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# THE SURGICAL DISEASES

OF

# THE EAR.

BY

PROF. VON TRÖLTSCH.

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THE

# MECHANISM OF THE OSSICLES

AND

# THE MEMBRANA TYMPANI.

BY

PROF. HELMHOLTZ.

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TRANSLATED FROM THE GERMAN

BY

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## THE MECHANISM OF THE OSSICLES AND THE MEMBRANA TYMPANI.

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THE

# EXTERNAL EAR AND ITS DISEASES.

## CHAPTER I.

### THE ANATOMY OF THE EXTERNAL EAR.

1. The *external ear*, consisting of the auricle, the external meatus, and the membrana tympani, presents in this combination of its parts a slightly curved funnel, the widest part of which is formed by the

Carl Jos. Beck, "Die Krankheiten des Gehörorgans," ein 'Handbuche zum Gebranche seiner Vorlesungen,' Heidelburg and Leipzig, 1827. Linke, 'Sammlung auserlesener Abhaudlungen und Beobachtungen aus dem Gebirte der Ohrenheilkunde,' 5 Heft, Leipzig, 1836—41. Linke, 'Handbuch der Theoretischen und Praktischen Ohrenheilkunde,' Leipzig, 1837—45. Itard, 'Traité des Maladies de l'Oreille et de l'Audition,' 2nd edition, 2 vols., Paris, 1842. Martell Frank, "Practische Auleitung zur Erkenntniss und Behandlung der Ohrenkrankheiten," ein 'Handbuch der Pract. Ohrenheilkunde,' Erlangen, 1845. Wilh. Kramer, 'Die Erkenntniss und Heilung der Ohrenkrankheiten,' 2nd edition, Berlin, 1849. Will. Wilde, 'Practical Observations on Aural Surgery and the Nature and Treatment of Diseases of the Ear,' London, 1853; German translation by Dr. v. Haselberg, Göttingen, 1855. Wilh. Rau, 'Lerhbuch der Ohrenheilkunde für Aerzte und Studirende,' Berlin, 1856. Toynbee, 'A Descriptive Catalogue of Preparations illustrative of Diseases of the Ear,' London, 1857. Bonnafont, 'Traité théorétique et practique des Maladies de l'Oreille et des Organes de l'Audition,' Paris, 1860. Toynbee, 'The Diseases of the Ear; their Nature, Diagnosis, and Treatment,' 1860; with a Supplement by James Hinton, 1868; the former translated into German with additions by Moos. Von Tröltsch, "Die Anatomie des Ohres in ihrer Anwendung und auf die Praxis und die Krankheiten des Gehörorganes," 'Beiträge zur Wissenschaftlichen Begründung der Ohrenheilkunde,' Würzburg, 1860. W. Kramer, 'Die Ohrenheilkunde der Gegenwart,' 1860, Berlin, 1861. Von Tröltsch, "Die Krankheiten des Ohres, ihre Erkenntniss und Behaudlung," ein 'Lehrbuch der Ohrenheilkunde in Form Akademischer Vorträge,' 1st and 2nd editions, Würzburg, 1862. Schwartze, 'Practische Beiträge zur Ohrenheilkunde,' Würzburg, 1864. Adam Politzer, "Die Beleuchtungsbilder des Trommelfells in Gesunden und Kranken Zustande,"

auricle and the apex closed by the membrana tympani. Its function is to receive sound from without, and to transmit it in a collected form to the membrane.

2. The auricle, consisting of flexible cartilage and an expansion of the common integument over it, is continuous with the outer portion of the meatus. Thus, the cartilaginous meatus forms a tube, which in one direction, backwards and upwards, is open, and presents besides several slit-like openings, which are closed by loose connective tissue, so that this part of the meatus is capable of a considerable degree of movement and expansion. The latter properties are increased by the cartilaginous meatus being attached to the temporal bones, not directly and fixedly, but by an intermediate membranous layer. This layer forms in the adult only a thin ring, while in the child it is much more developed, and supplies as a membranous tube the place of the as yet absent osseous meatus.

The osseous meatus, entirely absent at birth, is only very gradually developed to the length which is normal in the adult.

It should be observed here that in the antero-inferior wall of the child's meatus, often until the sixth year, a gap is left in the ossification, which only diminishes very gradually, and, from its sharp irregular edges, might very easily be considered morbid and the result of caries,[1] and at any rate might facilitate the spread of inflammatory processes to the maxillary articulation and the parotid gland.

3. In the adult the bony meatus is longer than the cartilaginous, and together they are, from the tragus to the membrane, about one inch in length. They do not lie in one line, but their areas form at their junction a very obtuse angle, projecting into the tube at its anterior and inferior wall. As, however, the cartilaginous meatus is movable, it is only necessary to draw it upwards and backwards to make the canal nearly straight.

Klinische 'Beiträge zur Erkenntniss und Behandlung der Ohrenkrankheiten,' Vienna, 1865. Von Tröltsch, 'Lehrbuch der Ohrenheilkunde mit Einschluss der Anatomie des Ohres,' 3rd Edition, Würzburg, 1867; 4th, 1868.

[1] As these peculiarities in the development of the osseous meatus are very little known, and as far as I know have not been specially represented, I give under Fig. 2 of the anatomical plate a representation of the temporal bone of a child about three years old.

Without such traction on the auricle in the examination of the ear only the roof of the meatus, and at most the upper and posterior part of the membrane, are visible, and not the parts situated anteriorly and below. The direction of the meatus backwards and upwards must also be considered in injections and sounding, and other operations on the ear. The upper wall is straighter.

Just in front of the membrane the floor of the meatus forms a well-marked hollow, or depression,[1] generally bounded by a distinct ridge arched over by the lower part of the membrane; this depression is, consequently, of practical importance, since bits of dried wax as well as small foreign bodies, as shot, are frequently wedged in there, and may easily escape the eye of the examiner.

In very young children the inner half of the exceedingly narrow meatus has scarcely any open calibre, since the membrane, which lies horizontally, is in contact in its whole extent with the membranous floor of the meatus—this contact being due in part to the fact that the epidermis covering the membrane has at this time very considerable thickness.

In the new-born child, also, the meatus is filled with vernix caseosa, so that man, in the earliest period of his life, in relation to the open calibre of his auditory canal, as well as to distinctness of hearing, can really scarcely be distinguished from those animals of equal age which are born with closed meatus.

As in children the desquamation from the membrana tympani, as well as from the surface of the meatus, even under normal conditions, is exceedingly active, occasional injections should be employed;[2] for violent attacks of pain, and even inflammation, frequently result from such collections of epidermis in this extremely narrow meatus, which, having become dry and hard, press upon and irritate the sensitive membranes. The membranous lining of the external meatus is very thick and dense, in part covered with strong hairs; towards the membrane it becomes gradually thinner and more delicate, and there has only fine woolly hair, and no longer sebaceous or ceruminous glands, without, however, becoming a mucous mem-

[1] This spot is named by Hermann Meyer the sinus of the external auditory meatus, and is well seen in Fig. 5, and especially in Fig. 4.

[2] It is extremely probable that many of the early inflammations of the ear in children, often permanently disastrous to the hearing, are due to this cause, which, therefore, always demands consideration, though the cases calling for treatment may be exceptional.—Ed.

brane, as is frequently stated. In the osseous meatus the cutis is most intimately united with the periosteum of the temporal bone.

4. The membrana tympani, which forms the boundary between the external meatus and the tympanum, being inserted in a groove in the bone, is an extremely thin, slightly diaphanous membrane, of a delicate pearl grey or dull silver grey colour, the whole surface of which, in a healthy condition, glistens slightly, and presents below and in front, towards the maxillary articulation, a triangular spot, which reflects light very strongly (*Lichtkegel or Trommelfellreflex*). Into it the malleus, the most external of the chain of ossicula, is inserted by its handle, and this is seen, on external examination, as a reddish-yellow streak, nearly equally distant from the anterior and posterior margin of the membrane, extending from above downwards nearly to its centre, and inclined somewhat obliquely from before backwards. At its upper part the handle of the malleus presents a small projection of bone, the processus brevis, which projects externally as a white roundish little prominence, close to the roof of the meatus, and may very easily be seen.

The handle of the malleus becomes somewhat broader as it ends —and this spot is called the umbo or the umbiliform depression— the membrane being there most concave; and the greater the concavity the more the handle of the malleus appears directed inwards towards the tympanum, and the more the processus brevis projects forward towards the observer.

At birth the membrana tympani is situated almost horizontally nearly in the same plane with the base of the skull; but in the adult it is placed obliquely, and forms with the floor of the meatus a very acute angle, and with the roof a slightly rounded obtuse angle of about 140°. The height of the membrane is from 9 to 10 millimètres, the width from 8 to 9. In the child it is more uniformly round, but has at birth almost reached its full size.

5. The membrana tympani consists of three layers, viz., a fibrous layer peculiar to it, and two coverings, which are continued over its surfaces from the adjacent walls. The external coat, a direct continuation of the skin of the meatus, consists not only of several layers of epidermis, but also of connective tissue elements, in which the principal nerves and vessels of the membrane run. Along the handle of the malleus, and at the extreme edge of the

membrane, these cutis elements are most abundantly present. In children this outer coat is especially well developed, and thus in them the membrane as a rule is thicker and duller. The proper or fibrous layer of the membrane is seen under the microscope as a compound of peculiar homogeneous band-like fibres, among which are a great number of ramifying nucleated cells—a kind of connective tissue corpuscles known also as the corpuscles of the membrana tympani.

These fibres are arranged in two entirely distinct layers; one of them, attached to the outer coat, is called the radiating layer, because its fibres radiate from the handle of the malleus; the other, situated internally, the circular layer, since the fibres in it have a circular arrangement.

With the latter, the mucous membrane of the membrana tympani, the coat derived from the mucous membrane of the tympanum, is in immediate contact. This layer, in a normal state, consists of several layers of squamous epithelium, but is subject to very frequent and sometimes considerable thickenings, which appear earliest and most distinctly on the extreme margin of the membrane. This mucous membrane is provided with peculiar villi containing capillaries.

Looking at the membrane from its tympanic side, two tolerably large hollow spaces come to view above, one on each side of the handle of the malleus and opening downwards, known as the posterior and anterior pouches of the membrana tympani. The larger of these is formed by a fold of the fibrous layer, 4 mm. wide, which proceeds from the posterior and superior osseous margin of the membrana tympani, and is attached to the neck and upper part of the handle of the malleus, contributing essentially to the support of this bone. Along its free margin the chorda tympani runs.

6. The meatus receives its blood-vessels from the posterior auricular branch of the external carotid, and from the deep auricular branch of the internal maxillary, the latter passing along the maxillary articulation into the ear furnishes also the principal vessels of the membrana tympani; these pass from the upper wall of the meatus along the handle of the malleus, as far as the umbo, and may frequently be seen in the living subject very distinctly injected. Smaller branches also pass everywhere from the edge of the meatus to the membrane. This vascular network belongs to the cuticular layer. A much smaller proportion of the vessels of the membrana

tympani comes from the small arteries which supply the tympanum, and these ramify on its mucous membrane. The intermediate fibrous coat appears to be entirely without vessels.

As regards the nerves, the back of the auricle receives several fair-sized branches from the third cervical nerve, the front some from the anterior auricular of the third division of the fifth. The meatus, also, besides a branch from the vagus, receives several branches from the auriculo-temporal, the nerve of sensation of the fifth; from which, also, a considerable twig goes to the membrana tympani.[1]

[1] For particulars of the more exact morphological relations of these parts, and especially of the membrana tympani, see, besides, the well-known anatomical works—

Wharton Jones, 'Cyclopædia of Anatomy and Physiology,' article, "The Organ of Hearing," London, 1838, vol. ii, p. 545; and 'Cyclopædia of Practical Surgery,' "Ear and Hearing, Diseases of," London, 1841, t. ix.

Toynbee, 'Philosophical Transactions,' 1851, P. I, p. 159—168; and also his 'Manual on Diseases of the Ear.'

Gerlach, 'Mikroskopische Studien aus dem Gebiete der Menschl Morphologie,' Erlangen, 1858, pp. 54—64.

Von Tröltsch, in Siebold's and Kölliker's 'Zeitschrift für wissenshaftl Zoologie,' 1857, ix B., pp. 91—97; and also in his practical "Anatomie des Ohres," 1—20.

Politzer, 'Beleuchtungsbilder,' pp. 6—29.

Prussak, in 'Archiv für Ohrenheilkunde,' B. iii, pp. 255—280.

J. Gruber, 'Anatomisch-physiologische Studien über das Trommelfell und die Gehörknochelchen,' Vienna, 1869.

## CHAPTER II.

### DISEASES OF THE AURICLES.

7. Among the injuries which happen to this part, so much exposed to external violence, bruises from blows or falls are, perhaps, the most frequent. The effused blood collects between the external skin and the cartilage in the hollows on the concave surface of the auricle, so that its inequalities disappear, or the formerly concave surface itself appears as a bluish-red roundish elevation. As the injured part, generally the upper, either bulges very much, or is flattened, the whole appearance of the auricle is essentially changed by such effusions of blood. If reabsorption is not complete, or the cartilage itself is wounded, changes in form and colour, and consequent deformities which have certain characteristics, always remain. The auricle contracts both longitudinally and transversely, bulges in some parts, shrinks in others, and so assumes a peculiar shape, as if "shrunken." These deformities, occurring most frequently in the upper part of the auricle, are found in pugilists,[1] and also may be observed as a characteristic ornament on the ancient statues of boxers, and also of some demigods,[2] as Hercules or Pollux, famed for their powers of fighting.

Similar in its appearance, progress, and results to these effusions of blood, arising on the concave surface of the auricle from injury, is the often described blood tumour of the ear in the insane (Othœmatoma).[3] As these tumours occur most frequently on the left side,

[1] A case of this kind is reported by Toynbee in his 'Handbook,' p. 23.

[2] Gudden, 'Allg. Zeitschrift für Psychiatrie, 1860, xviii, 2, p. 121. According to Wilde similar tumours of the auricle occur frequently in hunting dogs.

[3] The numerous recent observations on this subject by Gudden, Stahl, Jung, Leubuscher, Franz, Dumesnil, Foville, Joire, Marcé, Motet, and Hofman, may be found condensed in an able article by Flinzer, in Schmidt's 'Jahrbücher'

the one most exposed to blows on the ear, most physicians of the insane recently (emphatically Gudden) are of opinion that they are for the most part of traumatic origin, and by no means peculiar to the insane, amongst whom, especially maniacs and the paralysed, they occur so much more frequently because they injure themselves, or are exposed to injury from those around, much oftener than other men.

Lately Virchow[1] and Ludg. Meyer[2] have called attention to the fact that, even after any severe injury inflicted on the ear, no such tumours were formed; and, on the other hand, that they did occur where undoubtedly only slight traction had been made on the auricle. A normal auricle offers extreme resistance to every kind of violence, and consequently a diseased condition of the tissues must be assumed in those cases which so easily result in fracture of the cartilage and effusion of blood. Virchow demonstrates as such predisposing causes old processes of softening, and L. Meyer, in addition, enchondromatous degeneration and growth of the vessels of the cartilage, by which tissue-changes its elasticity is always diminished, and the occurrence of extravasation and rupture essentially favoured.

This view of the nature and causes of these othœmatomata is strengthened by the fact that such tumours of the auricle, with partly bloody and partly albuminoid contents, have been frequently observed in the sane, and even in cases where no injury and no mechanical violence whatever had taken place.[3]

With regard to their treatment, also, there are different opinions. While some writers recommend evacuation of the effused blood by incisions, others maintain, on the other hand, that after incisions the tumour soon fills again, so that healing is only delayed, and the remaining deformity rendered greater than when the case is left alone. Others think the introduction of a seton the most useful. The treatment of traumatic tumours, of course, ought to be different from that of those which owe their origin chiefly to a pathological condition of the cartilage of the ear.

Incised wounds of the auricle present no peculiarities; on account

(1863, B. 117, p. 77). An abstract of the essays of the first three mentioned is given by Schlager in the 'Wiener Medicin Jahrbücher,' 1861, B. ii, p. 68.

[1] 'Die Krankhaften Geschüwlste,' Berlin, 1863, p. 135.

[2] Virchow's 'Archiv,' xxxiii, H. 4, p. 457.

[3] Chimani, 'Archiv für Ohrenheilkunde,' ii, p. 169; Schwartze, ibid., p. 213; Wendt, B. iii, p. 29; Brunner, B. v, p. 26.

of the unevenness of surface not allowing the application of plaster, they must be united by sutures.

Auricles entirely detached unite again, and in India the loss of an ear is often replaced by transplantation from a living subject.[1] With us artificial ears are used for the same purpose. The hearing does not seem, however, to suffer perceptibly from loss of the auricle: many observations prove this.[2]

8. Among tumours occurring in the auricles, besides several kinds of sebaceous tumour, and hypertrophy of the lobules[3] which sometimes reaches a very large size, those hard roundish fibrous tumours should be mentioned, which sometimes, "as a punishment for the barbarous custom of wearing earrings," grow to a considerable size from the misused lobule on both sides, and must be removed with the scalpel.[4]

Erectile and other vascular tumours have also been frequently observed in the auricle,[5] and have been removed. Cancerous degeneration of the auricles occurring alone seems to be not very unfrequent.[6]

9. It is frequently observed that the most varied diseases of the skin may extend from adjacent parts to the auricle. Among the cutaneous diseases localised there, or even appearing spontaneously, only *eczema of the auricle*[7] need be mentioned as presenting anything of special practical importance. This, in its chronic stage, appears either as the moist scab-forming or as the scaly form of

[1] According to Beck, l. c., p. 65, a successful transplantation of this kind is recorded in the 'Gazette de Santé,' 1817, No. IX.

[2] Linke, i, p. 612, and ii, p. 418; Rau, p. 329; Toynbee, p. 12.

[3] Boyer's Surgical Diseases, translated by Textor, Würzburg, 1820, vol. vi, p. 2.

[4] Wilde, p. 164, where are also two drawings of such a tumour. Hinton, 'Lancet,' March 12, 1860.

[5] Virchow, 'Die Krankhaften Geschwülste,' Berlin, 1867, B. iii, H. i, p. 341, "Ueber Auriculäre Angiome."

[6] Christian Ernst Fischer, 'Vom Krebse des Ohres,' Lüneburg, 1804; with drawing of a case operated upon.

Arnold Pagenstecher, 'Deutsche Klinik,' 1865, p. 400.

[7] The most exhaustive work on this affection was recently published by Auspitz (s. 'Archiv für Ohrenheilkunde,' I, 2, p. 123). Wilde gives a very good drawing of an auricle deformed by chronic eczema, though under the name of "chronic erysipelas," p. 127. Kramer's 'Ohrenkrankheiten,' p. 189; Rau, p. 155; Toynbee, p. 20; Schwartze, p. 1.

eczema. Attacks of eczema confined to the ear appear to occur most frequently in children, and especially in women during the climacteric years, and may become, chiefly through their difficulty of cure and frequent recurrence, very troublesome. In the course of this disease not only does the auricle, previously so graceful, change into a misshapen, inelastic, raw mass, so that it appears brownish-red, and thickened, covered with scales, scabs, and easily bleeding fissures, with its hollows and ridges obscured or obliterated, but the patients also frequently complain of very troublesome itching, and, with each exacerbation of the attack, of violent tearing pains or excruciating sensation of heat, while the ear is red and shining, and so swollen that it projects from the side of the head. When the entrance to the meatus is involved difficulty of hearing is also produced by narrowing of the canal.

In acute eczema treatment is confined to excluding the external air, and this is best done by the application of starch or rice flour. On the other hand, too warm covering for the ear and head is to be avoided. Tepid fomentations with astringent lotions, especially dilute acetate of lead, usually shorten the acute stages, and lessen the burning and itching. Salves and ointments, as a rule, are suitable only for the chronic form, and care must then be taken that the parts come thoroughly and completely into contact with them. Diachylon plaster with oil in equal parts, ointments with the addition of oxide of zinc, of white precipitate, or of iodide of sulphur, may be especially recommended. In the very obstinate dry forms the daily application of preparations of tar or a coating of collodion frequently proves useful. It is very important to include in the treatment the skin of the neighbouring parts, and especially of the hairy scalp when it in like manner suffers from eczema, or even only from seborrhœa.

In the diffused forms of eruption cold rain water douches several times daily prove especially beneficial, but the meatus must be protected from the entrance of cold water.

As deposits of urate of soda occur pretty frequently in the auricle among gouty patients, most frequently in the upper part of the groove of the helix, an attack of gout sometimes shows itself first by a slight inflammatory painful redness of the upper part at the auricles.[1]

[1] Wilde, p. 168; Garrod, 'The Nature and Treatment of Gout,' London, 1859; Charcot, 'Gazette Médicale de Paris,' 1860, p. 487; Von Tröltsch, 'Anatomie des Ohres,' p. 2.

