THE OSSIFICATION OF THE MIDDLE AND INTERNAL EAR OF THE GOLDEN HAMSTER (Cricetus auratus)

by

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THE OSSIFICATION OF THE MIDDLE AND INTERNAL EAR OF THE GOLDEN HAMSTER (Cricetus auratus)

Introduction

Although the literature on the development and morphological relations of the ear region in mammals is very extensive, there remains much of a very desirable nature to be done on this subject including a clarification of a number of misinterpretations.

Summaries and discussions of the ear region of mammals generally include those of Van Kampen (11), de Beer (5, et passim) and Gaupp (7), the latter concentrating on the processus anterior of the mammalian malleus.

Papers concerned with the ear region of certain mammals only, are those of McClain (12) who outlined the development of the ear in a marsupial (the opossum); Bast and Anson (1, et passim) who compiled a volume on the development and anatomy of the human ear; Ridewood (13) who studied the ear region in developing whale skulls; Cockerell, Miller and Printz (4) who described and compared rodent auditory ossicles with those of Insectivora said to possess a "low type of malleus" similar to that of Marsupials in that the malleus is united to the ectotympanic ring; Jenkinson (9) who was concerned mainly with the cartilaginous development of mouse ear bones; Strong (14) and Johnson (10) who made ossification studies in the rat and mouse respectively; and Doran (6) who, in his investigations on Cricetus frumentarius, concluded that unlike most other rodents, the orbicular apophysis mallei was absent in the Cricetinae.

The ossification study of the early hamster skeleton by Beatty and Hillemann (2) did not include a complete investigation of the ear region. The present paper is restricted to the ossification of the internal, middle and external ear along with associated portions of the hyoid arch of the golden hamster, Cricetus auratus.

Materials and Methods

The 225 animals for this study, obtained from a colony established in the Department of Zoology at Oregon State College, were fed a diet consisting of vegetables, dog biscuits, whole grain, salt licks and water.

The hamsters were mated in the evening sometime between 9 and 12 P. M. and the exact time of mating recorded. The animals were sacrificed at the end of 24 hour intervals following mating, except for a few half-day stages.

The specimens were prepared as outlined by Beatty and Hillemann (2) except for the fact that the specimens were left in the stain for 2 to 6 days and destained in a 0.5% KOH in lieu of acid. A weaker KOH solution was used for the smaller embryos. In addition 6 vascular injection preparations (3 latex, 3 india ink) were prepared along with a dozen dry skulls of various ages.

Observations

Malleus: Ossification

The initial ossification in the malleus occurs on the 15th day

of gestation and lies medial to the upper end of the anterior horn of the U-shaped ectotympanic. The position of this initial ossification in relation to Meckel's cartilage and its perforation by the chorda tympani is very similar to that pictured by Gaupp (7) in the rabbit and seems to be the condition for mammals in general. This ossification becomes a portion of the definitive malleus and is homologous with the prearticular (goniale, post opercular) of reptiles and birds. (Figs. I, II, and III) Goodrich (8, pp.462-466) points out that this perforation of the prearticular by the chorda tympani may be observed in the lower tetrapods. Ridewood (13) mentions that the prearticular arises as a typical membrane bone and that its ossification may spread later to the cartilage of the malleus. Similarly, McClain (12) notes in the opossum that the prearticular fuses with the cartilaginous malleus and that the ossification center in the prearticular spreads to the cartilage of the malleus. Only one ossification center was observed for the malleus (in the prearticular portion) of the hamster. Thus in the hamster also, a cartilage bone (malleus) is ossified by extension from an adjacent membrane bone (prearticular). In man, the malleus is said to ossify from 2 centers (5, p.372).

On the first postnatal day the prearticular ossification has extended anteriorly to the chorda tympani foramen, and then spreads caudad to the cephalic process of the malleus on its way to the head of the malleus. By the third day the head and the entire anterior process which includes the processus cephalicus, lamina and processus gracilis, are nearly completely ossified.

The shapes of the articular surfaces of the malleus and incus are defined on day 3 but a layer of cartilage still separates the incus and malleus. This condition is reminiscent of the thick chondral plates which make up the incudo-malleolar joint of children, as reported by Bast and Anson (1, p.352).

