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Research Article

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Anatomical Study on the Middle Ear of Donkey (*Equus acinus*)

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Abstract

Studying the anatomical features of the middle ear of donkey was significant among scanty available literatures. The work was established on 14 formalized heads and dried skulls from both sexes of healthy donkeys of different ages. The samples were intended for the bony structural examination and dissection. Extraction of the auditory ossicles was difficult due to the rigidity of the temporal bone during sawing. The article discussed the anatomical features of the middle ear, bony boundary and ossicles. Examination of the latter detected four ossicles and described their posture and their relation to right or left for forensic purposes. Our study provided a good idea about donkey's middle ear for the comparative anatomy. Although intended donkeys as training model for otosurgeons due to the normal continuity to the Eustachian tube and guttural pouch.

Keywords: Middle ear, anatomy, temporal, ossicles, Donkey

Introduction

The anatomical consideration around the middle ear was scanty researched. Among the domestic animals, some authors shed a dim of light on studying the anatomical features of the middle ear Ghandi (1975) in ruminants, Evans & Christensen (1979) in dog, Ragab & Osman (1987) in buffalo, Booker (2004) in camel and cattle and Koing & Liebich (2014) in domestic animals. The auditory ossicles were studied by Arnautovic and Osman (1985) in camel and donkey. Even in the recent years the available literatures are poor in this field in the donkey. The main significant side of view that the direct connection between the middle ear and the pharyngeal cavity and in turn with the cranial cavity *via* the inner ear; Evans & Christensen (1979) in dog, Sisson and Grossman (1975) and Budras et al. (2012) in horse, Nickle et al. (1973), Dyce et al. (1987) &König and Liebich (2014) in domestic animals. Thus accentuates the clinical and surgical importance of middle ear and guttural pouch; Abdel- Hamid et al. (1988) in donkey. Most of the lastly performed works spot a light on the clinical significant of the middle ear and studded it in practically applied form, Somnerauer et al. (2012) in equine. The donkey has been the chosen one for the present research as experimental animal, many authors tried to apply that among the domestic animals, Lavinsky & Goycoolea (1997) a &b in sheep, Pracy et al. (1998) in pig, Seibel et al. (2006) in sheep, Seibel et al. (2006) in human and sheep, Zirkle et al. (2007) and Gurr et al. (2009) in pig. Mean while others compared the middle ear of animals to human Hoffstetter (2011) in human in pig.

Materials and Methods

Eight formalin fixed collected samples include the temporal area from heads of apparently healthy adult donkeys from both sexes and different ages in addition to six donkey dried skulls from the department of veterinary anatomy, Assiut University, New Valley

branch. The study includes the bony structure of the auditory ossicles and the macroscopic dissection of middle ear. The bony features of the ossicles were investigated and achieved by using fine saw and vernier caliper.

The right and left auditory ossicles were extracted from the dried skulls and examined in detail by the magnifying lens.

Results

The bony cavity

The cavity of the middle ear is a biconvex like appearance. It measures about 1.6cm latromedial, 1cm dorsoventral and 1.2cm rostrocaudally.It comprises three portions; the epitympanicum, mesotympanicum and hypotympanicum. Its dorsomedialaspect represents the epitympanic recess and major part of the tympanic cavity proper while its ventrolateral part forms the hypotympanicum and the tympanic membrane which facing laterally. The epitympanicum, represented in a recess (the epitympanic recess) (Fig:1) is a dome shaped cave located dorsally to the mesotympanicum, above the level of the tympanic membrane. It's peak facing laterally and regresses medially.

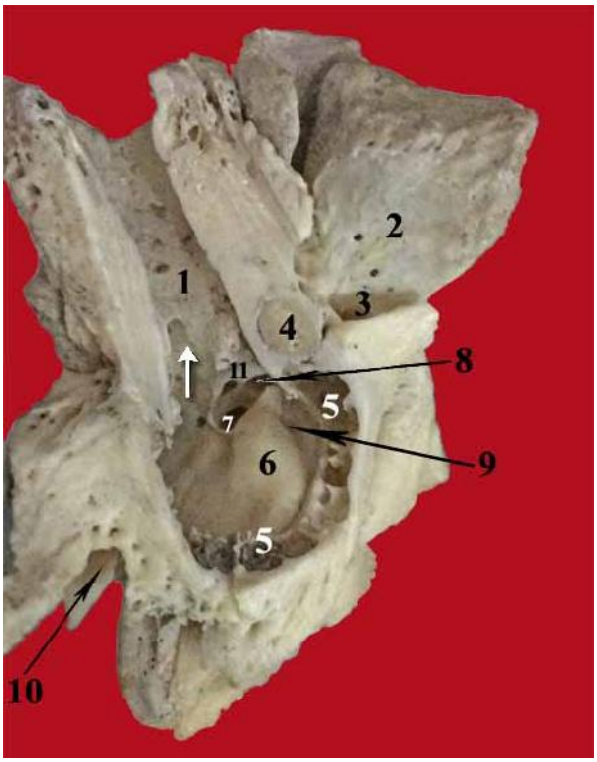

FIG. (1): A photograph of petrous and tympanic parts of the left temporal bone sagittal view (after removal parts of the tympanic bulla and external acoustic meatus)

