XI. *The Physiology of the Stapes, one of the Bones of the Organ of Hearing; deduced from a comparative View of its Structure, and Uses, in different Animals.* By Anthony Carlisle, *Esq. F. R. S.*

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Anatomical descriptions of the mechanism of the eye have importantly contributed to the advancement of optics, a branch of science which has conferred numerous benefits on mankind. Whether a more intimate knowledge of the structure of the organs of hearing may illustrate the doctrines of acoustics, and thus become a source of similar advantages, can only be determined by future investigations, and experiments. The following is an attempt to exhibit a part of the instrument of hearing, taken from several orders of animals, with an intention to shew the office it holds, and the relation it bears to other parts of the auditory mechanism. The minuteness of this research will not require any apology to that learned Body, who for a long series of years have witnessed the dependance of all the systems of natural knowledge on simple particulars, well chosen, and applied to the establishment of general laws.

Doubtless the whole organ of hearing is an apparatus to collect occurring sounds, and to convey them to the seat of that peculiar sensation, regulating their intensity, or facilitating their progress, according to the degree of impetus. In these respects the ear resembles the eye.

The ossicula auditûs in man, and in the mammalia, form a series of conductors, through which sounds are transmitted, from the membrana tympani, into the sensitive parts of the organ. The number, forms, and relative junctions of these ossicles are various; but, in all cases, their office seems limited to the conveyance of sounds received through the medium of air; because fishes have no parts corresponding with them. In two classes of animals, the aves, and amphibia, of LINNÆUS, one bone, in the situation of the stapes, is the only ossicle of the tympanum: in all other animals it is placed next to the seat of sensible impression, and most remote from that part of the organ on which sounds first impinge.

The ossicula auditûs are formed of bone, resembling that of teeth; it is close in texture, and brittle: in the growing state, composed of a vascular pulp, the ossification of which is completed soon after birth; and, like the teeth, they cease to grow after that process is finished. The malleus and incus are hollow, and possess an internal periosteum; and the whole series is covered by a reticular membrane which has no red blood-vessels in the adult. It has been asserted by many authors that fat, or marrow, is contained in these bones, but I am induced to attribute their occasional greasy appearance to transudation from the neighbouring parts, during the stage of putrefactive maceration, seeing that all such bones when taken from recent subjects, are free from the marks of fat. Although density seems to be a requisite condition, yet it is convenient that the bones should not be massive, as their figures and relative adaptations evidently show.

The malleus is united to the membrana tympani throughout half its long diameter, by a process called manubrium; its

detached end forms a rounded enlargement, which is articulated by a sort of hinge joint to the body of the incus. Three muscles are fixed to the malleus, the most powerful of which draws the manubrium, and membrana tympani perpendicularly inward; the next in strength is inserted upon a slender stem of bone which forms a right angle with the manubrium, and on the plane of the membrana tympani. The smallest muscle is fixed to the processus major, pulling the malleus backward, and pressing its head against the joint of the incus. These muscles are all restricted in their actions to the changes produceable on the membrana tympani, because the strong connections of the joints between the malleus and incus, and the incus and stapes, admit of little motion; indeed the former joint is deficient in many animals. The incus has no muscles, and forms only a passive intervention between the malleus and stapes, which last bone has a peculiar muscle appropriated to itself. Hence it appears, that the first series of ossicula auditûs has a different office from the stapes, as will be subsequently explained.

The bone, to be now particularly considered, has been called stapes, staffa, stapha, or stapeda, from its resemblance to the stirrup of a saddle. It was first observed about the middle of the sixteenth century; and PHILIP AB INGRASSIAS, REALDUS COLUMBUS, and BARTHOLOMÆUS EUSTACHIUS, have contested the honour of its discovery.

The human stapes is $\frac{6}{40}$ of an inch in height, and $\frac{5}{40}$ in width at its basis: it weighs, when dried, $\frac{1}{32}$ of a grain.

It is divided into the following parts, *viz.*

The capitulum, or articulating head, which joins the os lenticulare.

The collum, which unites the capitulum to the two crura. And

The basis, on which the expanded crura rest and terminate.

