

Topographical anatomy and morphometry of the temporal bone of the macaque

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Based on the dissections of 24 bones of 12 macaques (Macaca mulatta), a systematic anatomical description was made and measurements of the chosen size parameters of the temporal bone as well as the skull were taken. Although there is a small mastoid process, the general arrangement of the macaque's temporal bone structures is very close to that which is observed in humans. The main differences are a different model of pneumatization and the presence of subarcuate fossa, which possesses considerable dimensions. The main air space in the middle ear is the mesotympanum, but there are also additional air cells: the epitympanic recess containing the head of malleus and body of incus, the mastoid cavity, and several air spaces on the floor of the tympanic cavity. The vicinity of the carotid canal is also very well pneumatized and the walls of the canal are very thin. The semicircular canals are relatively small, very regular in shape, and characterized by almost the same dimensions. The bony walls of the labyrinth are relatively thin. (Folia Morphol 2009; 68, 1: 13–22)

Key words: anatomy, inner ear, macaque, middle ear, temporal bone

INTRODUCTION

The temporal bone containing the vestibulocochlear organ is significant in the pathology of humans and animals. The middle and inner ear of many animals, including the macaque [2, 7], are used as laboratory models in various research projects. The anatomical description of the ear structures in animals, as found in veterinary anatomy textbooks, is scarce, schematic, and does not go beyond a rough enumeration of the structures often with no data on topography and variability. This work is a continuation of a program of investigation of the temporal bones of laboratory animals [16]. The aim of undertaking this study has been to come up with a systematic anatomic description of the temporal

bone, including the topographic aspects for clinical needs in the selected animal species.

MATERIAL AND METHODS

The material included 24 heads (12 males and 12 females) of macaques (*Macaca mulatta*, Linnaeus, 1758) provided by the Department of Normal Anatomy at the Medical University in Warsaw. Macaques were imported in the 1950s from India for testing polio vaccinations and were conveyed to the Department. The whole specimens had been previously fixed in 10% formaldehyde solution. For the purposes of this study, the heads were isolated and then the temporal bones prepared under an operating microscope. Anatomical description and

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Table 1. Results of measurements of selected size parameters of the macaque's temporal bone. All values are in millimetres. Arithmetical means with ranging below

Structure	Parameter	Value
Whole skull	Full length of skull	116.17 (105.0–137.0)
	Full length of neurocranial basis	62.67 (56.0–73.0)
Whole bone	Full length of bone	44.92 (32.0–53.0)
	Length of petrous part	29.4 (26.1–32.7)
	Height of petrous part	11.28 (9.2–14.7)
	Length of external auditory meatus	9.3 (7.4–12.5)
External auditory pore and its vicinity	Height	3.08 (2.2–5.2)
	Width	2.97 (2.2–3.6)
	Distance between stylomastoid foramen and posterior wall of external auditory meatus	10.41 (7.4–15.1)
Internal auditory meatus	Height	2.87 (2.0–3.4)
	Width	3.12 (2.2–3.8)
	Length	4.64 (4.1–5.8)
Subarcuate fossa	Height	3.26 (2.4–4.3)
	Width	2.97 (2.3–3.4)
	Depth	4.21 (3.1–5.2)

measurements of the temporal bone selected size parameters were made. Measurements of the middle and inner ear structures were made using an eyepiece (ocular) with 0.05 mm to 0.1 mm accuracy gauge (depending on the size of the objective used). Neither thorough investigation of the interior of the cochlea nor measurements of its scalae had been performed and previous studies dealing with this problem are available [14]. The dimensions of the skull and the dimensions of the whole temporal bone were made with linear callipers with an accuracy of 1 mm. The full length of the skull was measured as the distance between the opistocranium and prosthion points. The length of the neurocranial basis was evaluated as the distance between the hornion and opisthion points. The Student-t test was used for the evaluation of differences between genders and body sides.

RESULTS

The morphological description is illustrated with figures, and the measurements are presented in Tables 1–3. The acquired numerical values (data) are presented combined (together) for males and females as well as for right and left side of the body, since no statistically significant differences depending on sex or the side of the body were found.

Morphology of the temporal bone

The temporal bone of the macaque is composed of three parts: squamous, tympanic and petrous, which in adult individuals are combined totally into one part. The temporal bone borders with the occipital bone caudally, rostrally with the sphenoid and zygomatic bones, and with the parietal from the dorsal side (Fig. 1).