1- External acoustic meatus
2- Mastoid process
3- Stylomastoid foramen
4- Styloid process of temporal bone
5- Mastoid air cells within the wall of tympanic bulla
6- Promontory
7- Fenestra vestibuli
8- Mastoid antrum
9- Fenestra chocleae
10- Auditory tube
11- Facial canal

The white arrow indicates the epitympanic recess

The mesotympanicum (tympanic cavity proper) (Fig:1) is the largest portion of the middle ear. It encloses the auditory ossicles and the intra auricular muscles. The cavity is bounded laterally by the tympanic ring (11-13 mm. length &7-8mm. width) (Figs.8&9/1) which gives the bony attachment of the tympanic membrane. Medially by a bony prominence (the promontory) which occupies the major part of the medial wall of the mesotympanicum. It is a pear shaped like appearance, has bulbous medial and lateral pointed end. It measures about 10-12mm.length & 4-6mm. width. The promontory (Fig:1) hides the cochlea medially, while its pointed apex (Subiculum) is related dorsally and ventrally to the fenestra vestibulae and cochleae respectively. The former, is the oval window which is (2.5-3mm. length &1-1.5mm. width) and situated caudolaterally in direction. Its margin is related to the foot plate of stapes and connected by the annular stapedial ligament. The round window (fenestra cochleae) is smaller than the oval one and more circular in circumference (1- 1.3mm. diameter). It is covered by the secondary tympanic membrane of the lining mucosa of the tympanic cavity.

The laterally extended end of promontory (Fig:1/8) terminates at the entrance border of the mastoid antrum. The later is ovoid in shape opening (3-3.5mm. length &1-1.5mm. width) it leads to the mastoid air cells (Fig:1/5) which occupies the mastoid process of temporal bone and the tympanic bulla. The mastoid antrum is related laterally to the facial canal which traverses the tympanic cavity proper from the medial to the lateral aspect. It has an opening laterally situated to the fenestra vestibule for the detached chorda tympani nerve (Figs: 7/9& 8/7).

The rostroventral aspect of the mesotympanicum contains the tympanic opening of auditory tube (Fig: 1/10) It is oval in outline and measures about (4.4-5mm. in length &2-2.5mm.in width). The hypotympanicum is the ventrally concaved portion of the tympanic cavity, ventral to the level of the tympanic membrane. It is enclosed in the tympanic bulla and continues to the mastoid air cells which are varied in number and sizes. The later, differ according to their location so they are wider and larger in the caudal aspect of the tympanic bulla while rostrally they regress gradually.

The intra-auricular ossicles

There are fourtiny intra auricular ossicles; malleus, incus, stapesand lenticular axis which connecting the tympanic membrane to the fenestra vestibuli (Oval window). The first three are arranged from the lateral to the medial aspect in order. The first one is the largest while the third is smaller by a ratio of 3:1.6:1 respectively. The forth smallest lenticular axis attaches to the bending angle of the long root of the incus and intern articulates with the head of stapes (Fig.6/8).In about 7% of the examined cases it was absent due to its ossification with the long root of incus in the old ages. The auditory ossicles are connected together in a chainy arrangement. The ossicles are articulated within by the malleoincudal and incudostapedial joints (Figs.5& 6), the former between the malleus and incus while the later formed by incus and stapes. The playing action of the ossicles is controlled by an antagonistic intratympanic muscles; the tensor tympani and stapedius muscles.

The malleus

The most outer ossicle the hummer, (Figs.: 2 A & B) drum stick like. The malleus positured in rostroventral direction with slightly medial inclination. It have lateral and medial surfaces, the former is attached to the tympanic face of the tympanic membrane while the later facing the tympanic cavity proper. The ossicle has dorsal concave and ventral convex borders. Its dorsal half is inclined dorsally so the whole length reaches about 12mm. The malleus consists of head, neck and manubrium. The distance from the head to its lower point is 9-10mm. the malleolar head (1.5-2mm. width &2-2.5mm length) is ovoid in circumference and itsconvexity is directed laterally and the medial aspect carries a saddle shaped malleolar articular facet (0.8-1mm. width &2- 2.5mm. length) is occupied by articular cartilage for the articulation to the incudal articular facet forming the malleoincudal joint (Figs.5&6/2). The malleolar head is completely embedded in the epitympanic recess. The head and neck are directed in a caudodorso-lateral direction. The neck (3-3.5mm. length &0.7-1mm. width) connects the head to the handle. It bears medial muscular and rostral processes; the former (0.8-1mm. length) is the larger and directed caudomedially and gives attachment for the tensor tympani muscle. The rostral process is very short and arises rostral to the malleolar handle. It fixes the malleus to the petrotympanic fissure. The manubrium (handle) of the malleus is the largest part (5-6mm. length), it is directed in rostro-ventro-medial direction. It resembles spiny triangular in shape, with base and apex. The base (1.2-1.5mm width) is proceeds with the neck of malleus and represents the breaking point between the head, neck and the handle. It carries a malleolar prominence or the lateral malleolar process. The later fixes the malleus to pars flaccida of the tympanic membrane (Figs.8&9/2). The apex of the handle is pointed rostrally and attached to the umb of the tympanic membrane.