10. Congenital malformations and deficiencies in the auricles occur more rarely alone than accompanied by deficient development of the meatus, the tympanum, and even the labyrinth, and therefore the operation of opening a congenitally closed meatus could comparatively seldom be of use, apart from the difficulty of keeping open the newly made canal. Most frequently these deformities appear only on one side.[2]

According to Virchow,[3] these congenital abnormalities in the external ear and its surrounding parts may be traced back to early arrest in the closure of the fœtal visceral arches and clefts, and generally accompany fistulous openings in the cervical visceral arches, and cleft palate.

11. Before proceeding to the consideration of the diseases of the internal ear we must first briefly describe the examination of the meatus and membrana tympani, without which we are not in a position to arrive at any diagnosis.

In no other form of disease are the history and the subjective symptoms of so little value for the correct diagnosis of any special case as in diseases of the ear, and the objective examination of the parts accordingly of such preponderating value. Only the entrance of the meatus is exposed to the eye; but if the tragus be pressed forwards by the thumb and the auricle drawn backwards with the other hand, we can see, by thus widening the entrance, the front part of the meatus, and in some cases even a portion of the membrana tympani. Generally the meatus is too narrow (and in the cartilaginous part the hairs projecting into the passage prevent the light from entering too much) to allow the deeper parts, and especially the membrane, to be sufficiently illuminated. Besides, the meatus does not run in a straight line, but is slightly incurved. Care must be taken at the examination to overcome all these obstacles. This is done completely and most easily by introducing a funnel-shaped tube called the ear speculum into the

[1] A collection of the older literature of these malformations, with careful reports of several cases, may be found in Linke's 'Handbuch,' i, pp. 582—623. For more recent information, see Welcker, in 'Archiv für Ohrenheilkunde,' i, 3, p. 163; also Förster, 'Missbildungen des Menschen,' Jena, 1861, p. 170. An almost complete absence of both auricles with occlusion of both meatus, in a newly born girl, is described by Heer, in 'Der Preuss. Med. Zeitung,' 1862, p. 75).

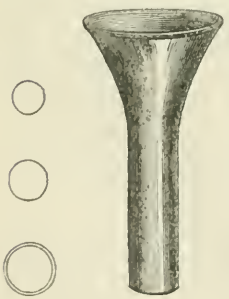
[2] 'Virchow's Archiv,' B. xxx, p. 221, and xxxii, p. 518.

meatus, and while the latter is made straight by traction (backwards and upwards) on the auricles, at the same time throwing daylight by means of a concave mirror on to the deeper parts.

This method,[1] which of late years has proved very generally useful, according to the opinion of all who have tested it, presents essential advantages over the methods formerly adopted for examining and illuminating the ear.

12. As regards the simple ear specula they are much more handy, more convenient, and more suited to their purpose than the forceps-like dilators, still much in use, which were designed by Fabricius Hildanus more than two hundred years ago, and without being essentially changed, have been used ever since, usually under the name of Itard's or Kramer's ear speculum.[2] This, besides more easily causing pain, demands one hand to hold it, while the ear-funnel, if properly introduced, will often keep in position, leaving the hand free. It is much more difficult to examine with the divided speculum, for on separating the two halves of the cone from one another two interspaces are formed, into which the hair of the meatus, masses of epidermis, &c., protrude, and so to a certain extent diminish the advantages of the instrument. As only the entrance, which is the narrowest part of the external meatus, requires dilating, and through the elasticity and yielding of the cartilaginous meatus this is effected by any tube widening externally, a special dilator is unnecessary.

FIG. 1.



There are very many kinds of the simple ear-funnel which do not differ essentially from one another in usefulness. Besides those designed by Wilde, in Dublin, and which resemble truncated cones, the form lately invented by Politzer may be chiefly recommended; this has borrowed its round opening from Wilde's instrument, and its funnel shape from Toynbee's (an oval cylinder with funnel-shaped widening of the outer end—Fig. 1).

[1] Von Tröltsch, 'Verhandlungen der Phys. Med. Gesellshaft zu Würzburg,' ix, p. xxxv; and 'Deutsche Klinik,' 1860, N. 12—19.

[2] See plates in the works of Fabricius Hildanus, opera quæ constant omnia, Franco, 1646, p. 17; and also 'Linke,' B. ii, tab. i, fig. 1.

Politzer uses those made of caoutchouc, I have them made of silver, and prefer this form, on the whole, to Wilde's specula. A set of these consists of three little tubes, fitting into one another, the opening of the funnel measuring 22 m.m., and of the cylinder 4, 5, and 6 m.m., according to the diameter of the meatus to be examined. They should be made thin and light, and the small opening well rounded, so that the meatus may not be injured. They are introduced with a slight rotatory movement, while the auricle is drawn backwards and upwards, and the meatus thus made straight. When the speculum is pressed deeply enough, its under margin should be supported by the thumb, while the fore and middle finger hold the auricle between them, and thus the little tube can be moved in all directions, so that the membrane and meatus can be examined on all their surfaces and margins. The most frequent error is not to insert the speculum deep enough, and not to draw the meatus sufficiently upwards, whereby only the wall of the meatus, or, at most, the upper and posterior part of the membrane is brought into view.

13. As regards the illumination of the meatus and the membrana tympani, the rule was to allow daylight or sunlight to fall directly into the patient's ear. For this purpose it was necessary to bring the patient to the window, which needed to be in as bright and open a situation as possible, and besides this, the physician who had to stand between the source of the light and the object to be illuminated, easily caused shadows with his head, or, to avoid this evil, had to stand on one side and so far from the illuminated ear that more delicate and accurate observations were no longer possible, even to the long sighted; and, above all, clear bright weather was necessary to allow of any examination being made. To meet this difficulty, viz., dependence on the weather, recourse has long since been had to illumination by artificial light, and there are a great number of devices —some very complex—for this purpose, which, however, from their very nature, could never come into general use.[1] It is sufficient, however, to throw ordinary daylight, condensed by a concave mirror, into the ear, in order to see the parts quite distinctly, and by this simple mode of illumination all the above-mentioned difficulties are removed.

[1] See the plates in 'Linke,' B. ii, tab. i; and in M. Frank's 'Ohrenkrankheiten,' Erlangen, 1845, p. 45. See also Rau, p. 23; and my "Essay on the Examination of the Outer Ear," in the 'Deutsche Klinik.'

Mirrors adopted for this purpose should have a focal distance of 5″—6′, and a diameter of not under 2¾″—3″. The most useful are glass mirrors silvered, with a hole, or deprived of their coating in the centre. Smaller mirrors and those of less focal power, as, *e. g.* the metal mirrors used for ophthalmoscopic purposes, are suitable only for more general examination, if recourse be not taken to lamp and other artificial light. In important operations on the ear, for which both hands must be free, *e. g.* the removal of foreign bodies, &c., the same mirrors, fastened by means of a ball-and-socket joint to a strong spectacle frame, are most advantageously employed. It is well to give a slight inclination or side turn to the head of the patient, because in so doing a very much larger part of the mirror comes into operation. White and light grey clouds, or walls lighted up by the sun, give the best light. Direct sunlight is too dazzling.[1]

Fig. 2.

Adults are examined best standing; for elder children the physician sits down, or puts them on a stool; younger children must be held in the arms.

The examination of the deeper parts is often prevented by cerumen, epidermis, scales, hairs detached and matted together, &c., lying in front of the opening of the speculum. To press such things against the wall or to remove them, one may use either a blunt probe or bent forceps (Fig. 2), which also may be used for the removal of *small* foreign bodies. Short probes are most adapted for the ear, and, to avoid casting a shadow with the hand, they are placed at an obtuse angle on an ivory handle. The ear-scoops used by myself are also of similar shape.

[1] Dr. Lucae, of Berlin, strongly recommends the use of a *plane* mirror to reflect the direct rays of the sun. The mirror has an additional advantage for purposes of demonstration, inasmuch as the image of the membrane reflected in

14. As soon as the membrana tympani is seen, the handle of the malleus, running as a thin streak, of the colour of bone, from above downwards to the middle of the membrane, should be looked for; then the colour of the membrane should be examined, whether the colouring is uniform or varied, whether the reflection from it is normal, the *cone of light* (*Lichtkegel*) situated in front below unaltered, whether the membrane is abnormally flat, oblique, or concave; the best guide to this is the position of the handle of the malleus, which, in the latter case, is very much drawn inwards, and so appears shortened in perspective; and also the impression of the size of the membrane,[1] whether the posterior half looks unusually small, whether distinct variations of curvature appear, whether in some place or other there is abnormal reflection of light, whether vessels are to be seen on the handle of the malleus or elsewhere, &c.

The beginner is advised to simply illuminate the ear of each patient with the concave mirror before introducing the speculum. If the auricle is drawn backwards and upwards, and at the same time the entrance of the meatus widened by a finger placed on the tragus, part of the membrane will generally be seen already illuminated, so that it will be exactly known in what direction and depth it is proper to look for the membrane. The walls of the meatus are furthermore very well examined in this way, and the quantity of secretion present and the nature of it seen, and an accurate idea formed of the surfaces, relations, and course of this canal, especially of the well-marked downward inclination of the floor of the cartilaginous portion and the more horizontal direction of the whole roof.

the mirror may be seen by a person standing beside the patient much better than in the concave form.—Ed.

[1] According to Politzer, a. a. O. (p. 27), the less the inclination the larger the membrane seems, and long ago it occurred to me that very frequently after inflation the membranes appear strikingly larger.

## CHAPTER III.

### DISEASES OF THE EXTERNAL MEATUS.

15. The *secretion of the meatus* known as cerumen or ear-wax is by no means only produced by the ceruminous glands, but also by the sebaceous glands, which occur very abundantly in the outer part of the meatus; a quantity of epidermic cells are also always mingled with it, and generally loose hairs. The secretion of the meatus seems to continue, as a rule, uniform as to its nature and quantity, as the secretory activity of the common integuments of the body, and especially of the face, usually is, and formerly an importance too independent and generally too great was attached to it in relation to hearing. It is very doubtful whether—apart, of course, from suppuration of the ear—the quantity or quality of secretion from the meatus ever stands in a constant ratio to abnormal secretions and chronic inflammatory conditions of the deeper parts of the ear, especially the lining membrane of the tympanum, and, therefore, whether it possesses any diagnostic value.

16. *Occlusion of the meatus with cerumen* arises from a disproportion between its production and escape; either an unusual quantity of secretion is produced, or it is retained in the meatus under certain special conditions. The first occurs constantly in chronic eczema of the external ear, and also in persons whose scalp produces excess of sebaceous matter, or whose heads perspire very much; the secretion is increased temporarily (a kind of seborrhœa) in frequently recurring congestive conditions of the skin of the meatus, especially after repeated boils.

On the other hand, the too neglected use of an ear-pick, abnormal tenacity of the secretion, unusual abundance of hairs in the meatus, which may become matted together by the cerumen, and, lastly, con-

tractions of the meatus, may lead to injurious accumulations, even when only the usual quantity is secreted.

As a rule, in all cases, we have to treat accumulations arising very slowly, and which in the course of many years, even of decades, grow to such a size that at last they block up the canal. Apart from those cases in which little masses of cerumen happen to lie on the membrana tympani, accumulations of wax usually produce any symptoms whatever only when they have led to a complete closure of the meatus. Till then they remain, as a rule, quite unnoticed. It happens, therefore, that when all at once closure of the meatus occurs from any additional external causes, the dripping in of water from perspiration or bathing, poking the ear with the finger or a penholder, &c., the patient is put suddenly in an abnormal condition, and thinks himself quite right in believing it not to have been previously present. Many physicians made the same mistake, and, deceived by the statements of their patients, considered these accumulations always the result of acute specific inflammatory processes, accompanied by sudden excessive secretion; whereas, really, their extreme hardness, their stratiform structure, their being matted together with loose hairs, all of which frequently occur, point distinctly to their slow and gradual formation.

These occluding masses of cerumen frequently produce very injurious effects; not only is the difficulty of hearing produced by them often very extreme, approaching complete deafness, but a foreign body of this kind, that is constantly increasing in size and irritating and pressing on the walls of the meatus, as well as on the outer surface of the membrana tympani, causes not only a troublesome sensation of fulness and weight or very unpleasant itching in the ear, but very often most violent tinnitus, frequently, also, obstinate and oft-recurring earache, and even, apparently, very alarming attacks of giddiness. This giddiness is the result of pressure caused by the masses on the membrana tympani, by which the whole chain of ossicula is drawn much inwards, and increased pressure is thus exerted on the fluid in the labyrinth.

The sudden changes which may occur in all the symptoms due to them under definite external conditions, and which are immediately due to changes in the position of the mass or in its size, are almost characteristic of such accumulations.

It is a well-established fact, from anatomical observations, that such masses constantly increasing may lead to perforation of the

bistoury (Fig. 3), on the same handle with Daniel's scoop, may be recommended. By the scoop the position of the abscess may be first explored, and then it may be employed very advantageously to thoroughly clear out the matter, either by pressure on the walls or by its introduction into the cavity. I have often seen boils of the meatus, in their early stages, disperse entirely after painting them with strong solution of sulphate of zinc (ʒss—ʒj to the ℥j of water); but this, however, sometimes occurs by itself. Occasional lubrication of the meatus, *e.g.* with white precipitate ointment, with syringing now and then, appears still to be the best safeguard against the frequent recurrence of this follicular inflammation—a true furunculosis. It should always be noticed whether the skin of the meatus remains normal in the interval, whether impetiginous or scaly eczema is not present, by the treatment of which alone a stop can be put to the continual recurrences of these abscesses.

Fig. 3.

19. *Diffuse inflammation of the meatus or otitis externa* occurs most frequently in children; it is a disease which has many varieties, since it may arise under the most varied conditions, amongst which may especially be named the acute exanthemata, measles, scarlatina, and smallpox; then eczema, syphilis, and whatever operates injuriously on the external ear. To this category belongs especially cold water. The ear should be more carefully protected than is usually the case from the entrance of water while bathing, especially in a rough sea, and especially, too, during the application of ice to the head.

Inflammatory conditions of the meatus of this kind, and especially obstinately recurring formation of epidermis, frequently result from the growth of masses of fungus (Aspergillus) in the ear. It is, however, most probable that before the appearance of this fungoid growth an abnormal condition of the meatus, associated with desquamation of the surface, must be present.[1]

[1] Schwartze, 'Archiv für Ohrenheilkunde,' 1865, B. ii, p. 5. Wreden, ibid., iii, p. 1; also, 'The Myringo-mykosis Aspergillina,' St. Petersburgh, 1865. Steudener, 'Archiv für Ohrenheilkunde,' v, p. 163. Bezold, ibid., p. 1.

The acute form often shows itself first by great tenderness of the meatus, especially on pulling, and by diffuse swelling of it, while hyperæmia is most conspicuous in the deeper parts of the canal, and on the outer surface of the membrana tympani, which always participates more or less in the process. On the appearance of exudation, mostly in the form of otorrhœa, the patient experiences considerable relief. At the same time the surface of the meatus, which at first is only swollen and œdematous, appears in part stripped of its epidermis, red and uneven like the granulating surface of a wound. At the beginning of a painful inflammation of the meatus, or when it has become impossible to examine the deeper parts, it is not always easy to determine whether a local inflammation starting from a hair-follicle, or a diffuse form, is present. The latter keeps more in the superficial layer of the cutis, very soon produces general œdema of the epidermis, and an extensive concentric narrowing of the canal; while in follicular inflammation, which presents itself in the deeper layers of the cutis, and occurs only in the outer part of the meatus, the swelling is more local, rising like a tumour from a point in the meatus, and often quite obliterating its calibre. This does not usually occur in diffuse otitis externa. Difficulty of hearing in the case of boils corresponds to the mechanical narrowing or closure of the meatus in otitis externa, it is dependent upon the extent of thickening of the membrane. In the latter form suppuration generally occurs earlier; moreover, certain mixed forms also occur, as, *e. g. diffuse phlegmonous inflammation* of the subcutaneous cellular tissue after severe injuries. In the chronic form, as a rule, moisture in the ear first draws attention to this organ, and pain only occurs in special cases. Difficulty of hearing, as well as the gravity of the whole process, increase in proportion to the affection of the membrana tympani. Where this is involved its cutis layer is always thickened, but not unfrequently it leads to ulceration and perforation, through which inflammation spreads to the tympanum.—The development of polypi and granulations on its walls is a frequent result of neglected inflammations of the meatus.

But even without such extension inwards through the membrana tympani, otitis externa may lead by itself to serious consequences, since its seat, the skin of the meatus, is most intimately connected with the periosteum of the temporal bone, so that periostitis and disease of the neighbouring bones may very easily arise from severe forms of inflammation. It must be remembered that the posterior

wall of the bony meatus belongs to the mastoid process,[1] so that it is only separated from the sigmoid fossa in which the lateral sinus of the dura mater (so frequently participating in diseases of the ear), is situated by a small and for the most part cellular layer of bone. The roof of the osseous meatus, which, as is known, is covered on its upper surface by dura mater, is much thinner still, and generally provided with hollow spaces, so that even those parts whose participation in the disease is usually only feared in *inflammation of the deeper parts of the ear*, and when perforation of the membrane is present, also lie quite close to the external meatus. This is confirmed also by a series of observations, in which fatal diseases, especially thrombosis of the sinuses, pyæmia, or meningitis,[2] resulted from inflammation of the external meatus simply, the membrana tympani being completely intact, and without any participation of the tympanum. Cases of this kind may be not at all rare in children, especially during scarlatina.

The treatment in otitis externa at the beginning of the acute form, as well as at each exacerbation of the chronic form, should be antiphlogistic; besides restricted diet and laxatives, leeches should be applied in front of, or on the entrance to, the patient's ear. Furthermore, warm ear-baths afford very much relief. As soon as secretion has commenced frequent gentle syringing with warm water should be employed, and astringent lotion used to limit the discharge; quite weak solutions in the acute and stronger in the chronic forms (details on this subject will be given afterwards in the *résumé* on suppuration of the ear). If the discharge be scanty, intelligent patients may be allowed to clean their ears occasionally with a little brush. Warning must here be given against the so much used poultices, which are only employed advantageously in the case of boils, and which in other forms of inflammation of the ear easily lead to extensive softening and breaking down in the soft as well as in the hard parts of the ear, and, especially, frequently to perforation of the membrana tympani. Vesicants and pustulants behind the ear increase the irritation and pain, in acute inflammatory affections and, at the least, are useless in chronic forms.

[1] See Fig. 1 of the Anatomical Plates.

[2] See Toynbee, l. c., p. 63. Gull, 'Medico-Chirurgical Transactions,' xxxviii, p. 157. Pagenstecher, 'Langenbeck's Archiv,' B. iv, "Zur Anbohrung des Warzenfortsatzes."

20. The mastoid process is usually selected for the *application of leeches,* without any regard to the cases, in every form of inflammation of the ear. It is, however, a matter of experience that in inflammation of the meatus and of the membrana tympani a few leeches applied directly in front of or on the entrances to the ear, are very much more useful than twice the number applied behind the ear.[1] This is easily explained by the fact that the meatus and membrana tympani, in common, receive the greatest part of their blood-vessels from the deep auricular artery which passes in front of the aperture of the ear, and supplies, first, the tragus, and then the anterior part of the meatus. The principal vessel of the outer ear is also situated there.

In applying the leeches the ear should be carefully stopped up, that no leech may crawl into the meatus, and also that blood may not run in. When the bleeding, often profuse, has stopped, one should never fail to keep the leech-bites, especially in otorrhœa, covered up with plaster till they are healed, lest any poisoning of the little wounds occur. In such cases dangerous erysipelas or painful little ulcers sometimes result.

21. It is needful to say a few words about *syringing the ear* and the instrument required for this purpose. Syringes of vulcanite, which have a nozzle well rounded and not too long, and a ring for the thumb on the piston, are the best. The part made to unscrew lying next to the ring should be provided with a groove to receive the fingers, in order that the syringe may be easily held between two of them. One similar in shape, but smaller, may be given to patients, for a long continued or forcible stream of water should usually be avoided. Similar pewter syringes also, if not made too heavy and bulky, prove equally useful. Glass and horn syringes are quite unsuitable, so also are those with long pointed nozzles or with a button-like end to the piston instead of a ring.

The syringing itself should always be done slowly and gently, since greater force frequently produces severe giddiness, whether the membrane be perforated or not. In case of a very tender inflamed membrane its rupture might easily occur in this way. The best method is to introduce the nozzle of the instrument along the roof of the meatus, and at the same time draw the auricle upwards and

[1] Wilde, p. 86.

backwards. If the nozzle be too thick, the meatus, especially in children, would be easily closed, and so the escape of water from the ear obstructed. Moreover, if the tympanum be exposed, separation of the ossicula, or injury to the walls, if carious, might be caused by a powerful stream.

