., Eckel, L. J., Guerin, J. B., Silvera, V. M., Diehn, F. E., Hunt, C. H., Schwartz, K. M., & Lane, J. I. (2020). Review of temporal bone microanatomy: Aqueducts, canals, clefts and nerves. *Clinical Neuroradiology, 30*(2), 209–219. https://doi.org/10.1007/s00062-019-00864-3

Cassano, P., Ciprandi, G., & Passali, D. (2020). Acute mastoiditis in children. *Acta Biomedica, 91*(1-S), 54–59. https://doi.org/10.23750/abm.v91i1-S.9259

Czako, L., Simko, K., Thurzo, A., Galis, B., & Varga, I. (2020). The syndrome of elongated styloid process, the Eagle's syndrome—from anatomical, evolutionary and embryological backgrounds to 3D printing and personalized surgery planning. Report of five cases. *Medicina, 56*(9), 458. https://doi.org/10.3390/medicina56090458

Dalley, A. F., II, & Agur, A. M. R. (2023). *Moore's clinically oriented anatomy* (9th ed.). Wolters Kluwer.

Grzonkowska, M., Baumgart, M., Kułakowski, M., & Szpinda, M. (2023). Quantitative anatomy of the primary ossification center of the squamous part of temporal bone in the human fetus. *PLOS ONE, 18*(12), e0295590. https://doi.org/10.1371/journal.pone.0295590

Gupta, S., Mends, F., Hagiwara, M., Fatterpekar, G., & Roehm, P. C. (2013). Imaging the facial nerve: A contemporary review. *Radiology Research and Practice, 2013*, 248039. https://doi.org/10.1155/2013/248039

Hernández-Nuño de la Rosa, M. F., Keith, D. A., Siegel, N. S., & Moreno-Hay, I. (2022). Is there an association between otologic symptoms and temporomandibular disorders? An evidence-based review. *Journal of the American Dental Association, 153*(11), 1096–1103. https://doi.org/10.1016/j.adaj.2021.07.029

Isaacson, B. (2018). Anatomy and surgical approach of the ear and temporal bone. *Head and Neck Pathology, 12*(3), 321–327. https://doi.org/10.1007/s12105-018-0926-2

Johnson, F., Semaan, M. T., & Megerian, C. A. (2008). Temporal bone fracture: Evaluation and management in the modern era. *Otolaryngologic Clinics of North America, 41*(3), 597–618. https://doi.org/10.1016/j.otc.2008.01.006

Juliano, A. F., Ginat, D. T., & Moonis, G. (2013). Imaging review of the temporal bone: Part I. Anatomy and inflammatory and neoplastic processes. *Radiology, 269*(1), 17–33. https://doi.org/10.1148/radiol.13120733

Kennedy, K. L., & Lin, J. W. (2023). Mastoidectomy. In *StatPearls*. StatPearls Publishing.

Kennedy, T. A., Avey, G. D., & Gentry, L. R. (2014). Imaging of temporal bone trauma. *Neuroimaging Clinics of North America, 24*(3), 467–486. https://doi.org/10.1016/j.nic.2014.03.003

Nada, A., Agunbiade, S. A., Whitehead, M. T., Cousins, J. P., Ahsan, H., & Mahdi, E. (2021). Cross-sectional imaging evaluation of congenital temporal bone anomalies: What each radiologist should know. *Current Problems in Diagnostic Radiology, 50*(5), 716–724. https://doi.org/10.1067/j.cpradiol.2020.08.005

Rosito, L. P. S., Canali, I., Teixeira, A., Silva, M. N., Selaimen, F., & Costa, S. S. D. (2019). Cholesteatoma labyrinthine fistula: Prevalence and impact. *Brazilian Journal of Otorhinolaryngology*, *85*(2), 222–227. https://doi.org/10.1016/j.bjorl.2018.01.005

Standring, S. (Ed.). (2020). *Gray's anatomy: The anatomical basis of clinical practice* (42nd ed.). Elsevier.

Ueda, K., Yamazaki, H., Michida, T., Shinohara, S., & Naito, Y. (2024). High riding jugular bulb protruding into tympanic cavity: Longitudinal radiologic study in a deaf child. *Ear, Nose & Throat Journal*, *103*(11), 707–710. https://doi.org/10.1177/01455613221079494

# SEX ESTIMATION USING CRANIAL PARAMETERS IN THE TURKISH POPULATION

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## 1. INTRODUCTION

In forensic anthropology, the identification process is based on the construction of an individual's biological profile from skeletal remains. The main components of this biological profile include sex, age, stature, and population origin (Krishan et al., 2016; Spradley, 2016). Sex estimation is considered one of the first and most important steps in identification studies, as it directly affects the assessment of other biological parameters. Particularly in incomplete, fragmented, burned, or severely decomposed human remains, accurate sex estimation contributes to narrowing the pool of possible identities and enables the forensic process to proceed more reliably (Wang et al., 2024).

### 1.1. The Role of the Cranium in Sex Estimation

The cranium is an important structure in sex estimation due to its durability and the presence of many sexually dimorphic anatomical features (Spradley and Jantz, 2011). It includes dimorphic regions such as muscle attachment sites,

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facial skeletal structures, frontal and occipital morphology, orbital region, mastoid process, and mandible. Male crania generally show larger dimensions, thicker cortical structure, more prominent muscle attachments, and developed supraorbital, mastoid, and occipital prominences, whereas female crania tend to be more gracile, with sharper supraorbital margins, a more vertical frontal region, and a more delicate facial skeleton (Mello-Gentil and Souza-Mello, 2021; Musilová et al., 2016). Craniometric measurements provide valuable metric data for sex estimation. These measurements may differ significantly between sexes, and population-specific standards are essential for reliable evaluation (Zaafrane et al., 2018; Zhan et al., 2019).

## 2. ANATOMICAL STRUCTURE OF THE CRANIUM

The cranium refers to the entirety of the bony structures that form the skeleton of the head. Anatomically, it is a complex skeletal structure closely associated with the brain, meninges, sensory organs, and the initial parts of the upper respiratory and digestive tracts. The skull should not be regarded merely as a bony box that protects the brain; it is also a functional structure that forms the basic shape of the face and constitutes the bony boundaries of the orbit, nasal cavity, and oral cavity (Arıncı and Elhan, 2010; Moore et al., 2018). The cranial bones can be preserved for a longer period than some soft tissues and skeletal regions despite trauma, burning, decomposition, or environmental effects causes the cranium to be frequently evaluated in identification studies. In this respect, the cranium can provide important information in the assessment of an individuals age, sex, and some morphological characteristics (Ozan, 2014; Mello-Gentil and Souza-Mello, 2021).

## 2.1. Divisions of the Cranium

### 2.1.1. Neurocranium

Anatomically, the cranium is examined in two main divisions: the neurocranium and the viscerocranium. The neurocranium is the part of the cranium that surrounds and protects the brain. This division forms the superior and posterior parts of the skull and creates the cranial cavity, called the cavitas cranii. The neurocranium consists of the frontal, parietal, temporal, occipital, sphenoid, and ethmoid bones. The anatomical importance of the neurocranium does not arise solely from its protection of the brain. The frontal bone, parietal bones, temporal bones, and occipital bone located in this division are also important in morphological evaluations due to their external surface shapes, muscle attachment areas, and cranial prominences (Arıncı and Elhan, 2010; Moore et al., 2018; Ozan, 2014; Arifoğlu, 2021).

### 2.1.2. Viscerocranium

The viscerocranium is the part of the cranium that forms the facial skeleton. This division contributes to the formation of the bony boundaries of structures such as the orbit, cavitas nasi, and cavitas oris. The viscerocranium consists of bones such as the maxilla, zygomatic bone, nasal bone, lacrimal bone, palatine bone, inferior nasal concha, vomer, and mandible. The maxilla and mandible play a role in mastication because they are the bony structures in which the teeth are located; the nasal bones and surrounding structures are involved at the beginning of the respiratory tract; and the orbital bony structures serve to protect the eyeball (Moore et al., 2018; Arifoğlu, 2021). The importance of the viscerocranium in forensic anthropology arises from the fact that the facial skeleton may show individual and sex-related morphological differences (Arıncı and Elhan, 2010; Mello-Gentil and Souza-Mello, 2021).