The squamous part is flat, low, and elongated in the antero-posterior direction. It has sharp ends in the anterior and posterior part, which intussuscept between the sphenoid and parietal as well as occipital and parietal bones, respectively. Zygomatic and postglenoid processes come out from the squamous part. A not very prominent articular tubercle and a mandibular fossa are located between the epiphyseal parts of the processes. The temporal canal and its external opening, the postglenoid foramen, are not always found and are rather small.

The tympanic part has the form of a wide, incomplete ring, opened in the dorsal part, complemented in this place by a fragment of the squamous part. Then, together with the squamous part, it forms the external acoustic meatus (Fig. 2).

The petrous part of the temporal bone is elongated, slender, and has the shape of a regular four

Table 2. Results of measurements of selected size parameters of tympanic cavity of the macaque's temporal bone. All values are in millimetres. Arithmetical means with the ranging below

Structure	Parameter	Value	
Auditory ossicles	Malleus — full length	4.93 (4.35–5.25)	
	Incus — full length	3.42 (3.25–3.65)	
	Stapes — full height	1.76 (1.15–2.05)	
Tympanic cavity	Full height of tympanic cavity	8.78 (7.1–10.6)	
	Full length of tympanic cavity	6.63 (5.8–9.3)	
	Height of epitympanic recess	2.28 (1.4–3.8)	
	Length of epitympanic recess	4.18 (3.2–5.8)	
	Mastoid cavity	Length	5.23 (4.2–6.8)
		Height	4.86 (3.4–5.8)
		Width	2.34 (1.8–3.2)
	Distance between round window and internal orifice of Eustachian tube	11.48 (9.2–16.5)	
	Distance between round window and internal carotid artery	3.31 (2.8–4.3)	
Eustachian tube	Full length of its bony part	6.92 (6.1–8.9)	

Table 3. Results of measurements of selected parameters characterizing magnitude of internal ear of the macaque. All values are in millimetres. Arithmetical means with ranging below

Structure	Parameter	Value	
Semicircular canals	Superior	Vertical diameter	4.68 (4.25–5.35)
		Horizontal diameter	4.17 (3.15–5.0)
	Posterior	Vertical diameter	4.19 (3.25–4.85)
		Horizontal diameter	4.12 (3.75–4.8)
	Lateral	Vertical diameter	4.18 (3.8–5.1)
		Horizontal diameter	4.08 (3.65–4.85)
Cochlea	Diameter of base of cochlea	5.28 (4.25–5.85)	
	Height	2.87 (2.4–3.65)	
Oval window	Height	0.72 (0.65–0.85)	
	Width	1.68 (1.45–1.95)	
Round window	Height	1.29 (1.0–1.65)	
	Width	1.31 (1.05–2.1)	

parietal pyramid with sharp edges (Fig. 3). The apex of the pyramid wedges between the basilar part of the occipital bone and the body and greater wing of the sphenoid bone. The base of the pyramid faces caudally and laterally and changes into a flat, narrow ending intussuscepted between the occipital and parietal bone. The dorsal part of the pyramid, in its caudal part, is smooth, flat, and forms a little mastoid process. In the anterior part, its sur-

face is irregular and develops a short, wide, and sharply tipped styloid process. The external opening of the internal carotid artery canal, stylomastoid foramen, and the opening of the musculotubal canal are situated here as well (Figs. 2, 3).

There are several important structures visible on the walls of the pyramid. The medial wall of the petrous part has two large recesses (depressions) in the central 1/3 (Fig. 3). The rostral recess constitutes

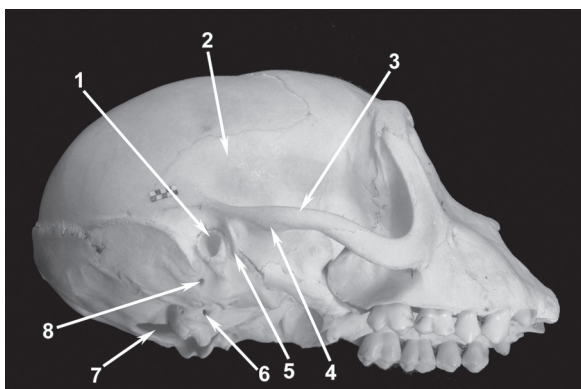


Figure 1. Localization of the macaque's temporal bone in the neurocranium and viscerocranium. Lateral wall of the skull from the right side. One millimetre gauge on the figure; 1 — external acoustic pore; 2 — squamous part of temporal bone; 3 — zygomatic arch; 4 — articular tubercle; 5 — postglenoid process; 6 — hypoglossal canal; 7 — foramen magnum; 8 — stylomastoid foramen.