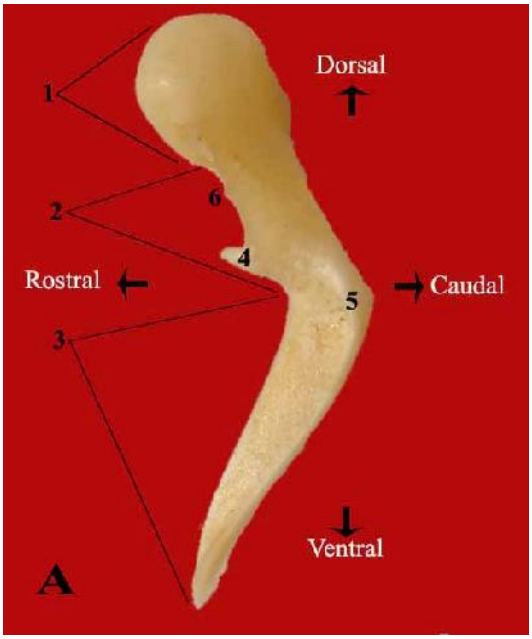

FIG. (2) A: A photograph of the left malleus (Lateral view) (x7)
1-Head 2-Neck 3-Manubrium4- Muscular process 5- Lateral process 6- Rostral process 7- Malleolar articular facet

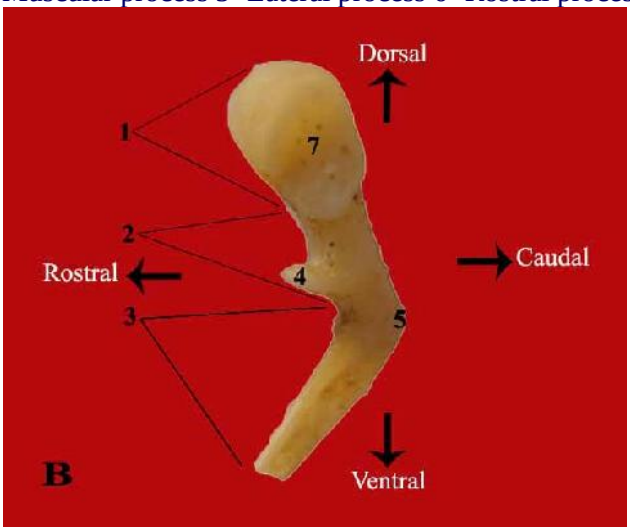

FIG. (2) B: A photograph of the right malleus (Medial view) (x7)

The incus

The anvil (Figs.3) is the connecting point of the malleus to the stapes. It looks like the human bicuspid tooth with divergent roots. The ossicle is presented in a rostrolateral in attitude and with medial and lateral surfaces; the former is related to the medial wall of the epitympanic recess while the lateral one related to the malleolar head and the tympanic cavity proper. The incus consists of body or base and two horns or roots; dorsal and ventral. Its base is directed rostrallywhile the roots caudally. The former with the dorsal root are hidden in the epitympanic recess while the ventral root extends ventromedially in the tympanic cavity proper.

The body is the largest part of the incus and is quadrilateral in shape (2.5-3mm.width &1.8-2mm. thickness).It carries a saddle shaped articular facet on itsrostrolateral aspect and is covered by articular cartilage for the articulation with that of malleus forming the malleoincudal joint. The dorsal incudal root is triangular and somewhat wider than the ventral one (1.7-2mm. width&1.8-2mm. length). The root is directed caudomediallyand dose not exceedsthe level of the articular facet. The ventral incudal root descends ventromedially for about (2.7-3mm. in length) and its terminal apex blends medially to articulate with the head of stapes through a nodular bone (The lenticular process(Figs.6/8).

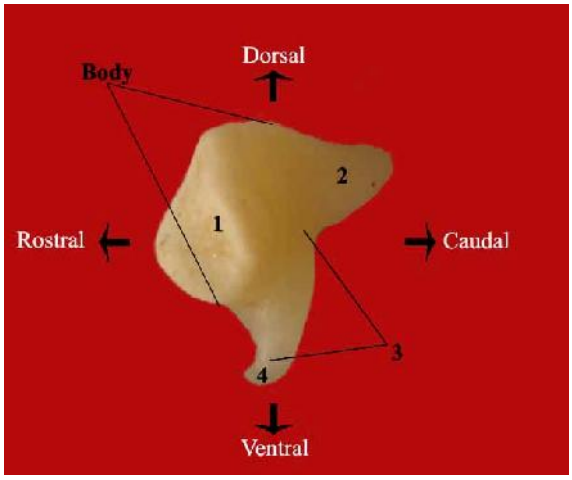

FIG. (3): A photograph of the left incus (Lateral view) (x10)
1-Incudal articular facet 2-Dorsal root 3- Ventral root 4- Lenticular process