## 3. SEX ESTIMATION STUDIES CONDUCTED USING NEUROCRANIAL REGIONS

### 3.1. Frontal Bone

The frontal bone is an important cranial structure used in sex estimation, particularly through the glabella, supraorbital region, and frontal sinus morphometry. In the Turkish population, studies have mainly focused on frontal sinus dimensions and related morphological features. Tatlisumak et al. reported that frontal sinus width, height, and anteroposterior length may vary according to age and sex (Tatlisumak et al., 2017). Türk et al. found that bilateral frontal sinus width, anteroposterior depth, and total width were significantly higher in males on Cone-Beam Computed Tomography (CBCT) images (Türk et al., 2019). Similarly, Boyacioglu et al. emphasized the importance of frontal sinus volume, especially right frontal sinus volume, in sex estimation in the Turkish sample (Boyacioglu et al., 2020). Durum Polat et al. also reported that frontal and maxillary sinus diameters could assist sex estimation (Durum Polat et al., 2020). Frontal sinus morphometry has also been evaluated in archaeological and radiographic materials. Demiralp et al. showed that frontal sinus parameters could be assessed in ancient skulls, although their discriminative ability was limited (Demiralp et al., 2019). Emekli reported that frontal sinus height and width on direct skull radiographs were significantly higher in males and could provide moderate accuracy in sex estimation (Emekli, 2023). Morphological criteria have also been investigated; Yaşar and Sağır stated that the glabella showed marked sexual dimorphism, while Apaydın and İçöz reported that the glabella was one of the strongest dimorphic features on 3D CBCT reconstructions (Yaşar and Sağır, 2023; Apaydın and İçöz, 2025). In addition, Kalkan and Kalkan found that frontal sinus measurements were significantly higher in males when evaluated together with mandibular ramus length (Kalkan and Kalkan, 2026). Overall, frontal bone studies in the Turkish population mainly emphasize frontal sinus morphometry and glabellar morphology.

### 3.2. Occipital Bone

The occipital bone and cranial base are frequently evaluated in sex estimation, especially through the foramen magnum, occipital condyles, posterior cranial fossa openings, external occipital protuberance, and nuchal crest. In Turkish studies, foramen magnum morphometry is the most commonly examined parameter. Uysal et al. reported that foramen magnum diameter, area, and circumference were higher in males on 3D computed tomography (CT) images (Uysal et al., 2005). İlgüy et al. showed that foramen magnum parameters contributed to sex estimation, although better classification was achieved when combined with mandibular measurements (İlgüy et al., 2014). Meral et al. similarly found that foramen magnum length, width, area, and circumference were higher in males and useful in discriminant analysis (Meral et al., 2020). Recent studies have also incorporated computational and broader cranial base approaches. Kartal et al. compared discriminant analysis and artificial neural networks using foramen magnum measurements and reported higher accuracy with artificial neural networks (Kartal et al., 2022). Depreli et al. evaluated posterior cranial fossa openings, including the foramen magnum, jugular foramen, and internal acoustic opening, and reported that these structures may show significant sexual dimorphism in the Turkish population (Depreli et al., 2025). Overall, occipital bone studies indicate that foramen magnum and posterior cranial fossa measurements are useful parameters for sex estimation.

### 3.3. Sphenoid Bone

The sphenoid bone has been evaluated mainly through sphenoid sinus morphometry due to its location at the cranial base. Kaplanoglu et al. reported that some surgically relevant sphenoid sinus measurements were longer in males and should be considered in clinical interventions (Kaplanoglu et al., 2013). Koç found that right, mean, and total sphenoid sinus volumes were higher in males, with right sphenoid sinus volume being the strongest parameter for sex estimation (Koç, 2020). Özeren Keşkek and Aytuğar reported that sphenoid sinus pneumatization types did not differ significantly by sex, although clival extension and some anterior clinoid process pneumatization types may show sex-related differences (Özeren Keşkek and Aytuğar, 2021). Gurlek Celik and Akman found that sphenoid sinus volumes, particularly left sphenoid sinus volume, were significantly greater in males (Gurlek Celik and Akman, 2024). Keleş et al. also reported that sphenoid sinus volume was higher in males and that sphenoid sinus shape may show anthropometric differences between sexes (Keleş et al., 2024). Thus, sphenoid sinus volume appears to be a useful cranial base parameter in sex estimation.

### 3.4. Ethmoid Bone

The ethmoid bone is a complex structure related to the orbit, nasal cavity, and anterior cranial base. In the Turkish population, direct sex estimation studies on the ethmoid bone are limited; available studies mostly focus on ethmoid sinus volume, ethmoid cells, agger nasi cell, ethmoid bulla, Haller cell, Onodi cell, and lamina papyracea variations. Borahan et al. evaluated paranasal sinus variations on CBCT images and examined ethmoid-related structures such as agger nasi, infraorbital ethmoid, and Onodi cells (Borahan et al., 2019). Bora et al. assessed sinonasal variations in 1532 CT cases and reported that the Onodi cell was more common in females, while ethmoid bulla and some variations differed by age (Bora et al., 2021). Gruszka et al. compared Polish and Turkish Cypriot populations and found that the agger nasi cell was one of the most common variations in the Turkish Cypriot group (Gruszka et al., 2022). Overall, the ethmoid region is not as strong as the sphenoid sinus for sex estimation, but it provides valuable anatomical variation data for evaluating the orbit, nasal cavity, and paranasal sinus complex.

## 4. SEX ESTIMATION STUDIES CONDUCTED USING VISCEROCRANIAL REGIONS

### 4.1. Mandible

The mandible is an important structure in forensic anthropology due to its robust morphology, prominent muscle attachment areas, and ease of radiological measurement. İnci et al. reported that mandibular ramus measurements, particularly vertical ramus parameters, showed marked sexual dimorphism on 3D CT images (İnci et al., 2016). Acar et al. found that corpus length, corpus height, ramus height, ramus width, and bicondylar width were significantly higher in males using multidetector computed tomography (MDCT) (Acar et al., 2017). Direk et al. reported that the gonial angle was higher in females, whereas some mandibular foramen-related distances and lingula height were higher in males (Direk et al., 2018). Apaydın et al. showed that mental foramen-related distances were higher in males, while gonial and antegonial angles were larger in females on panoramic radiographs (Apaydın et al., 2018). Studies based on CBCT also support the value of mandibular measurements in sex estimation. İçöz and Akgünlü found that condylar length, coronoid length, bigonial width, and bicondylar width were significantly higher in males (İçöz and

Akgünlü, 2019). Okkesim and Sezen Erhamza stated that all ramus-related measurements differed significantly between sexes in the Central Anatolian Turkish population (Okkesim and Sezen Erhamza, 2020). Sertel Meyvaci et al. found significant sex differences in mandibular angular parameters, including gonial, mentomandibular, α, and β angles (Sertel Meyvaci et al., 2021). Recent studies also confirmed that coronoid length, condylar length, bigonial width, condylar measurements, sigmoid notch depth, and general mandibular linear measurements are useful for sex estimation (Çelebi et al., 2025; Doğan et al., 2025; Mutlu et al., 2025). Overall, ramus height, condylar length, coronoid length, bigonial width, bicondylar width, mandibular length, and symphysis height are among the most dimorphic mandibular parameters in the Turkish population.

### 4.2. Maxilla and Maxillofacial Measurements

Sex estimation studies related to the maxilla and maxillofacial region in the Turkish population have mostly focused on maxillary sinus morphometry, although the hard palate, bizygomatic breadth, bigonial width, craniofacial diameters, and skeletal patterns have also been evaluated. Teke et al. reported that maxillary sinus dimensions may support sex estimation but have limited accuracy when used alone (Teke et al., 2007). Ekizoğlu et al. found that all maxillary sinus measurements were significantly smaller in females than in males on thin-slice MDCT images (Ekizoğlu et al., 2014). Studies on maxillary sinus volume have produced different findings. Güleç et al. found no significant relationship between maxillary sinus volume and age or sex in a Turkish subpopulation (Güleç et al., 2020). Kolak et al. found that some maxillary sinus height and width values were higher in males, with right maxillary sinus height being the most discriminative parameter (Kolak et al., 2024). Doğan and Uluışık also reported significantly higher right and left maxillary sinus volumes in males (Doğan and Uluışık, 2024).

### 4.3. Zygomatic Bone and Arch

In Turkish sex estimation studies, the zygomatic bone and arch have generally been assessed through bizygomatic diameter or breadth rather than as independent structures. Ekizoğlu et al. reported that bizygomatic diameter was one of the most prominent sexually dimorphic craniofacial parameters and was higher in males (Ekizoğlu et al., 2016). Meral et al. found that maximum cranial length, maximum cranial breadth, bimastoid diameter, bizygomatic diameter, and bigonial width could contribute to sex estimation (Meral et al., 2022). Kalkan et al. evaluated several linear craniometric parameters and reported that all measurements were higher in males, with bizygomatic breadth showing one of the most notable sex differences (Kalkan et al., 2025). Alkan also found that bizygomatic breadth was higher in males in direct cephalometric measurements, although it was recommended to use this parameter together with other craniofacial measurements (Alkan, 2025). Overall, bizygomatic breadth appears to be a valuable and commonly used indicator of craniofacial sexual dimorphism in the Turkish population.