The articular head continues to enlarge and by the fifth day the prearticular portion of the malleus has extended its limits downward medially toward the mid-point of the anterior horn of the ectotympanic.

Ossification spreads slowly in the rest of the malleus until the eighth day when the base of the manubrium (retroarticular process of reptilian articular) is reached. The manubrium is fully ossified by day 11.

On day 9 the prearticular portion of the malleus becomes firmly attached on its medial side in a circumscribed area to an anterior extension of the anterior cochleo-canalicular center of the petrosal. At about 25 - 30 days the prearticular fuses with the medial aspect of the anterior horn of the ectotympanic and adheres to it rather than to the petrosal when the bulla is removed. A similar fusion has been shown by Ridewood (13) for the whale and by McClain (12) for the opossum.

An examination was made also of the skulls of a 23-day white rat (Fig. V) and adult mouse, Mus musculus (Fig. VI-5), and it was found that the mallei of both had a prearticular portion which secondarily united with the ectotympanic as in the golden hamster.

If an attempt is made to remove the malleus from the ear after the fusion of the prearticular portion with the ectotympanic, a break will readily occur at the weak spot where the prearticular is continuous with the anterior process of the malleus (processus cephalicus plus lamina plus processus gracilis), and the prearticular is left adherent to the ectotympanic. This fragility may explain the failure of Doran (6) and Cockerell et al. (4) to picture, in different species of rodents, the prearticular portion of the malleus.

Inspection of a late human foetus in this laboratory disclosed a long anterior process on the malleus as described by Doran (6). No literature was found which mentions whether the anterior process (including the prearticular in human anatomical usage) similarly fuses with the ectotympanic. Thus it remains a question whether this process anterior in man degenerates entirely or only into ligaments at the narrowest point thereby leaving part of the malleus (the prearticular portion) attached to the ectotympanic.

On the eleventh day the processus muscularis is ossified on the lower posterior surface of the cephalic peduncle at about the same level as the processus brevis mallei. In the adult this processus muscularis is hardly discernible presumably due to differential growth of adjacent areas.

Malleus: Anatomy

The definitive hamster malleus bears a rounded head except for a deeply excavated articular surface on its postero-ventral

aspect. (Fig. V) The cephalic peduncle is sturdy and three planes of lamellar bone extend from the anterior surface of the head and peduncle of the malleus and comprise the anterior process of the malleus; these are the processus cephalicus, the lamina and the processus gracilis. The prearticular portion of the malleus originated just distal to the apex of the lamina and in the angle formed by the planes of the processus cephalicus and processus gracilis. The proximal end of the prearticular bears the chorda tympani foramen. This prearticular portion which earlier is attached to the petrosal, later fuses with the medial aspect of the anterior horn of the ectotympanic and usually breaks away from the malleus when the ectotympanic is lifted from the skull. Extending ventrally from the cephalic peduncle is the manubrium. It is dagger-shaped and bimarginate; the medial margin is curved with its convexity facing mediad while the lateral margin is straight and adherent to the tympanic membrane. A thin lamina of bone, concave from an anterior view, lies between these margins. The processus brevis manubrii mallei is very small, and the processus muscularis for the attachment of the tendon of the tensor tympani muscle is found as a small mound on the posterior aspect of the processus brevis. No orbicular apophysis is present on the malleus of the golden hamster; this accords with the findings of Dorland (6) and Cockerell et al. (4) for the Cricetinae in general.

Malleus: Ossiculum accessorium mallei

On day 2, two adjacent dots of ossification appear on both

sides of the animal inside the skull in an area bounded by the antero-ventral surface of the petrosal, the alisphenoid and the ectotympanic. (Figs. II, IV, and V) In some specimens of day 9, these islands have fused and enlarged into a shoe-sole shaped structure; in others the ossiculum accessorium mallei became united to the free posterior margin of the squamosal but in most instances it lay free. By day 14 this structure is considerably enlarged and may assume the shape of a boomerang with the legs directed dorsad. The posterior leg may extend beyond the posterior margin of the squamosal to make a light attachment to the antero-medial surface of the petrosal.