The stapes

The excavated ossicle (Fig.: 4) is smaller and deeply hidden in the tympanic cavity proper. It connects the incus to the fenestra vestibule and bounded laterally by the long root of the incus and the lenticular process. Medially it related to the oval window. The stapes is pyramidal in shape having a head or apex, a neck and a base which are connected by two limbs or roots with intervening obturator canal. The apex is oval in outline (0.8-1mm. length & 0.4-0.5mm width) and is articulated with the lenticular process forming the incudostapedial joint (Fig. 5/7) and it is directed ventrolaterally. The stapedial neck is very short and marked caudally by the muscular process for stapedius muscle. The stapedial limbs are diverging from the head to attach the base and they range from (2.8-3mm.) in length, they are rostral and caudal, separated by the obturator canal. The later connects the dorsal and ventral obturator foramina (0.9-1mm. length &0.6-0.7mm width). The roots are excavated and they are convex externally and concave internally from side to side, the excavation extends to the stapedial neck. The obturator canal is obliterated externally by the obturator membrane which is a part of the lining mucosal membrane of the tympanic cavity. The stapedial base is directed mediodorsal and is represented by elliptical foot plate with small indentation medially (2.7-3mm. length &1.3-1.5mm. width). It is attached to the margin of the oval window by the annular stapedial ligament.

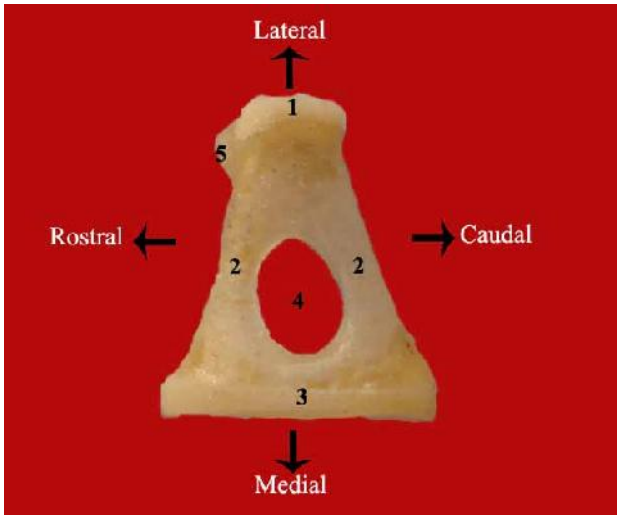

FIG. (4): A photograph of the left stapes (Lateral view) (x10)
1-Head 2- limbs 3- Foot plate 4- Obtiurator canal 5- Muscular process

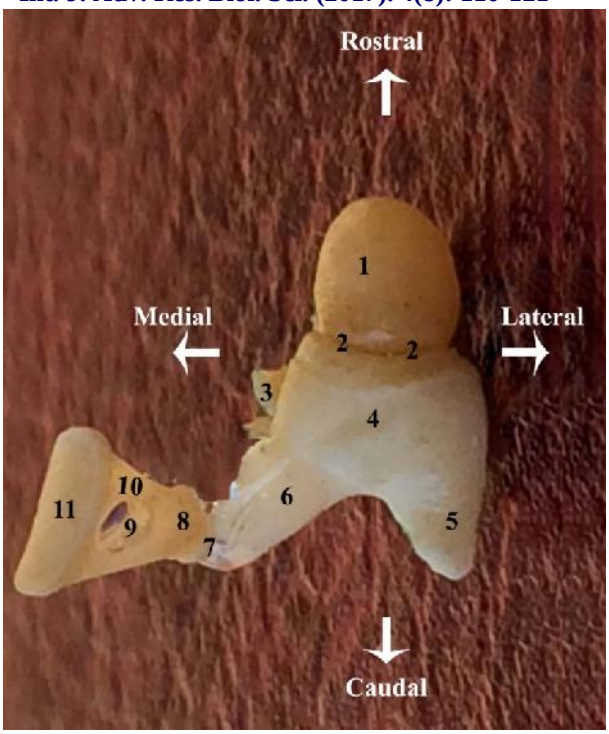

FIG. (5): A photograph of the right auditory ossicles (dorsal view) (articulated):
1- Head of malleus, 2- Malleoincudal joint, 3-Malleus muscular process, 4-Body of incus, 5- Short root of 4, 6- Long root of 4, 7- Incudostapedial joint, 8- Head of stapes, 9- Obturator canal, 10- Stapedial limb, 11- Stapedial foot plate