### 4.4. Orbit and Surrounding Region

Orbital studies in the Turkish population have evaluated orbital breadth, orbital height, orbital index, biorbital and interorbital breadth, orbital aperture dimensions, globe volume, optic nerve measurements, and medial orbital wall morphology. Kaya et al. reported that left orbital breadth was more discriminative in males and left orbital height in females, but orbital measurements alone were not sufficiently reliable for sex estimation (Kaya et al., 2014). Özer et al. found significant sex differences in orbital aperture dimensions, axial globe length, globe volume, optic nerve diameter, and right optic nerve length (Özer et al., 2016). Meral et al. reported that orbital measurements could be used in discriminant analysis, although their overall accuracy was moderate (Meral et al., 2022). Can et al. showed that orbit-related parameters, especially biorbital width, may contribute to sex estimation and become more effective when combined with zygomatic and maxillofacial widths (Can et al., 2022). Erdem et al. evaluated orbital width, height, depth, and volume using 3D MDCT and reported that orbital measurements were generally higher in males, while side differences should also be considered (Erdem et al., 2023). Overall, orbital parameters have auxiliary value and are more effective when combined with other craniofacial measurements.

### 4.5. Nasal Bones and Piriform Aperture

The nasal bones and piriform aperture are midfacial structures that have been evaluated less frequently than the mandible and orbit in Turkish sex estimation studies. Karadağ et al. reported that nasal bone length was higher in males, while piriform aperture width alone was not a strong parameter for sex differentiation (Karadağ et al., 2011). Yüzbaşıoğlu et al. found that most nasal bone and piriform aperture measurements were higher in males on MDCT images, supporting the value of this region in sexual dimorphism (Yüzbaşıoğlu et al., 2014). Sertel Meyvaci et al. measured piriform aperture dimensions and adjacent cranial structures and found significant sex differences in most parameters, except for vertex–rhinion distance, rhinion–supraorbital foramen distances, and piriform aperture width at the infraorbital foramina level (Sertel Meyvaci et al., 2019). Kabakcı et al. also reported that piriform aperture height and width were generally higher in males (Kabakcı et al., 2020). Parlak et al. used 3D CT and machine learning methods and showed that piriform aperture measurements provided moderate accuracy with discriminant analysis, while machine learning, especially ensemble methods, improved classification performance (Parlak et al., 2025). Overall, nasal bones and piriform aperture measurements have supportive value and should be evaluated together with other craniofacial parameters.

### 4.6. Palatine Region

The palatine region and hard palate may provide auxiliary morphometric data for sex estimation in the Turkish population. Studies have mainly focused on hard palate length, width, height/depth, palatal index, palatal vault angle, greater palatine foramen, and nasopalatine canal measurements. Ortug and Uzel evaluated the greater palatine foramen together with palatal index and sex variables (Ortug and Uzel, 2019). Ayyildiz and Dursun reported that hard palate asymmetry and sex-related differences may be present in the Turkish population (Ayyildiz and Dursun, 2021). Tassoker et al. found that palatal width, length, and depth were higher in males, whereas palatal vault angle did not differ significantly between sexes (Tassoker et al., 2024). Overall, palatine measurements should not be used alone for definitive sex estimation, but may support evaluation when combined with other craniofacial parameters.

### 4.7. Vomer, Lacrimal Bone, and Inferior Nasal Concha

The vomer, lacrimal bone, and inferior nasal concha have limited direct use in sex estimation studies in the Turkish population. The vomer has mostly been evaluated indirectly through nasal septum and nasal cavity morphology. Okumuş reported that bony nasolacrimal canal measurements may show sex-related variation, particularly in the angle between the canal and nasal floor (Okumuş, 2020). Açar et al. examined inferior concha-related variations and reported that inferior concha thickness did not differ significantly by sex (Açar et al., 2025). Overall, these structures do not appear to be strong independent markers for sex estimation, but they may provide supportive morphometric data in the holistic evaluation of the nasal cavity, orbit, maxilla, and sinonasal complex.

## 5. CONCLUSION

Studies on sex estimation from the cranium in the Turkish population show that cranial and maxillofacial structures provide valuable information for forensic identification. The mandible, bizygomatic breadth, foramen magnum, and some sinus measurements stand out in sex differentiation. However, the most reliable results are obtained not from a single measurement, but from the combined evaluation of multiple cranial and maxillofacial parameters. CT, CBCT, three-dimensional imaging, and machine learning methods contribute to more objective and reproducible assessments.

## REFERENCES

Acar, M., Alkan, S. B., Tolu, İ., Arslan, F. Z., Çağlan, F., Vermez, H., ... Okutan, Ş. (2017). Morphometric analysis of mandibula with MDCT method in Turkish population. Asian Journal of Biomedical and Pharmaceutical Sciences, 7(62), 13–15.

Açar, G., Gökşan, A. S., & Magat, G. (2025). Three-dimensional CBCT analysis of how sinonasal variations affect maxillary sinus volume in individuals with different skeletal malocclusion. Scientific Reports, 15, 34040. doi:10.1038/s41598-025-13624-w

Alkan, Y. (2025). Sex estimation using cephalometric data in a Turkish population: A logistic and ROC-based analysis. International Journal of Morphology, 43(6), 1987–1994. doi:10.4067/S0717-95022025000601987

Apaydın, B. K., & İçöz, D. (2025). Assessment of cranial traits for gender determination by using 3D models: A retrospective CBCT study. Cyprus Journal of Medical Sciences, 10(4), 264–271. doi:10.4274/cjms.2025.2025-8

Apaydın, B., İçöz, D., Yaşar, F., & Akgünlü, F. (2018). Evaluation of mandibular anatomical formation for gender determination in Turkish population. Balkan Journal of Dental Medicine, 22(3), 133–137.

Arıncı, K., & Elhan, A. (2010). Anatomi (1–2. cilt, 5. baskı). Güneş Tıp Kitabevleri.

Arifoğlu, Y. (Ed.). (2021). Her yönüyle anatomi (3. baskı). İstanbul Tıp Kitabevleri.

Ayyildiz, V. A., & Dursun, A. (2021). Evaluation of hard palate asymmetry in Turkish population. Annals of Medical

Research, 28(5). doi:10.5455/annalsmedres.2020.09.901

Bora, A., Koç, M., Durmuş, K., & Altuntaş, E. E. (2021). Evaluating the frequency of anatomical variations of the sinonasal region in pediatric and adult age groups according to gender: Computed tomography findings of 1532 cases. The Egyptian Journal of Otolaryngology, 37, 58. doi:10.1186/s43163-021-00122-9

Borahan, M. O., Ulay, G., Yıldız Sadıkoğlu, A. N., & Namdar Pekiner, F. (2019). The prevalence of paranasal sinus anatomic variations on cone beam computed tomography scan images of Turkish population. Clinical and Experimental Health Sciences, 9(1), 42–48. doi:10.5152/clinexphealthsci.2018.1001

Boyacioglu, H., van der Stelt, P. F., Kamburoglu, K., Goksuluk, D., & Avcu, N. (2020). Assessment of the frontal sinus dimensions using CBCT for gender determination among samples of Dutch and Turkish individuals. Romanian Journal of Legal Medicine, 28(3), 288–293. doi:10.4323/rjlm.2020.288

Can, A. R., Korkmaz, İ., Atamtürk, D., Karazincir, S., & Duyar, İ. (2022). Üst yüz ve orbita bölgesinden alınan genişlik ölçülerinin cinsiyet tayininde kullanımı. The Medical Journal of Mustafa Kemal University, 13(47), 296–302. doi:10.17944/mkutfd.1022278

Çelebi, E., Ersoy Kölege, S. N., Koşkan, Ö., & Görmez, Ö. (2025). Evaluation of sex estimation through mandibular morphometric measurements on cone-beam computed tomography images. Journal of Health Sciences and Medicine, 8(6), 1011–1017. doi:10.32322/jhsm.1752625

Demiralp, K. O., Cakmak, S. K., Aksoy, S., Bayrak, S., Orhan, K., & Demir, P. (2019). Assessment of paranasal sinus parameters according to ancient skulls' gender and age by using cone-beam computed tomography. Folia Morphologica, 78(2), 344–350.

