Experimental Studies / Deneysel Çalışma

Microscopic guide to the middle ear anatomy in guinea pigs

Kobaylarda orta kulak anatomisi için mikroskopik kılavuz

Arif Şanlı, M.D.,[1] Sedat Aydın, M.D.,[1] Resul Öztürk, M.D.[2]

[1]*Department of Otolaryngology, Dr. Lütfi Kırdar Kartal Training and Research Hospital, İstanbul, Turkey;*
[2]*Department of Otolaryngology, Finike State Hospital, Antalya, Turkey.*

Objectives: To reveal microscopic surgical anatomy of the middle ear in guinea pigs (GPs).

Materials and Methods: Twenty ears of GPs were dissected under dissection microscopy via inferior approach. By using digital equipment, the most suitable photograph was taken for each step. Differences and similarities between the ears of GPs and those of human beings are discussed to show the advantages and disadvantages of the GP ear for experimental studies.

Results: Tympanic membrane of the GP merely consists of pars tensa and above this there is a bony segment called as supratympanic crest. There were two spaces called bulla and hypotympanium in the GP's middle ear. Cochlea, which is normally found in the inner ear in humans, separates these two spaces. Upper part of this space which is called epitympanium is a slit like cavity having a bony complex called malleoincudal complex. Bulla, the largest cavity in the middle ear, is a hemispherical cavity having a smooth surface. It corresponds to hypotympanum and mesotympanum of human middle ear. Cochlea has 3.5 turns from basal turn to apical turn. While the oval window is placed vertically, the round window is placed horizontally. While the stapes is almost identical to that of the humans, there is a bony bridge between the crura of the stapes called crista stapedius. Stapes can not removed unless this bony bridge is taken.

Conclusion: The middle ear in GP differs from the human middle ear in many aspects. Researchers who are planning to the study with this animal model should be aware of all these differences.

Key Words: Experimental study; guinea pig; microscopic surgical anatomy; middle ear; nomenclature.

Amaç: Kobaylarda mikroskopik cerrahi yöntemi ile orta kulak anatomisi ortaya kondu.

Gereç ve Yöntem: Yirmi kobay kulağı diseksiyon mikroskobu altında inferior yaklaşım kullanılarak diseke edildi. Dijital cihaz kullanılarak her aşama için en uygun fotoğraflar çekildi. Deneysel çalışmalar için kobay kulağının avantaj ve dezavantajlarını göstermek için kobay ve insan kulağı arasındaki farklılıklar ve benzerlikler ele alındı.

Bulgular: Kobay timpanik membranı sadece pars tensadan ibaret olup yukarıda supratimpanik krest diye isimlendirilen kemik yapı bulunur. Kobay orta kulağında epitimpanum ve bulla diye iki boşluk bulunur. Bu iki yapıyı normalde insanlarda iç kulakta bulunan koklea ayırır. Üst kısımdaki boşluk epitimpanum olup içerisinde füzyon haline uğramış malleoincudal kompleks bulunur. Bulla en büyük boşluk olup yarım küre şeklinde ve düzgün yüzeylidir. İnsan kulağındaki mezotimpanum ve hipotimpanuma karşılık gelir. Koklea bazal kıvrımdan apikale kadar 3.5 tur döner. Oval pencere vertikal planda yerleşirken yuvarlak pencerenin yerleşimi horizontal plandadır. Stapes insanlardaki gibi şekle sahipken bacaklarının arasında krista stapedius olarak bilinen kemik köprü bulunur. Stapes bu kemik köprü çıkarılmadan kaldırılamaz.

Sonuç: Kobay orta kulağı birçok bakımdan insan orta kulağından farklıdır. Bu hayvan modeli ile araştırma yapmayı planlayan araştırmacıların orta kulağa yönelik tüm bu farklılıkların farkında olmaları gerekmektedir.

Anahtar Sözcükler: Deneysel çalışma; kobay; mikroskopik cerrahi anatomi; orta kulak; nomenklatör.