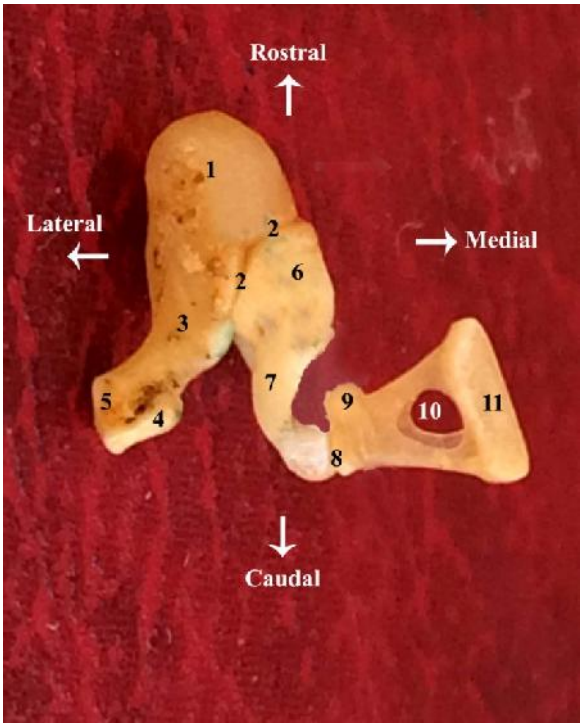

FIG. (6): A photograph of the right auditory ossicles (ventral view) articulated:
1- Malleolar head,2- Malleoincudal joint, 3- Malleolar neck, 4- Muscular process of malleus, 5- Base of the malleolar handle, 6- Body of incus, 7- Long root of 6, 8-Lenticular process, 9- Muscular process of stapes, 10- Obturator canal, 11-Stapedial foot plate

The internal dissection

The anatomical structures within the cavity of the middle ear, comprises the tympanic membrane (Ear drum), the membranous lining and intra auricular muscles. The former is an incomplete semitransparent barrier, separates the external acoustic meatus from the tympanic cavity. It considered the lateral limit of the latter and the medial for the external acoustic meatus. The membrane (Fig. 7,8 & 9) is a tear shaped like in appearance, having proximal narrow and distal wider poles. Its longitudinal axis measures about (12.5-13mm.) and the width reach about (7.4-8mm.) and inclines dorsolaterally forming an acute angle of 60-65 degreeswith the longitudinal axis of the external acoustic meatus. The tympanic membrane having two surfaces; lateral and medial, the former is concave while the other side is convex. The periphery of the membrane is attached to the tympanic ring while its proximal pole fills the tympanic incisura. The membrane comprises from two parts; pars flaccida and pars tensa. The former (Figs. 8&9/2) is the proximal, smaller and represents the part of the tympanic membrane in the tympanic incisura. The lateral process of malleus evaginates laterally and folding the membrane into rostral and caudal folds. The pars tensa (Figs.8&9/3) is the largest part and resembles saddle shape in appearance. It is strongly convex medially for about (2mm.) forms the umbo which is related to the distal end of the malleolar handle.