The capitulum stapedis has a shallow, concave surface, to receive the os lenticulare, or epiphysis connected to the long leg of the incus. (*Vide* Plate IV. letter *c.*) Around this joint a strong membrane is applied in the manner of a capsular ligament. The capitulum is seldom placed exactly on the top of the Gothic arch formed by the crura, and the crus immediately under the stapedeus muscle, is always the thickest, and most curved. (*Vide* letter *a.*)

The collum is hollow, being only a thin shell of bone; on its side is a small tubercle, to which the tendon of the stapedeus muscle is affixed. See letters *a* and *b.*

The crura are curved, and their interior surfaces are grooved, leaving only a thin osseus plate.

The basis is exactly adapted to the the fenestra ovalis, more properly called fenestra vestibuli by modern anatomists, and the two ends project beyond the crura. The upper surface is generally concave, the under surface slightly convex; and here a rising border marks the insertion of the membrane which connects it to the edges of the fenestra vestibuli. *Vide* letter *c.* The outline of the basis somewhat resembles a long semi-ellipsis, one side being nearly straight, and the other convex. This figure appears adapted to the expansion of the basis, without increasing the bulk of the bone, whilst it gives leverage to the muscle.

When the stapes rests on its basis, with the straight side next to the observer, if the more curved leg be toward the left, then it is the stapes of the right ear; but if on the right,

then it is the left stapes. The arch above the straight side of the basis is more rounded than that above the curved side; the latter being an intersection of two curves like the Gothic arch. I have never seen that expansion of membrane across this arch, described by DU VERNEY; and, from the great number of ears which I have attentively examined, am induced to think that a pellicle of mucilaginous fluid, which often covers the recent bone, has been mistaken for a membrane.

The stapes stands perpendicular to the plane of the membrana tympani; a plane drawn through the crura, parallel to the length of the basis, equally bisects the cavity of the tympanum.

The stapedeus muscle arises within a special cavity in the petrous portion of the temporal bone; it is a short, thick mass of red fibres, covered by fascia; and sends forth a round tendon through a small osseous aperture at the point of the pyramidal eminence, which unites to the collum stapedis in an angle of 50 degrees, toward a line drawn perpendicular to the plane of the basis, and obliquely across its convex side, in an angle of 5 degrees from the bearing of its straight side. The action of the stapedeus muscle is to draw the capitulum downward, and toward the curved side of the basis. This oblique motion depresses the end of the basis under the curved crus, whilst it rotates the incus upon its short leg, and presses its articulation with the malleus into closer contact: but the stapes is not withdrawn from under the long leg of the incus, being prevented by the strong connecting ligaments.

The smaller angle of the tendon crossing the parallel of the crura over the convex side of the basis, necessarily depresses that edge, the straight side acting as a hinge. The externus

muscle of the malleus rotates the incus back again, and restores it to its passive perpendicular situation; becoming on such occasions the antagonist of the stapedeus. It is worthy of remark, that all the muscles of the ossicula auditûs act nearly at right angles, or in straight lines, contrary to the ordinary course of muscular application, by which their forces are comparatively augmented.

The varieties in the human stapes are few: they appear in the relative curvature of the crura, and in the degree of slenderness or symmetry of its general form.

The fenestra vestibuli admits the basis of the stapes to pass into the vestibulum, when the connecting membrane is destroyed, there being no other obstacle to its descent.

None of the external similitudes in form, nor any correspondence in the habits, or voices of animals, appear to govern the configuration of these ossicles, except in those mammalia inhabiting the waters, such as the seal, walrus, and whale tribes,* where the stapes is always more massive: but in the otter, which only dives occasionally, the stapes does not vary from that of the fox. In the tiger, dog, and other feræ, the crura are straight, meeting in an acute angle; but the same figure occurs in the horse, beaver, goat, and many more herbivorous quadrupeds; so that no inference can be drawn from these different habits of life.

In the cete, exemplified in the Plate by the porpoise, whose organs of hearing precisely resemble those of whales which I have seen, and agree with the descriptions of others by Professor CAMPER, the muscle of the stapes pulls the capitulum at an angle of 45 degrees, with the plane of the basis, so as

* I have not had an opportunity of examining the ossicles of a hippopotamus.

remarkably to depress its subjacent end into the fenestra vestibuli; besides the thickness of the basis, and its exact adaptation to the fenestra, exhibit a joint of considerable motion. In those animals there is only a small perforation, instead of the crural arch. *Vide* letter *n*.*

I have discovered a very remarkable singularity, in tracing the comparison of this bone, in the marmot, and Guinea-pig. The stapes in these animals is formed with slender crura, constituting a rounded arch, through which an osseus bolt passes, so as to rivet it to its situation. This bolt I have named *pessulus*. *Vide* letter *l*. It is placed near the top of the arch, so that by the action of the stapedeus muscle the upper part of the straight crus is brought into contact with the *pessulus;* and by this means the depression of the basis is limited. It does not seem obvious for what further end this provision is designed, because, excepting the shrill whistle, there is nothing peculiarly different in the habits of those animals from others which are destitute of such mechanism.