Received / *Geliş tarihi:* August 15, 2008 Accepted / *Kabul tarihi:* February 4, 2009

Correspondence / İletişim adresi: Sedat Aydın, M.D. İstasyon Cad., Merdivenli Sok., Özkan Apt., No: 5/6, 34860 Kartal, İstanbul, Turkey.
Tel: +90 216 - 473 20 23 Fax *(Faks):* +90 216 - 352 15 78 e-mail *(e-posta):* sedataydin63@yahoo.com

Experimental animal studies, as in other medical fields, are a scientific method used also in the ear, nose, throat and head-neck surgery. In these studies, other experimental animals such as chinchillas and guinea pigs (GPs) are also used as well as animals like rats and rabbits.[1-6] However, the technologies employed in these studies belong to a period dated a minimum of 10-15 years before our time and therefore, they are limited with the possibilities in those years.[1-3] Dissection studies are considered as anatomical studies. Anatomical training and visual materials are fairly effective tools for the learning process when combined with theoretical information. In the present study, our aim is to combine theoretical information with an advanced level of imaging studies and use a surgical microscope and a video camera equipped with a high-level technology. A computer with a "video-capture" card installed was employed to avoid deteriorations in the image quality and images were transferred to the computer in a digital medium.[7]

Before starting the experimental otology research, it may be necessary for the investigator to study the ear anatomy of the experimental animals in detail. Since there are not many studies related with the surgical anatomy of GP ears, which are frequently used in such researches, any otological experimental studies today may cause unnecessary loss of such experimental animals and a delay in these studies that may lead to a failure in achieving results at optimum conditions.[5] To overcome the above-mentioned negative conditions and provide a contribution to the investigators, this study concerning the surgery of the middle ear anatomy in GPs has been conducted.

MATERIALS AND METHODS

The ten GPs in this study were also used for previous studies carried out at the Pendik Veterinary Research Institute. The animals were routinely sacrificed after the completion of the study, and therefore, no permit from the ethical board was required in order to carry out the present study. Thus, we conformed to all the related articles of the Helsinki Declaration regarding experimental studies. The animals were sedated by an intraperitoneal injection of 100 mg/kg ketamine hydrochloride (Ketalar, vial, 50 mg) and then decapitated after an injection of 2 mg/kg vecuronium bromide (Norcuron, ampoule, 4 mg).[8] During the progress of this study, an inferior approach was oriented both to the tympanic membrane and to the structures of the middle ear, which involved the same dissection method preferred from among other dissection methods. All images were obtained from the left ear of the GPs to provide a better orientation.

During the dissection, an excision was made primarily at the auricula and external ear canal and then the bony cortex was removed and a middle ear exploration was performed. After the bone covering the aditus was removed, the bony chain, windows area, cochlea and the facial nerve were examined. Microsurgical materials were used during the dissection as in routine ear operations. Images were viewed by a Zeiss opmi-pico operation microscope (with an enlargement ratio of 10x, 16x, 25x; Carl Zeiss, Germany, 2000). These images were then transferred to a computer equipped with a Pinnacle DV500 plus video capture card (Pinnacle, USA, 2002) via the S-Video connection by the means of a Sony handycam DCR-PC8E camera (Sony, Japan, 2003). Photos were selected in a computerized medium and then arranged by various programs such as Adobe photo deluxe (Adobe, USA, 2000) and paint shop pro 5 (Jasc software, USA, 1998), and then filed and stored in a JPEG (Joint Photographic Expert Group) format.[7]

RESULTS

After the tympanic ring located on the lateral tympanic annulus and the bulla was drilled and removed, the real tympanic membrane (TM) can be viewed with its original dimensions of 8x7 mm. If this dissection was not performed, only 50% of the TM could be viewed. On the other hand, the extensions of the tympanic ring, that extend towards the anterior and the posterior sides, do not combine at the superior. A bony lamella recognized as the supratympanic crest (STC) is located at this region, covering the un-combined area and extending alongside the medial. Unless this structure is drilled and removed, it may not be possible to reach the epitympanum that contains the malleo incudal complex (MIC). The tympanic annulus in which the TM is located is adhered to the bulla at the lateral side and ends at the independent edge of the medial. The diameter of the tympanic annulus becomes larger towards the medial starting from the tympanic annulus (1 mm thickness) and then achieves its largest diameter at the independent edge. The TM adheres onto the annulus at this point (Fig. 1). The tympanic annulus is located

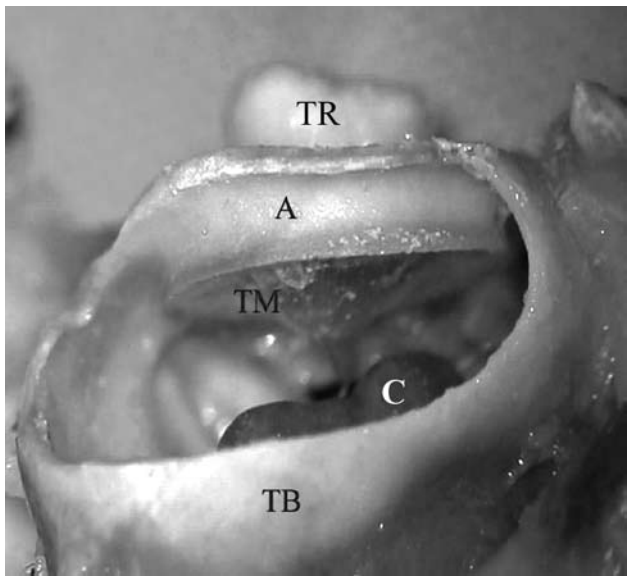

Fig. 1. *Inferior medial appearance of the tympanic annulus via inferior approach (x10).* *TR: Tympanic ring; A: Annulus; TM: Tympanic membrane; TB: Tympanic bulla; C: Cochlea.*