22. *Contractions of the meatus* occur in the cartilaginous as well as in the osseous part. To the former belongs the slit-form contraction of the cartilaginous meatus, in which the anterior and posterior walls are abnormally close together, so that the orifice of the meatus, in other cases roundish or oval, is converted into an elongated fissure, or even completely obliterated. If not produced by external pressure, *e.g.* by a parotid tumour or something similar, this form depends, for the most part, upon a relaxation of the cartilaginous meatus itself or of its fibrous attachments, and I have observed the more advanced degrees of it at least only in elderly people. It may be one of the causes why collections of cerumen are specially frequent in advanced life, since its escape is, of course, obstructed by such a form of the meatus.

If the collapse be excessive, wearing a little silver tube will improve the hearing, since thereby the walls are kept apart.

A general circular or concentric contraction of the cartilaginous meatus is sometimes observed as a congenital formation.[1] This I once saw existing to such an extent on both sides, that I thought at first I had to do with a congenital closure of the meatus, until it was found that a very narrow passage was present on both sides, into which a probe (without a knob) ½ mm. thick could be introduced and pushed forward only with difficulty.

These general contractions are more frequently developed as the results of long-continued inflammation, which has led to thickening of the skin of the meatus; also after long-continued otorrhœa; after frequent recurring boils, and most frequently with chronic eczema of the external ear. Besides treatment of the thickened skin and its causes, recourse must frequently be had to mechanical dilatation, consequently to the introduction of wedge-shaped pieces of compressed sponge, or of laminaria digitata, certainly not very well suited for such cases.

Among the contractions of the osseous meatus exostoses not

[1] Von Tröltsch, 'Archiv für Ohrenheilkunde,' B. iv, p. 28.

unfrequently occur.[1] They present themselves as roundish tumours of various sizes more often rising from a wide base than pedunculated; the skin over them is usually somewhat reddened, seldom quite pale, and touching them with a probe, as a rule, causes much pain. They occur at the commencement of the osseous meatus, as well as close to the membrana tympani, and are found almost always on both sides, and generally several in each ear. These exostoses sometimes reach such a size that they considerably contract, or even completely close the meatus. They are much more frequent in men than in women, and are developed much seldomer as the result of painful inflammation than quite unmarked. Their growth proceeds, for the most part, very slowly; any connection with syphilis cannot yet be established.

From mechanical measures of dilatation by compressed sponge and laminaria digitata, or from painting with iodine, &c., benefit can be expected only after very long-continued and very energetic treatment.

It is very important to advise the patient, after previously injecting water, to periodically cleanse the meatus of any secretion by the syringe, or better by a brush, as small masses of epidermis being constantly thrown off may, no doubt, in such a case, lead to obstruction of the canal.

In cases where the meatus is completely closed by such an osseous tumour relief can be afforded only by an operation; and perforation of the exostosis by Middeldorpf's[2] *akidopeirastic* perforator would be most useful.

In hyperostosis we have to deal with a contraction for the most

[1] See on the subject, amongst others, Wilde, p. 204. Autenrieth, Reil's 'Archiv für Physiologie,' 1809, ix, p. 349. Toynbee, 'Catalogue,' p. 9, and 'Handbook,' p. 107, with many plates. O. Weber, 'Die Exostosen und Enchondrome,' Bonn, 1856, p. 37. Seligmann, 'Sitzungsberichte der Wiener Academie,' 1864, p. 55. Bonnafont, 'Union Méd.,' 1862, June 17th, and 1868, May 30th. Welcker, 'Archiv für Ohrenheilkunde,' i, 3, p. 171, with drawings on plate ii. Pitta and Billroth, 'Chirurgie,' Bd. iii, I Abth., 2 Heft.

[2] See the representation of this instrument very useful also for perforation of the mastoid process in 'Arch. für Ohrenheilkunde,' B. iv, p. 225.

[See also a successful case, by means of perforation, reported by Bonnafont, 'L'Union Médicale,' 1868, May 30th. This patient was afterwards seen by me and the relief given by the operation found to be quite satisfactory, after the lapse of more than a year. But lately a case has been treated quite successfully, under my own observation also, by Mr. Clark of Clifton, by means of the continuous galvanic current. After two applications by three needles, under

part general, extending over the whole meatus, which, however, frequently presents rough irregularities. As these elevations, the result of a decided periostitis, are not sharply defined, but more diffused, they merge properly into the flat osteophytes.

This form of contraction of the osseous meatus occurs especially during and after chronic otorrhœa. It is met with also undoubtedly during non-suppurative catarrh of the middle ear, and must then be regarded as the result of inflammatory action accompanied by tissue and bone-formation, and this occurs throughout the whole petrous bone. While suppuration is going on these osseous growths may prevent the external escape of pus, and so indirectly be the cause of death.[1]

chloroform, the exostosis came away in a mass, and the hearing was restored. —Ed.]

[1] A case of this kind is recorded by Roosa in 'New York Medical Journal,' May, 1866.

## CHAPTER IV.

### DISEASES OF THE MEMBRANA TYMPANI.

23. *Inflammation of the membrane* is very common; but it occurs spontaneously and alone comparatively seldom, since the membrane more often participates in the inflammation of the meatus and the tympanum, with both of which portions of the organ, alike through its position and its anatomical structure, it stands essentially in a relation of dependency

*Acute inflammation of the membrane.*—Myringitis acuta mostly commences suddenly and at night, after any determining cause, with very severe boring and tearing pains in the bottom of the ear, which are accompanied by a sensation of weight and fulness in the ear, as well as by very severe tinnitus, and these continue with slight intermissions until suppuration is fairly established. These pains sometimes cease with slight bleeding from the ear. It is characteristic of this condition that the meatus does not appear at all injected or changed, or only at its innermost part, while the membrane presents very marked deviation from the normal state. At first it is strongly injected, but the distended vessels appear less distinct as soon as the infiltration of the epidermis is more advanced. The surface then loses all lustre, and appears dull, the handle of the malleus becomes indistinct from infiltration of the layer of cuticle which covers it, is represented at most by a reddish vascular line, and the membrane appears uniformly flat.

In a later stage the epidermis becomes more or less raised and thrown off, and the corium lies exposed, red, swollen, and softened, for the most part covered with thin secretion. Ecchymoses[1] sometimes arise or abscesses between the layers of the membranes, and

[1] The gradual wandering of such ecchymoses, whether they have arisen from traumatic or idiopathic causes, towards the periphery of the membrane from which they entered towards the roof of the meatus, is most interesting.

ulceration and perforation of the inflamed membrane often quickly follow. Under favorable conditions slight suppuration gradually subsides, as a rule, and only superficial thickening of the membrane remains.

In *chronic myringitis*, apart from slight otorrhœa and a varying degree of difficulty of hearing, patients frequently complain only of occasional very troublesome irritation in the ear. It leads not unfrequently to polypoid excrescences from the surfaces of the membranes, or to partial inequalities and depressions, pointing to adhesions with parts of the tympanum.

With proper treatment the prognosis in acute myringitis is very favorable, for even if the membrane has been perforated complete restoration to a healthy condition can still be accomplished, a thing that can scarcely ever be attained in the chronic form, since in the latter the process generally extends to the tympanum.

Treatment is the same as in otitis externa, only somewhat more vigorous. In the acute form the patient must be directed to avoid, as much as possible, blowing his nose or sneezing violently, for the softened and inflamed membrane very frequently ruptures during such violent expiratory movements. Stimulating injections and applications are recommended for the remaining thickening of the membrane, but only under the strict observance of the physician. Larger isolated granulations are removed with the polypus snare, or painted with strong solutions of zinc, acetate of lead, or Liq. Ferri Perchlor. In employing the latter measure, however, care must be taken to completely remove any metallic deposit which is formed, that it may not remain attached, and so cause loss of elasticity of the membrane.

24. *Injuries to the membrana tympani* are not at all uncommon. This is easily explained by its delicate structure and by its position being considerably exposed to external influences.

Linear rents in the membrane, generally behind the handle of the malleus, and running parallel with it, are frequently seen, as the result of violent atmospheric pressure affecting the membrane from without, either in consequence of blows with the palm of the hand or of explosions in the vicinity. In children, especially, ruptures of the membrane, frequently followed by inflammation and suppuration, occur so frequently in the former way, that parents and schoolmasters should be specially reminded by the physician how

utterly unadapted the region of the ear is for the application of corporal punishment, and how much mischief is caused in this way. Among artillerymen, also, it frequently happens that during the firing of the cannon the membrana tympani is ruptured, and this, as a rule, takes place with a sudden, very severe sensation of pain and slight bleeding from the ear. Sometimes the deafness attributed to such an accident, however, is so great that a still further important change in the deeper parts must be assumed.

It is traditional among the artillery while firing the heavier guns, especially in covered places, to open their mouths as a protection against the extremely loud sound or pressure of air, and it is so far rational, as on wider separation of the jaws the mucous membrane of the throat is stretched, and so a certain amount of dilatation of the Eustachian tubes takes place.

Stopping up the ears, drawing up the shoulder towards the most exposed ear, and especially adopting Valsalva's process (forcible expiration with mouth and nose closed) immediatetely before firing, that the Eustachian tubes may be as open as possible, would, in my opinion, still more protect the membrane, in any case, from the effects of such violent atmospheric concussion. I have found severe pharyngeal catarrh with diminished patency of the corresponding Eustachian tube remarkably often in persons whom I have examined soon after accidents to the membrane arising from violent external atmospheric pressure. It is in the nature of the case that during more complete closure of the tube any sudden condensation of the external air must tend to act much more injuriously on the membrane thus impeded in its vibrations, as well as on the contents of the tympanum, and even of the labyrinth, than when the air present in the tympanum can escape on any sudden concussion of the membrane unimpeded through the tube.

Ruptures of the membrane, with or without bleeding from the ear, also occur not at all rarely in whooping-cough, as well as in fractures of the base of the skull, and sometimes in suicides by hanging.

Women sometimes perforate the membrane when scratching the ear with knitting-needles, and I have twice seen the same produced in country people by a straw penetrating the ear. The pain was of excruciating violence. More frequently the membrane is ruptured during examination with a sound, an instrument which is still too often employed about the ear without sufficient knowledge and with-

out the necessary illumination of its deep parts, and in this way much damage is done. Surgeons not unfrequently want to arrive at a diagnosis as to whether the membrane is perforated or not by a sound, by which a perforation is very easily first produced. In most cases in which surgeons still sound the ear, the eye, *i. e.* a careful examination with good light, affords us much more accurate information about the condition of the deep parts than the sense of touch. Even in caries of the ear, whereof more subsequently, the latter is the case.

All wounds of the membrana tympani without complication, as a rule, heal very rapidly, provided all injurious influences are kept at a distance.

# II. THE MIDDLE EAR AND ITS DISEASES.

## CHAPTER V.

### ANATOMY OF THE MIDDLE EAR.

25. Under the term anatomy of the middle ear are included the tympanum, the mastoid process, and Eustachian tube. The function of the tympanic apparatus is to collect the pressure of the vibrating air on the relatively larger surface of the membrane, and to transmit it by the chain of ossicula through the very much smaller surface of the fenestra ovalis to the fluid of the labyrinth.

It is of the utmost importance for the practitioner to have a clear idea of the tympanum, for most of the diseases of the ear occur in this space. The difficulty consists in the fact that the space is very small, that very many structures deserving notice are contained in it, and that a basis is seldom laid by actual observation and personal inspection of the entire structure. It will be best to consider only what is most important, following each wall of the tympanum, the description of which will help to place the chief points before us.

The tympanum represents an irregularly shaped octagon. Its surface directed outwards, or the outer wall, may be described as the wall of the membrana tympani, the inner as the labyrinth wall, the lower or floor as the wall of the jugular vein, the upper or roof as the wall of the dura mater, while the posterior wall presents irregularly bordered openings into the appendix of the tympanum, the mastoid process, and anteriorly it terminates in the channel, which, serving for the escape of fluid as well as ventilation, is directed somewhat downwards—the Eustachian tube.

26. We have already become acquainted, for the most part, with

the outer or membrane wall; for the membrana tympani, with the malleus inserted in it and the incus articulating with this, represents its most important part. We observe the insertion of the tendon of the tensor tympani muscle beneath the neck of the malleus, and immediately above this, the chorda tympani from the facial as a plainly visible nerve-branch. This running under the long process of the incus to the free edge of the posterior pouch of the membrana tympani crosses the neck of the malleus, and then, helping to form the anterior pouch of the membrane, leaves the ear through the Glaserian fissure. Again, it is of importance to know that the mucous cavities of the temporal bone often present a considerable development above and behind the head of the malleus, so that they enter some distance beyond the membrana tympani into the osseous layer, which represents the upper and posterior wall of the meatus.

Thus a way is here afforded by which affections of the middle ear, and especially suppuration, may extend outwards without involving the membrana tympani, so that deep-seated abscesses of the ear may discharge themselves into the meatus through its upper wall. Such secondary collections of pus seem to occur by no means rarely under the skin of the roof of the meatus, and here also a way would be indicated by which deeper seated abscesses of the ear might be opened artificially, and so great danger to the life of the patient averted.[1]

The petrous bone generally presents an endless number of individual differences in the minutiæ of its construction, so that scarcely two pairs are exactly alike, and this becomes very conspicuous on the under wall or floor of the tympanum, which sometimes is several lines thick, formed partly of compact and partly of cancellous bones; sometimes, again, is thin to transparency, and then it always has the internal jugular vein lying close under it. This immediate proximity of the jugular vein is very important, for it explains how venous murmurs can be easily transmitted to the ear and perceived there as internal murmurs, as noises in the ears; and, further, because it points out to us one of the ways by which suppuration of the ear may gain entrance to the vascular system, and lead to fatal general disease.

The roof or upper wall of the tympanic cavity also varies much

[1] See Fig. 1 and Fig. 5 of the Anatomical Plate, where the hollow spaces above the meatus are very much developed, and in Fig. 1 only separated from it by a thin layer of bone.

in thickness, and not infrequently is extremely thinned, sometimes even presenting pretty extensive gaps, and certainly in cases where there can be no question of caries, &c.[1]

These differences of structure may acquire great importance, for this wall forms the partition between the cranial cavity and the ear, and its upper surface is covered by the dura mater. In these cases of thinning of the tympanic roof, the dura mater and mucous membrane of the tympanum lie in the closest proximity to one another without any solid intermediate layer, and extensions of morbid processes can take place the more easily as the middle meningeal artery, the principal vessel of the dura mater, sends considerable branches through the tympanic roof into the middle ear; and there also is situated, usually still present even in adults, the squamo-petrosal suture, through which, in children, the dura mater sends a vascular process into the tympanum.

We now turn to the inner or labyrinth wall; it deserves this name, as it possesses both the openings or fenestræ which lead to the labyrinth, both the principal divisions of which are situated immediately behind it.[2] The fenestra ovalis leads, as is known, to the vestibule, and the base of the stapes is attached on all sides to it by means of its circular membrane of insertion, while the fenestra rotunda, situated lower down, leads to the cochlea, and is closed by the delicate membrane of the fenestra rotunda or the second membrana tympani. The oval or vestibular opening lies almost parallel with the membrana tympani; on the other hand, the round or cochlear opening makes nearly a right angle with the plane of the membrana tympani, and can be the less easily seen from the external meatus, as it lies at the end of a canal about 1 mm. long, opening towards the mastoid process. This is the case in adults; in the fœtus the secondary membrane of the tympanum lies parallel with the membrana tympani, and gradually assumes an oblique direction towards it.

Exceptionally this membrane and canal, in very rare cases, retains its fœtal position in the adult. In front of these fenestræ and

[1] Toynbee, 'Med.-Chir. Transactions,' 1851, p. 249; and 'Catalogue,' pp. 42—44. Hyrtl, "Spontane Dehiscenz des Tegmen Tympani," &c., Wien, 1858; aus den 'Sitzungsberichten der Wiener Academie,' xxx B. Retzius, 'Schmidt's Jahrbücher,' 1859, No. II, p. 153. Luschka, 'Virchow's Archiv,' B. xviii, p. 166.

[2] See Anatomical Plate, Figs. 3 and 4.

between them we find the promontory, a smooth, broad projection, behind which the commencement of the most external turn of the cochlea is situated. The promontory, with its abundant vascular network, may very often be seen from without in cases of central perforation of the membrana tympani. Still further forwards, where the Eustachian tube opens, lies the internal carotid artery, only separated from the cavity of the tympanum by a thin, frequently even imperfect, layer of bone, which constantly presents cellular depressions, by which collection and decomposition of pus with subsequent ulceration of the tissues is made the more easily possible. Caries, therefore, is rather common in this part, and not unfrequently leads to ulceration and perforation of the arterial coats. A whole series of cases are reported in the literature of the subject of bleeding from the ear, which originated in this way, and led on to fatal consequences or necessitated ligature of the carotid. Along the upper part of the labyrinth wall runs the tensor tympani muscle, and this immediately in front of the fenestra ovalis gives off its tendon, which runs transversely across the tympanum. The second internal muscle of the ear, the stapedius, is also, like the former, surrounded by a canal-like bony case, so that their tendons only lie free, and are surrounded by the mucous membrane of the tympanum. The stapedius muscle is situated behind and below, near the openings which lead to the mastoid process. Curving around it, and close behind, passes the aqueductus Fallopii, with the facial nerve, which, while immediately above the stapes, is only separated from the cavity of the tympanum by a thin translucent bony layer. The more intense disturbances in the nutrition of the tympanum lead the more easily to disturbances of function, especially paralysis, of the facial nerve, because both parts, the mucous membrane of the tympanum and the neurilemma of the nerve, are supplied by the stylo-mastoid artery which runs in the Fallopian canal.

27. The labyrinth wall lies opposite and exceedingly near to the membrana tympani, and the distance of the inner from the outer wall or the *depth* of the tympanum is the smallest of all its diameters. The cavity may, therefore, be compared to a flat snuffbox, for it represents a cylinder comparatively long, moderately high, and very flat. The long diameter is the greatest, which measures from the mouth of the Eustachian tube or the front edge of the membrana tympani to the entrance of the mastoid cells about 13 mm. The

height or perpendicular diameter is much less in front, at the entrance of the tube, than further back; at the centre it is about 9 mm. The *depth* measures in front, at the opening of the tube, 3—4½ mm.; measured in the vertical plane of the malleus, it varies from 2 to 5 mm.; and the narrowest part, 2 mm., lies between the end of the malleus, or point of greatest convexity inwards of the membrane, and the promontory. More towards the mastoid process the space again becomes somewhat wider, measuring about 6 mm., but just here the two ossicula, the incus and the stapes, proceeding from the opposite walls, meet, and the head of the latter is distant only 3 mm., while the end of the bony process of the incus is only 2 mm. from the posterior half of the membrana tympani (a little above the middle).

The chain of ossicula and, further, the tendon of the tensor tympani connect these walls, the inner and outer (which lie so near together), so that it is the less surprising if, from thickening or inflammatory swelling of the mucous membrane lining all these structures and walls, parts otherwise separate come into contact, and in consequence abnormal adhesions, contractions or connections by false membranes, either between the walls of the tympanum themselves, or between the ossicula and the walls arise.

28. Turning now to the mastoid process, this represents, with its air-containing cellular spaces, a kind of air reservoir or pneumatic appendage of the tympanum. In the mastoid portion of the temporal bone two divisions must be distinguished, viz. first, the horizontal part (*antrum mastoideum*), a large bony cavity immediately behind and above the tympanum, and thus directly below its roof, and which, even in the child, is very large; and, second, the *mastoid process* proper, lying lower and more superficially, and which contains, in adults, a whole series of smaller and larger bony spaces. It is this latter or the vertical part of the mastoid portion which is usually and specially understood by the name "mastoid process." Very small, and consisting only of cancellous bone in childhood, it first becomes completely developed at puberty, but varies very much in its structure, even in adults, for sometimes compact, sometimes cancellous bone predominates, sometimes the hollow spaces are found very large, sometimes only small, with thin or thick partitions. The thickness of the compact outer wall, both that towards the cranial cavity, close behind which the

lateral sinus is situated, and towards the outer skin, varies much. Very considerable thinnings, and even *deficiencies*, which may be of importance in practice, occur here also. In this way, *e.g.* emphysema might proceed spontaneously, or, after trifling operations, such as inflation by the catheter from the posterior part of the ear, and spread over a portion of the face. One or more lymphatic glands are situated on the mastoid process just above the insertion of the sterno-mastoid muscle, which, in inflammation of the ear, but also without any, often swell and become painful, sometimes even suppurate.