Depreli, A., Sahin, N. E., Sonmez, S., Ozgen Sonmez, M. N., Sahin, M., Dogan, B., ... Bakan, H. U. (2025). Morphometric analysis of the openings in the posterior cranial fossa and their relationship with sex. Diagnostics, 15(24), 3189. doi:10.3390/diagnostics15243189

Direk, F., Uysal, I. I., Kivrak, A. S., Unver Dogan, N., Fazliogullari, Z., & Karabulut, A. K. (2018). Reevaluation of mandibular morphometry according to age, gender, and side. The Journal of Craniofacial Surgery, 29(4), 1054–1059. doi:10.1097/SCS.0000000000004293

Dogan, M. E., Turkoglu, B. N., & Şengul, I. (2025). A morphometric evaluation of the mandibular condyle, coronoid process, and gonial angle: Age and gender differences in CBCT imaging. Diagnostics, 15(12), 1459. doi:10.3390/diagnostics15121459

Doğan, M. E., & Uluışık, N. (2024). Analysis of maxillary sinus volume of a group of population living on the southern border of Southeastern Anatolia. Anatolian Current Medical Journal, 6(3), 210–214. doi:10.38053/acmj.1433517

Durum Polat, Y., Tellioğlu, A. M., Şahmelikoğlu, A. G., Çapacı, B., & Karaman, C. Z. (2020). Use of maxillary and frontal sinus diameters in sex determination: Which is superior? Cerrahpaşa Medical Journal, 44(1), 27–34. doi:10.5152/cjm.2020.19013

Ekizoglu, O., Hocaoglu, E., Inci, E., Can, I. O., Solmaz, D., Aksoy, S., ... Sayin, I. (2016). Assessment of sex in a modern Turkish population using cranial anthropometric parameters. Legal Medicine, 21, 45–52. doi:10.1016/j.legalmed.2016.06.001

Ekizoglu, O., Inci, E., Hocaoglu, E., Sayin, I., Kayhan, F. T., & Can, I. O. (2014). The use of maxillary sinus dimensions in gender determination: A thin-slice multidetector computed tomography assisted morphometric study. The Journal of Craniofacial Surgery, 25(3), 957–960. doi:10.1097/SCS.0000000000000734

Emekli, E. (2023). Sex determination using frontal sinus diameters on direct radiography. Cureus, 15(10), e47476. doi:10.7759/cureus.47476

Erdem, H., Tekeli, M., Cevik, Y., Kilic Safak, N., Kaya, O., Boyan, N., & Oguz, O. (2023). Three-dimensional (3D) analysis of orbital morphometry in healthy Anatolian adults: Sex, side discrepancies, and clinical relevance. Cureus, 15(9), e45208. doi:10.7759/cureus.45208

Gruszka, K., Aksoy, S., Różyło-Kalinowska, I., Gülbeş, M. M., Kalinowski, P., & Orhan, K. (2022). A comparative study of paranasal sinus and nasal cavity anatomic variations between the Polish and Turkish Cypriot population with CBCT. Head & Face Medicine, 18(1), 37. doi:10.1186/s13005-022-00340-3

Gulec, M., Tassoker, M., Magat, G., Lale, B., Ozcan, S., & Orhan, K. (2020). Three-dimensional volumetric analysis of the maxillary sinus: A cone-beam computed tomography study. Folia Morphologica, 79(3), 557–562. doi:10.5603/FM.a2019.0106

Gurlek Celik, N., & Akman, B. (2024). Analysis of sphenoid sinus and ethmoid sinus volume and asymmetry by sex: A 3D-CT study. Surgical and Radiologic Anatomy, 46(5), 551–558. doi:10.1007/s00276-024-03319-8

Inci, E., Ekizoglu, O., Turkay, R., Aksoy, S., Can, I. O., Solmaz, D., & Sayin, I. (2016). Virtual assessment of sex: Linear and angular traits of the mandibular ramus using three-dimensional computed tomography. The Journal of Craniofacial Surgery, 27(7), e627–e632. doi:10.1097/SCS.0000000000002979

İçöz, D., & Akgünlü, F. (2019). Cinsiyetin mandibuler parametreler üzerine etkisi: Retrospektif KIBT çalışması. Selcuk Dental Journal, 6(4), 55–59.

İlgüy, D., İlgüy, M., Ersan, N., Dölekoğlu, S., & Fişekçioğlu, E. (2014). Measurements of the foramen magnum and mandible in relation to sex using CBCT. Journal of Forensic Sciences, 59(3), 601–605. doi:10.1111/1556-4029.12376

Kabakci, A. G., Polat, S., Öksüzler, M., Öksüzler, F. Y., & Yücel, A. H. (2020). The determination of the piriform aperture morphometry and golden ratio in healthy Turkish subjects: A CT study. International Journal of Morphology, 38(2), 444–447. doi:10.4067/S0717-95022020000200444

Kalkan, E. D., Baransel, A., Akşamoğlu, M., Akbaba, M., & Kalkan, H. (2025). Sex determination using craniometric parameters: A computed tomography-based assessment. Adli Tıp Dergisi, 39(2), 125–135. doi:10.61970/adlitip.1700509

Kalkan, H., & Kalkan, E. D. (2026). Forensic application of CT-based frontal sinus and mandibular ramus measurements for sex and age estimation in a Turkish population: A retrospective analytical cross-sectional study. Medicine, 105(5), e47496. doi:10.1097/MD.0000000000047496

Kaplanoglu, H., Kaplanoglu, V., Toprak, U., & Hekimoglu, B. (2013). Surgical measurement of the sphenoid sinus on sagittal reformatted CT in the Turkish population. The Eurasian Journal of Medicine, 45(1), 7–15. doi:10.5152/eajm.2013.02

Karadag, D., Ozdol, N. C., Beriat, K., & Akinci, T. (2011). CT evaluation of the bony nasal pyramid dimensions in Anatolian people. Dento Maxillo Facial Radiology, 40(3), 160–164. doi:10.1259/dmfr/35578628

Kartal, E., Etli, Y., Asirdizer, M., Hekimoglu, Y., Keskin, S., Demir, U., ... Celbis, O. (2022). Sex estimation using foramen magnum measurements, discriminant analyses and artificial neural networks on an eastern Turkish population sample. Legal Medicine, 59, 102143. doi:10.1016/j.legalmed.2022.102143

Kaya, A., Uygun, S., Eraslan, C., Akar, G. C., Koçak, A., Aktaş, E., & Govsa, F. (2014). Sex estimation: 3D CTA-scan based on orbital measurements in Turkish population. Romanian Journal of Legal Medicine, 22(4), 257–262. doi:10.4323/rjlm.2014.257

Keleş, H., Yakar, H., Kaya, İ., Çiçek, F., Ceranoğlu, F. G., Çiftçi, A. T., & Karadağ, H. (2024). The relationship between sphenoidal sinus and sella turcica morphometry in the Turkish population: A retrospective study. Surgical and Radiologic Anatomy, 46(7), 977–984. doi:10.1007/s00276-024-03392-z

Koç, A. (2020). Are maxillary and sphenoid sinus volumes predictors of gender and age? A cone beam computed tomography study. Cumhuriyet Dental Journal, 23(4), 348–355. doi:10.7126/cumudj.795870

Kolak, M., Sunar, M., & Ocak, A. (2024). Sinus maxillaris morphometric measurements and comparative anatomy between genders. Archives of Basic and Clinical Research, 6(2), 140–145. doi:10.5152/ABCR.2024.23235

Krishan, K., Chatterjee, P. M., Kanchan, T., Kaur, S., Baryah, N., & Singh, R. K. (2016). A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic Science International, 261, 165.e1–165.e8. doi:10.1016/j.forsciint.2016.02.007

Mello-Gentil, T., & Souza-Mello, V. (2021). Contributions of anatomy to forensic sex estimation: Focus on head and neck bones. Forensic Sciences Research, 7(1), 11–23. doi:10.1080/20961790.2021.1889136

Meral, O., Toklu, B. B., Meydan, R., Kaya, A., Karadayı, B., & Acar, T. (2020). Sex estimation from foramen magnum parameters in adult Turkish population: A computed tomography study. Legal Medicine, 47, 101775. doi:10.1016/j.legalmed.2020.101775

Meral, O., Meydan, R., Toklu, B. B., Kaya, A., Karadayi, B., & Acar, T. (2022). Estimation of sex from computed tomography images of skull measurements in an adult Turkish population. Acta Radiologica, 63(11), 1513–1521. doi:10.1177/02841851211044978

Meral, O., Toklu, B. B., Meydan, R., Kaya, A., Karadayı, B., & Acar, T. (2022). Sexing from the orbital measurements using computed tomography images and discriminant function analysis in Turkish population. The Imaging

Science Journal, 70, 207–213. doi:10.1080/13682199.2023.2165237

Moore, K. L., Dalley, A. F., II, & Agur, A. M. R. (2018). Clinically oriented anatomy (8th ed.). Wolters Kluwer.

Musilová, B., Dupej, J., Velemínská, J., Chaumoitre, K., & Bruzek, J. (2016). Exocranial surfaces for sex assessment of the human cranium. Forensic Science International, 269, 70–77. doi:10.1016/j.forsciint.2016.11.006

Mutlu, İ., Asirdizer, M., Kartal, E., Etli, Y., Keskin, S., Sever, D., & Göya, C. (2025). Sex estimation from mandible by computerized tomography images and discriminant function analysis in an Eastern Turkish population. Eastern Journal of Medicine, 30(3), 367–381. doi:10.5505/ejm.2025.71780

Okkesim, A., & Sezen Erhamza, T. (2020). Assessment of mandibular ramus for sex determination: Retrospective study. Journal of Oral Biology and Craniofacial Research, 10(4), 569–572. doi:10.1016/j.jobcr.2020.07.019

Okumuş, Ö. (2020). Investigation of the morphometric features of bony nasolacrimal canal: A cone-beam computed tomography study. Folia Morphologica, 79(3), 588–593. doi:10.5603/FM.a2019.0099

Ortug, A., & Uzel, M. (2019). Greater palatine foramen: Assessment with palatal index, shape, number and gender. Folia Morphologica, 78(2), 371–377. doi:10.5603/FM.a2018.0088

Ozan, H. (Ed.). (2014). Ozan anatomi (3. baskı). Klinisyen Tıp Kitabevleri.