on the internal surface of the bulla's lateral wall and, as a consequence, it cannot be seen from the outside. The bony structures must be drilled and removed in order to expose the tympanic annulus. There are two routes to approach the tympanic annulus. The first one is the lateral approach in which the tympanic ring located at the lateral side of the annulus and the bulla is removed so that the tympanic annulus can be reached. The second one is the inferior approach where the inferior wall of the bulla is drilled and removed so that the middle ear can be entered. During this procedure, it is possible to expose the tympanic annulus from the medial side. This approach is the dissection method with a minimal trauma. When the middle ear cavity is viewed from the inferior medial side, the TM and the annulus can be viewed completely (Fig. 2).[1]

The color and shape of the TM is similar to that of a human TM, although this one is thinner and more transparent. During the dissection, this transparent structure may easily rupture. The TM without a fibrous annulus is firmly attached to the independent edge of the bony annulus. As the manubrium mallei (MM) pulls the membrane towards the medial side, a convex structure may form at the membrane with an aperture facing the lateral side. However, the vertical diameter is about 1 mm shorter than the horizontal diameter due to the presence of the supratympanic crest (STC) located at the superior part of the TM. The MM ascends directly downwards without making any vertical angles to the front and rear. Along this route, the surface area of the MM may increase and resemble a tennis racket.

After the elevation of the tympanic annulus, the middle ear can be entered. The middle ear cavity consists of the combination of two spaces: The epitympanum and the bulla; with the epitympanum composing the upper section of the middle ear (Fig. 3). In this space, the head of the malleus and the body of the incus are fused together to form the MIC.

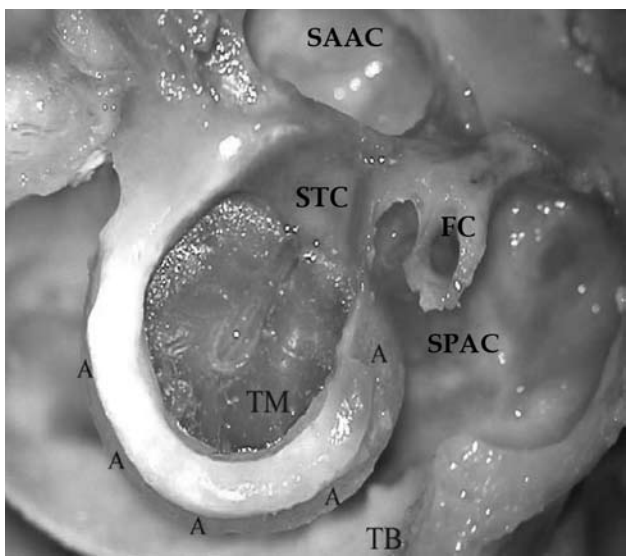

Fig. 2. *Disclosure of the tympanic annulus via lateral and inferior approach (x10).* *SAAC: Superior anterior air cell; FC: Facial canal; SPAC: Superior posterior air cell; A: Annulus; TM: Tympanic membrane; TB: Tympanic bulla; STC: Supratympanic crest.*

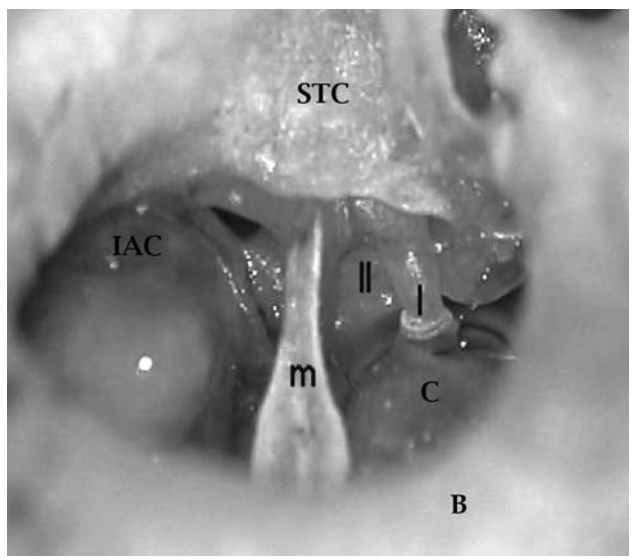

Fig. 3. *Lateral appearance of the epitympanum with its content (x16).* *STC: Supratympanic crest; IAC: Inferior air cell; M: Malleus; C: Cochlea; I: Inkus; B: Bulla; II: Tympanic segment of the facial nerve.*