This ossification may be the ossiculum accessorium mallei of van Kampen (11) who regarded it as the representative of the coronoid. Watson (15), Broom (3) and Ridewood (13) suggest that it may represent the supra-angular. Van Kampen states that the ossiculum accessorium mallei may be found between the squamosal, alisphenoid and petrosal, and immediately against the dura mater. A similar position for this ossification in the hamster would identify it as the ossiculum accessorium mallei which, however, in contrast with the sheep (van Kampen 11), does not become in any way associated with the malleus. Ridewood (13) shows that the ossiculum accessorium mallei of the whale Balaenoptera fuses with both the ascial process of the prearticular (goniale) portion of the malleus and the ectotympanic.

Incus: Ossification

The incus, homologue of the reptilian quadrate, begins to ossify on the second or third postnatal day as a small center, which

in relation to the definitive ossicle, lies on a ridge of the head of the cartilaginous incus between the processus brevis and the articular surface. (Fig. II) Ossification spreads slowly until day 7 when it has included the processus longus incudis (stapedial process, crus longus incudis). On this same day the processus brevis incudis (crus breve incudis), which represents the otic process of the palatoquadrate, is also ossified, and points toward the pit in the ossified petrosal to which it is attached by a fine ligament. By day 8 the processus longus (stapedial process) has ossified merely to the head of the stapes and the peduncle of the Sylvian apophysis (lenticular process) is ossified on the eleventh day. Day 12 brings ossification to the apophysis. The incudo-stapedial articular surfaces are completely ossified by day 17 and, as in rodents generally, the articulation between the incus and stapes remains free. The incus in man is said to ossify from 2 centers (de Beer 5, p.372).

Incus: Anatomy

The articular surface of the incus opposite the malleus is extensive; the processus brevis is very short but massive with a small spicule of bone at its apex. The processus longus (stapedial process) is of moderate length and bears a wide but thin peduncle in continuity with an oblong Sylvian apophysis bearing a flat articular surface resting against the head of the stapes. (Figs. V and VII)

Stapes: Ossification

The stapes, homologous in part with the hyomandibula of fishes, and with the otostapes of the sauropsid columella, initiates

its ossification on day 5 in 3 centers, one in the foot plate and one each in the crura. (Fig. III) This contrasts with the statement in de Beer (5, p.372) for the stapes of man which ossifies from the two crural centers and with the contradictory claim of Bast and Anson (1, p.349) for man in whom the stapes is said to ossify from one center in the footplate. By day 6 the stapedial centers in the hamster have coalesced and on day 9 the crural centers have united inter se on the underside of the neck. On day 11, ossification has proceeded up from the base of the neck. The anteroventral crus is more sturdy in comparison with its postero-dorsal mate. No bony canal is laid down between the crura for the stapedial (facial) branch of the internal carotid artery. By day 17, the head of the stapes is completely ossified.

No evidence of either Paauw's cartilage (representing the hyostapes) or the os quartum (an ossification in Paauw's cartilage) was found in the tendon of the stapedial muscle. Spence's cartilage, above the chorda tympani and between the stapes and hyoid cornu, was noted.

Stapes: Anatomy

The completed stapes is a light structure of little substance since the crura are thin-walled incomplete cylinders with their open sides facing the intercrural aperture. Unlike that of man, the antero-ventral stapedial crus of the hamster is usually arched. The neck of the stapes is short and the stapedial head is a flat oval. A stapedial process arises from the stapedial neck near its juncture

with the postero-dorsal crus and serves for the insertion of the stapedius muscle which extends postero-dorsally to its origin on the petrosal. The transverse base has a convexity facing the fenestra ovalis (fenestra vestibule); its margin is thin and elliptical. (Figs. V, VI, and VII)

Ectotympanic: Ossification and Derivatives

The ectotympanic, a membrane bone homologous with the angular of the lower jaw of reptiles, begins to ossify on day 15 (prenatal) in the form of a horse-shoe open dorso-laterally. (Figs. I, II, and III) On day 2 (postnatal) ossification has extended the arms and the dorsal end of the anterior member then lies at a level slightly dorsal to that of the upper limits of the prearticular. By the fifth day the dorsal end of the anterior ectotympanic limb has expanded into a plane just lateral to the head of the malleus. At this stage the ectotympanic has assumed the form of a truncated cone whose larger aperture faces the lower region of the internal ear.