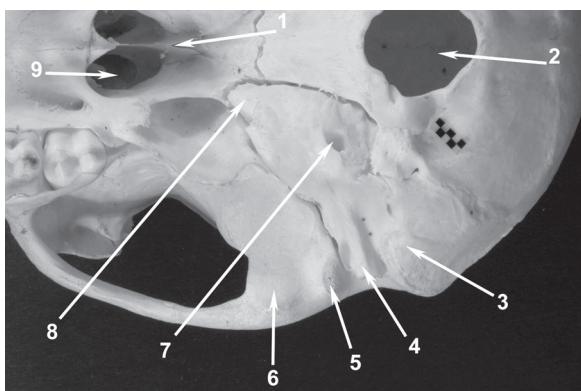


Figure 2. Skull base of the macaque; 1 — vomer; 2 — foramen magnum; 3 — mastoid process; 4 — inferior wall of external auditory meatus; 5 — postglenoid process; 6 — articular tubercle; 7 — external opening of carotid canal; 8 — apex of pyramid; 9 — right opening of choanae.

the internal acoustic meatus, and the caudal, the subarcuate fossa. The petrous crest does not appear on the superior border of the petrous part as it does in other animals.

The internal acoustic meatus is a short, bony canal. It runs obliquely from the anterior and medial part caudally and sideward, forming about a 45-degree angle with the axis of the pyramid. The subarcuate fossa holding the cerebellum flocculus is a slightly bigger recess surrounded caudally and dorsally by a bony prominence, in which the superior semicircular canal runs. Directly inferiorly and caudally from the internal acoustic meatus lies the external opening of the cochlear canaliculus, and di-

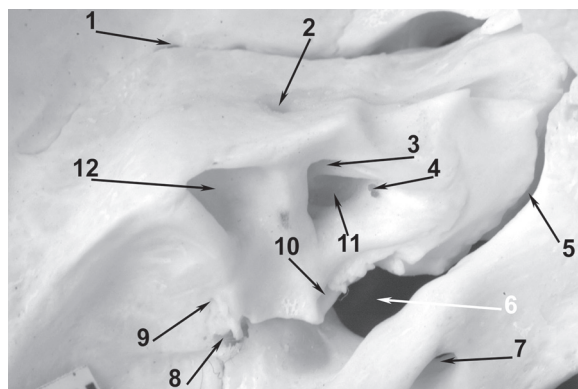


Figure 3. Medial wall of petrous part of macaque's left temporal bone and its closest vicinity. View from posterior part of cranial cavity. Macerated bones; 1 — petrosquamous sinus; 2 — hiatus for greater petrosal nerve; 3 — entrance to facial canal in sole of internal acoustic meatus; 4 — accessory venous foramina; 5 — sulcus of inferior petrous sinus; 6 — jugular foramen; 7 — hypoglossal canal; 8 — mastoid emissary (internal opening); 9 — external opening of vestibular aqueduct; 10 — external opening of cochlear canaliculus; 11 — area of cochlear nerve; 12 — interior of subarcuate fossa.

rectly inferiorly and caudally from the entrance to the subarcuate fossa is the external opening of the vestibular aqueduct. Both openings are veiled by small bony overhangs. In the antero-inferior and postero-inferior part of the medial wall of the petrous part lie rather shallow grooves for the inferior petrosal sinus and the sigmoidal sinus, respectively. The superior petrosal sinus groove occupies the lateral 1/3 of the superior border of the petrous part. The groove for the inferior petrosal sinus runs along the facing borders of the basilar part of the occipital and temporal bones. A prominent groove for the sigmoid sinus ends in the considerable jugular foramen. Sometimes the internal opening of the mastoid emissary vein is found close to it.

The dorsal wall of the petrous part in the macaque, which is called the anterior wall in human anatomy, has openings of lesser and greater petrosal nerve canals in its central part, and the trigeminal impression can be found rostrally from them. A shallow groove for the petrosquamous sinus runs towards a rather small (and not always found in the macaque) postglenoid foramen in the posterior wall of the petrous part. The internal opening of the internal carotid canal is visible at the apex of the petrous part.