29. *The Eustachian tube* forms the communication between the tympanum and the pharynx, and serves at once as a passage for the escape of the tympanic secretion, and as a way for the renewal of the air in the middle ear; which renders it possible that the strata of air before and behind the membrana tympani may always be of the same density, so that the air in the middle ear always remains of the same tension as the outer atmosphere. The tympanic opening of the tube (ostium tympanicum) lies directly opposite the irregularly shaped entrances to the mastoid cells, and both are situated nearer the roof than the floor of the tympanum.

*The Eustachian tube* consists, like the external meatus, of an osseous and a (peripheral) cartilaginous portion; only here the cartilaginous portion is by far the larger. The average length of the Eustachian tube measures about an inch and a half, more accurately 35 mm.; 24 mm. of which belong to the cartilaginous, 11 mm. to the osseous canal. The tube is narrowest where the cartilage and bone join, and this spot may be called the "isthmus of the tube." It is for the most part 2 mm. high, and scarcely 1 mm. wide, not seldom, however, much wider tubes occur. From this spot it widens in both directions, and is by far the widest at the pharyngeal opening (ostium pharyngeum), which is patent in the adult, and projects into the cavity of the pharynx. It is formed like the mouth of a trumpet, and measures 9 mm. in height, 5 mm. in width. The tympanic opening ("ostium tympanicum tubæ") is far smaller, for it is only 5 mm. high and 3 mm. wide.

It is very important to know that these conditions are essentially different in children. The tube is naturally shorter in the child; on the other hand, the isthmus is far less pronounced and the child's tube is wider in the middle, not only relatively, but absolutely, than

the adult's. The entrance of the tube into the tympanum also is relatively much larger in the child than in the adult; and so far, therefore, much more may be expected from a discharge of purulent fluid through the tubes in the child than in later age. On the other hand, the pharyngeal opening is much less developed in width in children; the cartilaginous lips are very small, not yet projecting, and lie so very close together that the pharyngeal opening does not appear patent as in the adult, but simply like a fissure, and in the dead body of a child it cannot very easily be distinguished from other folds of mucous membrane. In catheterising children, also, the posterior cartilaginous lip, which in the adult forms a distinct projection, is felt much less, and, therefore, the opening of the tube is less easily found. Closure of the tube at its pharyngeal orifice occurs in the child, at any rate, much more readily on any swelling of the pharyngeal mucous membrane, and this serves as an explanation of many cases of difficulty of hearing in children. Moreover, while in adults the tube proceeds very obliquely from above downwards, the position in childhood is nearly horizontal, so that the pharyngeal orifice scarcely lies lower than the tympanic.

The so-called cartilaginous Eustachian tube does not consist entirely of cartilage, but properly represents only a cartilaginous *semi-canal*, which below (in front) and externally is closed by fibrous membrane. This membranous part of the cartilaginous tube is very wide at the pharyngeal orifice, and there forms about a third of the whole circumference, whilst above, towards the bone, it gradually becomes narrower. This membrane is usually in contact, by its mucous surface, with the mucous membrane of the cartilaginous canal lying opposite. In a state of rest, therefore, the canal, or more properly the fissure of the cartilaginous Eustachian tube, is not patent, but lightly closed like other canals lined with mucous membrane (rectum, vagina, &c.) The tube is really open only at the ostium pharyngeum, and at the junction of the cartilaginous with the osseous portion. When, however, the secretion from the tube is not very viscid, and especially when it is in a normal condition, we have to do not with any firm closure, but only with a light contact of the mucous surface, which offers no resistance.

In each act of swallowing[1] the membranous wall is retracted and the

[1] Observations and investigations by Aug. Lucæ and Schwartze show that in many cases, with a normally patent tube, even the simple respiratory move-

tube opened, as may be demonstrated in various ways, and everything favours the idea that this opening of the tubes is effected by the tensor palati, which, therefore, must be regarded as an abductor of the membranous tube.

30. The two superior palatine muscles, the tensor and levator palati, must therefore be regarded as belonging to the Eustachian tube, and we shall accordingly briefly describe them.[1] (See Anatomical Plate, fig. V.) The circumflexus or tensor palati (Spheno-salpingo staphylinus) rises partly from the cartilaginous Eustachian tube, not alone from the portion which is immovably united to the bones, but also by means of a considerable number of fibres from the membrane closing the cartilaginous grooves, which has been spoken of before. Further, then, the flat belly of this muscle lies so close upon the membranous tube, and is united to it by such short, dense connective tissues, that on each contraction of the muscular fibres which run at an acute angle to the axis of the tubes, the whole length of the membranous tube is necessarily raised from the surface of mucous membrane opposite, and so the calibre of the tube is enlarged and made patent. As this muscle is of far greater importance for the tubes, at any rate, than for the palate, the name "Abductor tubæ membranaceæ," or "Dilator of the Eustachian tube," would most suitably be given to it.

The levator palati or petro-salpingo-staphylinus has a different relation to the Eustachian tube, for it rises only from its upper fixed part, and its fibres run parallel to the membranous tube and under its floor, without receiving any fibres from itself. When it raises the soft palate, its contraction causes at the same time narrowing of the pharyngeal orifice of the Eustachian tube. The inferior curved edge of the orifice of the tube is hereby drawn more into a straight

ments effect a certain change in the air of the tympanum, which in some cases produces visible appearances of movement in the membrane. ('Archiv für Ohrenheilkunde,' i, 2, p. 96 and 139; and iii, 3.)

[1] See further particulars on this subject in 'Archiv für Ohrenheilkunde,' i and ii, 3. Von Tröltsch, 'Beiträge zur Anat. und Physiologischen Würdigung der Tuben- und Gaumen-Muskulatur;' and 'Beiträge zur Vergleichenden Anatomie der Ohrtrompete.' Further, Rüdinger, 'Beiträge zur Anatomie und Histologie der Tuba Eustachii,' München, 1865. [Mr. Yule, in the 'Journal of Anatomy and Physiology,' Nov., 1873, has given reasons for believing that the opening of the tube is effected by the joint action of the salpingo-pharyngeus and the palato-pharyngeus.—Ed.]

line upwards. In this way it is protected on raising the soft palate, and so, *e.g.* in swallowing and eating, against all mechanical influences from below, especially against morsels of food, which sometimes may reach the upper part of the pharynx during vomiting or sneezing.

31. The lining membrane of the middle ear is a mucous membrane, a continuation of the nasal and pharyngeal mucous membranes, all the peculiarities of which appear still preserved at the pharyngeal opening and in the lowest part of the Eustachian tube, for the membrane there is thick, puffy, and contains a quantity of large mucous follicles, whose openings, like pricks of a needle, may be very easily seen with the naked eye. The mucous membrane becomes thinner and more delicate in the course of the tube, and until now glands have been found only at the junction of the tube with the cavity of the tympanum, nowhere else in the upper two thirds of the tube, and just as few in the tympanum or mastoid process. In the delicate investiture of these last-named portions the mucous and periosteal layers cannot be demonstrated as separate layers, so that the membrane usually called mucous at the same time conveys vessels to the bone, and consequently discharges also the function of periosteum. The way in which the bone is nourished, both in the cavity of the tympanum and in the mastoid process, is essentially dependent on the condition of the mucous membrane. Every inflammation, every catarrh in this part, is at the same time also a periostitis, and from this double relation it is plain how from simple catarrhal affections deeply extending disease of bone may arise.

Suppurative catarrh of the ear is the commonest starting-point for caries of the petrous bone, just as hyperostosis or eburnation of the mastoid process appears frequently to be the result of simple (mucous) chronic catarrh of the ear.

The epithelium of the tympanum is tesselated, and in the lower part of the cavity provided with ciliæ. The Eustachian tube, on the other hand, is everywhere lined with cylindrical epithelium, which is usually thrown off in masses mixed with abundant mucus from the tube.

32. The *vessels of the middle ear* are derived partly from the region of the external carotid (the stylo-mastoid and ascending pharyngeal), partly from the internal maxillary (the middle meningeal); and the

internal carotid also during its passage through the petrous bones, gives off some branches directly to the tympanum and the Eustachian tube.

The *nerves of the middle ear* are derived from quite as many different sources. The tensor tympani muscle, as well as the abductor tubæ membranaceæ (the tensor palati) are supplied from the trigeminus and by the motor internal pterygoid nerves of the third division. Both these muscles also receive a small branch from the otic ganglion, while the levator palati receives its nerves from the vagus, the stapedius from the facial. Sensation is supplied to the mucous membrane of the tympanum and Eustachian tube by the glosso-pharyngeal, and further by the sympathetic. The otic or Arnold's ganglion—the special ganglion for the organ of hearing—is formed by branches from the fifth, from the glosso-pharyngeal, and from the sympathetic. From this branches are sent off to the different parts of the outer as well as the middle ear, and it is of the same importance for the ear as the ciliary ganglion for the eye. Lastly, the chorda tympani from the facial passes through the tympanum without giving off any branch there.

## CHAPTER VI.

### CATHETERISM OF THE EUSTACHIAN TUBE.

33. Before passing on to the diseases of the middle ear we must first consider catheterism of the Eustachian tube, without which operation it is plainly impossible, in many cases, to investigate these diseases thoroughly or to treat them satisfactorily.

The catheter is employed to lengthen the Eustachian tube outwards, as it were, and so to enable it and the tympanum to be directly reached.[1] The tube described by the name of ear-catheter serves, therefore, only as an accessory means for further operations, inflation, injection, &c., and is by no means used on its own account.

[1] As is well known, a layman, postmaster Guyot, at Versailles, first practised the introduction of a tube into the Eustachian tube on himself, through the mouth, and in 1724 he communicated with the Academy at Paris on the subject. The Academicians pronounced the tin tube, bent like a knee, which was laid before them, as "very ingenious," and thought that "the mouth of the Eustachian tube at least might be washed out by it, and that this might be useful in certain cases."—'Histoire de l'Académie Royale des Sciences,' année 1724, Paris, 1726, p. 37. An English physician, in 1741, made a communication to the Royal Society of London on the introduction of a curved silver tube through the nose into the Eustachian tube. We may justly wonder at the length of time physicians needed to gain any practical advantage from the Eustachian tube if we consider that even the ancients, as Alcmaion and Aristotle had a very clear idea of this connecting canal between the ear and the throat. Yet it sounds strangely free from misgiving when Bartholomeus Eustachius, in the 'Epistola de Auditûs Organis,' Oct., 1562, in which the tube, again discovered by him and named after him, was fully described for the first time, exclaims joyously, "*The knowledge of this canal will be most useful also to physicians for the proper employment of remedies, because they will know after this that bodies, even large ones, can either be expelled by nature from the ears, or easily removed by the assistance of remedies, not through narrow foramina, but by a very wide passage.*"—'Barth Eustachii, Opuscula Anatomica' first appeared Venetiis, 1565; Delphis, 1726, p. 140, and yet 162 years passed, to Guyot, who was not a physician.

Fig. 4.

Its beak must, moreover, be simply introduced into the funnel of the pharyngeal opening, and by no means be pushed further into the tube, as surgeons so often think. Silver catheters are generally the most useful, with the end well rounded; a ring is attached by the side of the funnel-shaped mouthpiece, in the direction of the curved end, partly that the instrument may be manipulated more easily during the operation, and partly that the position of the no longer visible end may be always known.

As the inferior nasal meatus is sometimes narrower, sometimes wider, and also the distance from the posterior end of the septum nasi to the opening of the tubes varies very much, several catheters are necessary, in which, however, the calibre of the tube is of less importance than the curve and length of the beak. When the formation allows the introduction of a tube strongly curved and not too narrow, a relatively more powerful effect will be produced. Three different catheters are usually enough, two of which, differing only in the length of the curved end, may measure 3 mm. in diameter, rising to 4 mm. at the point (Fig. 4), while the third, applicable for children, and generally when the nasal meatus is narrow, is thinner, and measures 2 and 3 mm. Elastic catheters are much less to be commended than unyielding tubes. As a rule it is more difficult to operate with flexible instruments, as the safe sense of touch is wanting; it is also much easier with such instruments to get out of the right passage; as a rule, also, scarcely any pain is caused by silver tubes. All elastic catheters, besides, even those more recently recommended by Politzer, of vulcanite, are exposed to the risk of breaking during the operation. The least useful are the elastic catheters which are provided with a directing wire, and which are still frequently employed in France. Oiling the instrument, as a rule, is at the least superfluous; but in

order possibly to remove some obstacle and to moisten the passage a little, the patient should blow his nose before the operation.

34.—That catheterism of the ear is regarded by most physicians as an unusually difficult and painful operation—and, in fact, experimental attempts generally cause much pain to the patient without relieving him to a corresponding extent—depends upon this, that physicians generally think that they can here entirely dispense with the preliminary conditions necessary for every operation, namely, thorough knowledge of the parts, and repeated previous practice on the dead subject. It is best to practice first on the skull divided in half in the sagittal suture, and afterwards to make further attempts on entire skulls, or on the dead subject, in which the right position of the catheter must be ascertained by the introduction of the finger into the mouth. Afterwards the physician may practice and make use of what he has learned upon himself, blowing air into his ear through the catheter by means of an elastic bag.

The chief points in the operation are the following:—The extremity of the instrument, with the point directed downwards, is introduced into the inferior meatus of the nose, the outer part of the catheter then quickly raised, while the point remains at rest in the entrance to the nose, and the tube, held uniformly horizontal, the ring directed downwards, is now gradually and slowly pushed further in, until the posterior wall of the pharynx is reached. The catheter is then drawn back about $\frac{1}{4}$—$\frac{1}{2}''$ towards the operator, and three eighths of a turn outwards and upwards is given to the end (which has been till now directed downwards), so that the ring is turned towards the external ear.[1]

We may briefly mention the chief causes of failure. The instrument should not be kept long at the entrance to the nose, as this part is very ticklish. In order to dilate it the upper lip may be gently drawn down, or the alæ of the nose may be drawn a little on one side. In raising the catheter there is danger of its passing into

[1] In cases of difficulty the septum nasi affords an index of the position of the tube, and Löwenberg, in such cases, and Politzer in all, recommends the following method of passing the catheter. The catheter is introduced in the ordinary manner as far as the posterior wall of the pharynx; its point is then turned inwards or towards the opposite side, and the instrument withdrawn until the slight resistance of the septum nasi is felt. By then rotating the catheter with its point downwards, it is easily passed into the Eustachian tube, the ring pointing towards the ear.—Ed.

the middle meatus of the nose, unless the point of the instrument is kept at rest, and fixed, to serve as a fulcrum for raising the rest of the catheter from the oblique to the horizontal position. If the catheter lies properly in the inferior meatus of the nose, it forms nearly a right angle with the plane of the face; on the other hand it makes an acute angle with it, and is inclined downwards if it has passed into the middle meatus.

The mistake occurring most frequently is that the operator does not, in the last stage, draw the catheter far enough forward from the wall of the pharynx, so that the point is turned too soon, or is allowed to slip backwards again during the turning, in consequence of which it lodges in Rosenmüller's fossa, a rather deep and very glandular depression behind the cartilaginous tubes. This mistake is the less obvious, as almost the same feeling of elastic resistance in moving the catheter is generally experienced there as when it is actually introduced into the mouth of the tube. As a rule this position causes much more pain to the patient, and he does not now feel the air blown into the ear, but in the throat. It is very often necessary to treat irregularities in the formation of the nares by corresponding lateral deviations of the point of the instrument, and especially outwards. In cases in which the operation is impossible or too painful on one side, the catheter may be introduced from the opposite nostril, for which purpose it should generally have a rather long beak. When once the catheter lies in the tube, the patient has no inconvenience, either in speaking or swallowing; on the other hand, both impede the last part of the operation, as every movement of the soft palate—every contraction of the pharyngeal muscles, narrows the space, and by pressure of the mucous membrane on the point of the instrument, causes pain. It is a further proof of the proper position of the catheter, if it cannot be turned upwards without slipping out of the mouth of the Eustachian tube.

35. The catheter is most frequently by far used to blow air into the middle ear; this "air douche" is applied either by the mouth, or by an india-rubber bag (to the mouthpiece of which a horn point, fitting into the funnel of the catheter, is attached, by a piece of india-rubber tube), or less frequently, where the resistance on the part of the walls of the tube is especially great, by means of a condensing pump. To observe the sounds which are produced in this

way in the patient's ear, our own ear may be applied to the patient's, either directly or more conveniently by means of an india-rubber tube, 20—24 in. long, quite appropriately called an "otoscope."

By testing the hearing again after auscultation of the ear by means of the air-douche, a series of conclusions may be drawn—not only how far the tube is pervious and moist, but also how far the difficulty of hearing depends upon closure of the tube, and upon other changes in the tympanum (accumulation of mucus, fixation of the membrane, &c.), which can be attacked by purely mechanical means. These conclusions are of the greatest importance for diagnosis, prognosis, and treatment. For it is this inflation with air through the catheter, which not only separates the abnormally adhering mucous surfaces of the Eustachian tube from each other, and so restores the atmospheric equilibrium, essential to the normal state of the tympanum, between it and the pharynx; but the membrana tympani is also driven further outwards by it, of which we may convince ourselves by inspection at the same time; any abnormal contractions and adhesions of the same are in like manner necessarily pulled upon, and possibly stretched or torn.

The catheter, moreover, serves as a tube for conducting vapours and gases, or medicated injections, into the tympanum, or for the introduction of mechanical dilators, in the form of bougies, into the tube.

36. We here have to refer to a new process which, in many cases, may answer the same purpose as the catheter, and which is distinguished by its simplicity and the facility of its employment. This is "*Politzer's process* for opening up the Eustachian Tube."[1] It consists in this, that the air in the naso-pharyngeal space is condensed, by inflation from without, while the patient swallows. The application of this process is extremely simple, for only a straight or slightly curved tube, open at both ends, is required. This is introduced about half an inch into the anterior nares. The nares are then closed air-tight over the tube by gentle pressure with the fingers on both alæ nasi, and care need only be taken further that the patient swallows exactly at the same moment that air is strongly blown into the tube. The latter may be done by the mouth or by means of an india-rubber bag. The best arrangement is to unite the bag to the

[1] 'Wiener Med. Wochenschrift,' 1863, No. 6, u. ff.

tube for insertion into the nose, the end of which should be thick and flattened laterally, by a short elastic tube. By this process air can likewise be blown into the tympanum—*i.e.* the air there condensed—and it is especially applicable where any obstacle prevents the performance of catheterism, either through an unfavorable structure of the part, or the peculiarity of the patient, as in children, or through absence of practice in the physician. This method is of special value for self-treatment on the part of the patient. Inflation through the catheter produces more powerful effects in most cases, and has the advantage that its action can be more localised; it admits also of much more varied applications.[1]

37. *Rhinoscopy*[2] must yet be briefly considered: a new method of examining the naso-pharyngeal space, by which it is possible to investigate, more or less accurately, the posterior or upper surface of the soft palate, the posterior nares, with the turbinated bones; the faucial opening of the Eustachian tube, and its adjacent parts; as well as the roof of the pharyngeal vault, and the posterior wall of the pharynx, and to bring under observation their normal or diseased condition. In this examination we use mirrors similar to those used in laryngoscopy, only they must be bent nearly at a right angle with the handle. If sunlight cannot be obtained, a very bright lamp is necessary, since the light must be considerably stronger than for examining the larynx. It is either allowed to fall directly into the patient's throat, or thrown in by a concave mirror, which is best attached by a ball-and-socket joint to a spectacle frame (Semeleder). Palate hooks, for raising the uvula, are not often borne. The tongue may be pressed down with the finger or a broad spatula.

[1] See my Essay on this process in 'Archiv für Ohrenheilkunde,' i, 1, pp. 28—43.

[2] Czermak, 'Wiener Wochenschr.,' 1858, N. 13 and 16; 1859, N. 32; 1860, N. 17; 1861, N. 6 and 7. Also 'Der Kehlkopfspiegel und seine Verwerthung, &c.,' Leipzig, 1860, p. 31. 'Virchow's Archiv,' xxiii. Voltolini, 'Virchow's Archiv,' xxi, p. 45. 'Deutsche Klinik,' 1860, N. 21; 1861, N. 42. 'Rhinoscopie und Pharyngoscopie,' Breslau, 1861. 'Jahrbuch der Gesellschaft der Wiener Aerzte,' 1861, ii, p. 93. Semeleder, 'Zeitsch. der Wiener Aerzte,' 1860, N. 19, 47. 'Oesterr. Zeitschr. f. prakt. Heilkunde,' 1860, N. 21, 22. 'Wiener Allg. Med. Zeitg.,' 1860, N. 27. 'Die Rhinoscopie und ihr Werth für die Ärztliche Praxis,' Leipzig, 1862. Störk, 'Zeitschr. der Wiener Aerzte,' 1860, N. 26. Dauscher, ibid., 1860, N. 38. Merkel, 'Die Functionen des Menschl. Schlund. und Kehlkopfes,' Leipz., 1862.