By the end of the seventh day the posterior horn has extended obliquely antero-dorsally to reach a point immediately lateral to the postero-dorsal crus of the stapes. On day 8 this horn has extended beyond the stapes to lie lateral to the processus longus incudis (stapedial process).

On the ventro-medial edge of the truncated cone, a narrow strip ossifies dorso-medially toward the lower limits of the cochlea and represents the beginning formation of the tympanic bulla. (Fig. VI-1) The bulla has extended its association with the ectotympanic

nearly to the dorsal ends of its limbs. By day 11 the bulla has been elaborated nearly to the internal ear capsule and on day 12 it reaches the internal ear postero-dorsally. On day 14 the antero-dorsal portion of the bulla completes the ventro-lateral wall of the cranium between the alisphenoid in front, the petrosal behind and dorsally, and the basisphenoid medially. The bony Eustachian tube is circumscribed as a notch in the bulla at its antero-ventral margin just dorso-lateral to the hamulus of the pterygoid and ventral to the postero-lateral corner of the basisphenoid. It remains an incomplete foramen after day 13.

Another notch is formed (carotid canal) in the bulla on its medial border where it contacts the base of the petrosal. The stapedial (facial) artery enters here (Fig. VI-1 and 2), and passes forward within the middle ear cavity ventral to the stylo-mastoid foramen. It continues through a bony canal elevated on the posterior bank of the fenestra ovalis and then passes between the crura (inter-crural aperture). There is no intercrural bony canal as in many other rodents such as Spermophilus. From the crura the artery travels medially to the incus and exits through the anterior wall of the petrosal to continue forward as the sphenopalatine artery.

Day 10 marks a lateral extension of ossification from the original ectotympanic horse-shoe to form the beginning of the bony external auditory meatus. (Fig. VI-1) At this time a difference in texture can be seen between that of the bulla and that of the bony ectotympanic anlage, which is laid down in curved parallel

spicules while that of the bulla appears diffusely granular.

On day 15 a notch is generally found at the low point on the edge of the external auditory meatus. In some later specimens a complete foramen is found in the hamster as in guinea pigs; but the foramen is rare in adult hamsters.

On the inner or medial surface of the bulla there extends on day 11 a low curved ridge of membrane bone along the course of the lower or medial edge of the original ectotympanic. This becomes the annulus tympanicus (Fig. VI-1) for the support of the tympanic membrane and is complete on day 21. Thus in the hamster the entire bulla is of membrane bone elaborated as an extension medially from the ectotympanic anlage and does not arise from an endotympanic cartilage bone (metatympanic), not identified in the hamster. Both the annulus tympanicus and the bony shell surrounding the external auditory meatus also arise as membrane bone extensions from this same rudiment.

Internal ear: Ossification

On prenatal day 14 there appear 2 small calcareous deposits, one dorsal to the other. These are the beginnings of the 2 otoconia (otoliths), 1 of which belongs to the macula of the utriculus, the other to the macula of the sacculus. (Figs. I and II)

The first ossification centers appear on day 2. One center, the posterior cochlear, is medial and posterior to the posterior horn of the ectotympanic. Another center, the posterior canalicular, appears in the petrosal medial to the posterior cochlear center. The

The third center, the anterior cochleo-canalicular, appears anterior to the utricular and saccular otoliths.

By day 3 the posterior cochlear center has expanded and joined with the anterior cochleo-canalicular center. The anterior cochleo-canalicular center has sent down a process (prefacial commissure) over the antero-medial border of a 4th center, the medial cochlear center of the cartilagenous cochlea. The medial cochlear center unites with the posterior canalicular center.