The kanguroo has this bone like the corresponding ossicle in birds, called Columella; but it has also the malleus and incus, which birds have not.

In the ornithorhynchus paradoxus, and ornithorhynchus hystrix, the resemblance to the columella is still more striking; and forms an additional point of similarity between these strange quadrupeds and birds. Their columellæ are not, how-

* The stapes of the seal has solid rounded crura, and a small aperture; that of the walrus is entirely solid, and the edges as well as the plane of the sides, are a little twisted, agreeing with the observation of M. CUVIER, *Leçons d'Anatomie comparée*, Tome II. p. 505. In all these aquatic mammalia the fenestra rotunda, called also fenestra cochleæ, is large, being three or four diameters more than in other animals of similar bulk.

ever, articulated to a cartilage, as in birds; but to a small bone performing the office of the manubrium of the malleus.

In birds, a slender bone passes to the fenestra vestibuli, from a cartilage fixed to the membrana tympani: it is called columella, having received that name from JULIUS CASSERIUS.

The capitulum of the columella in birds is slightly expanded, and is joined to an obtuse-angled triangular plate of cartilage, which I have called cartilago columellæ, *(vide* letter *t,)* the longest side of the triangle is attached to the membrana tympani. In some species of birds a small foramen occurs in the middle of this plate, but in many others it is entire.

A strong muscle is inserted into the shorter angle of the cartilage, which draws it downward, and thus elevates the opposite angle in the center of the membrana tympani, so as to render it conical externally. Two lateral ligaments steady the articulation of the cartilage with the head of the columella.

The columellæ in birds are less brittle than the ossicula auditûs in the mammalia; their bases are exactly fitted to the fenestra vestibuli; and that part of those columellæ nearest the base is generally of a reticulated texture.

The amphibia are provided with columellæ, in their form and adaptations resembling those of birds: the cartilage is here, however, united to the under surface of the true skin, without any apparent application of muscles to alter its tension. The substance of the columella is even less hard than in birds; and its basis is considerably smaller than the fenestra vestibuli. The cavity of the tympanum has no lateral cells, and the Eustachian tube is short, and wide, seemingly for the purpose of receiving sounds conveyed through the medium of air.

From the evidence of these facts, together with the com-

parative view exhibited in the Plate, I am led to the following conclusions. In man, and the most numerous orders of the mammalia, the figure of the stapes is an accommodation to that degree of lightness which, throughout the series of ossicles, seems a requisite condition. It is also a conductor of vibrations in common with the other ossicles: but most especially it is designed to press on the fluid contained in the labyrinth by that action which it receives from the stapedeus muscle, and the hinge-like connection of the straight side of its basis with the fenestra vestibuli; the ultimate effect of which is an increase of the tension of the membrane closing the fenestra cochleæ.

It does not appear that any degree of motion ever subsists between the ossicula auditûs as wholes, which bears any relation to the peculiar vibrations of sounds; but rather that the different motions of these bones only affect the membrana tympani, and alter the degrees of contact in their articulations, so as to influence the intensity of violent impulses; sounds of less impetus, not requiring such modulation, are transmitted through the conducting series by the vibrations of the integrant parts of these bones, unaccompanied by muscular action.

This reasoning is suggested by the columellæ in the aves and amphibia: and as many birds are known to imitate a variety of artificial sounds with great accuracy, it may be inferred that they hear such sounds as acutely, and with the same distinctness as mankind.

It seems that all the muscles of the ossicula auditûs are of the involuntary kind, and the peculiar stimulus to their action is sound. The chorda tympani, which supplies them, is a gangliated nerve: if this supposition be true, then the muscles should be considered as all acting together, and it is well

known that persons who hear imperfectly are more sensible to sounds in a noisy place, as if the muscles were by that means awakened to action.