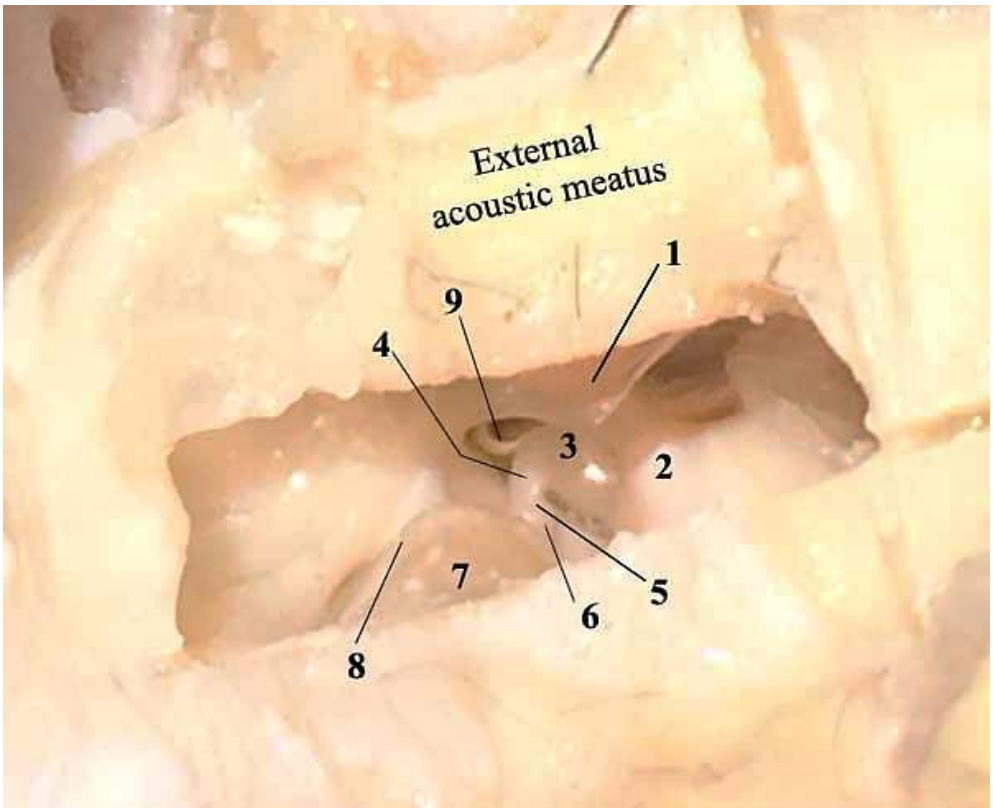

FIG. (7): A photograph of the middle ear (ventral view) opened bulla tympanica
1- Tympanic membrane (Umbo)., 2- Tensor tympani muscle., 3- Ventral root of incus, 4- End of 3.
5- Lenticular process, 6- Head of stapes,7- Promontory, 8- Jacobson's nerve (Tympanic n.),9- Chorda tympani nerve

The membranous lining of the tympanic cavity is the continuation of the Eustachian tube. It lines the walls, auditory ossicles, intra auricular muscles and the medial face of the tympanic membrane, covers also the fenestra cochleae to form the secondary tympanic membrane. It closes the obtiuratorforamina forming the stapedial membranes. The lining membrane of the middle ear invaginates ventrally to line the tympanic air cells of the tympanic bulla. The chorda tympani nerve (Figs.7/9&8/7) traverses the tympanic cavity from the facial canal caudally, crossing the neck of malleus to emerge rostrally from the petrotympanic fissure. The lining membrane suspense it by double folds (Chordafalte) to the dorsal aspect of the tympanic cavity (Fig.8/8). On the promontory, the membrane fixes the Jacobson's nerve (Tympanic nerve) on its lateral surface (Figs. 7/8&8/14).

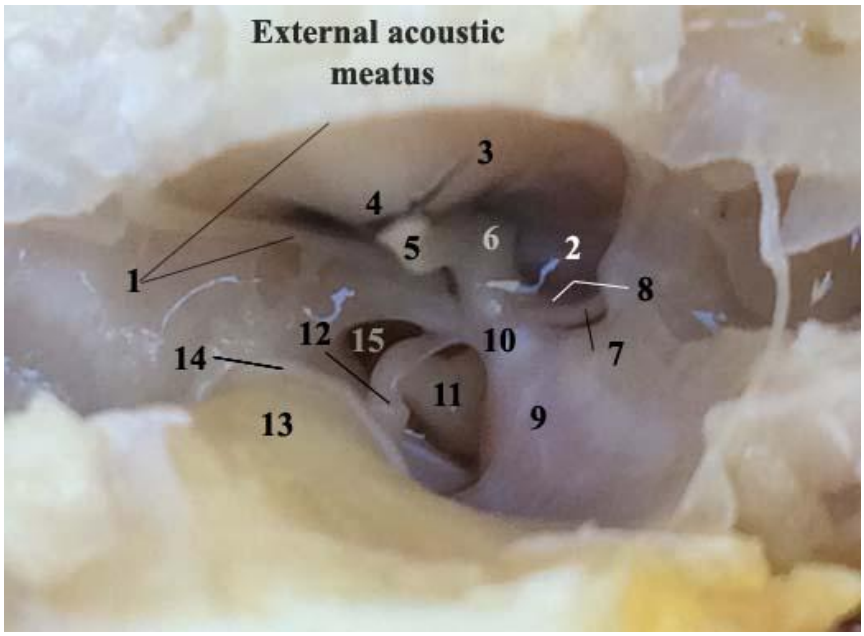

FIG. (8): A photograph of the right middle ear (ventral view) opened bulla tympanica

1-Tympanic ring, 2-Tympanic membrane (Pars flaccida), 3-Tympanic membrane (Pars tensa)
4-Umbo, 5-Distal end of malleolar handle, 6-Lateral process of malleus, 7-Chorda tympani nerve
8-Fold of 7, 9-Tensor tympani muscle, 10-Malleolar inrestion of 9, 11-Ventral root of incus, 12-Lenticular process, 13-Promontory, 14-Jacobson's nerve, 15-Epitympanic recess