On day 4 a fifth center, the anterior cochlear, appears on the anterior aspect of the cochlea. The anterior and posterior cochlear centers have each formed a fraction of a hemisphere in their respective areas and have nearly joined, but the posterior cochlear center is the larger of the two. The process (prefacial commissure) being sent down by the anterior cochleo-canalicular center has reached the anterior portion of the posterior cochlear center on its medial surface. The internal aperture of the facial canal is seen just lateral to this commissure and the internal acoustic meatus lies postero-ventral to the internal facial canal. Ossification has proceeded in such a manner that the anterior cochleo-canalicular and posterior canalicular centers are also fused with the posterior cochlear center. The anterior cochleo-canalicular center has extended laterally and is ossifying around the horizontal (lateral) semi-circular canal.

On day 5 the anterior cochleo-canalicular and posterior cochlear centers have so united on the lateral aspect of the petrosal that the fenestra ovalis which accommodates the stapedial footplate

is outlined except for a notch at the extreme postero-dorsal region. The posterior cochlear center has expanded and united with the posterior canalicular center and the stylomastoid foramen is completely outlined posterior to the fenestra ovalis. This posterior cochlear center lies on the postero-medial surface of the cochlea lateral to the lateral wing of the basi-occipital and anterior to the anterior process of the exoccipital. The bony labyrinth of the cochlea has so progressed that the enclosed spiral can be clearly seen.

By day 8 the ossification is progressing upwards from the anterior cochleo-canalicular and posterior canalicular centers toward the anterior semi-circular canal. Two new centers have arisen; one lies on the lateral aspect of the posterior canal, and is the lateral center of the posterior semi-circular canal. The other center lies on the outer surface of the lateral semi-circular canal and is the intermediate center of the horizontal canal.

By day 9 these 2 centers have united with the lateral center of the posterior semi-circular canal. On day 10 the mastoid process of the petrosal is beginning to form from the posterior canalicular center just above the stylomastoid foramen. On day 11 the ossification is completed around the anterior and posterior semi-circular canals. On the medial aspect of the petrosal and ventral to the anterior semi-circular canal is seen the para-floccular fossa. (Fig. VII-right) There is an extension of the petrosal just ventral to the middle region of the lateral semi-circular canal which unites with the flat surface of the uppermost end of the posterior horn of the

ectotympanic and forms the styloid process in part. The ossification of the petrosal is complete except for a portion of the lateral wall in the region of the semi-circular canals. This area of the skull is being walled over by extensions of ossification from the anterior cochleo-canalicular center anterior to the posterior canalicular center, from the intermediate center of the horizontal canal and from the lateral center of the posterior semi-circular canal.

By day 12 the walling over is almost complete in the lateral area of the petrosal and by day 15 the side wall of the cranium in this region is complete.

Hyoid arch elements associated with the ear

The tympanohyal begins to ossify on day 12 as a horizontal bar which lies immediately above the dorsal end of the posterior horn of the ectotympanic. It lies in Spence's cartilage extending from the stapes to the hyoid cornu. On day 15 the tympanohyal fuses with a styloid process from the lateral center of the lateral semi-circular canal to form the definitive styloid process extending horizontally caudad as a ventral border to the stylomastoid foramen. Thus the definitive styloid process is compounded of the tympanohyal and an extension of the petrosal and does not involve the stylohyal. Also on day 12 the stylohyal begins to ossify in several fragments in Spence's cartilage immediately behind the upper end of the posterior horn of the ectotympanic. In the adult the stylohyal fragments are tied by connective tissue to the posterior surface of the bulla.

Table 1 records the earliest observed ossification in the ear and associated structures.

Table 1.

First Appearance of Ossification Centers

in the Golden Hamster

CENTERS and events	AGE IN DAYS Prenatal	Postnatal
I. MALLEUS and associated structures		
Articular surface of head of malleus		3
Lamina		5
Processus gracilis		5
Manubrium		9
Processus muscularis		11
Processus brevis manubrii mallei		11
Prearticular portion of malleus with chorda tympani foramen	15	
Ossiculum accessorium mallei		2
II. INCUS		
Dorsal end		2
Processus longus incudis		5
Processus brevis incudis		7
Sylvian apophysis		11
Peduncle		11
III. STAPES		
2 crural centers and 1 footplate center		5
Head of stapes ossified		8
Margin of footplate outlined		8