Middle ear

The tympanic membrane separates the external acoustic meatus from the tympanic cavity. Its shape,

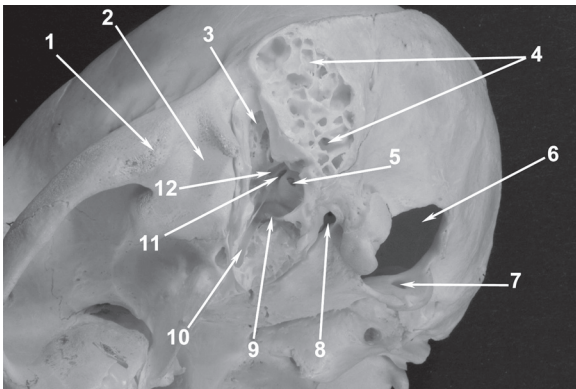


Figure 4. View of lateral left wall of macaque's skull and skull base from ventroposterior side. Opened mastoid process and removed inferior and lateral wall of the tympanic cavity; 1 — articular tubercle; 2 — mandibular fossa; 3 — superior wall of external acoustic meatus; 4 — mastoid air cells; 5 — round window niche; 6 — foramen magnum; 7 — internal opening of right hypoglossal canal; 8 — left jugular foramen; 9 — carotid canal; 10 — semicanal for auditory tube; 11 — oval window niche; 12 — opened facial canal.

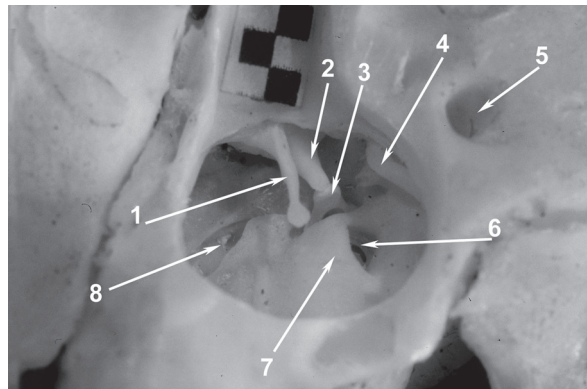


Figure 6. Macaque's left tympanic cavity interior with auditory ossicles inside. Widened external acoustic meatus. Macerated bone; 1-milimeter scale bar; 1 — handle of malleus; 2 — long limb of incus; 3 — incudostapedial joint; 4 — bony trabecula on posterior wall of tympanic cavity; 5 — stylomastoid foramen; 6 — round window niche; 7 — promontory; 8 — tympanic opening of auditory tube.

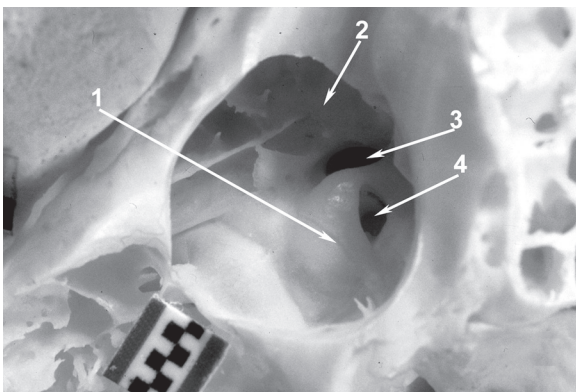


Figure 5. View of macaque's left tympanic cavity from side of external acoustic pore which has been widened for better insight. Macerated bone; 1-milimeter scale bar; 1 — promontory; 2 — prominence of facial canal; 3 — oval window; 4 — round window niche.

viewed from the lateral side, is elliptic, with the longer diagonal running from the anterior and superior caudally and inferiorly. The dimensions of the ellipse vary slightly and on average are 4.51×5.54 mm. The angle between the tympanic membrane plane and the horizontal plane is about 50–60 degrees, and the angle formed with the sagittal plane is about 50 degrees. Both angles are opened rostrally.

Similarly to humans, the macaque's middle ear consists of the tympanic cavity, mastoid cavity, and auditory tube. The shape of the tympanic cavity can be described as a biconcave lens embraced in a small cuboid block, in which the wide surfaces form later-

al and medial walls, and the rest of the walls are much narrower. The width of the cavity is greatest in the superior part and, unlike in humans, also in the inferior part.

The lateral wall of the tympanic cavity is formed mainly by the tympanic membrane, from the superior by the petrous part and from the inferior by tympanic part. The quite well-defined superior part of the tympanic cavity is the epitympanic recess (a term drawn from human anatomy, absent in animal anatomy). The lateral bony wall of the recess is thick and lies deep under the initial part of the zygomatic process. It corresponds to the lateral wall of the "attic" (clinical term) in humans.

The medial wall of the tympanic cavity has the most diversiform carving. The promontory forms a distinct, centrally located prominence of that wall (Figs. 4–6). The caudoventral edge of the promontory curves dorsally and caudally, forming a prominent lateral labium of the entrance (aditus) to the fossa of the round window. The apex of the promontory is visible by looking in the axis of the external acoustic meatus.