This part is a cleavage shaped as a rectangular prism and contains an inferior air cell located at the anterior side. The mastoid segment of the facial nerve is located at the posterior; a superior anterior air cell takes place at the superior side, and finally the tympanic segment of the facial nerve lies at the inferior side (Fig. 4).

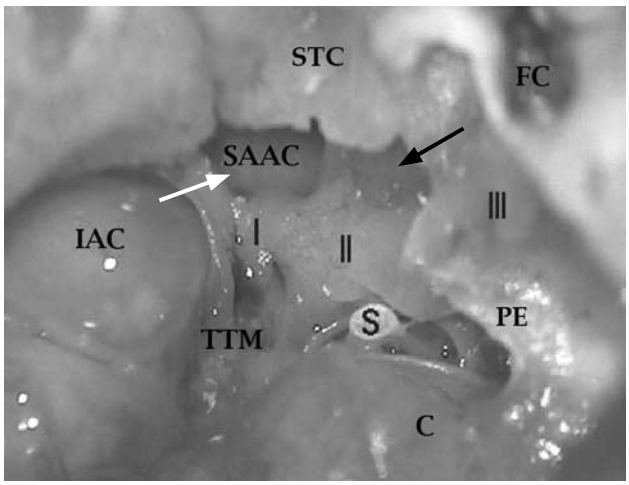

Fig. 4. *Appearance of the epitympanum cavity after the STC and MIC has been removed (black arrow). Anterior superior of the epitympanum, It was seen passing to superior anterior cell (white arrow). (x25).* *STC: Supratympanic crest; FC: Facial canal; IAC: Inferior air cell; I, II, III: The labyrinth, tympanic and mastoid segments of the facial nerve; S: Stapes; C: Cochlea; TTM: Tensor tympani muscle; PE: Pyramidal eminence; SAAC: Superior anterior air cell.*

The thick lateral wall of bulla becomes thinner as it approaches the posterior side. Especially the postero-inferior wall can be very thin. Therefore, the utmost attention must be given during the dissection of this region. Medial, lateral, anterior and posterior margins of the bulla are constructed by the bulla itself. The bulla is separated from the epitympanum by the cochlear projection. The eustachian tube orifice is located at the anterior side of the bulla. The bulla extends at the anterior-superior by an inferior cell. This continuity is not a regular passage and is precluded by three thin horizontal bony ridges (Fig. 5). The first superior ridge is located at the lower border of the inferior air cell. Meanwhile, the third inferior ridge immobilizes the apical turn of the cochlea onto the bulla's medial wall. The most important structure located in the bulla is the eustachian tube orifice seated on the base of this third inferior horizontal ridge.

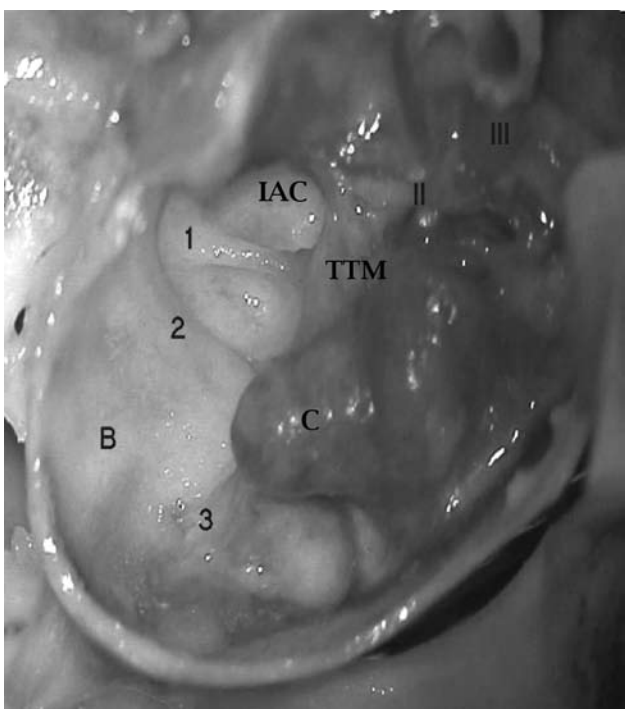

Fig. 5. *It was seen that three horizontal bony ridge was found between bulla and inferior air cell (x16).* *1, 2, 3: Horizontal bony ridges; TTM: Tensor tympani muscle; IAC: Inferior air cell; C: Cochlea; B: Bulla; II, III: The tympanic and mastoid segments of the facial nevre.*