IV. ECTOTYMPANIC and associated Stylohyal

	AGE IN DAYS	
	Prenatal	Postnatal
Ectotympanic anlage	14	
Bulla formation		8
Eustachian foramen		12
Carotid canal		12
Facial canal		12
External auditory meatus		10
Annulus tympanicus		11
Stylohyal		12

V. PETROSAL and associated Tympanohyal

Utricular otolith (calcified)	14	
Saccular otolith (calcified)	14	
Posterior cochlear center		2
Posterior canalicular center		2
Anterior cochleo-canalicular center		2
Prefacial commissure		3
Medial cochlear center		3
Anterior cochlear center		4
Facial canal outlined		4
Internal acoustic meatus outlined		4
Fenestra ovalis incompletely outlined		5
Stylomastoid foramen completely outlined		5
Lateral center of the posterior semicircular canal		8
Intermediate center of the horizontal semicircular canal		8
Basic mastoid process		10
Paraflocculer fossa outlined		11
Tympanohyal		12

Summary

1. Two hundred and twenty-five skeletons of the golden hamster (Cricetus auratus) varying in age from day 13 prenatal to the adult were prepared for a study of the ossifications in the ear

and associated portions of the hyoid arch.

2. The malleus ossifies from 1 center, the prearticular homologue, by means of which it becomes united to the medial aspect of the anterior horn of the ectotympanic. The malleus of rodents was found to be more extensive than previously reported. The ossiculum accessorium mallei was found but the obicular apophysis was absent.

3. The incus appeared in one center and the stapes in three.

4. The ectotympanic bony anlage gave rise by extensions to the annulus tympanicus, the bony external auditory meatus and the tympanic bulla bearing the carotid canal and Eustachian tube in the form of grooves adjacent to the petrosal. No evidence of an endochondral endotympanic (metatympanic) was found. The stylohyal, developed in Spence's cartilage, became attached to the posterior wall of the bulla.

5. The first indications of the petrosal arose in the form of the calcareous utricular and saccular macular otoliths (otoconia). The petrosal proper was formed from 7 separate centers which in turn defined the parafloccular fossa, prefacial commissure, basic mastoid process, internal auditory meatus and several foramina. The tympanohyal fused to the basic mastoid process of the petrosal to form the definitive mastoid process.

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APPENDIX

KEY TO ABBREVIATIONS

Figs. I and II

a - alisphenoid
c - anterior cochleo-canalicular center
e - ectotympanic
f - chorda tympani foramen
h - posterior cochlear center
i - incus
n - posterior canalicular center
o - ossiculum accessorium mallei
p - prearticular
s - saccular otolith
u - utricular otolith

Fig. III

e - ectotympanic (reflected laterally and ventrally)
f - chorda tympani foramen
h - head of malleus
i - internal ear or petrosal
p - prearticular
s - squamosal

Fig. IV

b - basisphenoid
o - ossiculum accessorium mallei
p - petrosal
s - squamosal

Fig. V - Row 1

a - articular surface
b - processus brevis manubrii mallei
c - processus cephalicus
d - peduncle of malleus
f - chorda tympani foramen
g - processus gracilis
h - head of malleus
l - lamina
m - manubrium
p - prearticular portion of malleus

Rows 2 and 3

a - sylvian apophysis of incus
b - processus brevis incudis
c - crus of stapes
f - footplate of stapes
h - head of stapes
l - processus longus incudis
p - peduncle of incus

Row 4

Malleus - same as row 1
Incus - same as row 2

Fig. VI

a - annulus tympanicus
b - bulla
c - carotid canal
d - facial or stapedial canal
e - Eustachian canal
f - stylomastoid foramen
g - corda tympani foramen
h - head of malleus
i - incus
k - cochlea
l - parafloccular fossa
m - manubrium
n - external auditory meatus
o - anterior semicircular canal
p - prearticular with chorda tympani foramen
q - stapedial or facial artery
s - stapes
t - prefacial commissure
v - internal acoustic meatus
x - petrosal

EXPLANATION OF FIGURES

Fig. I. Lateral view of left side of ear region showing early centers of ossification. Day 15 prenatal. 27 X.

Fig. II. Lateral view of right side of ear region showing additional centers of ossification. Note particularly the anlage of the ossiculum accessorium mallei behind the alisphenoid. Day 2½ postnatal. 31 X.