The office which the basis of the stapes holds, and which the stapedeus muscle is especially destined to perform, seems to throw considerable light on the use of the cochlea. It cannot be allowed that the pressure of the watery fluid in the labyrinth is a requisite condition to produce the sensation of hearing, since all birds hear without any mechanism for that purpose, but as such pressure must ultimately give increased tension to the fenestra cochleæ, it follows that we inquire at this part for the principal use of the stapes.

As the membrane of the fenestra cochleæ is exposed to the air contained within the cavity of the tympanum, it appears adapted to receive such sounds as pass through the membrana tympani, without exciting consonant motions in the series of ossicula auditûs.

Experiment.

My head being laid on a table, with the meatus auditorius externus perpendicular to the horizon, my friend, Mr. WILLIAM NICHOLSON, pulled the tragus toward the cheek, and dropped from a small vial, water, at the temperature of my body, into the meatus. The first drop produced a sensation like the report of distant cannon, and the same effect succeeded each following drop, until the cavity was filled.

In this experiment the vibrations of the membrana tympani must have been impaired, if not wholly destroyed, by the contact and pressure of the water; yet the motions of the whole membrane, from the blow of each drop of water, affected

the air contained in the tympanum sufficiently to produce a sensible impression.

That something like this occurs in many kinds of sounds is more than probable; and as the cochlea consists of two hollow half cones, winding spirally, and uniting at their apices, it follows that the sounds affecting either the cone terminating in the vestibulum, or that which forms the fenestra cochleæ, must each pass from the wide to the narrow end; and the tension of the parts, in either case, will necessarily aid the impression.

I have already trespassed beyond the usual limits, and must reserve the more ample details of this subject for a work expressly directed to the anatomy and physiology of the organs of hearing.

EXPLANATION OF PLATE IV.

a, The left* stapes of a human ear magnified two diameters; presenting the curved edge of the basis, and the more elevated and pointed arch.

b, The opposite side of the same stapes, shewing its rounded arch.

c, Two figures, the uppermost being the articulating surface of the capitulum, and the one beneath shewing the under surface of the basis, of the same stapes.

d, Stapes of a hedge-hog, (*Erinaceus Europæus*,) magnified four diameters.

e, Stapes of a mole, (*Talpa Europæa*,) magnified six times.

f, Stapes of the musk ox, (*Bos moschatus*,) twice magnified.

* The other stapedes are all from the right ears.

g, Stapes of the elephant, (*Elephas maximus*,) natural size.

h, Stapes of the tiger, (*Felis Tigris*,) twice magnified.

i, Stapes of the dog, (*Canis familiaris*,) three times magnified.

j, Stapes of the horse, (*Equus Caballus*,) twice magnified.

k, Stapes of the pig, (*Sus Scrofa*,) three times magnified.

l, Stapes of the marmot (*Arctomys Marmota*) with its pessulus, magnified four times.

m, Stapes of the seal, (*Phoca vitulina*,) twice magnified.

n, Stapes of the porpoise, (*Delphinus Phocæna*,) twice magnified.

o, Stapes of the walrus, (*Trichechus rosmarus*,) natural size.

p, Stapes of the kanguroo, (*Macropus Kanguroo*,) four times magnified.

q, View of the under surface of its basis.

s, Columella of the duck-bill, (*Ornithorhynchus paradoxus*,) magnified four times.

r, Basis of the same columella.

t, Columella and cartilago columellæ of a goose, (*Anas Anser*,) twice magnified.

u, Columella of the Egyptian ibis, (*Tantalus Ibis*,) taken from a mummy, three times magnified.

v, Columella of a turtle, (*Testudo Midas*,) natural size, with its cartilage.

w, Columella of the Gangetic crocodile, (*Lacerta Gangetica*,) natural size.

x, Columella of a turtle, (*Testudo coriacea*,) natural size.

y, Columella and cartilage of a frog, (*Rana temporaria*,) twice magnified.

z, Columella of a toad, (*Rana Bufo*,) twice magnified.

The third and last lines of objects in the Plate, exhibit the outlines, and under surfaces, of the bases of the stapedes, and columellæ, immediately above. In some, the surface is convex, in others concave, but neither the one nor the other are constant attendants on any common affinity.

STAPEDES and COLUMELLÆ compared.