Özer, C. M., Öz, I. I., Şerifoğlu, I., Büyükuysal, M. Ç., & Barut, Ç. (2016). Evaluation of eyeball and orbit in relation to gender and age. The Journal of Craniofacial Surgery, 27(8), e793–e800. doi:10.1097/SCS.0000000000003133

Özeren Keşkek, C., & Aytuğar, E. (2021). Investigation of sphenoid sinus pneumatization in Turkish population with cone-beam computed tomography. European Journal of Rhinology and Allergy, 4(2), 41–47. doi:10.5152/ejra.2021.21826

Parlak, M. E., Etli, Y., Beyhan, M., Kanat, K., & Kızıloğlu, H. A. (2025). Sex estimation with ensemble learning: An analysis using anthropometric measurements of piriform aperture. Egyptian Journal of Forensic Sciences, 15, 10. doi:10.1186/s41935-025-00426-4

Sertel Meyvaci, S., Göller Bulut, D., Öztürk, A. T., & Ankaralı, H. (2021). Gender estimation from angular parameters of mandible in Turkish adults. Medical Journal of Western Black Sea, 5(2), 240–247. doi:10.29058/mjwbs.873771

Sertel Meyvaci, S., Kosif, R., Bamaç, B., Hizal, M., & Ankarali, H. (2019). Evaluation of apertura piriformis and related cranial anatomical structures through computed tomography: Golden ratio. Folia Morphologica, 78(4), 839–846. doi:10.5603/FM.a2019.0021

Spradley, M. K. (2016). Metric methods for the biological profile in forensic anthropology: Sex, ancestry, and stature. Academic Forensic Pathology, 6(3), 391–399. doi:10.23907/2016.040

Spradley, M. K., & Jantz, R. L. (2011). Sex estimation in forensic anthropology: Skull versus postcranial elements. Journal of Forensic Sciences, 56(2), 289–296. doi:10.1111/j.1556-4029.2010.01635.x

Tassoker, M., Öztürk, B., & Aydın Kabakçı, A. D. (2024). Investigation of the relationship of palatal arch morphometry with maxillary sinus volume: CBCT study. Balkan Journal of Dental Medicine, 28(1), 71–79.

Tatlisumak, E., Asirdizer, M., Bora, A., Hekimoglu, Y., Etli, Y., Gumus, O., & Keskin, S. (2017). The effects of gender and age on forensic personal identification from frontal sinus in a Turkish population. Saudi Medical Journal, 38(1), 41–47. doi:10.15537/smj.2017.1.16218

Teke, H. Y., Duran, S., Canturk, N., & Canturk, G. (2007). Determination of gender by measuring the size of the maxillary sinuses in computerized tomography scans. Surgical and Radiologic Anatomy, 29(1), 9–13. doi:10.1007/s00276-006-0157-1

Türk, E., Görmez, Ö., Çelebi, E., & Koşkan, Ö. (2019). Frontal sinüs boyutlarının yaş ve cinsiyet ile ilişkisinin değerlendirilmesi. Selcuk Dental Journal, 6(4), 119–124.

Uysal, S., Gokharman, D., Kacar, M., Tuncbilek, I., & Kosa, U. (2005). Estimation of sex by 3D CT measurements of the foramen magnum. Journal of Forensic Sciences, 50(6), 1310–1314.

Wang, X., Liu, G., Wu, Q., Zheng, Y., Song, F., & Li, Y. (2024). Sex estimation techniques based on skulls in forensic anthropology: A scoping review. PLOS ONE, 19(12), e0311762. doi:10.1371/journal.pone.0311762

Yasar, B., & Sağır, M. (2023). Testing of morphological sex estimation traits with a sex-known collection: Ottoman period skulls. International Journal of Osteoarchaeology, 33(6), 1042–1051. doi:10.1002/oa.3265

Yüzbaşioğlu, N., Yilmaz, M. T., Çicekcibasi, A. E., Şeker, M., & Sakarya, M. E. (2014). The evaluation of morphometry of nasal bone and pyriform aperture using multidetector computed tomography. The Journal of Craniofacial Surgery, 25(6), 2214–2219. doi:10.1097/SCS.0000000000001063

Zaafrane, M., Ben Khelil, M., Naccache, I., Ezzedine, E., Savall, F., Telmon, N., ... Hamdoun, M. (2018). Sex determination of a Tunisian population by CT scan analysis of the skull. International Journal of Legal Medicine, 132(3), 853–862. doi:10.1007/s00414-017-1688-1

Zhan, M. J., Cui, J. H., Zhang, K., Chen, Y. J., & Deng, Z. H. (2019). Estimation of stature and sex from skull measurements by multidetector computed tomography in Chinese. Legal Medicine, 41, 101625. doi:10.1016/j.legalmed.2019.101625

# THE HYOID BONE: EMBRYOLOGY, ANATOMY, CLINICAL SIGNIFICANCE, AND ITS ROLE IN FORENSIC ANTHROPOLOGY

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## 1. INTRODUCTION: The Position of the Hyoid Bone Within the Axial Skeleton

The human skeleton is divided into two main components, the axial skeleton and the appendicular skeleton, according to its topographical and functional characteristics. The axial skeleton comprises the bones forming the central skeletal framework of the head, neck, and trunk, whereas the appendicular skeleton consists of the upper and lower extremities together with the girdles that connect them to the axial skeleton. The anatomical classification of the hyoid bone has not reached complete consensus in the literature. In some sources, the bone is regarded as a sesamoid-like structure because of its freely movable nature and its location within the muscle–tendon complex, whereas in other anatomical classifications it is not assigned to a distinct category. Nevertheless, according to the modern anatomical approach, the hyoid bone is considered a component of the axial skeleton because it is located in the midline of the head and neck, develops embryologically from the pharyngeal arch system, serves as the central attachment site of the suprahyoid and

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infrahyoid muscle complexes, and contributes to the functional integrity of the upper respiratory and digestive systems.

The hyoid bone is one of the unique anatomical structures located at the junction of the head and neck within the axial skeleton. Commonly referred to as the "tongue bone," this bone occupies an exceptional position in human anatomy because, unlike any other skeletal element, it does not articulate directly with any other bone. Situated in the anterior midline of the neck, the hyoid bone is suspended by muscles and ligaments associated with the mandible, the styloid process, the larynx, and the scapular region.

From a functional perspective, the hyoid bone plays a central role in swallowing, phonation, respiration, and upper airway stability. In addition to serving as a major attachment site for the suprahyoid and infrahyoid muscle groups, it functions as a biomechanical link between the base of the tongue and the laryngeal complex. Therefore, the hyoid bone should be regarded not only as a component of the locomotor system but also as a dynamic anatomical structure that contributes to the functional integrity of the upper respiratory and digestive systems (Arifoğlu, 2021; Snell, 2007; Moore & Dalley, 2007).

## 2. EMBRYOLOGY OF THE HYOID BONE AND DEVELOPMENTAL CONSIDERATIONS

The prenatal development of the head and neck region is based on the pharyngeal arch system (*arcus pharyngei*), which appears during the fourth and fifth weeks of intrauterine life. The pharyngeal arches are embryological structures that play a fundamental role in the morphological organization of the face, neck, and upper respiratory and digestive systems. Each arch consists of a mesenchymal core surrounded externally by ectoderm-derived epithelium and internally by endoderm-derived epithelium. While the mesodermal components contribute to the development of muscular structures, migrating neural crest cells are responsible for the formation of the cartilage, vascular structures, and cranial nerve components specific to each arch.

There are different views regarding the embryological origin of the hyoid bone. According to the classical embryological concept, the hyoid bone develops from the ventral segments of the second and third pharyngeal arches. According to this model, the second pharyngeal arch, also known as Reichert's cartilage, gives rise to the cornu minus and the superior portion of the corpus hyoidei, whereas the third pharyngeal arch contributes to the development of the cornu majus and the inferior portion of the corpus (Moore et al., 2002; Sadler, 2018).

In contrast, more recent embryological studies suggest that the second and third pharyngeal arches may not directly determine the development of the corpus hyoidei. According to the model proposed by Rodríguez-Vázquez et al., the corpus hyoidei develops from an independent mesenchymal condensation originating from the hypobranchial eminence, located at the base of the pharyngeal arches. According to the same model, the cornu minus originates from the caudal segment of Reichert's cartilage, whereas the cornu majus is derived from the cartilage of the third pharyngeal arch (Rodríguez-Vázquez et al., 2011).