Fig. III. Lateral view of left side of petrosal area with ectotympanic turned down to reveal the prearticular, the 3 centers of the stapes in the fenestra ovalis and the petrosal. Day 5 postnatal. 18.8 X.

Fig. IV. View into skull from above showing the ossiculum accessorium mallei lying medial to the squamosal. Day 14 postnatal. 71 X.

Fig. V. Row 1 (unstained): medial aspect of right and left malleus with prearticular portion attached and bearing the foramen for the chorda tympani. Day 25 postnatal. Row 1 (alizarin stained): medial aspect of right malleus for comparison, and lateral aspect of left malleus of rat to show the orbicular apophysis, processus cephalicus, lamina, processus gracilis, peduncle, head, manubrium, processus brevis and prearticular portion. Day 23 postnatal. Row 2: several views of the definitive incus; except extreme right, the boomerang-shaped ossiculum accessorium mallei removed from skull of day 18 postnatal hamster. Row 3: several views of the definitive stapes. Row 4: medial aspect of right malleus and incus showing incudo-

malleolar articulation and anterior process and with prearticular portion of malleus broken off. Adult. (Cockerell et al. 4) 7.2 X.

Fig. VI. (1) Medial aspect of right ectotympanic showing the carotid canal (groove), Eustachian tube (groove), bulla, annulus tympanicus, external auditory meatus and malleus fused to anterior horn of ectotympanic via the prearticular portion. Note chorda tympani foramen. Adult. (2) Left lateral view of petrosal with stapedial (facial) artery injected with latex and passing through the bony facial canal and intercrural aperture. Adult. (3) Right lateral view of petrosal with malleus, incus and stapes in place (some shrinkage distortion). Adult. (4) Right lateral view of petrosal, latex injected. Adult. (5) Medial aspect of left ectotympanic of a mouse (Mus musculus) bearing the malleus fused to the anterior horn of the ectotympanic via the prearticular portion. Note the foramen for the chorda tympani in the prearticular. Alizarin stain. Adult. 8 X.

Fig. VII. Left: right lateral view of petrosal with stylomastoid foramen, facial canal, stapes in fenestra ovalis, sylvian apophysis of incus in contact with head of stapes, and crus breve incudis attached to petrosal, and cochlea. Adult. Right: medial aspect of left petrosal showing anterior semi-circular canal, paraflocculer fossa, facial commissure, and internal acoustic meatus. Adult. 8 X.