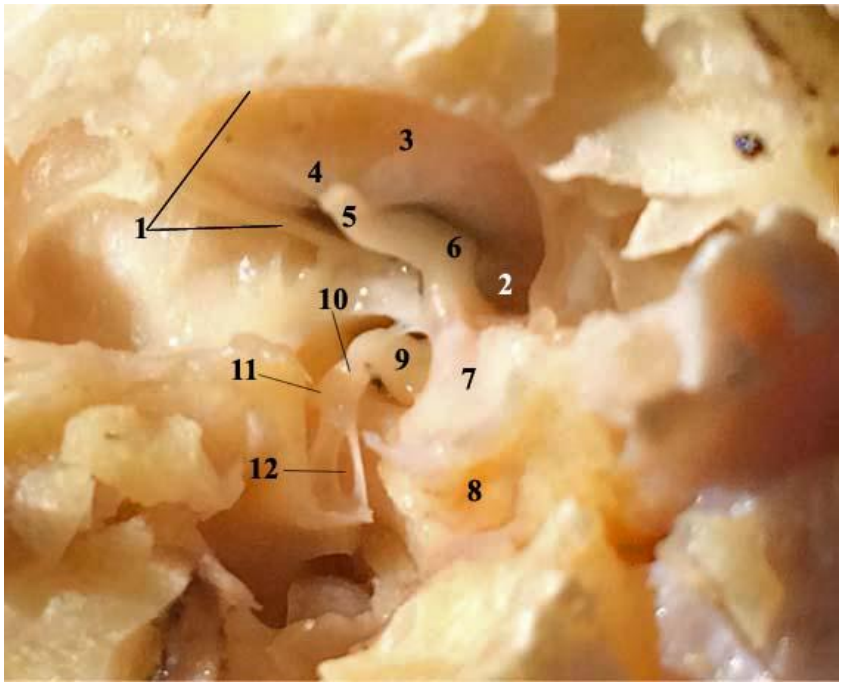

FIG. (9): A photograph of the right middle ear (ventral view) opened bulla tympanica& promontory

1-Tympanic ring, 2-Tympanic membrane (Pars flaccida), 3-Tympanic membrane (Pars tensa), 4-Umbo, 5-Distal end of malleolar handle, 6-Lateral process of malleus, 7- Lining membrane covering tensor tympani muscle, 8-Fatty coat of tensor tympani muscle, 9-Ventral root of incus, 10-Lenticular process, 11-Stapedius muscle, 12-Obturator canal

The intra auricular muscles are the tensor tympani and the stapedius muscles. The first (Figs. 7/2,8/9 &9/8) is larger and cone shaped like. It has a fleshy base directed medially while its apex is tendenous and attached to the muscular process of malleus. The muscle originates from a depressed area rostrally situated to the promontory, where the fleshy part is enclosed in a fatty coat which covered externally by the tympanic lining membrane. The stapedius muscle (Fig.9/11) is the smallest, shorts and finest one. It arises from a depressed area adjacent to the fenestra vestibulae and is directed laterally to attach the muscular process of stapes.

Discussion

The current work considered the rarely cited available literatures around the anatomy of the middle ear.

The present study has been taken in mind the consideration of fragility of the temporal bone and auditory ossicles are too difficult to obtain the ossicles in situ as well as dissection of the tympanic cavity after sawing the temporal bone and bulla tympanica. Similarly achieved trials by Eichentopf et al. (2014) in horse.

It was interested to notify that, the anatomical structural of the middle ear was recently a point of view and described the middle ear as the tympanic cavity which included the epitympanicum, mesotympanicum and hypotympanicum. Aresult which were totally in agreement with that of Ragab& Osman (1987) in buffalo and Nitovski et al. (2014) in cattle and pig. While Eichentopf et al. (2014) in horse added the tympanic bulla to the previously mentioned parts. While König and Liebich (2014) in domestic mammals has the opinion that the middle ear consisted of tympanic cavity, auditory ossicles and auditory tube, the former comprised the epitympanicum, mesotympanicum and hypotympanicum. On the other hand, Pracy et al. (1998) in pig classified the middle ear into Eustachian tube, tympanic cavity and air cell system within the tympanic bulla. Regarding the proceeding recorded system, the present results pointed out that the gate of entrance to the tympanic air cells was referred to the mastoid antrum which was the part of the mesotympanicum. In constrast to the opinion Pracy et al. whom considered that the air cell system was a separate portion.

The present work confirmed the presence of the middle ear within the tympanic and petrous parts of temporal bone, meanwhile Ragab & Osman (1987) in buffalo and König and Liebich (2014) in domestic mammals mentioned that the middle ear in the petrous part. While Poleksic et al. (2003) mentioned that it located within the tympanic part only.

Concerning the bony anatomical relations of the middle ear in the current study revealed that it resembles a biconvex lens with dorsomedial and ventrolateral faces. A result which was in contrast to that cited by Pracy et al. (1998) in pig which declared that it was look's like a biconcaved lens with six walls; roof, anterior, posterior, lateral, medial and floor. In this respect, Ragab & Osman (1987) in buffalo reported dorsal, ventral, lateral and medial walls.

In the donkey, the anatomical structures of the internal bony cavity we found that the promontory in a pear shaped osseous prominence with apex pointed laterally and bulbar part bulged medially, however Ragab & Osman (1987) in buffalo mentioned it as a rounded elevation. In agreement with Ragab & Osman (1987) in buffalo and Evans (1993) in dog, the lateral end of the promontory directed toward the mastoid antrum which measured about 3.5mm.length & 1.5mm. width and leads to the mastoid air cells which distributed along the mastoid process and bulla tympanicain addition to the floor of the tympanic cavity was opened directly in numerous air filled bony chambers connected together. In contrast with the description of Pracy et al. (1998)& Gurr et al. (2009) in pig and Seibel et al. (2006) in sheep they noted the absence of mastoid antrumand only mentioned that the hypotympanicum open in spongy like air cells and cited that the mastoid process wasn't pneumatized. In this respect, Gandhi (1975) in horse denied the air cells in the floor of the middle ear and Sargent et al. (2006) reported the relatively smallest size bulla tympanicain horse.