The recognition of parts will be much facilitated by the previous introduction of a brightly polished ear catheter through the nose. Great sensitiveness of the pharynx, so that directly it is touched the pharyngeal muscles contract, and especially narrowness of the pharynx, are obstacles which often render this examination much more difficult than laryngoscopy.

## CHAPTER VII.

### SIMPLE OR MUCOUS AURAL CATARRH.

38. The diseases of the middle ear consist of inflammation of its mucous membrane, as in catarrh, and this may show itself either as simple, *e.g. mucous catarrh*, or with a more intense degree of the inflammatory process, as *suppurative catarrh* with abundant cell-formation accompanying. Of both varieties there is an acute and a chronic form. It has lately been observed that serous effusion into the tympanum also occurs pretty often, especially after long obstruction of the Eustachian tube. Periostitis of the tympanum, as a primary and independent form, cannot be recognised; yet the nutrition of the bone suffers secondarily in all severe diseases of its membranous lining, which, as has been mentioned, serves not only as mucous membrane, but also as periosteum.

39. *Simple acute catarrh of the ear* is characterised by the rapid appearance of hyperæmia and swelling of the entire mucous tract of middle ear, with considerable increase of secretion, which, however, still preserves its mucous character. This state is generally associated with other catarrhal diseases, influenza, pharyngeal or bronchial catarrh, or even pneumonia. Syphilitic disease of the throat is a not uncommon starting-point for it. A very extreme degree of difficulty of hearing generally quickly supervenes, and in severe cases with violent pain radiating from the ear over the whole side of the head, aggravated on any action of the pharyngeal muscles or any movement of the head, and frequently lasting for weeks. In milder cases patients complain, at least, of a troublesome feeling of pressure and weight in the affected ear. Violent and frequently extremely harassing noises and throbbing in the ears are never absent, and besides this oppression and weight of the head, giddiness, even while at rest, is very often present. Cases in which the fever or

giddiness is very severe, and, as may be often observed, the pain is diffused more over the head, and less confined to the ear, while at the same time the difficulty of hearing is only on one side and so scarcely noticeable, may easily be mistaken for congestion of the brain or meningeal irritation, and the origin of the whole disease in the ear may be entirely overlooked.

As regards the objective appearances, it is very important in the diagnosis of the disease in question, that the meatus is found completely unobstructed, and the membrane shows only such changes as may be produced by a process behind it and in its layer of mucous membrane, viz. diffused redness from the deep parts, followed by disappearance of the glistening of the surface, and infiltration, frequently with partial bulging or yellowish colour.

The prognosis is so far favorable, as perforation of the membrane only occurs rarely, and then nearly always during violent sneezing or blowing the nose, and only transiently. The hearing of the patient can be very considerably improved by early local treatment; but by such an acute attack the foundation is not unfrequently laid for insidious aural catarrh, since thickening of the mucous membrane of the Eustachian tube and tympanum, abnormal bands of adhesion, &c., are very apt to remain after it. The main point, consequently, is to prevent the development of such conditions by removing, as soon as possible, the mucus accumulated in the ear. This is most thoroughly done by an early incision of the membrana tympani, followed by air-douches,[1] by which the mucus is driven from the tympanum into the meatus. In milder cases, air douches (catheterism or Politzer's process), undertaken as soon as possible, are sufficient, since in this way a mode of escape is provided for the mucus present, and the adhering surfaces of mucous membrane in the Eustachian tube and the tympanum are separated from one another. The effect of the paracentesis and the air douches, which operations can never be undertaken too early, is mostly immediate, and the pain ceases, for the most part, directly on their application. Further, local bleeding, purgatives, and subsequently gargles, are useful.

[1] Aural surgeons have only lately begun to *appreciate* paracentesis of the tympanum by means of incision of the membrane, and Schwartze's publications have here opened the right path. See "Studien und Beobachtungen über die Kunstliche Perforation der Trommelfells," in 'Archiv für Ohrenheilkunde,' B. ii, 1 and 4, also B. iii, 2—4; and also his work 'Über die Paracentese des Trommelfells,' Halle, 1869.

40. *Simple chronic aural catarrh* is by far the most common disease of the ear, and, consequently, also the most frequent cause of deafness. Two very different forms of this affection, which present so very many varieties, must be especially distinguished—dry and moist catarrh.

*In dry catarrh*—sit venia verbo!—the process, for the most part interstitial, goes on in the tissue itself, and, therefore, causes especially a thickening of it, a sclerosis of the lining membrane of the middle ear, which becomes denser and more inelastic. Indurations and cretaceous deposits, partly molecular, partly also of a macroscopic nature, frequently result. The course is remarkably slow and insidious, attended for the most part by the later occurrence of very harassing noises in the ears.

Properly catarrhal symptoms, according to the common use of the word, hyperæmic swelling, increased formation of mucus in the Eustachian tube or pharynx, closure of the tube, dependence on the weather, &c., are often entirely absent. The meatus and membrana tympani appear abnormally dry, the latter frequently extremely glistening. Its colour is little changed; perhaps at the edge it is of a somewhat darker grey, with a reddish-yellow mixed up over the rest of it, especially in the middle of the posterior half; calcifications also are often plainly visible, running, as yellowish-white elongated streaks, in the zone between the attached margin of the membrane and the umbo. The handle of the malleus stands out very sharply, and inclines forwards with very distinctly marked outline. Air blown in through the tube strikes with a full, sharp, dry sound, and the air douche is at most only followed by some diminution in the noises in the ears and a somewhat easier feeling in the ear and head. Prognosis is unfavorable; very frequently it is impossible even to check the progress of the disease, and to save the patient from an extreme degree of deafness, which is caused by a gradually developing immobility of the chain of ossicula through calcification of the membrane surrounding the stapes (osseous anchylosis of the stapes) or of the membrane of the fenestra rotunda. This form seems to occur extremely often in thin people with dry, delicate skin, and very excitable nervous system, and is, therefore, as a rule, looked upon as a "nervous" affection. An active cold-water cure is, in these cases, strikingly mischievous; they often even seem to arise[1] after such a course.

[1] On the frequent injurious effects of cold water treatment on the ear, see, also, Schwartze, in 'Archiv für Ohrenheilkunde,' 3, p. 212.

41. The other form, *moist catarrh,* is characterised more by hyperæmia, with subsequent swelling and hypertrophy of the tissues, as well as by increased secretion, partly mucous, partly serous. This process is sometimes more localised in the Eustachian tube, with gradual contraction and often closure of it, and sometimes it shows itself more especially in hyperæmia and tumefaction of the tympanum itself. The first-named form, which is usually known as "Tube Catarrh," arises most frequently from a cold in the head, or pharyngeal catarrh, and so is observed by far most frequently in children and other persons subject to nasal and pharyngeal catarrh, *e.g.* not seldom in tuberculosis. Should the closure of the tube continue long, it necessarily exerts an injurious influence on the deeper-seated structures of the ear. As the air confined in the tympanum becomes gradually absorbed, atmospheric pressure acts upon the outer surface only of the membrane, which thus becomes unnaturally forced inwards, and with it also the chain of ossicula, and especially the foot of the stapes. By the abnormally increased pressure upon these structures—the membrana tympani, the ossicula, and the contents of the labyrinth—changes are necessarily produced in their structure and equilibrium, which may remain even if the normal communication between the ear and the pharynx is again restored.

For the most part this form is marked by the position of the membrana tympani, which appears abnormally concave, deeply sunken in, or, more correctly, forced in. In many cases the membrana tympani, though in no way altered in colour, gives an impression as if it were thinned or atrophied, and then the long process of the incus, which may be almost in actual contact with the membrana tympani, behind and parallel to the handle of the malleus, is very plainly visible through it. If a marginal thickening of the mucous coat of the membrana tympani has taken place in the earlier stages the centre and periphery differ extremely from one another in colour and curvature. Whilst a wide marginal zone of denser tissue and whitish-grey appearance remains in its normal plane, the translucent, thin, greyish-red centre, bounded externally by a sharp line, projects, funnel-like, inwards.[1]

Besides a frequent dull hearing of the patient's own voice, and *tinnitus* often extremely harassing, transient attacks of really severe pain occur in this form. When the disease is not of too long stand-

[1] A masterly description of the condition of the membrana tympani in long closure of the Eustachian tube is given by Politzer, a. a. O., p. 131—134.

ing the prognosis is favorable, for mere opening the tube, either by the catheter or simply by Politzer's process, as a rule, not only extremely improves the condition momentarily, but also, by proper treatment of the nasal or pharyngeal affection and regularly keeping the tube open, a very fair, often even a very good, condition of the ear may be maintained permanently. Many cases of difficulty of hearing in the aged or in anæmic persons appear to arise from deficient action of the muscles which open the tube; in this way the same results follow as in the above-mentioned closure of the tube. Tonics and gargles are often of the greatest use in such cases.

42. *Chronic aural catarrh*, however, shows itself most frequently in hyperæmia and a thickened condition of the tympanum itself, which is, of course, often accompanied then by contraction and closure of the Eustachian tube, the latter not infrequently proceeding from thickening and swelling of the mucous membrane at the tympanic opening of the tube.[1] Transient tearing and throbbing pains frequently occur in a more subacute course, otherwise all subjective symptoms, even noises in the ears, are absent, so that the constantly increasing difficulty of hearing alone points to an affection of the ear. In these cases a very remarkable dependence of condition upon the state of the weather is observable; also in proportion as a nasal or pharyngeal catarrh is present, the deafness and confusion of the ear are subject to morning exacerbations. That there is hereditary predisposition to chronic aural catarrh cannot be denied.[2]

The changes visible in the membrana tympani correspond to the thickened condition of its mucous coat, and therefore generally show themselves earliest and most markedly at the periphery of the membrane, where, in a normal condition, the mucous layer is most developed. This margin appears denser, duller, and more whitish-

[1] A complete closure of the tympanic orifice of the Eustachian tube by increased growth of connective tissue is described by Schwartze, in 'Archiv für Ohrenheilkunde,' i, 3, p. 215.

[2] If we consider that certain family resemblances, propagated through generations, are evidently based only on a similar structure of the skull, it becomes a question whether in like manner great narrowness of the tympanum, and especially of the naso-pharyngeal space, is not peculiar to certain forms of skull, and may be inherited in the same way; as, *e. g.* the form of the osseous part of the nose. The dimensions of these parts are individually extremely different; but that a certain congenital narrowness of them is a favorable condition for the development of closure of the Eustachian tube, adhesions, &c., cannot be denied. Thorough anatomical investigations on this subject are wanting.

grey. But the whole membrana tympani often seems changed in a similar way. In more severe cases, this thickening of the mucous membrane extends over the whole tympanum, and therefore the covering of the ossicula, and especially the mucous membrane of the two fenestræ, present the same change.

Very important *contractions* also occur thus in the niches at the end of which the membrane of the fenestra rotunda and the stapes are situated. As the mucous membrane there becomes hypertrophied, these niches or depressions by degrees become completely filled up and closed, and this must exert a most injurious influence on the functions of the above-named parts, and, from their great importance for conducting sound, on the acuteness of hearing. How through such swelling opposite portions of the tympanum come into contact, and so give rise to abnormal adhesions, has been already described.

The prognosis is not always unfavorable, because the progress of the disease can very frequently be arrested and the condition improved. In any case no definite prognosis at all can be given after the first examination; indeed, the treatment must decide it.[1] More recent cases may, as a rule, also be subdued, and the result of treatment, therefore, will always be found more favorable if fresh cases come to the surgeon more frequently than old ones, but these constitute hitherto a really numerous contingent.

43. The treatment of all these varieties[2] of chronic catarrh must consist, above everything, in frequent application of the air douche, by which the tube becomes at once more pervious, any mucus contained in it or the cavity of the tympanum removed, and further, a mechanical pressure exerted on the elastic walls of the tympanum (the membrana tympani and the membranes of the fenestræ), which extends and stretches them, thus opposing any commencing loss of elasticity, or rigidity, and also obviating any abnormal fixations. The catheter is best used for this purpose, air being blown through it either by the mouth or an india-rubber bag.

[1] Schwartze, 'Prakt. Beiträge,' p. 24.

[2] In attempting to better demonstrate the extreme variety in which the chronic catarrhal process shows itself in the middle ear, by representing certain prominent manifestations of disease in apparently separate groups, I have not, meant to establish different forms of disease, and I would lay special stress upon the fact that the three forms alluded to occur much less frequently alone than combined in various ways and the one passing into the other.

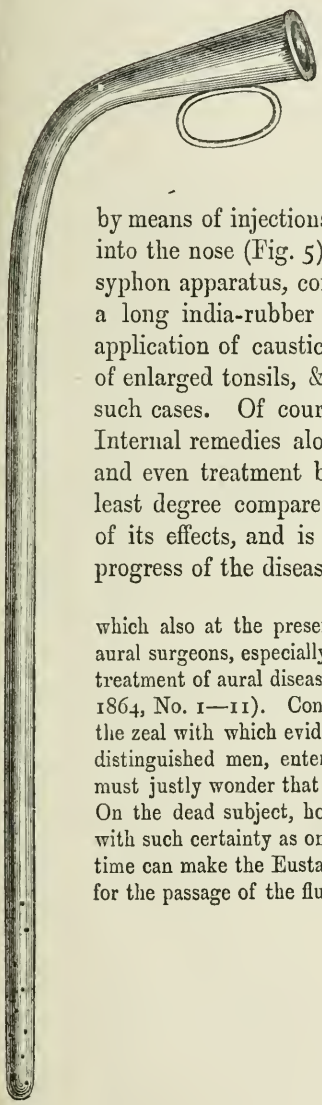
In milder cases, and in simple closure of the tube, Politzer's process is sufficient; and, after the tube is once pervious, regular and frequent use of Valsalva's method should be recommended to patients (self-inflation of air, with closed mouth and nostrils, after a previous deep inspiration). But in all cases not quite recent and simple the abnormally secreting and morbidly swollen or already hypertrophied mucous membrane must be still further acted upon. This is done by blowing in vapours or injecting fluids, both by means of the catheter. In moist swelling, and where increased secretion of the mucous membrane is present, vapours of chloride of ammonium are most useful, best evolved in a nascent state (from caustic ammonia and hydrochloric acid), whilst in a dry and thickened condition of parts, tepid or warm water vapours, alone or with iodine, introduced with a certain degree of pressure into the tympanum, most speedily promote reabsorption. Injections of astringent or slightly stimulating fluids (solutions of zinc, chloride of ammonium, iodide of potassium, iodine, caustic potash, &c.) often produce the same effect, and are preferable in the case of a narrow Eustachian tube, and when a too extensive irritation of the nasal mucous membrane would be produced by warm vapours.

The application is very simple, nothing being needed but a glass tube, to convey into the catheter the desired number of drops. If the catheter is rightly placed (which by no means wholly occludes the tube), and if the patient be made to swallow during inflation, a portion of these drops will always enter the tube and tympanum, even though a further portion of them escapes into the throat or is forced into the mastoid process.[1] In extreme contraction of the Eustachian

[1] The sensation of the patients, besides the scarcely doubtful auscultatory phenomena, prove that by a proper process fluids can be blown into the tympanum through the catheter, for they complain as a rule of a very definite sensation at the same moment, and where more irritating substances are used, of more or less pain in the ear. This is demonstrated also by examination of the membrana tympani, which immediately after the operation usually appears more or less red and injected, according to the character of the fluid. Experiments on the dead body also afford convincing proofs, as those undertaken by Dr. Schwartze, in conjunction with Professor Theodor Weber, in Halle—see 'Deutsche Klinik,' 1863, p. 367; where, at the same time, the sources of error are pointed out by which, in all probability, the "*Otiatrische* Committee" of the Berlin Medical Society were led to different conclusions from their experiments on the dead subject to settle this question (ibid., p. 250). Josef Gruber, of Vienna, also, on the strength of many experiments on dead subjects and extensive observations on the living, declares himself thoroughly in favour of such injections,

tube it must be dilated with catgut or whalebone sounds before further operations are resorted to. Treatment of the nasal and pharyngeal mucous membrane, by the morbid condition of which the whole process is frequently maintained, or even set up, is also very important in the treatment of aural catarrh. Pharyngeal and nasal douches, either by means of injections through a perforated tube introduced into the nose (Fig. 5), or, which is very much simpler, by a syphon apparatus, consisting of a perforated lead plate and a long india-rubber tube (Theodor Weber), gargles, the application of caustic by a brush or little sponge, excision of enlarged tonsils, &c., are very frequently of great use in such cases. Of course, the general condition is regarded. Internal remedies alone, however, are scarcely of any use, and even treatment by baths and drinks cannot be in the least degree compared with local treatment in the certainty of its effects, and is scarcely ever capable of arresting the progress of the disease.

Fig. 5.



which also at the present time are, perhaps, performed daily by all aural surgeons, especially those who use the catheter regularly in the treatment of aural diseases ('Oestr. Zeitschrift für prakt. Heilkunde,' 1864, No. 1—11). Considering the importance of the question, and the zeal with which evidently the Berlin Committee, containing such distinguished men, entered upon the solution of this question, one must justly wonder that the experiments were not again undertaken. On the dead subject, however, such injections cannot be performed with such certainty as on the living, who by swallowing at the same time can make the Eustachian tube patent, and so dilate the canal for the passage of the fluid.

## CHAPTER VIII.

### ACUTE SUPPURATIVE CATARRH OF THE MIDDLE EAR, OR ACUTE OTITIS MEDIA.

44. *Acute Suppurative Catarrh* of the middle ear (*Acute Otitis Media*) is observed most frequently in connection with or as sequelæ of the acute exanthemata, typhus, and tuberculosis. Thus, it is developed in the cachectic and scrofulous after injuries, which, in the healthy, in all probability, would have produced only simple aural catarrh. The objective and subjective symptoms are essentially the same as in simple acute aural catarrh, except that the disturbance, as a rule, appears much more severe, and the general condition of the patient is more seriously involved. Cases occur, however, here and there, in which such abscesses in the tympanum lead to perforation of the membrane without any pain.[1]

Perforation of the membrana tympani occurs with great frequency even after few days, and may, under certain conditions, be regarded as a favorable turn, since the abscess in the ear is discharged externally through it. The more resistent the membrana tympani, *e. g.* from previous thickening processes having occurred, the more violent will be the symptoms with which the disease runs its course, and cases are described in which, under such conditions, the inflammation extended to the meninges and brain, and a fatal result rapidly followed, with most violent symptoms, and after most agonising pain.

*Suppurative catarrh of the middle* ear is by far the most common cause of perforation of the membrana tympani. This may arise simply from pressure exerted by the continually accumulating secretion; but, perhaps, more frequently it depends upon rupture of the inflamed, softened, and consequently spongy, membrana tympani, as the result of sudden fluctuation of atmospheric pressure

[1] Schwartze, 'Archiv für Ohrenheilkunde,' i, 2, p. 144; Politzer, p. 65.

within the ear. This is indicated by the fact that, as a rule, air first hisses through the ear during blowing the nose or sneezing, and that, at the commencement, a longitudinal rent is found, and not a round orifice, as would be the case after bursting of an abscess. Perforation much more rarely results merely from inflammatory destruction or ulceration in simple inflammation of the membrane or otitis externa.

Acute suppurative catarrh is so often developed during scarlatina and measles, and when left to itself so often produces serious otorrhœa and severe deafness, even deaf mutism, that a conscientious medical man ought to make it his duty, in any child with scarlatina and measles, to pay constant attention to the state of the ear, and not wait until he is directed to this organ by the patient or his friends, or, as is most frequently, by the escape of pus from the ear. By this means enormous mischief, and especially many cases of deaf mutism, might be warded off.

45. An important anatomical fact must be referred to here which evidently has not yet attracted the attention it deserves on the part of those who study children's diseases; namely, at post-mortem examinations of children the middle ear extremely often (perhaps in the majority of cases) is found in a state of acute exudative catarrh, *i. e.* the tympanum, as well as the adjacent Eustachian tube and mastoid cells, filled with pus or mucus and covered with a thick, swollen, and hyperæmic membrane. No one knows hitherto why inflammation of the ear is so extremely common in children, and the question now arises whether this pathological condition, which in the adult would express itself in very marked symptoms during life, can exert no perceptible effect upon the well-being of children, remaining latent, as it were? or whether, hitherto, a whole series of symptoms of disease in children have been incorrectly diagnosed?