The cochlea is the most significant structure in the middle ear with a conical shape and lies between the epitympanum and the bulla (Fig. 6). Starting from the basal turn, the cochlea makes 3.5 turns up to the apical one. The basal turn is the first drive and begins from the recess of the round window and ends at the point where the tensor

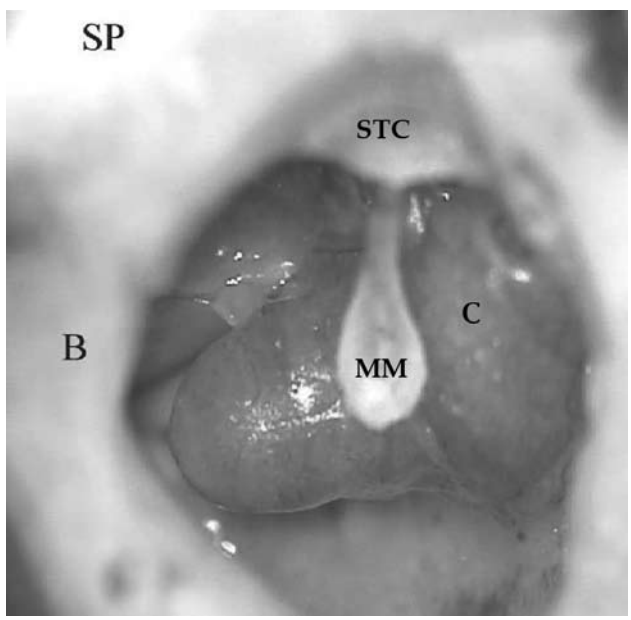

Fig. 6. *The appearance of the cochlea in mesotympanum (x10).* *C: Cochlea; MM: Manubrium mallei; B: Bulla; STC: Supratympanic crest; SP: Squamous part.*

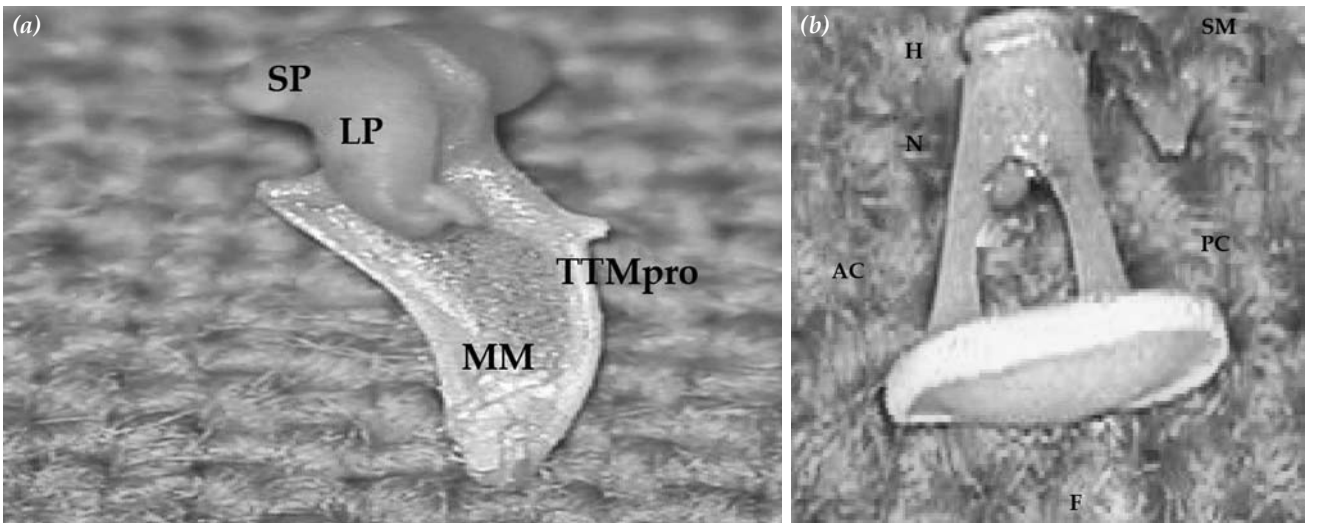

Fig. 7. ***(a)*** *The appearance of the malleo-incudal complex from the laterally (x10).* ***(b)*** *The appearance of the stapes (x10).* *SP: The short process of inkus; LP: The long process of inkus; TTMpro: The prominence of tensor tympani muscle; MM: Manubrium mallei. N: Neck; AC: Anterior crus; H: The head of stapes; PC: Posterior crus; SM: The stapedius muscle; F: Footplate.*