The oval window has a beanlike shape. The inferior border of the oval window is slightly concave; the superior is convex and seems to be hollower, owing to the underlain prominence of the facial canal. The round window is slightly oval and extends caudally and a little laterally. The round window is situated in a rather deep small cavity called the niche or the fossa of the round window.

The round window niche has a sphenoidal shape with the apex at the round window membrane and the base at the entrance (aditus) to the niche. The niche is deeper in the posterior and shallower in the anterior. Posteriorly from the round window fossa lies a concavity, which, by analogy with human anatomy, would be called the tympanic sinus. It undermines the facial nerve canal and the pyramidal eminence from the ventral side.

Directly over the oval window lies the horizontal segment of the facial nerve canal, forming a distinct bony eminence on the medial wall of the tympanic cavity — the prominence of the facial canal. At the level of the canal, but rostrally from the oval window, lies an opening (foramen) with irregular borders, intended for the tendon of the tensor tympani. The prominence of the lateral semicircular canal is situated caudally and dorsally from the facial nerve canal, at the place of passage from the tympanic to the mastoid cavity. It curves superiorly and posteriorly, limiting the fossa of incus dorsally.

The anterior part of medial wall of the tympanic cavity is smooth and elongates into the bony canal of the auditory tube in its superior part. The bony part of the auditory tube lies directly laterally from the internal carotid canal. In some cases the internal carotid artery may be visible in the canal itself because the canal walls are thin and often incomplete, having small natural defects called dehiscences. Dorsally from the auditory tube canal runs the semicanal and farther the canal for the tensor tympani muscle. Dorsally from these structures, on the medial wall of tympanic cavity and on the border with its superior wall (the tegmental wall), there is a relatively deep bony niche already belonging to the epitympanic recess.

The anterior wall of the tympanic cavity, the wall of the carotid artery, is very thin. It is strongly pneumatized in the macaque by a few tympanic cells (Fig. 4). It is perforated by the mentioned tympanic opening of the auditory tube and the tensor tympani semicanals. In the vicinity of these structures there is a prominence formed by the carotid artery canal, highly visible on all the studied bones, as it has only a thin bony wall around itself. Here, the entrance to a series of pneumatic cells of the anterior part of pyramid is located.

The inferior wall of the tympanic cavity is also pneumatized. Depending on the degree of pneumatization, the space between the capsule of the bony labyrinth and the inferior tympanic wall may have a different thickness. The petrous bulla is the larg-

est of pneumatic cells in this part of the temporal bone. It spreads from the posterior wall of the tympanic cavity to the top of the pyramid. In the superior wall of the bulla, and then in the inferior wall of the hypotympanum, runs the tympanic canaliculus with the tympanic nerve inside. The bulla is usually so big that it undermines the labyrinth as well as the carotid and musculo-tubal canals.

The posterior wall (the mastoid wall) is very narrow, reaches superiorly to the lateral semicircular canal, and inferiorly turns into the inferior wall without any visible border. The facial nerve canal forms a distinct prominence on the posterior wall, surrounded by an array (range) of pneumatic cells. A small bony process, a pyramidal eminence, lies laterally from the canal, on the level of the oval window. It holds the stapedial muscle. A small opening of the chorda tympani canaliculus lies more laterally and below. The largest of all the pneumatic cells of the pyramid posterior part is the mastoid cavity. It has four walls: anterior, posterior, medial, and inferior, through which it communicates with the rest of the pneumatic cells of the mastoid process and the epitympanum. The prominence of the lateral semicircular canal lies on the medial wall. The superior wall of the tympanic cavity is the tegmen (cover) of the tympanic cavity, which also forms part of the middle cranial fossa.

The interior of the macaque's tympanic cavity, similarly to that of humans, can be divided into three spaces: hypotympanum, mesotympanum and epitympanum. The epitympanum, i.e. the epitympanic recess of the tympanic cavity, is located in the superior area of tympanic cavity. It is medially limited by the prominence of the lateral semicircular canal and facial canal, laterally by a bony wall above the tympanic ring (by analogy with human anatomy or as a clinical term, the wall may be called the "attic"). This space contains the body of incus and the head of malleus together with their ligaments (Fig. 6). The epitympanic recess occupies about 1/3 of the middle ear space. Caudally, it communicates with the mastoid cavity — the largest air cell pneumatizing the mastoid process and the posterior part of the temporal bone pyramid.