We observed before that inflammations of the middle ear, besides violent pain and difficulty of hearing, often enough led on to irritable and comatose conditions of the sensorium, such as have hitherto been recognised as properly belonging only to processes within the cranial cavity. If it is possible, then, to be mistaken about the origin of such symptoms in the adult, how much more easily will this be the case in the child, who can give us little or no information about the position and seat of his morbid sensations, and in whom we are

always more or less restricted to a conjectural explanation of the general symptoms of disease. Perhaps, in just such cases treatment directed against the collection of secretion in the ear, especially Politzer's process, would be the best means to enable us to recognise the real bearing of this striking pathological condition.[1]

46. The treatment in acute suppurative aural catarrh, besides local and general antiphlogistic remedies, consists mainly in strict attention to the inflammation of the nasal and pharyngeal mucous membrane, from which, for the most part, the aural disease proceeds. Cold applications to the throat, cleansing injections into the nose may be used, and in more severe cases the mucous membrane should be cauterised with nitrate of silver. Removal as speedily as possible of pus from the tympanum is, of course, most important in such cases; and Politzer's process is the mildest method of accomplishing this, for by it the Eustachian tube is made pervious, and the escape downwards of pus collected in the tympanum is promoted by a method easily practised by the surgeon and least troublesome to the patient.

In children it may be applied the more easily, as air usually passes into the ear without any simultaneous swallowing, so that one need simply blow vigorously into the closed nostrils to produce a favorable effect on the ear. Poulticing, so often employed in all inflammations of the ear, must be wholly avoided in these cases, as it tends to speedy perforation of the membrana tympani and further softening.

Only in a few rarer cases, where no other treatment is possible, and the symptoms are so extremely threatening that perforation of the membrana tympani and escape of the pus by this way seems absolutely desirable and even necessary, should this result be accelerated by temporary applications of hot fomentation.

The radical remedy, in all cases, is incision of the membrana tympani by a cataract needle or a needle for paracentesis of the cornea. This incision is best made in a part where the membrane is

[1] Particulars on this subject may be found in 'Verhandlungen der Würzburger physikalisch-medic. Gesellschaft' vom J., 1858, B. ix; 'Sitzungbericht,' lxxvii; also in my 'Anatomie des Ohres' (§ 27); and, lastly, in my 'Lehrbuch der Ohrenheilkunde,' 4 Aufl., pp. 323—338. See, further, Schwartze, in 'Behrend's Journal für Kinderkrankeiten,' 1864, p. 52; and 'Archiv für Ohrenheilkunde,' 1, 3, p. 202. Also Hinton, 'Medico-Chirurgical Transactions,' 1856.

pushed outwards by the secretion collected behind it; the inferior and posterior part of the membrane appears the best for incision, as the tympanum is certainly widest in that position, and there is not so much danger of injuring the opposite wall. Even here it is advisable not to go deeper than one line.

47. As further concerns the *operation of incision of the membrana tympani*,[1] it would, of course, be important as a means of improving the hearing in cases in which difficulty of hearing depends at least partly on thickening and loss of elasticity of the membrana tympani, which, therefore, acts directly as an obstacle to the conduction of the sound. Whether this is really the case, or whether the chief obstacle to the propagation of sound lies deeper, consisting especially in thickening of the membranes of the fenestræ, is a question which in special cases cannot be answered beforehand, as a rule, but can only be solved by an experimental incision of the thickened membrana tympani. The thickening which is seen in the membrana tympani is most frequently only a part of the general thickening which has affected the whole mucous membrane of the middle ear, and then, of course, an opening in the membrana tympani can be of no benefit to the hearing. Closure of the Eustachian tube, which could not be relieved by any other means—a true occlusion of the canal—would be a further indication for this operation. This

[1] This operation, first attempted on dogs by Willis and Valsalva, was performed, for the first time, for deafness, by a Parisian surgeon, Eli (about 1760). It was subsequently introduced into scientific surgery by Astley Cooper (1800). Himly was the first who performed it in Germany.

The literature of the subject, very extensive, especially in the first ten years of the last century, is found condensed in Beck, p. 41, &c.; then in Linke, vol. ii, pp. 152—154. For the history, see, further, Linke, iii (continued by Wolff), p. 316; Frank, p. 302; also Wilde, p. 19 and p. 293. Recently Schwartze published very exhaustive historical studies on this subject in the 'Archiv für Ohrenheilkunde,' ii, 1.

During the last ten years it was repeatedly performed in France by Menière, Deleau, and Bonnafont; in Germany, on the other hand, but seldom, till, more recently, Joseph Gruber, in Vienna, recommended excision of a portion of the membrana tympani (Myringodectomy) as a cure for deafness and tinnitus. 'Allgemein. Wiener Med. Zeitung,' 1863, No. 39, 40: as well as Gruber's 'Bericht über die im Wiener Allgemeinen Krankhausen' 1863 behandelten 'Ohrenkranken,' p. 12 and p. 22. See, also, 'Schwartze's prakt. Beiträge,' pp. 17—19.

condition, however, as far as we know, seems to occur very seldom.[1]

Artificial perforation of the membrana tympani has further been proposed (Wilde) and performed (Schwartze) in extremely severe and harassing noises in the ears, since it had been observed that people with holes in their membranes relatively seldom complained of severe tinnitus. The chief use of paracentesis of the membrana tympani will always be the surgical one of evacuating serous, mucous, or purulent fluid, which has accumulated behind the membrane. The operation should always be followed by the air douche.

Making an artificial opening in the membrana tympani is extremely easy: the pain of it, perhaps, for the most part sharp, is however of only brief duration. Exceptionally, of course, very severe reactionary symptoms follow this operation (as the cases communicated by Gruber and Schwartze show). An exploring trochar, or slightly curved cataract needle, is best used for the purpose; with the latter a portion may even be cut out of a thickened and resisting membrane. The numerous instruments invented for this purpose, for the most part extremely complicated, appear at least to be superfluous. However easily the operation may be performed, the benefit in improving the hearing and diminishing the noises in the ears, which it produces in perhaps not too many cases, is lost again as easily and quickly, since for all that is known, it seems perfectly impossible to keep an artificially made opening, or even an extensive loss of substance of the membrana tympani with any certainty from closing.

Difficult as it often is to cause a perforation of long standing, and that has been produced by disease, to close, it is, on the other hand, just as difficult to keep one made purposely, open. However often the aperture is cauterised—however often the patient is submitted to Valsalva's process, even though bougies or small tubes, &c., be introduced, the great healing power of the membrana tympani,[2] after a shorter or longer time, generally defies all these means. Of the many cases reported of favorable issue of the operation, none,

[1] A case of this kind, with its history, is reported by Lindenbaum, in 'Archiv für Ohrenheilkunde,' i, p. 295, &c.

[2] Bonnafont (p. 375) reports that he has performed this operation on one patient about twenty-five times in the last three years without being able to keep the opening patent for longer than a few months.

except those which have remained under observation a very long time, yield any proof of real advantage from it. Most clinical histories are incomplete in this respect, and we must therefore agree with Schwartze when he says ('Archiv für Ohrenheilkunde,' ii, p. 35), that hitherto "only in extremely few cases has any permanent result been established by thoroughly credible authors."

In a case where it seemed to me important to keep such an opening in the membrane permanent, I should make a large pointed flap of the membrane, and try if it was not possible to bring it, by means of long contact, into adhesion with a part of the tympanum, or the membrana tympani, previously made raw. In similar condi- certainly perforations of the membrana tympani are found, which are permanent, and resist all attempts to heal them.[1] On the other hand, perhaps, many perforations might be healed by mechanical separation of their marginal adhesions, either by means of a cutting operation, or gradually by frequent exhaustion of the air in the external meatus, by means of the introduction of an india-rubber tube.

[1] In 'Virchow's Archiv,' Bd. xxi, Heft 3, such a condition is described by me, and at the same time (p. 301) a suggestion is made to maintain the orifice by this method. Politzer recently introduced small rings of gutta percha into the opening in the membrane in order to keep it patent. ('Wiener Med. Wochenschrift,' 1868-9.)

## CHAPTER IX.

### CHRONIC SUPPURATIVE AURAL CATARRH, OR CHRONIC OTITIS MEDIA.

48. *Chronic Suppurative Aural Catarrh*, or *Chronic Otitis Media*, is much commoner than the acute form. It is either developed from the latter, or arises from an extension of myringitis or otitis externa to the tympanum. Perforation or partial destruction of the membrana tympani is always present in these cases.

Where there is great swelling or a very small perforation, it is very difficult, even after previously cleansing the ear by syringing or a brush, to say with certainty whether an abnormal communication exists between the external and middle ear. Shapeless flocculi, shown to be of the mucous character by remaining undissolved in water, indicate secretion from the tympanum; so also do bubbles of air or pulsating movement[1] of the drops of fluid in the bottom of the meatus give evidence of perforation of the membrane. The latter will generally be most distinct if the patient blow his nose or force air through the Eustachian tube. If the tube is pervious, the opening small, and the secretion not too scanty, a loud hissing sound is produced on doing this, and secretion often forced out into the meatus.

The symptoms are confined for the most part to difficulty of hearing, varying in degree and often changing considerably, and suppurative discharge from the ear. Pain, as a rule, only accompanies it after special injuries, or when the pus accumulates behind a not sufficiently large opening. When ulceration has already commenced however, or in caries, the pain is for the most part very violent, of long duration, and frequently apt to return.

We shall most conveniently include the diagnosis and treatment of chronic otitis media with that of otorrhœa.

[1] Pulsations also occur, but extremely rarely, in membranes that are not perforated. (Schwartze's 'Archiv für Ohrenheilkunde,' i, 2, p. 140. Politzer, p. 139.)

49. In order to diminish the injurious effects upon the hearing and on the tympanum, thus exposed to the entrance of the external air, which a large perforation of the membrane produces, surgeons have, for the last two hundred years, laboured at the construction of *artificial membranes*, by which the place of the lost membrane may be supplied.[1] The best known artificial membrana tympani is Toynbee's, which consists of a thin circular little plate of vulcanised india rubber, 5—6‴ in diameter, to the centre of which a fine silver wire about 1″ long is fastened by means of two little silver plates. This terminates at its outer extremity in a little ring, so that the instrument can be more easily withdrawn. As this silver wire very easily comes into contact with the wall of the meatus on any movement of the lower jaw, and so produces, especially during eating, a very harassing noise in the ear, Aug. Lucae[2] conceived the idea of substituting for this silver wire an india-rubber tube about 1″ long, and 2 mm. in diameter, which is fastened firmly to the little india-rubber disc by a solution of india rubber. This last-named instrument is introduced by means of a wooden or metal pin, which is inserted into the india-rubber tube. These membranes of Lucae's[3] have moreover the advantage of being much less irritating, much cheaper, and at the same time much more durable than Toynbee's. For instance, it not unfrequently happens that after long use of such an one, the india-rubber plate becomes detached from the two little silver rivets, and may then remain in the ear. (I have removed five such india-rubber plates from the ear of a lady.)

The artificial membrana tympani is pressed against the remaining portion of the natural one, and in many cases produces a sur-

[1] Marcus Banzer (disputatio II, de auditione læsâ, Wittebergae, 1640, Thes. 104) recommended for this purpose a tube of elk's hoof, closed at one end by a pig's bladder. As a suggestion, an artificial membrana tympani occurs further in Leschevin (1763). In this century (1815) Autenrieth, in the 'Tübinger Blättern für Naturwissenshaft und Arzneilkunde,' Band i, Stück 2, p. 129, proposed to make an artificial membrana tympani "from a narrow, elliptically compressed, short, leaden tube, over the inner end of which the membrane from the air-bladder of a little fish had been previously stretched when wet, and varnished when dried." Linke relates, in his 'Handbuch der Ohrenheilkunde,' B. ii, p. 446, that he has used tubes made essentially in this manner on several patients with good results, and depicts these little instruments (Bd. ii, Pl. ii, fig. 6).

[2] 'Virchow's Archiv,' B. xxix, p. 20.

[3] To be obtained of the India-rubber manufacturer, Miersch, Berlin.

prisingly favorable effect upon the hearing. It must first be discovered by frequent trials in each individual case, whether the patient is benefited, and by repeatedly changing the position of the instrument, the spot to which it must be pressed to improve the hearing must be found out. The action upon which the benefit mainly depends is the pressure on the remaining portion of the membrana tympani, and the chain of ossicula; whether it be that by this mechanical influence a morbid relaxation in the connection of the ossicula is removed, or the fluid in the labyrinth is put under increased pressure.[1] Such an india-rubber disc, like the real membrane, will act as a vibrating plate, and can transmit a considerable number of vibrations to one of the ossicula (Politzer).

As further concerns the hearing in perforation of the membrana tympani, it is, as is known, sometimes very tolerable, sufficient for even more than ordinary requirements, even where there is very extensive loss of substance. It is not the hole in the membrane which has the most effect on the disturbance of hearing, but certain further results of the original inflammatory process. A most injurious effect will be produced by any thickening or swelling of the mucous membrane investing the ossicula and the membranes of the fenestræ, such as can be developed, of course, from suppuration, as well as from simple catarrh. If still more secretion is present, the degree of hearing will depend essentially upon whether or not the secretion is accumulated on a spot important for the conduction of sound. Hence in such cases the extremely varying degrees of hearing. Where there is a small perforation it must further be considered how far the membrane is thickened; for very frequently a comparatively much slighter difficulty of hearing is observed in a large than a small deficiency.

[1] This latter explanation was first given by Aug. Lucae, supported on a case observed during life, afterwards anatomically examined ('Virchow's Archiv,' B. xxix, pp. 4—30). See, also, on this condition, Toynbee, 'On the Use of an Artificial Membrana Tympani,' London, 1863; Housselle, 'Deutsche Klinik,' 1854, No. 43; Erhard, 'Deutsche Klinik,' 1854, No. 52; and 'über Schwerhorigkeit heilbar durch Druck,' Berlin, 1857; 'Von Tröltsch Lehrbuch,' pp. 347—352; Politzer, 'Wiener Medicinal-Calender,' 1864; 'Beleuchtungsbilder des Trommelfells,' p. 117, note: in which, especially in practice among the poor, a quite simple instrument of a piece of india rubber, 4–5‴ long 1½–2‴ thick, attached to a simple wire, is recommended; also in cases in which the stapes is absent, the addition of a stapes taken from the dead subject to Toynbee's artificial membrane is recommended. (Moos, 'Archiv für Ohrenheilkunde,' i, 2, p. 119.)

## CHAPTER X.

### SUPPURATION OF THE EAR.

50. Although *Otorrhœa,* or *Purulent Discharge from the Ear,* does not indicate a special disease, since we have observed it in very various diseases of the ear, otitis externa, myringitis, and otitis media, as one of the symptoms of the disease, yet we must, for practical reasons, subject it to a comprehensive examination.

*Purulent discharge from the ear* is still habitually looked upon as a very slight disease, and is even not unfrequently regarded as an evil necessary for the general health, which should not be interfered with. Such prejudices are gradually becoming rarer, but are still far from having disappeared, and even haunt the brains of otherwise very able surgeons. Suppurative inflammation of the soft parts of the external and middle ear should never be considered indifferent and unimportant, because on the one hand, it easily leads to ulceration of the bone, or caries, and on the other, very favorable conditions indeed are afforded by the anatomical connections of these parts, for extension of the inflammation to important neighbouring structures, and for those processes within the blood-vessels which produce the well-known embolic and general septæmic diseases.

51. *Caries of the Petrous Bone* is very rarely a primary disease of bone, but is usually developed in the course of acute or chronic inflammation of the soft parts of the ear, which has been treated badly or not at all. As already noticed, the periosteum of the meatus and tympanum stand in the most intimate nutritive relationship with their cutis and mucous membrane respectively, so that severe disturbances in the nutrition of the soft parts there must almost necessarily lead to similar disturbances in the nutrition of the adjacent bone.

Caries of the bone, in whatever part of the body it may occur, is

generally very much feared, for this reason, that, besides local destruction, it gives occasion for embolism, blood poisoning, general cachexia, or special degenerations of the liver, spleen, &c. In the temporal bone, however, which is perhaps attacked by caries more frequently than any other of the vertebral or cranial bones, quite peculiar circumstances have to be considered, arising from its special relations. Even in caries confined to the external meatus the short distance of the dura mater and brain, the proximity of the mastoid process, and the transverse sinus of the dura mater must be well borne in mind.[1] Still more momentous are these relations in the tympanum, from the mucous membrane of which the internal carotid artery, the dura mater, and the superior petrosal sinus, often also the internal jugular vein, are only separated by a delicate and frequently even defective layer of bone. The tympanum, besides, is directly continuous with the cells of the mastoid process; and, lastly, its labyrinth wall, with its two fenestræ only closed by membrane, offers but slight resistance to an extension of the inflammation to the internal ear, and so to the internal auditory meatus, which is lined by the dura mater. There is consequently, perhaps, no part of the human frame which, in such a small space, borders upon so many important organs as the tympanum, and in which, on anatomical grounds alone, we ought so much to watch for and dread suppurative inflammation of the soft and hard parts. Clinical experience, moreover, proves that caries of the ear very often leads to diseases dangerous to life, and, not seldom, to death. Inflammation of the brain substance, terminating in suppuration, is one of its most frequent consequences, and perhaps half of all cases of abscess of the brain take their origin from suppurative inflammation of the ear.[2]

Furthermore, otorrhœa often leads to suppurative inflammation of

[1] See Fig. 1 of the Anatomical Plate.

[2] Lebert's three articles, "Uber Gehirnabscesse," in 'Virchow's Archiv,' B. x. See, further, 'Kramer's Handbuch,' Berlin, 1849, pp. 375 and 385; Wilde's 'Aural Surgery,' on this head. Toynbee, 'Catalogue,' No. 808, 811, 814, 823, 824, 830, 835, 838, 848, 851, 852. Wolff, 'Berliner Medic. Zeitung,' 1857, Nos. 35 and 36. Guckelberger, 'Wurtemb. chirurg. Zeitschrift,' 1854, vii, 3. Virchow, in his 'Archiv,' B. viii, p. 374. Heusinger, 'Virchow's Archiv,' B. xi, p. 92. William Gull, 'Guy's Hospital Reports,' 1858, vol. iii (also in the 'Medico-Chirurgical Proceedings,' 1859, i, p. 395). V. Tröltsch, 'Virchow's Archiv,' B. xvii, p. 39. Eight cases of cerebral abscess, five of them resulting from otorrhœa, are contained in the 'Medical Times and Gazette,' 1861, p. 196; others in the same place, p. 246 and p. 349.

the dura mater, the affection extending to the dura mater generally either upwards through the roof of the tympanum, or by an extension of the process to the labyrinth, and inwards through the internal auditory meatus. The first form has hitherto been much more frequently observed; this may arise partly from the fact that the roof of the typanum and the dura mater covering it are at once exposed to view on taking the brain from the cranial cavity, while suppuration of the portion of dura mater lining the internal meatus must first be looked for, and so may very easily be overlooked. It frequently leads, besides, through ulceration of the coats of the carotid artery, or internal jugular vein, or transverse sinus, to considerable hæmorrhage from the ear, sometimes even shortening life. Such hæmorrhage has been observed hitherto as coming most frequently from the internal carotid artery, and on this account the common carotid has been often ligatured, and sometimes with good effect.[1]

52. The question now arises, Are we in a position, apart, of course, from cases where the carious bone is exposed to view, to know with any degree of certainty, in a given case, whether suppuration in the ear has already led to superficial ulceration of the

Joire, 'Gazette des Hôpitaux,' 1857, No. 151. Blondeau, 'Bulletins de la Soc. Anatomique de Paris,' 1858, p. 371. Gruber, 'Zeitschrift der Ges. der Wiener Aerzte,' 1860, No. 52. Schwartze,' 'Archiv für Ohrenheilkunde,' i, p. 195.

[1] As early as 1833, Syme twice ligatured the carotid artery for hæmorrhage of this kind, and once with success ('Edinburgh Med. and Surg. Journal,' vol. xxxix). Exact post-mortem descriptions of every case of the kind, partly accompanied with detailed history, are given by Marc Sée, 'Bulletins de la Société Anatomique de Paris,' 1858, p. 6; see 'Medic.-Chirurg. Monatshefte, 1860, August, p. 150; by Boinet, in 'Archives générales de Médecine,' 1837; by Toynbee, in 'Medico-Chirurgical Transactions,' vol. xliii. Further, a case of Santesson's, from the 'Schwedischen Zeitschrift Hygiea,' B. xiv, 1855; and a similar one from the 'Gazette des Hôpitaux,' 1861, N. 88, is fully reported in Schwartze's 'Rückblick auf den Leistungen im Gebiete der letzten Jahrzehnte,' 'Schmidt's Jahrbücher,' B. 116, p. 250, and B. 118, p. 351; where also the previously mentioned cases by Boinet and Toynbee will be found in abstract. A similar case, terminating fatally, but without dissection, is published by Wilde, in his 'Aural Surgery.' Bilroth ligatured both carotids for the same purpose, but unsuccessfully, in Zurich, 1864 ('Archiv für Ohrenheilkunde,' iv, p. 53). Additional cases are reported by Baizeau ('L'Union Méd.,' 1861, p. 350); Broca ('Archives Générales,' 1866, July, p. 24); and Hermann ('Wiener Med. Wochenschrift,' N. 30—32). Many similar observations may still be found in places unknown to me.

bone? Besides general probabilities arising from the course, the duration of the disease, and the entire general condition of the individual, the character of the pain should be particularly noticed; for instance, as a rule, in caries of the petrous bone, it is unusually severe, or described as of a deep boring character, perhaps lasting for days and weeks without interruption, and often appears suddenly and without any external injury, especially during the night in bed.