tympanum muscle is located. This turn is the most significant protrusion of the cochlea. While the basal turn completes its drive inside the middle ear's medial wall, other turns end their drives entirely in the bulla cavity. The bony spiral lamina can be exposed when the external bony capsule of the cochlea is removed. Superior and inferior ducts of the spiral lamina open to an oval window and a round window respectively. The oval window is located on the vertical plane while the round window lies on the horizontal plane.

The middle ear bony structures of GPs, consisting of an MIC and a stapes, are different from the human bony structures in their number and formation. The head of the malleus joins with the corpus of the incus as a block and forms the MIC. There is a slight suture at the conjunction line. The reason why the MIC has a vertically long structure finds its answer in its significant manubrium having a half-moon shape that can be very fragile at the conjunction site of the neck region and therefore requiring utmost attention during the dissection (Fig. 7a). The incudal part of the MIC is about 1.5 mm in vertical length. This structure consists of a short and a long arm, and by the help of the Lenticular process located at the posterior end of the long arm, forms a joint with the stapes suprastructure. The stapes is the smallest bony structure of the GP's middle ear and it absolutely resembles the shape of a human stapes. The stapes is located more medially compared to the lenticular process of the incus. The vertical length of the stapes is about 1.5 mm and this is equal to the footplate's diameter. The stapes is very mobile when touched and the structures that form the stapes are the head, neck, anterior crus, posterior crus and the footplate (Fig. 7b). The footplate has an elliptic shape, its surface is convex and it is completely seated in the oval window. There is a very transparent stapes's ligament that extends from the posterior crus to the pyramidal eminence. This ligament keeps the

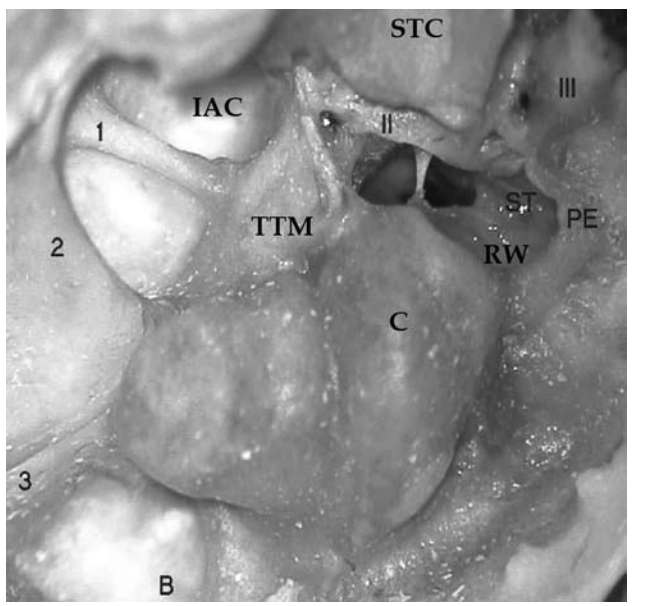

Fig. 8. *The appearance of the crista stapedius after the stapes has been removed (x25).* *STC: Supratympanic crest; IAC: Inferior air cell; TTM: Tensor tympani muscle; C: Cochlea; RW: Round window; ST: Sinus tympani; PE: Pyramidal eminence; B: Bulla; 1, 2, 3: Horizontal ridges of the bulla; II, III: The tympanic and mastoid segments of the facial nevre.*

mobile stapes immobilized. The shape of the stapes may resemble its human counterpart, but it also differs in its localization from the latter. The reason for this difference is the presence of a bony bridge that is recognized as crista stapedius and that suspends the stapes. The crista stapedius is a thin bony structure that begins from the niche of the round window and continues toward the tympanic segment of the facial nerve and passes between the crus of the stapes (Fig. 8). The crista stapedius structure is another prominent structure of the ear that must be well noticed during the dissection. To extract the stapes and view the oval window, this bony bridge must be removed at the first sight.