The remaining parts of the malleus i.e. the neck of malleus (to which the tendon of the tensor tympani is fixed), the handle of malleus, and the long limb of incus are located in the largest middle space of the tympanic cavity (mesotympanum). There is also the stapes, with its footplate situated in the oval window (Fig. 6).

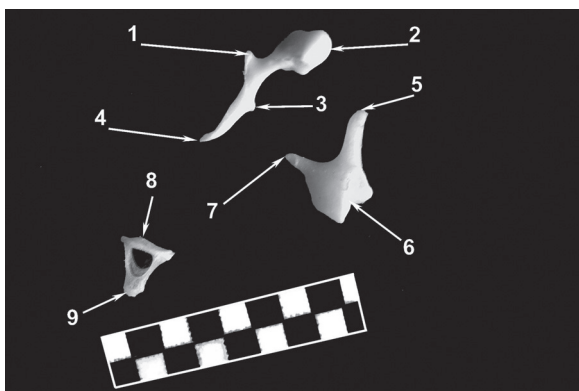


Figure 7. Isolated and disjoined auditory ossicles of macaque's right ear; 1-millimeter scale bar; 1 — lateral process of malleus; 2 — head of malleus; 3 — muscular process of malleus; 4 — handle of malleus; 5 — long limb of incus; 6 — body of incus; 7 — short limb of incus; 8 — base of stapes; 9 — head of stapes.

Auditory ossicles with their structure and proportions resemble human ones; however, the malleus possesses a prominent muscular process that is absent in humans (Figs. 6, 7).

The facial nerve canal, also known as the facial canal, originates in the fundus of the internal acoustic meatus and ends at the stylomastoid foramen. Unlike in humans, its wall does not have any natural defects — dehiscences. Three parts can be distinguished in the course of the facial nerve canal: labyrinthine, tympanic, and mastoid. In the labyrinthine part, the nerve runs between the basal turn of the cochlea and the superior semicircular canal, and appears on the anterior wall of the vestibule. The labyrinthine part of the facial canal ends in the place where it approaches the medial wall of the tympanic cavity and forms a distinct geniculum at an acute to almost right angle. Here lies the geniculate ganglion and here originates the first of the intratemporal branches of the facial nerve — the greater petrosal nerve. The second part of the facial nerve canal, the tympanic part, lies in the labyrinthine wall of the tympanic cavity, between the prominence of the lateral semicircular canal and the oval window. In this part, the nerve runs obliquely, caudally, and inferiorly, up to the area of the pyramid eminence in the posterior wall of the tympanic cavity. Here the canal passes into its mastoid part, which runs in a gentle arch towards the stylomastoid foramen. In the mastoid part, the facial nerve gives back the stapedia nerve and the chorda tympani. The tympanic chord emerges from the facial nerve just before it leaves the stylomastoid foramen. It runs between the handle of malleus and the long limb of incus, to leave

through a small opening in the anterior wall, on the border with the lateral. The opening lies above the tensor tympani canal and is separated from it by a recess on the medial wall. The recess has the shape of an ellipse, elongated in the antero-posterior direction.

The internal carotid artery in the macaque runs in a bony canal in the temporal bone at its full length (Fig. 4). The carotid canal participates in the formation of the anterior wall of the tympanic cavity, and is therefore called the carotid wall. The canal runs in a gentle arch, with the convexity heading caudally and slightly to the side. The vicinity of the canal is strongly pneumatized, so the canal is somehow suspended in a "cribriform" porous base. The internal carotid artery closely neighbours with other important structures of the temporal bone. Laterally from it lie the musculotubal canal, and medially, the external acoustic meatus and the cochlea.

Bony labyrinth

The bony labyrinth, the location of the vestibulo-cochlear organ, is situated in the central part of the pyramid. It is oblong, and its long axis is in line with the axis of the pyramid and equals about 10 mm. The bony labyrinth includes the vestibule, the cochlea, and the semicircular canals. The vestibule is an approximately oviform, 2 × 3 mm cavity, and six walls can be distinguished in it. The lateral wall separates the vestibule from the tympanic cavity, and in its great part is occupied by the oval window (Fig. 5). The medial wall, with the most complicated carving, has recesses including the utricle, the sacule and the initial part of the cochlear duct. The anterior wall is narrow and very thin and neighbours the facial canal in its labyrinthine part. In its inferior part, the anterior wall has an opening called the elliptic foramen, which leads to the scala vestibuli. The semicircular canals enter and leave the vestibule in its superior and posterior walls. The posterior wall has an opening leading to the ampulla of the posterior semicircular canal. The superior wall has four openings leading to the semicircular canals: the two anterior openings lead to the ampullar parts of the lateral semicircular canal (which lies more laterally) and to the superior canal (which lies more medially); the two posterior openings lead to the non-ampullar end of the lateral semicircular canal and to the common limb of the superior and posterior (also non-ampullar) semicircular canals. The inferior wall is formed by the spiral lamina.