If such attacks of pain, occurring often after very slight purulent secretion, frequently occur without any special cause, and without any appearance of more recent inflammation, and especially if they cannot be traced back to any blocking up of the opening in the membrana tympani, or any other impediment to the escape of the purulent secretion, the attention should always be directed to the probability of caries, for which, however, they do not establish any absolutely certain diagnostic indication. I have also, indeed, dissected cases of caries of the ear, which went on for many years without any pain in the ear, and in which it first appeared just before the close of the scene, but then often with fearful violence, even resembling fits of mania. It has frequently surprised me that when suppuration of the ear has taken a dangerous turn, lead lotions were coloured black, and, on the other hand, this colouring no longer occurred when the process tended to improvement. Perhaps, therefore, we possess in lead lotions a kind of test for caries, and probably it is less to a sulphur than a phosphorous compound of lead that the bone substance attacked by softening and disintegration of its surface would yield material. When, on syringing, the chief secretion removed consists of flakes of mucus which float about in water, and are not dissolved, extensive ulceration can scarcely be thought of; but otherwise the external appearance of the secretion often affords us no certain indication in this respect.

Special care must be taken not to diagnose a carious process from the sharp penetrating odour of the discharge. The older the puriform secretion, and the more material for forming the fatty acids it contains, the more offensive is its odour. The most disagreeable smells of all are, therefore, found in neglected suppuration of the external meatus on account of the secretion of sebum and cerumen which takes place there, and this certainly, in cases where only its lining membrane is diseased, and, as may be well ascertained by ocular inspection, the bone is nowhere implicated.

Repeated admixtures of blood are always suspicious when no mechanical cause or injury exists, *e. g.* no probe has been used, and no polypi are present. Many suppurating surfaces, however, and very markedly the membrana tympani, when in a state of granulation, bleed on simple syringing with warm water. Microscopic examination of the matter may reveal to us particles of bone which, in any case, is the safest indication of caries, very much safer than finding elastic fibres in the discharge,[1] since these are found also in the cutis layer of the meatus and of the membrana tympani.

The least suitable, although the most usual, method of gaining information as to the presence of caries in the deep parts of the ear is the probe, especially when sight does not guide the hand, *i. e.* when the parts examined are not carefully illuminated and inspected during sounding. If, however, parts of the tympanum which are visible are concerned, the appearance gives more information than the touch, by which, besides, pain is always caused, bleeding for the most part produced, and injury very easily inflicted. It must be remembered how thin the labyrinth wall is in just those places which are opposite to the membrana tympani, and so also to the exploring hand. If these, besides, are morbidly softened and delicate, the very slightest pressure is sufficient to cause an artificial opening into the cochlea or vestibule, which might very easily become dangerous to life, since by it a way would be afforded for the inflammation and pus to spread to the internal auditory meatus, and so to the cranial cavity.

As a rule, then, the probe is quite useless in the diagnosis of caries, while serious injuries may be very easily inflicted by it.

53. If then, in a given case, it often appears very difficult, or even impossible to know with certainty whether the inflammatory process has spread from the soft parts to the bones, it is doubly necessary to know that this is never of much importance in prognosis and treatment. With the exception, perhaps, of ulceration of the larger vessels, all the other morbid conditions we referred to, as resulting from caries of the petrous bone, may also be developed without it from suppuration of the ear, as sufficient observations on the subject prove. This is altogether apart from the fact that, even

[1] Moos, 'Über das Vorkommen und die Bedeutung elastischer Fasern im Ausfluss von Ohrenkranken;' 'Verhandlungen des Heidelberger Nat. Med., Vereins,' 1862, p. 218.

without disease of the temporal bone, the roof of the tympanum pretty often presents deficiencies, so that scarcely any obstacle is opposed to the extension of inflammation upwards into the cranial cavity; and foul gases, resulting from decomposition in the tympanum, may exert a directly irritating effect on the brain substance above.

It is therefore evident that otorrhœa very often leads to fatal diseases, without leaving even the slightest trace of caries of the ear visible on the dead subject. For the explanation of this fact we must above all consider that the membrane lining the meatus and the tympanum is of the same importance to the temporal bone as the pericranium to the other cranial bones, the vessels of which are always in direct communication with the vessels of the inner part of the bone. But this narrow-meshed vascular network of the bone, and especially of the extremely vascular diploe, stands in the same relation to the endocranium—the dura mater; so that in the vessels of the temporal bone, and especially in its finely cellular medullary spaces, a connecting link is afforded between the soft parts of the ear on the one side, and the dura mater with its venous sinuses on the other.[1] Now we know that with the exception of the veins of the pelvis and lower extremities, in no part of the vascular system are such favorable conditions present for the formation of blood-clots and thrombosis, as in the sinuses of the dura mater and in the venous capillary network communicating with them, which pervades all the hollow spaces of the cranial bones, making them such vascular organs. It is evident that such a formation of fibrinous occlusions in the blood-vessels is very much favoured by inflammation of the bone substance, which so easily results from disturbance in the nutrition of the soft parts adjacent

[1] The cranial bones receive their arterial blood, first, from the external soft parts, the pericranium, and, secondly, from within or from the dura mater; and in the same way their venous blood is discharged in both these directions. In the cellular spaces of the diploe the little vessels which have penetrated on both sides from the medullary canals of the bone form, themselves, a communicating vascular network, which very soon assumes a venous character, and everywhere is surrounded by the fluid marrow. From this vascular network, the larger veins of the bone, the venæ diploicæ, are then formed, which partly empty into the external veins and partly discharge their blood inwards into the sinuses of the dura mater. The most lucid and complete description of the vascular arrangement of the cranial bones is given by Bruns, 'Handbuch der practischen Chirurgie,' B. 1, p. 205, 581, 583, &c.

and in direct vascular connection with it. Besides this, in osseous spaces so minutely subdivided by septa as those which everywhere surround the tympanum and meatus, purulent masses very easily remain imbedded, and decompose; leading on the one hand often to extravasation and subsequent coagulation of the blood, which through the larger veins of the bone affect the contents of the sinuses; on the other, to the development of actual sloughing centres of infection, from which decomposing matters are conveyed into the blood. Both processes, putrid decomposition and blood coagulation in the injured vessels, are favoured by the free access of atmospheric air, which is scarcely ever absent in the interior of the temporal bone, especially in case of a perforated membrana tympani.

Surgeons have at all times pointed out that any injury, however slight, to the soft and hard parts of the skull is not to be thought lightly of, since inflammation and abscesses of distant parts of the body, leading to the death of the patient, very often result in consequence. We now know that this long-standing experience had its foundation in the participation in the inflammatory process of the bone substance, and most frequently of the extremely vascular diploe, by the veins and hollow spaces of which facilities are so very often afforded for the formation of thrombi and occlusion of the vessels, and, on the other hand, for blood poisoning. Such processes, as they are simply developed within the blood-vessels, occur indifferently in caries of the petrous bone and without it. These are the conditions which, in patients with otorrhœa, not unfrequently produce lobular abscesses of the lung or purulent pleurisy, or suppurative inflammation of distant joints, or lead to a fatal issue with symptoms for the most part pyæmic or typhoid. In England it has been for a long time past a matter of observation how very often patients with suppurative otitis die with such symptoms, and, by way of explanation, special stress has been laid upon disease of the neighbouring vessels, especially the sinuses of the dura mater and the jugular vein, produced by otitis. In Germany, Lebert was the first who directed attention to these frequent results of inflammation of the ear,[1] which, however, still seem very far from being sufficiently appreciated among ourselves.

[1] "Ueber Entzündung der Hirnsinus," in 'Virchow's Archiv,' B. ix, 1855. Some observations in reference to this subject are contained in Heussy, 'Die Phlebitis der Hirnsinus in Folge von Otitis Interna' (Zürich, 1855); Gull,

54. It is evident from all this that Wilde's observation is true:—"As long as discharge from the ear is present we can never know how, when, or where it may terminate, or to what it may lead." Any suppuration from the ear may under some circumstances become a disease dangerous to life, and little as we can determine in a special case whether deeper changes have already commenced, it is as little in our power to keep such sequelæ at a distance with any degree of certainty. It need only be considered how frequently even extensive cerebral abscesses become developed quite latently, and often show themselves first just before death. Individuals suffering with otorrhœa should not be accepted in any life insurance office, a principle which has frequently been adhered to recently in Germany and England,[1] and just as little should such patients be liable to military service.

55. It becomes the more important to prevent these results by timely and proper treatment. Such treatment has three objects to accomplish—1st. Most thorough removal of the secretion. 2nd. Avoidance of decomposition of purulent secretion, and of the formation of gases of decomposition. 3rd. Gradual diminution of the chronic inflammation, and so of the morbid secretion. Syringing is always required to keep the deep parts of the ear clean. This syringing should be done slowly, avoiding any force; for a strong stream of water from a powerful syringe may easily cause injury to the sensitive and generally softened parts. Even with the greatest precaution syringing easily produces giddiness and attacks of faint-

'Med. Times and Gazette,' 1855, April 7; Weill, 'De l'inflammation des Sinus cérébraux suite de l'Otite interne,' Strassbourg, 1858; V. Dusch, "Über Thrombose der Hirnsinus," 'Zeitschrift für rationelle Medicin' (1859, vol. vii); V. Tröltsch, 'Virchow's Archiv,' B. xvii, sect. v; Cohn, 'Klinik der Embolischen Gefässkrankheiten' (Berlin, 1860, p. 192); Wolf, 'Berliner Medicin Zeitung,' 1857, Nos. 35 and 36; Stäger, 'Rigaer Beiträge zur Heilkunde,' 1851, p. 258; Zandyk, 'Gazette Médicale de Paris,' 1859, No. 37. (The last three cases are of cerebral abscess in otorrhœa without caries.) Beck, 'Deutsche Klinik,' 1865, No. 48 (a case extremely carefully observed and dissected, which is most interesting, from the fact that paralysis of the vagus, the spinal acessory, the glosso-pharyngeal, and the hypoglossal, was produced through pressure of the thrombus in the jugular vein); Nagel, 'Wien. Med. Halle,' 1862, 41; Gruber, 'Wiener Wochenblatt,' 1862, 24, 25. Toynbee's 'Catalogue,' besides, contains a whole series of such cases.

[1] On these two points further particulars will be found in 'Archiv für Ohrenheilkunde,' B. iv, p. 108 and p. 116.

ness, even in cases where the membrana tympani is not perforated and fluid does not enter the tympanum. Where the secretion is scanty, or the patient subject to boils in the meatus, wetting it often should be avoided, and the ear should be often cleaned out with a camel's hair brush or charpie.

This external cleansing is not enough in cases where pus has also formed deeper, and so behind the membrana tympani, at least if the perforation is a small one, for then pus is retained more in the middle ear, and the influence of the syringing is of less value. In all such cases the pus must be driven from within outwards. This can be accomplished in the simplest way, especially before the external cleansing by frequent repetitions of Valsalva's process, better by Politzer's process, or by the air douche with the catheter. In this way not only is all the secretion that is not deposited in the most posterior part of the tympanum and mastoid cells thoroughly removed; but also the Eustachian tube, the natural way of escape, is kept patent. Warm water simply or weak solutions of common salt are generally used for this cleansing syringing. The favourite chamomile tea or other infusions and decoctions have the disadvantage of leaving organic particles in the ear, and thus promoting decomposition of the secretion. As this must be especially feared, good will be done in many cases by adding antiseptic and disinfecting solutions to the fluid injected; for instance, tar water, chlorine water, and especially acetic alum, carbolic acid, and permanganate of potash.

In not a few cases, especially recent ones, suppuration gradually diminishes, or may even entirely cease, and the hole in the membrane closes after a long continuance of thoroughly cleansing the ear; but more frequently it is further necessary to bring astringent substances, which diminish the secretion, into contact with the diseased parts. It is sufficient in external affections, or where the hole in the membrane is very large, to regularly drop in these ear waters. Where this is not the case, provision must be made in another way for thoroughly rinsing the mucous membrane of the tympanum.

This had been done by introducing the suitable solutions or vapours by the catheter; but Politzer has directed attention to the fact[1] that, in perforation of the membrane, medicated fluids might also be introduced into the tympanum by another method. The

[1] Wittelshöfer's 'Kalender für Civilärzte,' 1864, p. 64.

patient's meatus is filled with the astringent solution, his head inclined towards the other side, and now condensation of the air in the Eustachian tube and tympanum is produced in one of the three methods described [Valsalva's, Politzer's, or the catheter]. As soon as the air passes through the hole in the membrane it escapes with a bubbling noise through fluid in the meatus, and at the same moment, of course, the astringent fluid must enter the tympanum through the perforation in its place. In this simple way the fluid comes into extensive contact with the diseased mucous membrane of the tympanum and Eustachian tube, and this method has the double advantage that it can be applied, on every occasion for the use of ear waters, by the surgeon unskilled in catheterism, as well as by the patient himself or his friends, either with Valsalva's or Politzer's process.

56. As regards substances suitable for these astringent ear waters, acetate of lead and chloride of iron (Liq. Ferri Perchl.) should be placed first in relation to their power of diminishing secretion. But unfortunately both these possess the injurious property of easily forming precipitates in the ear. These precipitates on the one hand very often prevent examination of the state of the parts by their colour (white or rusty brown), and on the other when deposited in large quantities they easily give rise to retention of the secretion in the deeper parts. Lastly, they may even combine with the tumid and inflamed tissues and form deposits in them, such as are not unfrequently found imbedded in the cornea. In the tympanum and the membrana tympani they might therefore interfere with the functions of parts in the same way as in the eye, for they diminish the elasticity and uniformity of the vibrating parts. Where perforation of the membrane is present, it is better therefore to avoid these two remedies, especially if the surgeon cannot take measures himself for thoroughly cleansing the ear daily and for most completely removing all metallic deposits from the deep parts.

Sulphate of zinc (grs. i—x to ʒj of water) must be mentioned as an extremely useful astringent; acetate of zinc should only be employed in weaker solutions (1—3 grs.), and then it is not often borne well, and very easily decomposes. Chloride of zinc is recommended by Toynbee. Solutions of common alum have the disadvantage of extremely often giving rise to the formation of abscesses in the meatus; this I have not found the case with acetic alum, which is

best freshly prepared from common alum and acetate of lead. Nitrate of silver has not one advantage as an astringent over the above-mentioned remedies, but the great disadvantage of colouring all parts black, and so interfering with any further examination of the case; strong caustic solutions, on the contrary, with subsequent neutralisation by solution of common salt are very excellent remedies in obstinate otorrhœa in properly selected cases and when carefully applied.[1]

For further experiments I should recommend nitrate of lead, which has often done very good service for me. Sulphate of copper was very highly spoken of by Rau in caries.[2] Powdered alum answers very well in many cases. Mineral astringents are on the whole to be preferred to vegetable, of which one alone, tannic acid, has much value.

As all astringents lose their power after long application, the same one should be used at most for three or four weeks, and considering the long treatment required, a large choice of such substances is necessary. It is not advisable to use them for syringing, but is better to pour the astringent solutions in, the head being inclined to one side, and to leave them for five to fifteen minutes in the ear; during which time, if perforation of the membrane be present, air should be frequently forced through the ear, that the fluid may penetrate deeper.

[To the methods recommended by Dr. Von Tröltsch may be added one based on a slightly different idea, having for its main object the absolute removal of all secretion retained within the tympanum, which sometimes exists in astonishingly large quantity, and may be recognised by its consistence and its frequently dark colour. Solvent alkaline lotions are first used, and during their use a stream of warm solution of soda is passed at brief intervals from the meatus through the Eustachian tube, the patient's head being bent well forward that it may escape freely through the nostrils. A syringe with a broad nozzle to occlude the meatus and covered with india rubber, is used for this purpose, and the proceeding is repeated so long as any matter continues to be evacuated by it. Solutions of chlorate of potash or alum may be substituted in the later stages, and when the cleansing of the tympanum is complete, a lotion of

[1] Compare Schwartze, 'Die caustische Behandlung eitriger Ohrkatarrhe im Archiv für Ohrenheilkunde,' iv, pp. 1 and 233.

[2] 'Lehrbuch,' p. 262.

bichloride of mercury (½ gr.—℈j) with Tinct. Opii ℥v may be had recourse to. The necessity of any other astringents seems to be in some cases entirely avoided by this means; the mucous membrane recovering its healthy state rapidly when completely freed from the irritation of retained discharge. Of course care is always taken that the Eustachian tube is freely open and the method in no way interferes with the employment of caustics or any other remedy that may seem to be indicated.—Ed.]

57. The general health of the patient with suppuration from the ear must be carefully examined, for perhaps in no ear affection does general treatment and especially mineral waters and change of climate so much assist local treatment. But the latter will always remain the principal means, and it alone is always quite sufficient in healthy patients. That derivative measures, viz. diminishing the supplies and increasing the excretions, quickly lessens the amount of suppuration from the ear, is quite natural. With respect to its duration, no good and often enough evil is done by debilitating treatment. The condition of the nasal and pharyngeal mucous membranes should moreover never be neglected.

58. If inflammatory attacks of the subcutaneous tissue ensue, local abstraction of blood after temporary reduction of diet and strong derivative action by the intestines is of the most value, and for the deeper disturbances of the circulation in the ear the application of an artificial leech (Heurteloup's) to the mastoid process is especially recommended. If in the course of suppuration from the ear the mastoid process begins to be painful and to take part in the inflammation, a deep and tolerably long incision should be made without delay over the mastoid process, cutting through the soft parts to the bone. Since the time it was recommended by Wilde[1] this incision has been largely practised, and has been recognised as a means by which further extension of the inflammatory process may often be arrested. Even if no escape of pus follows, relief and even improvement of the condition will generally result. An incision extending to the bone in the soft parts of the posterior and upper wall of the meatus, to which the antrum mastoideum and the other hollow spaces of the temporal bone are closely adjacent, is often of equal value. Pus frequently accumulates in these cells and

[1] See his 'Aural Surgery,' p. 237.

may also collect between the bone and the skin of the meatus, so forming secondary abscesses of the meatus, which are generally wrongly considered boils. In this part of the osseous meatus therefore fistulas are by no means rare.[1]

59. When we are led to assume a collection of pus in the interior of the ear, especially in the mastoid process, the treatment required for abscesses of the bone in other parts has to be adopted. If circumstances allow waiting we may hope to hasten the opening of the abscess by applying poultices behind the ear. Much safer and, when the symptoms are urgent, the only treatment indicated is, under such circumstances, *artificial trephining of the mastoid process*, in order to evacuate the collected pus, and to establish a fistulous opening behind the ear. We not unfrequently, especially in children, see such a perforation of the bone behind the ear occur without artificial assistance and a remarkable improvement in the threatening condition of the patient always directly follows this escape of pus from the deep parts. That this operative measure has been so neglected, and even come into disrepute, is accounted for by the great misuse which has been made of it in the previous century, as well as by the exceptional position in which until recently medical men found themselves with respect to the knowledge of diseases of the ear. Maxims which elsewhere were counted the solely rational ones, modes of treatment which were pronounced absolutely necessary, had never yet gained application to the ear and its diseases.

When the external shell of bone is already softened, strong pressure with a knife or a strong sound will be sufficient to break through it and to open the mastoid cells. When the external bone is thicker and stronger, a small gouge or Lüer's gouge forceps might be applicable: only in those rarer cases where the external lamella of bone is unusually thick and hard, or where the whole mastoid process is converted into a hard bony mass, the hollow spaces being almost obliterated, as, of course, more often occurs after long-standing inflammation of the deeper parts, must the perforator or trephine be resorted to. Middeldorpf's akidopeirastic perforator,[2]

[1] Compare Tröltsch, "Anatomische Beiträge zur Lehre von der Ohren-Eiterung;" 'Archiv für Ohrenheilkunde,' iv, pp. 111, 119, 124.

[2] See cut, and description of it, in 'Archiv für Ohrenheilkunde,' iv, p. 224.

recently recommended by Jacobi, is most applicable for perforating the bone.