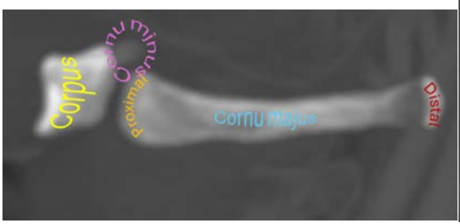
The multicentric embryological development of the hyoid bone may explain the developmental basis of the morphological asymmetry, variations in horn length, and fusion anomalies observed during adulthood.

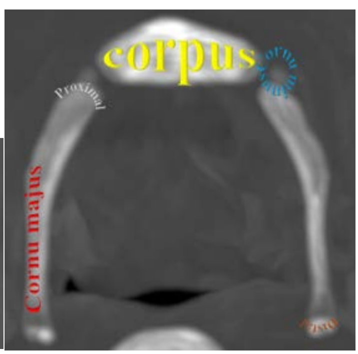
## 3. GROSS ANATOMY AND TOPOGRAPHY OF THE HYOID BONE

The hyoid bone is a horseshoe-shaped or "U"-shaped bone located in the anterior midline of the neck, superior to the thyroid cartilage (*cartilago thyroidea*), with its body approximately at the level of the third cervical vertebra (C3). Its name is derived from the Greek word *hyoeides*, meaning "shaped like the letter upsilon," because of its morphological resemblance to the Greek letter upsilon (Snell, 2007; Moore et al., 2002). The average length of the hyoid bone is 40.5 mm in males and 34.3 mm in females, whereas the average width is 47.2 mm in males and 42.6 mm in females (Verdi, 2025). The concave surface of the bone faces posteriorly, while its convex surface faces anteriorly.

The hyoid bone is suspended within the cervical region through muscular and ligamentous complexes associated with the mandible, the styloid process, the sternum, the scapula, and the laryngeal structures. This suspensory organization provides the hyoid bone with a wide range of mobility and contributes to the dynamic movements of the laryngeal complex during swallowing and phonation. Furthermore, this mobility may provide relative protection against fracture following blunt cervical trauma.

Anatomically, the hyoid bone consists of three main parts (Figures 1.1–1.2):




**a) Figure 1.1** **b) Figure 1.2**

### 1. Corpus ossis hyoidei (Body)

The corpus ossis hyoidei is the central quadrilateral segment located in the anterior portion of the bone. Its anterior surface is slightly convex and contains transverse ridges that provide attachment sites for the suprahyoid and infrahyoid muscles. The posterior surface is concave and relatively smooth and is related to the thyrohyoid membrane (*membrana thyrohyoidea*).

### 2. Cornua majora (Greater Horns)

The cornua majora are paired bony projections extending posteriorly and slightly superiorly from the lateral ends of the body.

### 3. Cornua minora (Lesser Horns)

The cornua minora are small conical projections situated superior to the junction between the body and the greater horns. The stylohyoid ligament (*ligamentum stylohyoideum*) attaches to these structures and contributes to the connection of the hyoid bone with the base of the skull. Owing to their small size and considerable morphological variability, the cornua minora may not always be reliably evaluated in osteometric studies (Urbanová et al., 2013).

## 4. ARTERIAL SUPPLY

The hyoid bone and its associated muscular structures are supplied primarily by branches of the external carotid artery (*arteria carotis externa*). These vessels form an extensive arterial anastomotic network in the anterior region of the neck.

**Lingual artery (*arteria lingualis*):** Courses superior to the hyoid bone and gives off branches to the root of the tongue and the suprahyoid muscle groups.

**Submental artery (*arteria submentalis*):** A branch of the facial artery (*arteria facialis*). It courses through the submental region and contributes to the vascular supply of the suprahyoid muscles and the anterior portion of the hyoid bone.

**Infrahyoid branch (*ramus infrahyoideus*):** A branch of the superior thyroid artery (*arteria thyroidea superior*) that supplies the infrahyoid muscles and the inferior portion of the corpus ossis hyoidei (Waschke et al., 2016; Moore & Dalley, 2007; Arifoğlu, 2021).

## 5. FUNCTIONAL MUSCULAR AND LIGAMENTOUS ATTACHMENTS

The hyoid bone serves as the central attachment site for the suprahyoid and infrahyoid muscle groups located in the anterior region of the neck. However, the sternothyroid muscle (*m. sternothyroideus*) is the only infrahyoid muscle that does not attach directly to the hyoid bone. Superiorly, the hyoid bone is connected to the base of the skull by the stylohyoid ligament (*ligamentum stylohyoideum*), whereas inferiorly it is connected to the laryngeal complex by the thyrohyoid membrane (*membrana thyrohyoidea*) (Arifoğlu, 2021; Garg et al., 2025; Moore et al., 2020; Moore & Dalley, 2007; Ozan, 2004; Pınar, 2019; Snell, 2007; Standring, 1998; Urbanová et al., 2013; Waschke et al., 2016).

The suprahyoid and infrahyoid muscle groups function in coordination and play essential roles in swallowing, phonation, mandibular movements, and upper airway stability. In general, the suprahyoid muscles elevate the hyoid bone, whereas the infrahyoid muscles are responsible for its stabilization and depression.

# 6. CLINICAL AND FORENSIC SIGNIFICANCE

The hyoid bone is an important anatomical structure located at the mechanical intersection of respiration, phonation, and deglutition. In addition to supporting the base of the tongue, it plays a crucial role in swallowing, speech, maintenance of upper airway patency, and the coordination of mandibular movements. Therefore, it is of considerable clinical importance in several disciplines, including anatomy, otorhinolaryngology, maxillofacial surgery, sleep surgery, and forensic medicine (Ito et al., 2012).

Although the hyoid bone does not articulate directly with any other bone, it maintains functional relationships with the mandible, the base of the skull (*basis cranii*), the tongue (*lingua*), the larynx, and the scapular complex. This unique characteristic explains not only its dynamic mobility but also its central role in upper airway biomechanics (Auvenshine & Pettit, 2020).

## 6.1. Hyoid Posture and Temporomandibular Disorders

The spatial position of the hyoid bone and the maintenance of this position by muscular tone are collectively referred to as hyoid 7ostüre. Since the hyoid bone lacks a fixed bony articulation, this balance depends entirely on the functional integrity of the surrounding muscular system (German et al., 2011).

Biomechanical relationships have been reported between temporomandibular disorders and the position of the hyoid bone and cervical spine (Opris et al., 2022). Radiological studies have demonstrated that long-term occlusal splint therapy and physiotherapy may result in alterations in hyoid position and changes in the dimensions of the lower oropharyngeal airway (Derwich & Pawlowska, 2022).

In rare cases, an elongated cornu majus has been reported to compress the carotid arteries, resulting in recurrent cerebrovascular events (Xia & Li, 2024).

### 6.2. Hyoid Bone Insertion Tendinitis (Hyoid Bone Syndrome)

The inflammatory process developing at the muscular attachment sites of the hyoid bone, particularly in the region of the cornu majus, is referred to as hyoid bone syndrome or insertion tendinitis. Clinically, it is characterized by chronic neck pain that is aggravated by swallowing and neck movements. The pain may radiate to the temporal region, the ear, the posterior pharyngeal wall, or along the course of the sternocleidomastoid muscle.

The diagnosis is primarily based on physical examination findings and localized tenderness. Imaging techniques are mainly used for differential diagnosis. Conservative management, nonsteroidal anti-inflammatory drugs, and local injections constitute the first-line treatment, whereas surgical intervention may be considered in refractory cases (Aydil et al., 2007).

### 6.3. Eagle Syndrome and the Stylohyoid Complex

First described by Dr. Watt Eagle in 1937, Eagle syndrome is a symptomatic clinical condition resulting from elongation of the styloid process or ossification of the stylohyoid ligament (Eagle, 1937; Eagle, 1958). Abnormal ossification of the stylohyoid complex may lead to symptoms such as neck pain, dysphagia, otalgia, and the sensation of a foreign body in the pharynx. However, ossification of the stylohyoid ligament may also be detected incidentally as an asymptomatic radiological finding (Öztaş & Orhan, 2012; Mahdian et al., 2014).

### 6.4. Obstructive Sleep Apnea and Upper Airway Collapse

Obstructive sleep apnea is a chronic respiratory disorder characterized by recurrent collapse of the upper airway during sleep (Heinzer et al., 2015; Peppard et al., 2013; Punjabi, 2008). An inferior and posterior position of the hyoid bone has been associated with narrowing of the pharyngeal airway. Imbalances in the muscle tone of the suprahyoid and infrahyoid muscle groups may increase upper airway collapsibility (Sforza et al., 2000; Tantawy et al., 2018). One of the surgical treatment options, hyoidothyroidopexy, aims to improve upper airway patency by stabilizing the hyoid bone in an anterosuperior position (Tantawy et al., 2018).