On the other aspect, our study suggested located the fenestra vestibuli dorsally situated on the subiculum and connected to the margins of the foot plate of stapes by the annular stapedial ligament. A findings which nearly similar to the most of anatomists; Gosku et al. (1992) in guinea pig, Lavinsky and Goycoolea (1997) a,b in sheep, Lavinsky et al. (1998) in human, (1999) in sheep, Seibel et al. (2006) in sheep, Guyton et al. (2008), Mohammadpuor (2011) in hamster and König & Liebich (2014) in domestic mammals. The current wok recorded that the diameter of the oval window was wider than that of round one. That was in contrast to that found by Ragab & Osman (1987) in buffalo, Pracy et al. (1998) in pig and Booker (2004) in camel and cattle.

The recent work declared the internal auricular skeleton and recorded that it was composed of ossicles and interossicular joints which represent the smallest bones in the body. A result which similarly met by Harvey et al. (2003) in mammals. The ossicles were three relatively larger; malleus, incus and stapes and one tiny; the lenticular process which was the connecting point of last two mentioned ossicles. The investigation suggested the forth ossicle, as the normal continuity of the long root of incus bended at the point of the lenticular process. The bending angle of latter and incus was very sharp which confirm that it was separate ossicle. Nearly achieved findings cited by Sijaki et al. (1997), Nitovski et al. (2009) and König & Liebich (2014) in domestic mammals and Nitovski et al. (2014) in cattle and pig. While some of anatomists had the opinion that they were three auditory ossicles; malleus, incus and stapesRagab& Osman (1987) in buffalo, Booker (2004) in camel and cattle.Our assumption was based on the finding that the lateromedial arrangement of ossicles was; malleus incus and stapes, traversed the tympanic cavity from the tympanic membrane laterally to the oval window medially. This statement was asserted by Ragab& Osman (1987) in buffalo, Pracy et al. (1998) in pig, Poleksic et al. (2003), Booker (2004) in camel and cattle, Cunningham et al.(2007), Guyton et al.(2008), Frandson (2009), Hoffister (2011) and Mohammadpuor (2011) in hamster.

Regarding to the malleus in this study which had head, neck and handle with medial, lateral and rostral processes as well as, medially located saddle shaped facet for incus and the malleolar handle was attached to the tympanic membrane. Such findings were suggested in previous study as those given by Arnautovic and Osman (1985) in camel and donkey, Ragab & Osman (1987) in buffalo, Booker (2004) in camel and cattle. On the other hand, Gurr et al. (2009) in pig cited only two parts of malleus; head and handle.Our examination defined that the malleolar posture was rostroventro-medial in the tympanic cavity this was in agreement with Pracy et al. (1998) in pig. We found that the malleus of the donkey resemble the drum stick with dorsally inclined its upper half rostrally. such statement wasn't recorded in the available literatures.

Our observations found that the incus was presented in rostrolateral in direction with medial and lateral surfaces. The opinion which was scanty in the available literatures.

The stapes was consisted of two equally measured limbs, connect the head to the foot plate. This record was similar to that of Arnautovic and Osman (1985) in camel and donkey, Ragab et al. (1986) in deer. While Arnautovic and Osman (1985) in cat and rabbit had the opinion that the rostral limb was curved and longer the caudal one.In consent with our description about the excavation of the stapedial limbs which were convex externally and concave internally from side to side, we suggested that they were connect double obturator foramina forming an obturator canal which is obliterated externally by the obturator membrane. This statement was not found in any of the respected studies.

The donkey's tympanic membrane of our findings was firstly described and found it in a tear shaped like while Ragab & Osman (1987) in buffalo and König & Liebich (2014) in domestic mammals cited that an ovoid in shape. Its inclination angle reached about 60-65 on the longitudinal axis of the external acoustic meatus, as that asserted by Ragab & Osman (1987) in buffalo. On the other hand, Pracy et al. (1998) in pig found it 35-40.

Our description on the tensor tympani muscle which was embedded in a fatty coat, nearly similar to the results of Wenig and Michaels (2007) and Eichentopf et al. (2014) in horse.

Regarding the membranous lining of the middle ear of our study, which suspended the chorda tympani nerve by Chordafalte with the dorsal aspect of the cavity, this result was affirmed by Pracy et al. (1998) in pig.

Conclusion

The middle ear of the donkey was described as the tympanic cavity. The present work recorded some unique features of the auditory ossicles, owning to the importance of the middle ear cavity and its contents, providing the priority of using donkey as a training model for the otosurgical interference.

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