There are two muscles located in the middle ear of the GP. These muscles are known as the TT and the stapedius muscles. The TT muscle originates from the bony canal and adheres to the protrusion located at the posterior of the manubrium. The canal of TT muscle is surrounded by an inferior air cell at the anterior, by an oval window at the posterior, by a facial nerve at the superior, by the basal turn of the cochlea at the inferior and finally, by the eustachian tube at the medial side. The direction of the manubrium and the canal where the TT muscle is located are almost parallel to one another. When the muscle departs the canal, it transforms into a tendon and then turns towards the lateral and adheres to the manubrium. The diameter of the bony canal where the TT muscle is located is about 1.5 mm and its length is about 2 mm. When compared to other structures of the middle ear, this numeric value for this muscle is somehow too large. Even though the TT muscle possesses a large body, its tendon is very thin and short. Its function may be withdrawing the MIC internally and externally when a passive contraction movement is conducted and it may also stretch the TM. This condition demonstrates that the TT muscle may act similarly in both the GP and the human. Viewing the tendon of the muscle during dissection can be very difficult because of the significant status of the manubrium. However, after the removal of the inferior wall of bulla via the inferior approach, the tendon of the TT muscle and its adherence site can be openly seen from the medial side (Fig. 4). The length of the stapedius muscle is about 1 mm and therefore it is thinner in comparison to the TT muscle. The pyramidal eminence is located on the bony ridge lying between the round window and the second genu of the facial nerve. After this eminence, the mastoid segment of the facial nerve begins. The stapes muscle that originates from the pyramidal eminence located at the superior of the sinus tympanum extends toward the inferior medial and adheres itself on the neck of the stapes right after surrounding it at the posterior crus. Opposite to the TT muscle, the body of the stapedius muscle is completely located at the outside.

The facial nerve enters the middle ear and then extends alongside the horizontal plan and forms the tympanic segment. The canal of the timpanic segment forms the inferior medial wall of fossa that contains the MIC. This canal extends alongside the horizontal plane located right on the stapes and ends at the superior side of the pyramidal eminence while the facial nerve here makes a second genu and then continues as a mastoid segment. This segment continues at the superior lateral direction and then the facial nerve ends in its temporal bone course. The facial nerve departs from the hole located between the mastoid-like prominence on the tympanic ring and then extends toward the inferior lateral side of the bulla without making any branches. There are no muscles and connective tissues laterally to the nerve except the fascia and the external skin. When the facial nerve arrives to the inferior level of the bulla, then it begins to form terminal branches.

DISCUSSION

The GP's TM apparently resembles the appearance of a human TM.[9] This TM is considerably thin and the middle ear structures can be easily viewed after the removal of the tympanic ring by a lateral approach. In their histological studies, Göksu et al.[3] and Kayhan and Algün[10] reported that a fibrous layer was absent in the TM and that collagen fibrils were scarcely encountered except at adjuvant sections near to the annulus. The said findings explain the reason why a GP's TM is so transparent and sensitive to trauma. Another important difference of the GP's TM, when compared with human's TM, is the absence of pars flaccida. This particular detail is not referred in many other studies,[2,3,11] but may come into view as one of the difficulties in reaching the TM in middle ear when approached by the tympanic route. Instead of the pars flaccida, a bony lamella recognized as STC, which extends in an oblique manner toward the medial from the lateral, is present. The STC is present in rats.[4,5] The TM is located at the medial of the annulus. In their other dissection studies, Göksu et al.[3] mentioned the Tympanic

sulcus. In fact, in our study, we observed that the annulus is seated in the bulla bone. As we have seen, compared with other experimental animal studies, it is easier to achieve the GP's TM by the trans-tympanic route.[4-6,12]

Except for a few details, the middle ear of the GP resembles the human ear. However, there are some differences that can be noticed: the projection of the cochlea in the middle ear, the MIC and the presence of a wide bulla where the hypotympanum and mesotympanum are located. Especially, if a study involves the middle ear or TM, it is recommended to prefer an inferior approach, which can be safer than a lateral approach.[11] Nevertheless, it is very easy to determine the location of the bulla. The bulla can be sensed at the anterior after the palpation of the occipital bony prominence. The bulla is located at approximately 1 cm deep at the lateral side where the skin, subcutaneous tissue and the fascia are present. The mandible can be retracted downwards to facilitate manipulation. Another point that must be considered during an inferior approach is that the bulla wall may become thinner when starting to palpate from the lateral towards the medial.[11] The bulla can notably become thinner at the adjacent section nearby the occipital bony prominence. During the drilling, the inferior medial wall of the bulla may easily fracture if the medial is compulsively pressed and if a low cycle is used. The drilling process must be applied with utmost care and it is important not to exceed a cycle rate over 40.000 cycles per minute to avoid a trauma.