The semicircular canals lie caudally and superiorly from the vestibule. Their geometry is irregular.

All three bony canals have a more or less elliptical shape and they are a little flattened in the transverse section. The semicircular canals originate and end in the vestibule. Therefore, each of them has two openings (apertures), but because the anterior and posterior canal have a common limb, there are in total 5 not 6 openings in the vestibule.

The lateral canal is visible in the medial wall of the tympanic cavity where, as mentioned, it forms its own prominence. The prominence is most distinct close to the aditus to the mastoid antrum (Figs. 5, 6). A little farther down, the canal sinks into the surroundings and disappears among the air cells. The plane of the canal runs strongly obliquely from the anterior and superior caudally, and forms an angle of approximately 45 degrees with the long axis of the oval window, thus it is situated more slantwise than in humans. Caudally from the prominence of the lateral semicircular canal lies an area deprived of bigger cells, constituting the base of the subarcuate fossa, and caudally from it there is an area corresponding to the sigmoid sinus, located in the cranial cavity. The superior semicircular canal limits the entrance (aditus) to the subarcuate fossa on the posterior wall of the pyramid. The posterior canal is difficult to find because it is not distinguishable by any topographic point either on the surface or inside the bone. It runs slightly arched around the external orifice of the vestibular aqueduct and after joining the superior canal as the common limb embraces inferiorly the entrance (aditus) to the subarcuate fossa.

The cochlea looks a little like a conch or the shell of a snail (Fig. 8). The long axis of the cochlea is directed rostrally and laterally and is nearly perpendicular to the long axis of the pyramid. The base of the cochlea is directed caudally and medially, precisely towards the internal acoustic meatus. The spiral canal forms from 2.5 to 2.75 turns. The cochlea neighbours medially with the internal acoustic meatus, laterally with the musculotubal canal and the promontory, anteriorly with the carotid canal, and superiorly with the facial canal, particularly with the area of geniculum

The cochlear canaliculus is a perilymphatic duct and the vestibule aqueduct is endolymphatic. The cochlear canaliculus unites the initial part of the scala tympani with the subarachnoid space of the posterior cranial cavity. The internal opening of the cochlear canaliculus, called the ear orifice, lies in the medial wall of the basal turn of the scala vestibuli near the round window. The external opening, called its cranial ori-

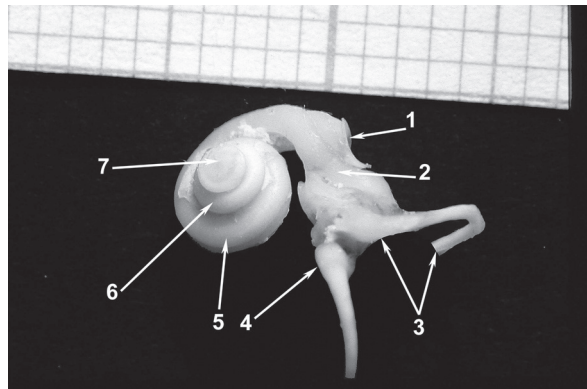


Figure 8. Rubber mould of perilymphatic spaces of macaque's labyrinth removed from bony frame; 1 — impression of round window membrane; 2 — impression of base of stapes; 3 — lateral semicircular canal; 4 — ampulla of superior semicircular canal; 5 — basal turn of cochlea; 6 — medial turn of cochlea; 7 — apical turn of cochlea.

fice, is located on the inferior surface of the temporal bone pyramid, close to the jugular fossa (Fig. 3). The vestibular aqueduct originates in the medial wall of the vestibule, then runs medially, and exits on the medial wall of the pyramid in a depression called the external opening of the vestibular aqueduct.

DISCUSSION

Data concerning the topographic anatomy of the temporal bone in macaques are accessible only in a dozen or so publications [1, 3–6, 9–16].

In the external morphology of the macaque's temporal bone, the deep subarcuate fossa attracts the most attention, as indicated by Stelmasiak and Wójtowicz [12] and Straus [13].