### 6.5. The Hyoid Bone in Forensic Anthropology and Autopsy Findings

The hyoid bone provides important morphological information for age and sex estimation in forensic anthropology. It has been reported that discriminant analysis and logistic regression models based on hyoid morphometry can achieve high levels of accuracy in sex estimation (Fisher et al., 2016; Balseven-Odabasi et al., 2013). In addition, bone density and the degree of fusion between the cornu majus and the corpus have been proposed as potential parameters for age estimation. However, considerable individual variation exists in the timing of fusion, and delayed fusion should not be misinterpreted as a traumatic fracture.

In forensic pathology, examination of the hyoid bone together with the laryngeal cartilage complex provides important postmortem findings in cases of manual strangulation, ligature strangulation, and hanging. Compressive forces applied to the neck may result in fractures of the hyoid bone and associated structures, as well as hemorrhagic lesions (Ito et al., 2012; Garg et al., 2025).

## 7. OSSIFICATION DYNAMICS AND FUSION CRITERIA OF THE HYOID BONE

The hyoid bone is an endochondral bone that develops from a total of six primary ossification centers. Two of these centers are located in the corpus ossis hyoidei, two in the cornua majora, and two in the cornua minora. The ossification centers first appear in the cornua majora toward the end of the fetal period, followed shortly thereafter by those of the corpus. Ossification of the cornua minora generally begins during the postnatal period, within the first one to two years of life (Arifoğlu, 2021; Arıncı & Elhan, 2006; By & Parsons, 1909; Waschke et al., 2016).

As age advances, these ossification centers gradually fuse to form a single bony structure. However, the degree and timing of fusion between the corpus and the cornua majora may vary considerably among individuals. In some individuals, complete bony ankylosis develops in advanced age, whereas in others the synchondrotic junction may persist throughout life (Balseven-Odabasi et al., 2013; Parsons, 1909; Gupta et al., 2008; Porrath, 1969).

The literature indicates that complete bilateral fusion is uncommon in young adults, that the frequency of fusion increases with advancing age, and that fusion tends to occur earlier in males than in females (Ito et al., 2012; Gupta et al., 2008). Nevertheless, studies investigating the ossification dynamics of the hyoid bone remain limited, and considerable variation has been reported among different populations.

### 7.1. Anthropological Classification of Fusion

The absence of standardized criteria for evaluating the degree of fusion between the corpus ossis hyoidei and the cornua majora is considered one of the principal reasons for the discrepancies reported in studies investigating age and sex estimation. Accordingly, a four-stage classification system has been proposed in the literature to grade the degree of fusion (Fisher et al., 2016):

**Grade 0 (Non-fusion / Open Joint)**

The distance between the corpus and the cornu majus is $\geq 2.5$ mm.

**Grade 1 (Early Approximation Stage)**

The joint space is less than 2.5 mm; however, no osseous bridge has formed.

**Grade 2 (Partial Fusion)**

Osseous fusion has begun; however, a residual joint line remains visible.

**Grade 3 (Complete Fusion / Ankylosis)**

The corpus and the cornu majus are completely fused, and no distinguishable joint space is present.

Some investigators combine Grades 0 and 1, classifying the fusion pattern into three principal categories: non-fusion, partial fusion, and complete fusion.

## 8. COMPUTED TOMOGRAPHY-BASED HYOID MORPHOMETRY AND ARTIFICIAL INTELLIGENCE APPLICATIONS

The fragile structure of the hyoid bone and its susceptibility to loss during the postmortem period have made it difficult to obtain reliable measurements using traditional osteometric methods. Today, high-resolution computed tomography (CT) imaging and three-dimensional (3D) reconstruction techniques are widely used 12ort he evaluation of hyoid morphometry. These methods enable highly accurate measurements without damaging the bone and allow large datasets to be analyzed in a digital environment.

CT-based morphometric analyses evaluate parameters including the total length and width of the hyoid bone, the dimensions of the corpus ossis hyoidei, the lengths of the cornua majora, the heights of their distal ends, and the intercornual angle. In particular, corpus width, overall hyoid dimensions, and the vertical parameters of the distal ends of the cornua majora have been reported to possess high discriminatory value for sex estimation.

Among conventional statistical approaches, linear discriminant analysis and logistic regression models have been shown to provide high accuracy in sex estimation based on hyoid morphometry. However, the anatomical variations, bilateral asymmetry, and age-related differences in fusion of the hyoid bone require the evaluation of nonlinear data patterns. Consequently, machine learning (ML) and deep learning (DL) approaches have gained increasing attention in recent years.

The literatüre has demonstrated that various machine learning algorithms, including Random Forest, Support Vector Machine (SVM), Extreme Gradient Boosting (XGBoost), and k-Nearest Neighbors (k-NN), can achieve classification performance comparable to or even superior to that of conventional statistical methods for sex estimation (Abdelkader et al., 2025; Mutlu et al., 2024; Ferraz et al., 2024; Nikita & Nikitas, 2020; Tyagi et al., 2021). In particular, studies conducted in the Turkish population have shown that CT-based hyoid morphometry, when combined with machine learning algorithms—including Logistic Regression, Linear Discriminant Analysis, Decision Tree, Random Forest, Support Vector Machine, k-Nearest Neighbors, and Gaussian Naïve Bayes—can achieve high levels of accuracy according to forensic anthropology standards (Verdi, 2025).

Deep learning-based approaches have attracted considerable interest because they enable direct analysis of pixel- or voxel-based image data. Studies employing convolutional neural network architectures such as DenseNet121 have reported balanced sensitivity and specificity values for sex estimation based on hyoid bone images (Bakici et al., 2024).

In conclusion, the integration of CT-based three-dimensional hyoid morphometry with artificial intelligence-assisted analytical methods has become a modern approach that provides objective and highly accurate assessments in forensic identification, the examination of skeletal remains, and postmortem analyses.

## 9. CONCLUSION

The hyoid bone occupies a unique anatomical position in the human skeleton because it is the only bone that does not articulate directly with any other bone. Owing to its critical role in swallowing, phonation, respiration, and upper airway stability, it should be regarded not only as a component of the head and neck anatomy but also as a functional biomechanical center.

Its multicentric embryological development contributes to the understanding of the morphological variations and differences in fusion observed during adulthood. Furthermore, the hyoid bone is of considerable clinical importance because of its association with temporomandibular disorders, obstructive sleep apnea, Eagle syndrome, and various cervical pathologies.

In recent years, the widespread use of computed tomography-based three-dimensional imaging techniques has enabled detailed and reproducible evaluation of hyoid bone morphology. In particular, studies conducted in the field of forensic anthropology have demonstrated that hyoid morphometry provides reliable parameters for age and sex estimation.

With the advancement of machine learning and deep learning-based artificial intelligence applications, analyses of the hyoid bone can now be performed more objectively, rapidly, and with higher accuracy. In the future, the availability of large datasets derived from different populations and the development of automated image analysis systems are expected to further expand the clinical and forensic applications of the hyoid bone.

**REFERENCES**

Abdelkader, A., Ali, S. A., Abdeen, A., Taher, E. S., Hussein, A. Y. A., Eldesoqui, M., ... Elmorsy, E. M. (2025). Hyoid bone-based sex discrimination among Egyptians using a multidetector computed tomography: Discriminant function analysis, meta-analysis, and artificial intelligence-assisted study. Scientific Reports, 15(1), 2680. https://doi.org/10.1038/s41598-025-85518-w

Arifoğlu, Y. (2021). Her Yönüyle Anatomi (3. baskı). İstanbul, Türkiye: İstanbul Kitabevi.

Arıncı, K., & Elhan, A. (2006). Anatomi (4. baskı). Ankara, Türkiye: Güneş Kitabevi.