The cochlea, located in the inner ear anatomy in human, should be expressed as a middle ear structure due to the projection in the middle ear in GPs. The status of the cochlea was also reported in other studies.[2,3,10,11] The said anatomical feature may provide an important advantage in the evaluation of the studies especially related with the inner ear. The cochlea resembles its human counterpart when its bony capsule is removed.[9] However, there are different opinions related with the number of turns in the cochlea which may differ from 3.25 to 4.25.[2,3,10,13] In our study the number of turns was found as 3.5.

Right on the top of the basal turn of the cochlea, a round window is present. Unlike in human-beings, this round window lies on a horizontal plane. This plane is perpendicular to the oval window located on the vertical plane. In some studies,[3,13] opinions parallel to the findings in our study can be found; however, Sütbeyaz and Karaşen[11] have stated that both windows are located on the horizontal plane. It was also found that the sinus tympani which is located between the oval and round windows is very large and extends towards the posterior superior side.[3,10,11]

The assessment of the status of MIC formed by the malleus and incus in the GP is also emphasized in other studies.[1-3,10,11,14] In a study, it is stated that the fusion line is made from cartilage.[10,14] Malleo incudal complex is located inside the epitympanum that forms the lateral wall of the STC. The most attractive feature of the MIC is that it has a significant manubrium. When we talk about the stapes, we must also mention the thin bony bridge called crista stapedius that suspends the stapes and extends vertically between the crura of stapes. This structure begins from the inferior niche of the round window and ends at the tympanic segment of facial nerve.[3] In order to view the oval window completely, first of all, this bony bridge must be removed and only then can the stapes be extracted. Its notable mobility is another feature of the stapes that is noticed during the dissection. Together with the crista stapedius, in this study we noticed a transparent ligament which was not mentioned in other dissection studies. This ligament allows the stapes to stand on the oval window.

Consequently, the middle ear anatomy of a GP generally resembles the human ear. In the present study we obtained higher resolution microscopic digital images of the GP's middle ear compared with earlier studies. These images are intended as a guide for researchers who are planning to study GP's middle ear. Also, investigators should have full knowledge of the above mentioned details and the middle ear anatomy and TM of these animals.

REFERENCES

1. Asarch R, Abramson M, Litton WB. Surgical anatomy of the guinea pig ear. Ann Otol Rhinol Laryngol 1975;84:250-5.
2. Sehitoğlu MA, Uneri C, Celikoyar MM, Uneri A. Surgical anatomy of the guinea pig middle ear. Ear Nose Throat J 1990;69:91-7.
3. Goksu N, Haziroglu R, Kemaloglu Y, Karademir N, Bayramoglu I, Akyildiz N. Anatomy of the guinea pig temporal bone. Ann Otol Rhinol Laryngol 1992;101:699-704.
4. Sichel JY, Plotnik M, Cherny L, Sohmer H, Elidan J. Surgical anatomy of the ear of the fat sand rat. J Otolaryngol 1999;28:217-22.
5. Judkins RF, Li H. Surgical anatomy of the rat middle ear. Otolaryngol Head Neck Surg 1997;117:438-47.

6. Browning GC, Granich MS. Surgical anatomy of the temporal bone in the chinchilla. Ann Otol Rhinol Laryngol 1978;87:875-82.
7. Preminger GM, Delvecchio FC, Birnbach JM. Digital image recording: an integral aspect of video endoscopy. Stud Health Technol Inform 1999;62:268-74.
8. Gürel Y, Bilgili A. Laboratuvar hayvanlarının anestezisi. Etlik Vet Mikrob Derg 2001;12:65-74.
9. Bojrab DI, Wiet RJ. Surgical anatomy of the temporal bone through dissection. In Glasscock ME, Shambaugh GE Jr, editors. Surgery of the ear. 4th ed. Philadelphia: W. B. Saunders Co; 1990. p. 579-618.
10. Kayhan FT, Algün Z. A histologic study on the temporal bone of guinea pigs. Kulak Burun Bogaz Ihtis Derg 2003;10:51-7.
11. Sütbeyaz Y, Karaşen M. Guinea pig temporal kemik anatomisi. Kulak Burun Boğaz İhtisas Dergisi 1998; 5:173-7.
12. Adamczyk M, Appleton CM, Parell GJ, Antonelli PJ. Stapedectomy in the guinea pig. Otolaryngol Head Neck Surg 1999;121:581-4.
13. Wysocki J. Topographical anatomy of the guinea pig temporal bone. Hear Res 2005;199:103-10.
14. Amin S, Tucker AS. Joint formation in the middle ear: lessons from the mouse and guinea pig. Dev Dyn 2006;235:1326-33.