According to Saad et al. [10], the shape of the middle ear space is similar to that in humans, and, certainly, this should be agreed with. He divided the tympanic cavity into three parts, similarly to how it has been done in this description of investigations. However, Bast [1] divided macaque's tympanic cavity only into two spaces; the tympanum and epitympanum, since according to him, the hypotympanum does not appear in the macaque as a distinct (separate) space. Similarly, Kirikae [8] stated that the mastoid antrum is well developed and the hypotympanum is underdeveloped, in the macaque.

Our own investigations confirm Saad's et al. observations [10] that the antero-posterior and superoinferior dimension of the middle ear space is about 9 mm, and including only the tympanic cavity, 6.3 mm. The promontory intussuscepts into the

tympanic cavity, narrowing it down to a width of 1 mm. As far as the shape and dimensions of the tympanic membrane are concerned, there are some controversies indicated by investigators. According to Saad et al. [10], the macaque's tympanic membrane is almost a round disc with both its diameters equal to about 5.8 mm.

Also according to Saad et al. [10], the narrow external acoustic meatus (diameter 2.5–3 mm) widens medially. One should agree with this statement which indicates that this meatus is relatively very long and potentially makes all surgical interventions through this approach more difficult. On the other hand, the vicinity of the meatus with the mastoid antrum, and through the atrium, with the lateral semicircular canal, allows for relatively easy access to the latter without causing any major surgical injury.

According to Saad et al. [10], the oval window is beanlike in shape and measures about 1.8 by 0.5 mm, which is in accordance with our observations. However, the value of the oval window height given by Saad is lower in comparison with our observations. The round window is a little longer in its horizontal diameter than in the vertical, measuring 1.5 mm and 1.2 mm, respectively, which is close to own measurements.

Our own observations concerning the vestibular aqueduct and cochlear canaliculus are in accordance with Neiger's [9] description.

The spiral canal of cochlea, according to previous studies, amounts to an average of 21 mm [14].

The course of the carotid canal is quite similar as in humans. According to Sikorska-Piwowska et al. [11], the external opening of the canal measures 1.11–2.4 mm (average 2 mm). The carotid canal in the macaque runs in two phases: the ascending part and the horizontal part. The angle between them amounts to about 80–119 degrees (average 89.6 degrees).

Some authors underline the good pneumatization of the macaque's temporal bone. The air cells spread from the mastoid process to the apex of the pyramid including the tegmen of the tympanic cavity and its fundus [6, 10].

It is impossible to agree with the statement that there is no subiculum of promontory in the macaque; therefore, the access to the round window is easy [6]. In my opinion, the access is easy because there is no promontory bridge, thus there is no natural limit (border) of the tympanic sinus superiorly: as it flattens and gradually declines dorsally.

According to Saad et al. [10], the malleus is about 6 mm, and the author gives separately the dimension of the head (2 mm) and the handle (4 mm). It is a little more than the dimension calculated in these studies. The difference probably comes from overlaying of the head and handle dimensions measured, in a way twofold, by Saad et al. [10]. The size of the body of incus is 3×2.5 mm. The long limb is 2 mm long, which gives a higher value, by around 4–5 mm, as the total length of the incus, compared with our measurements. The full length of the stapes given by Saad et al. [10] is about 2 mm, falling into the upper range of values obtained in this investigation.

The mastoid atrium, mastoid cells, petrous bulla, and apex of the pyramid cells belong to the system of the middle ear air cells. It is worth noting that none of the investigators mentions the clearly isolated (distinct) mastoid antrum as an element of the middle ear in the macaque. Indirectly related to this is a mention by Saad et al. [10], who noticed that 2/3 of the 9 mm long middle ear is occupied by the tympanic cavity. The pneumatic cells are unusually developed, are a different size and shape, and are surrounding and fixing the carotid canal with its bony walls, which, in a way, is suspended among them like inside a tracery construction designed by an engineer. Saad et al. [10] called one of them the pneumatic cell of the pyramid, because it is particularly big and accompanies the auditory tube canal along its full length; however, it was encountered only once during this study.

The macaque's auditory tube has many similarities with that of humans, as indicated earlier [3, 4].

The temporal canal and the postglenoid foramen do not always appear in the macaque, as confirmed earlier in our own investigations [15].

In conclusion, it should be stated that a number of evident similarities in the structure of the temporal bone in the macaque and in humans allows us to ascertain that the morphology of both species is based on an identical spatial plan. Knowledge of those spatial relations enables safe planning of experiments on the middle or internal ear in the macaque. Substantial differences between both species depend on different pneumatization of the temporal bone, morphology and length of the external acoustic meatus, and thin bony walls of the labyrinth, which makes the use of the macaque's temporal bone as a model for experiments and trainings in otosurgery impossible.

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