Auvenshine, R. C., & Pettit, N. J. (2020). The hyoid bone: An overview. CRANIO®, 38(1), 6–14. https://doi.org/10.1080/08869634.2018.1487501

Aydil, U., Ekinci, Ö., Köybaşıoğlu, A., & Kızıl, Y. (2007). Hyoid bone insertion tendinitis: Clinicopathologic correlation. European Archives of Oto-Rhino-Laryngology, 264(5), 557–560. https://doi.org/10.1007/s00405-006-0220-x

Bakici, R. S., Cakmak, M., Oner, Z., & Oner, S. (2024). Sex prediction of hyoid bone from computed tomography images using the DenseNet121 deep learning model. International Journal of Morphology, 42(3), 826–832. https://doi.org/10.4067/S0717-95022024000300826

Balseven-Odabasi, A., Yalcinozan, E., Keten, A., Akçan, R., Tumer, A. R., Onan, A., Canturk, N., Odabasi, O., & Hakan Dinc, A. (2013). Age and sex estimation by metric measurements and fusion of hyoid bone in a Turkish population. Journal of Forensic and Legal Medicine, 20(5), 496–501. https://doi.org/10.1016/j.jflm.2013.03.022

Derwich, M., & Pawlowska, E. (2022). Position of the hyoid bone and dimension of nasopharynx and oropharynx after occlusal splint therapy and physiotherapy in patients diagnosed with temporomandibular disorders. Journal of Clinical Medicine, 11(17), 4939. https://doi.org/10.3390/jcm11174939

Eagle, W. W. (1937). Elongated styloid processes: Report of two cases. Archives of Otolaryngology, 25(5), 584–587. https://doi.org/10.1001/archotol.1937.00650010656008

Eagle, W. W. (1958). Elongated styloid process; symptoms and treatment. A.M.A. Archives of Otolaryngology, 67(2), 172–176. https://doi.org/10.1001/archotol.1958.0073001017800

Ferraz, A. X., Schroder, Â. G. D., Gonçalves, F. M., Küchler, E. C., Santos, R. S., Zeigelboim, B. S., ... de Araujo, C. M. (2024). Artificial intelligence model for predicting sexual dimorphism through the hyoid bone in adult patients. PLoS ONE, 19(11), e0310811. https://doi.org/10.1371/journal.pone.0310811

Fisher, E., Austin, D., Werner, H. M., Chuang, Y. J., Bersu, E., & Vorperian, H. K. (2016). Hyoid bone fusion and bone density across the lifespan: Prediction of age and sex. Forensic Science, Medicine and Pathology, 12(2), 146–157. https://doi.org/10.1007/s12024-016-9769-x

Garg, R., Fakoya, A. O., & Menezes, R. G. (2025). Anatomy, head and neck: Hyoid bone. In StatPearls. Treasure Island, FL: StatPearls Publishing.

German, R. Z., Campbell-Malone, R., Crompton, A. W., Ding, P., Holman, S., Konow, N., & Thexton, A. J. (2011). The concept of hyoid posture. Dysphagia, 26(2), 97–98. https://doi.org/10.1007/s00455-011-9339-z

Gupta, A., Kohli, A., Aggarwal, N. K., & Banerjee, K. K. (2008). Study of age of fusion of hyoid bone. Legal Medicine, 10(5), 253–256. https://doi.org/10.1016/j.legalmed.2008.03.002

Heinzer, R., Vat, S., Marques-Vidal, P., Marti-Soler, H., Andries, D., Tobback, N., ... Haba-Rubio, J. (2015). Prevalence of sleep-disordered breathing in the general population: The HypnoLaus study. The Lancet Respiratory Medicine, 3(4), 310–318. https://doi.org/10.1016/S2213-2600(15)00043-0

Ito, K., et al. (2012). Morphological study of the human hyoid bone with three-dimensional CT images: Gender difference and age-related changes. Okajimas Folia Anatomica Japonica, 89(3), 83–92.

Mahdian, M., Moghaddam, E. J., Alzahrani, A., Rengasamy, K., & Tadinada, A. (2014). Calcification of the stylohyoid ligament in panoramic radiography and cone beam computed tomography among patients referred for dental implant treatment planning. Implant Dentistry, 23(4), 508–513. https://doi.org/10.1097/ID.0000000000000125

Moore, K. L., & Dalley, A. F. (2007). Kliniğe Yönelik Anatomi (4. baskı). İstanbul, Türkiye: Nobel Tıp Kitabevleri.

Moore, K. L., Dalley, A. F., Agur, A. M. R., & Moore, M. E. (2020). Temel Klinik Anatomisi (6. baskı). Ankara, Türkiye: Nobel Tıp Kitabevleri.

Moore, K. L., Persaud, T. V. N., & Torchia, M. G. (2002). İnsan Embriyolojisi: Klinik Yönleri ile (M. Yıldırım, İ. Okar, & H. Dalçık, Çev.; 6. baskı). İstanbul, Türkiye: Nobel Tıp Kitabevleri.

Mutlu, G. D., Asirdizer, M., Kartal, E., Keskin, S., Mutlu, İ., & Goya, C. (2024). Sex estimation from the hyoid bone measurements in an adult Eastern Turkish population using 3D CT images, discriminant function analysis, support vector machines, and artificial neural networks. Legal Medicine, 67, 102383. https://doi.org/10.1016/j.legalmed.2023.102383

Nikita, E., & Nikitas, P. (2020). On the use of machine learning algorithms in forensic anthropology. Legal Medicine, 47, 101771. https://doi.org/10.1016/j.legalmed.2020.101771

Opris, H., Baciut, M., Bran, S., Baciut, G., Armencea, G., Rominu, M., & Hedesiu, M. (2022). Lateral cephalometric analytical uses for temporomandibular joint disorders: The importance of cervical posture and hyoid position. International Journal of Environmental Research and Public Health, 19(17), 11077. https://doi.org/10.3390/ijerph191711077

Ozan, H. (2004). Ozan Anatomi (1. baskı). İstanbul, Türkiye: Nobel Tıp Kitabevleri.

Öztaş, B., & Orhan, K. (2012). Investigation of the incidence of stylohyoid ligament calcifications with panoramic radiographs. Journal of Investigative and Clinical Dentistry, 3(1), 30–35. https://doi.org/10.1111/j.2041-1626.2011.00081.x

Parsons, F. G. (1909). The Topography and Morphology of the Human Hyoid Bone. Journal of Anatomy and Physiology, 43(Pt 4), 279–290.

Peppard, P. E., Young, T., Barnet, J. H., Palta, M., Hagen, E. W., & Hla, K. M. (2013). Increased prevalence of sleep-disordered breathing in adults. American Journal of Epidemiology, 177(9), 1006–1014. https://doi.org/10.1093/aje/kws342

Pınar, Y. A. (2019). Baş ve Boyun Anatomisi. Ankara, Türkiye: Nobel Tıp Kitabevleri.

Porrath, S. (1969). Roentgenologic considerations of the hyoid apparatus. American Journal of Roentgenology, Radium Therapy, and Nuclear Medicine, 105(1), 63–73. https://doi.org/10.2214/AJR.105.1.63

Punjabi, N. M. (2008). The epidemiology of adult obstructive sleep apnea. Proceedings of the American Thoracic Society, 5(2), 136–143. https://doi.org/10.1513/pats.200709-155MG

Rodríguez-Vázquez, J. F., García-Garrigós, E., Mérida-Velasco, J. R., Sánchez-Montesinos, I., & Mérida-Velasco, J. A. (2011). Human fetal hyoid body origin revisited. Journal of Anatomy, 219(2), 143–149. https://doi.org/10.1111/j.1469-7580.2011.01387.x

Sadler, T. W. (2018). Langman's Medical Embryology (14th ed.). Philadelphia, PA: Wolters Kluwer.

Sforza, E., Bacon, W., Weiss, T., Thibault, A., Petiau, C., & Krieger, J. (2000). Upper airway collapsibility and cephalometric variables in patients with obstructive sleep apnea. American Journal of Respiratory and Critical Care Medicine, 161(2 Pt 1), 347–352. https://doi.org/10.1164/ajrccm.161.2.9810091

Snell, R. S. (2007). Tıp Fakültesi Öğrencileri İçin Anatomi (4. baskı). İstanbul, Türkiye: Nobel Tıp Kitabevleri.

Standring, S. (1998). Gray's Anatomy: The Anatomical Basis of Clinical Practice (International ed.). London, England: Churchill Livingstone.

Tantawy, A. A., Askar, S. M., Amer, H. S., Awad, A., & El-Anwar, M. W. (2018). Hyoid bone suspension as a part of multilevel surgery for obstructive sleep apnea syndrome.

International Archives of Otorhinolaryngology, 22(3), 266–270. https://doi.org/10.1055/s-0037-1607227

Tyagi, A., Tiwari, P., Bhardwaj, P., & Chawla, H. (2021). Prognosis of sexual dimorphism with unfused hyoid bone: Artificial intelligence informed decision making with discriminant analysis. Science and Justice, 61(6), 789–796. https://doi.org/10.1016/j.scijus.2021.10.002

Urbanová, P., Hejna, P., Zátopková, L., & Šafr, M. (2013). What is the appropriate approach in sex determination of hyoid bones? Journal of Forensic and Legal Medicine, 20(8), 996–1003. https://doi.org/10.1016/j.jflm.2013.08.010

Verdi, Y. (2025). Os hyoideum'un bilgisayarlı tomografi görüntüleri üzerinden antropometrik ölçümleri ile makine öğrenme algoritmaları kullanılarak cinsiyet tahmini (Tez No. 945275) [Doktora tezi, Düzce Üniversitesi]. Ulusal Tez Merkezi.

Waschke, J., Böckers, T. M., & Paulsen, F. (2016). Sobotta Anatomi Konu Kitabı (1. baskı). Ankara, Türkiye: Güneş Tıp Kitabevleri.

Xia, C., & Li, Z. (2024). Recurrent ischemic strokes due to anatomic variation of the hyoid bone and thyroid cartilage. Radiology, 313(1), e241186. https://doi.org/10.1148/radiol.241186

# ACADEMIC DISCUSSIONS IN THE FIELD OF ANATOMY

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