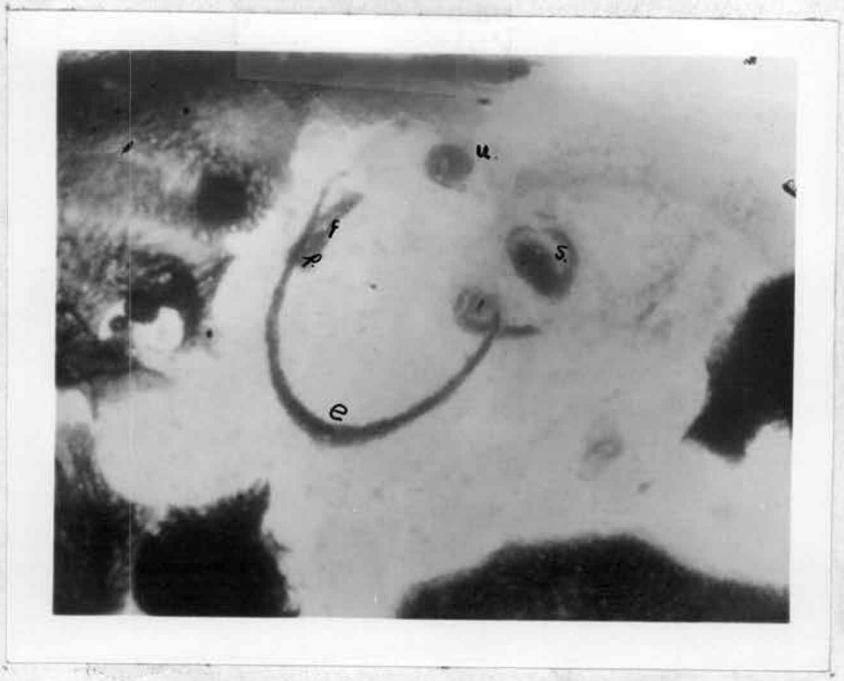

Fig. 1

Fig. 2

Fig. 3

Fig. 4

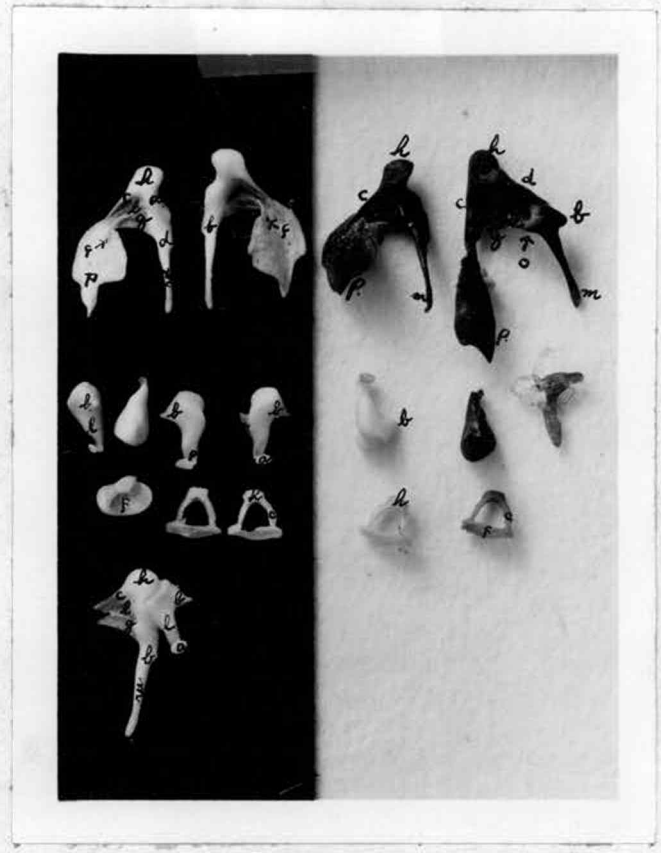

Fig. 5

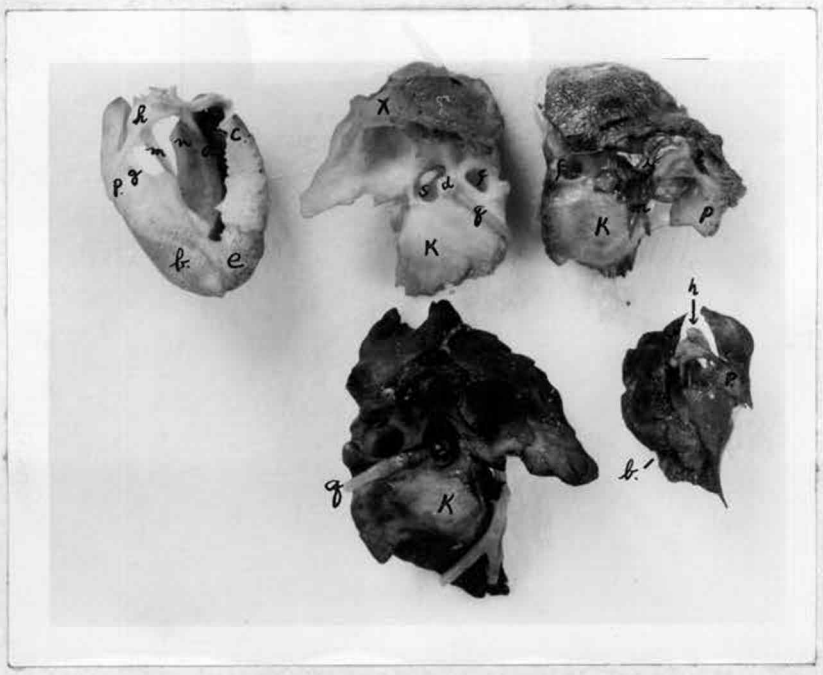

Fig. 6

Fig. 7