In order to avoid the dura mater and the lateral sinus, and at the same time to reach most directly the large hollow spaces (antrum mastoideum or horizontal part of the mastoid process), which are constantly present and lie close behind and above the tympanum, the instrument is introduced on a level with the upper end of the external opening of the ear ¼—½″ behind the attachment of the auricle, and allowed to work in a horizontal direction slightly forwards. A slow, cautious opening of the bone, interrupted by pauses, will prevent the surgeon from digging into it, as it were, with his instrument, and the necessary removal of any osseous septa may be accomplished by a strong pair of forceps when the external dense layer has been once penetrated.

When a free escape of the fluid pus collected in the interior of the ear has been obtained, the inspissated secretion and that which always forms again later must be removed by syringing with warm water. The whole secreting surface can be kept thoroughly clean by such a counter-opening, and we find it constantly reported, therefore, in successful cases, that otorrhœa of many years' duration entirely ceased soon after the operation.[1]

60. This operation is now to be included among those operative measures which may be demanded by the "vital indication," and just as every conscientious surgeon under definite circumstances will feel himself compelled to open the larynx, or to operate for hernia, just so urgent conditions occur when perforation of the mastoid process remains as the only possible means of saving life. And if further the slight danger of this operation, and the almost certain cure of otorrhœa which arises from such a counter-opening, be

[1] Particulars of the history of this operation, and eight such cases, are reported in 'Virchow's Archiv,' B. xxi, p. 295, by the author. Turnbull has since reported a similar case ('The Medical and Surgical Reports of Philadelphia,' 1862, Feb. 15, p. 22). Dr. Pagenstecher three cases in Elberfeld, in 'Archiv für Klinische Chirurgie,' B. iv, Heft 2, p. 525—529, and 533. Schwartze another in his 'Prakt. Beiträge zur Ohrenheilkunde,' p. 37. A case further reported by Mayer, of Hagenau, in 'Archiv für Ohrenheilkunde,' i, p. 226; and also Prof. v. Bruns, to whom I am indebted for a verbal account, has twice in caries of the petrous bone enlarged a narrow fistulous opening into the mastoid process by means of the trephine. See, also, 'Medico-Chirurgical Transactions,' vol. li, 1868, a case reported by J. Hinton, ending in almost complete recovery of hearing.

borne in mind on the one hand, and, on the other, the frequency with which even slight suppuration of the ear, after lasting for years, may lead to a sudden death, the origin of which is generally an accumulation and inspissation of secretion in the bone-cells behind and above the tympanum, it might hereafter appear at least justifiable for a circumspect surgeon to propose this operation in obstinate otorrhœa as a remedy against it, and for the safe removal of any accumulation of pus, even in cases where at the time scarcely any definite symptoms of danger urged such a proceeding.

The longer suppuration has continued in the deep parts, the seldomer the syringe has been employed, and the smaller the opening giving exit to the matter (which is, of course, in most cases the orifice in the membrane), the more regularly by blowing in the ear there is produced a foul odour, the more probable is the assumption that an accumulation of dried-up and caseous masses of pus has formed in the tympanum or in the antrum mastoideum, from which, as has been proved, those diseases that lead to death most frequently proceed. But it is almost impossible to remove these masses in any other way than by perforation of the mastoid process and subsequent syringing. We may finally remark that this operation, by which we are certainly enabled, in many cases, to prevent the subsequent appearance of such ill results, should not, according to all experience be thought in any way a very questionable proceeding.

61. As in many cases perforation of the mastoid process will alone open a way for the removal of a sequestrum from the ear, so the artificial or spontaneous removal of a bit of necrosed bone form the meatus or from behind the ear is not unfrequently necessary, in order that the suppurating process in the ear may come to an end. The entire bony labyrinth, or that part of the pyramid of the temporal bone which encloses the cochlea, vestibule, and semicircular canals, will be thrown off in a state of necrosis with remarkable frequency; and a whole series of cases is recorded in which, after the removal of this part, the patients not only escaped with their lives, but even recovered from the most varied general disturbances which had previously been present.[1]

[1] Many such cases were reported by me in 'Virchow's Archiv,' B. xvii, p. 47, and further in my Handbuch, p. 221.

See, further, an elaborate essay, full of cases, by Toynbee, "On the Detachment of the Osseous Labyrinth during Life," in 'Archiv für Ohrenheil-

62. *Polypi of the Ear* belong to those forms of disease which very often keep up obstinate otorrhœa.[1] These growths appear generally to be developed in the ear only as the result of long continued suppuration, and I have only twice seen aural polypi arise in the acute form, without previous suppurative inflammation. Their size and structure are very varied; sometimes they fill out the whole meatus as firm fibrous growths, and even project, mushroom-like, from the orifice, their surface becoming dense and no longer secreting; sometimes they are only to be found on thorough and careful examination of the deep parts of the ear enveloped in pus and secretion as red soft elevations scarcely as large as a hemp-seed. These little granulations occurring in the deep parts of the external meatus as well as on the membrana tympani and in the tympanum, and which very easily escape ordinary observation, cause the prolonged duration of many especially obstinate attacks of otorrhœa, as they do not disappear under the ordinary astringent injections, but require quite localised treatment.

Aural polypi appear to arise far more frequently from the mucous membrane of the tympanum than from the membrane and the external meatus.[2] As regards the membrana tympani, these growths

kunde' (i, 2, p. 112, with Supplement on p. 158). Then Gruber in the 'Allg. Wiener Med. Zeitung,' 1864, N. 41—45. (The last very remarkable case of detachment of both cochleæ during life is given in the form of a complete abstract in 'Archiv für Ohrenheilkunde,' ii, p. 73.)

[1] Besides chapters relating to this subject in the handbooks frequently mentioned, see Baum, "Über den Bau der Ohrpolypen," in 'Berichte über die 25 Versammlung deutscher Aerzte und Naturforscher in Aachen,' 1847; Meissner, in Henle's 'Zeitschr. für rat. Medicin,' 1853, p. 349; Billroth, 'Über den Bau der Schleim-polypen,' Berlin, 1855, pp. 27—32; and, especially, Förster's 'Atlas der Microsc.-pathologischen Anatomie,' Leipzig, 1854—59, p. 73, and plate xxxv, fig. 1—7; lastly, V. Tröltsch, in 'Virchow's Archiv,' B. xvii, pp. 41, 43, and 49. The most minute investigations on the structure of aural polypi we owe to Steudener. See 'Archiv für Ohrenheilkunde,' iv, pp. 199—212, with plate iv.

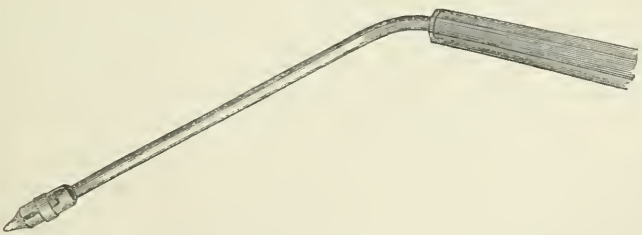
[2] A few cases have been observed where such polypoid growths took their origin entirely or partly from the mucous membrane of the osseous Eustachian tube; thus, by myself ('Virchow's Archiv,' xvii, section ix); by Schwartze ('Archiv für Ohrenheilkunde,' i, 3, p. 197); and, recently, a most remarkable case of the kind has been reported by Voltolini, in 'Virchow's Archiv,' xxxi, p. 220. The polypus arose from the tympanic orifice of the Eustachian tube extending from there in two processes. One passed through the tympanum into the meatus, filling it up as far as its external aperture; the other backwards through the whole Eustachian tube as far as its pharyngeal orifice, and

more frequently proceed from its external coat, but the membrane as a whole may also participate in the formation of such tumours, undergoing as it were polypoid degeneration. According to Steudener, the polypi which occur most frequently in the ear are mucous polypi, the firm fibromata are less common, and gelatinous myxomata the rarest.

Hitherto the name "aural polypus" has been employed chiefly in a practical sense, as under this term very different structures, only superficially alike, are included. A sharp division especially between developed connective-tissue granulations and real polypi in the ear can scarcely be carried out, at least during life, and such distinction also would have scarce any practical value. Both structures generally secrete much pus, and blood is also often mixed up with the discharge; both must be removed, if possible, if the inflammatory process is to be relieved or brought to an end equally whether ulcerative disease of the bone is present or not.[1] It is true, however, that these excrescences in many cases disappear spontaneously after a bit of necrosed bone, from whose presence the tissue irritation essentially proceeded has been thrown off, and on the other hand these excrescences became very quickly again developed to their original size while the bones continue diseased.

63. Smaller and especially softer growths in the ear may be made to disappear by the frequent application of pure acetate of lead, or

Fig. 6.



Liq. Ferri Perchloridi, by tincture of opium or sabin, or strong

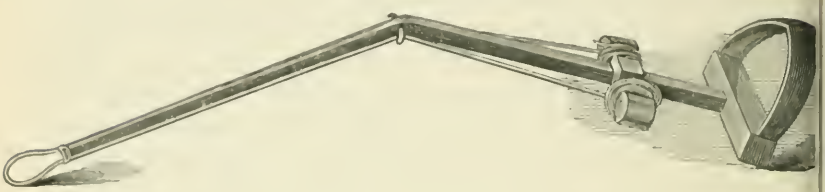
filled up the entire tube like a thin earth-worm. It had slightly dilated the tube. Had it still continued growing for some time, it would have appeared in the pharynx, and might have been visible by rhinoscopy.

[1] Schwartze reports a case in the 'Archiv für Ohrenheilkunde,' i, p. 147, in which paralysis and anæsthesia of one half the body was cured spontaneously directly after the removal of several aural polypi.

solutions of sulphate of zinc (40—60 grs. to the ounce of water). Touching them with solid nitrate of silver, which can be applied by means of a special caustic holder (Fig. 6) or by a silver probe bent in the same way and previously dipped into melted nitrate of silver, is much more certain, and in those of denser structure is the only application that answers.

Larger and denser growths must be removed by operation, and Wilde's polypus snare (Fig. 7) is very well adapted for this purpose,

Fig. 7.



as an instrument with which the deep parts can be tracked and the polypus cut away with the greatest safety to surrounding parts. The semicircle at the lower end is intended for inserting the thumb, while the transverse bar is drawn back with the index and middle fingers. Fine steel or silver wire is the best to use for the noose. Having ascertained by means of a probe how far the polypus is free laterally, the loop, made corresponding large and bent to an angle, is carefully passed as far as possible into the deep parts, and finally the transverse bar is strongly pulled upon it: by this the part surrounded by the noose is strangled and generally removed along with it. The bleeding which follows renders repeated operations necessary to remove the seat of the excrescences when there are several.

As regards the other methods in use, we can scarcely reach growths which fill up a narrow meatus with knives and scissors, however they be curved; with the latter also we may very easily incur the danger of injuring the wall of the canal, and as regards the so much employed method of extraction by means of polypi-forceps, it must be looked upon certainly as a violent and very questionable proceeding, even after long torsion of the tumour on its axis has been performed. We can never determine beforehand from what deeper parts the large polypi which fill up the meatus arise, and whether by such powerful traction we may not, to say nothing

of the membrana tympani, tear away a portion of the tympanic wall.

When by one or other of these methods the polypus has been removed to a certain point, and even after cauterizing the root, it is still not safe to leave the case; the inflammatory process (most frequently chronic suppurative catarrh of the tympanum) which lies at the root of the polypus-formation must be treated radically and, if possible, removed; otherwise the remedy has only been palliative, and after a longer or shorter time a similar tissue growth will again take place.

## CHAPTER XI.

### FOREIGN BODIES IN THE EAR.

64. Bodies introduced accidentally or purposely into the ear very often cause much less injury than the attempts to remove them, whether these are undertaken by surgeons or others, and the motto of this section might well be, "Blind zeal does nothing but hurt." For apart from the fact that attempts at extraction are often made with great energy, even before any trouble is taken to ascertain whether the statement of the patient is correct, and there is really any foreign body present in the ear, an amount of importance they do not deserve is often attached to their presence.

It may be safely assumed that many bodies, especially when rounded and not pointed, as long as they are not forcibly pressed inwards, either fall out of themselves, especially if the patient lies on that ear, or at least will produce no important injury,[1] so that in many cases patient waiting, accompanied perhaps by a special position of the head, will not only be allowable, but even the only treatment required. Destructive suppurative processes in the deep parts of the ear are treated as "noli me tangere," while, on the other hand, a harmless pellet of bread or paper, a small shot, or even a pea, which have just reached the external meatus, are pursued with unrelenting ardour, as if the life of the patient were certainly in obvious danger! The worst of it is that by this indiscriminate search after bodies which hitherto only remain in the meatus, and are scarcely felt as a disturbing element there, they are often driven

[1] A case is reported in the 'Preuss. Vereinszeitung,' 1862, No. 25, that a carious molar tooth lay for forty years in the ear without producing even the slightest disturbance, and a similar one in the 'Allgem. Wiener Med. Zeitung,' 1862, No. 31, where a cylindrical piece of graphite, $4\frac{1}{2}'''$ long and $3'''$ thick, remained eleven years in the ear without producing any symptoms. A whole series of such cases is reported in Linke's 'Handbuch der Ohrenheilkunde,' B. ii, p. 569.

more deeply on to the membrana tympani, or even forced inwards through it, and so the condition is really changed into a serious one. A considerable number of cases are on record in which patients have perished, or other important disturbances to their health, quite apart from deafness, have resulted, not from bodies entering the meatus, but from attempts at extracting them and their consequences.[1]

65. On the other hand it must, of course, be borne in mind that foreign bodies in the ear, when they cause great irritation to the lining membrane of the meatus and membrana tympani by long contained violent pressure may not only produce important local mischief, but also may give rise to general conditions of diseases. Pressure on the membrana tympani alone may occasion violent giddiness, and, as is known, many people feel irritation in the throat, or are obliged to cough if their meatus is touched in some parts. These reflex phenomena in the sphere of the pneumogastric, which, as is known, takes part in the nervous supply of the skin of the meatus, may sometimes occur in a very troublesome manner, as several cases recorded in literature prove. Dr. Arnold[2] relates the case of a girl who suffered for a long time from cough and expectoration, frequently vomited, and consequently visibly emaciated. On closer examination it was found that a bean was lodged in each ear, which had entered the meatus a long time previously while she was at play. The removal was accompanied by violent coughing, much vomiting, and frequent sneezing. The attacks immediately ceased, and the child completely recovered. Arnold also adduces

[1] Two cases, with fatal results, were only recently reported in the 'Wiener Spitalzeitung,' 1862, No. 21, in which unilateral facial paralysis and purulent meningitis were produced in the one case "by a pebble," in the other "by a coffee-bean entering the ear." A third time paralysis of the facial was produced by a currant, which was constantly forced deeper into the ear. One of the most interesting cases in the older literature is the following, which Sabatier describes in his 'Médecine Opératoire' (Paris, 1810, vol. iii, p. 10). The body in question here was a paper pellet; it was never, however, clear whether it had really entered the meatus. After useless attempts at removal, the patient remained well for several months, until at last he fell ill with malignant fever and violent pain in the head. After seventeen days he died, and a cerebral abscess, communicating with a quantity of pus in the tympanum, was found. In the latter was the paper pellet. The membrana tympani was destroyed.

[2] 'Bemerkungen über den Bau des Hirns und Rückenmarks,' &c., Zürich, 1838, p. 169.

another case as a further proof of the strong reciprocal relationship between the lungs and the ear, in which a "pulmonary affection" that physicians had treated in vain for a long time disappeared spontaneously after the removal of a foreign body from the ear. In a case observed by Toynbee[1] the patient suffered from violent cough, which was relieved by no treatment, but ceased immediately as soon as a bit of necrosed bone was removed from the meatus. A much more important case is the familiar one which Fabricius Hildanus reports.[2] A girl who, in her tenth year, had put a glass bead the size of a pea into her left ear, and which had resisted all attempts at removal, was later on attacked by pain on one side of the head, by violent pain alternating with anæsthesia of the whole of the left side of the body, to which were added, after some years, epileptic spasms and atrophy of the left arm. As there was no longer any pain in the ear, the ear was not thought of by any physician until the patient, in her eighteenth year, came under the treatment of Fabricius, and he accidentally heard of the glass bead. He took it out, and in this way relieved the patient of all her symptoms. "Restitutum est quoque brachium," he reported to his friend Bauhinus. (Observation v, p. 18, also contains a similar but slighter case.)

66. The greatest danger of the operation for removing foreign bodies from the ear arises from their slipping away on attempts to seize them, and being driven more towards the membrana tympani, or through it into the tympanum. This and nothing else is done by all the many instruments in the form of forceps, lever, or snare, invented specially for this purpose if the point of the instrument cannot easily be passed behind the foreign body. Besides the best possible illumination of the field of operation and perfect quietness of the patient, it is absolutely necessary for this purpose that open space should be present between the foreign body and meatus wall in one or even two directions. Under these circumstances, however, a much simpler method, and one which requires much less skill and knowledge of the ear, will succeed equally well, viz. a properly directed stream of water, to which, perhaps, some soap may be added to lubricate the passage as much as possible. The water

[1] Loc. cit., p. 39.
[2] L. c., "Centuria prima," Obs. iv, p. 15.

collects behind the offending body, sets it afloat, and gradually washes it towards the opening of the ear, from which it may be completely removed, if necessary, with a simple lever or pair of forceps. A suitable position of the head and as straight a direction as possible of the meatus by means of strong traction backwards and upwards on the auricule during and after syringing will essentially facilitate this. An inclined position with the ear directed downwards is generally most suitable; if, however, as often happens, the roundish body is fixed in the depression formed by the antero-inferior wall of the meatus and the membrana tympani (see Figs. 4 and 5 of the Anatomical Plate), then a recumbent position with the head hanging down backwards,[1] would most favour the escape of the body.

If swelling of the meatus has appeared round the foreign body, as is frequently the case after previous attempts at extraction, it will be best to first pay attention to the inflammation. Leeches in front of the tragus will diminish the congestion, and the application of poultices will, perhaps, most speedily reduce the impaction.

In a case in which a little brass ball, $3\frac{1}{2}$ mm. in diameter, had been driven through the membrane into the tympanum, and I could not drive it back again into the meatus by inflation, or even by injecting water through the catheter,[2] I came at last to the idea to place a wire loop, by means of Wilde's polypus snare, around the little ball, which was visible behind the fissure of the membrana tympani, and I drew it out so without any pain. I should think that the same instrument will be of great use in many similar cases, for it is possible with comparative ease and safety to the surrounding parts, to pass such a wire loop behind the foreign body, and then to exert a moderately strong extracting force with it.

In cases where, from the symptoms which are present, as speedy a removal as possible of the foreign body seems necessary; but it is so impacted, that there is no space between it and the wall, so that no water or even the finest instrument could pass behind it, it is necessary to try to get behind the body by splitting the wall of the meatus externally.

Paul of Ægina first, and after him several of the older surgeons,

[1] Voltolini, in 'Archiv für Ohrenheilkunde,' i, p. 153.

[2] Deleau once removed a pebble from the tympanum by injecting water through a catheter introduced as far as possible into the Eustachian tube. See p. 348 of his 'Recherches pratiques sur les Maladies de l'Oreille,' Paris, 1838.

in such desperate cases advised making a crescentic incision behind the ear down into the meatus, and then attempting the extraction through this. Tulpius[1] has performed this operation with successful results in one case for a cherry stone which could not be removed from the ear by any other means, and which caused such pain that he thought, according to the prognosis of Hippocrates, convulsions and death were to be feared. It appears to me it would be much better to make this incision above or beneath the meatus. The not unimportant posterior auricular artery, injury to which it would be impossible to avoid, runs close behind the auricle in the angle it forms with the mastoid process. Besides, separation of the auricle and cartilaginous meatus and, later, the introduction of instruments are much impeded by the arching of the mastoid process while operations on the dead subject have proved to me that it is very easy from above to separate the meatus from the squamous portion of the temporal bone with the knife, and from here to come close down on to the membrana tympani through an incision inwards, *e. g.* with a curved elevator. This operation would be doubly easy to perform on little children, in whom the depression of the squamous portion of the temporal bone, from which the roof of the osseous meatus is gradually formed, runs very obliquely inwards, so that it extends even to the membrane *in a very obtuse angle*. In children such accidents happen by far the most often, and through their restlessness the danger is greatest of driving the foreign body still further into the deeper parts in any of the other methods at extraction. In adults, in whom the upper wall of the meatus and the squamous bone are at right angles to each other, an incision through the inferior wall of the cartilaginous meatus from the auricle to the osseous portion of the tube might be the best adapted to reach a foreign body impacted in front of the membrane; in this way only a part of the parotid gland would be injured. In every case, however, such an incision, to get behind the seat of danger through the soft parts from above, would be far less serious, and would prove far safer in its effects and consequences, than the other usual proceedings. In the case of a body which had entered the tympanum whose removal appeared necessary and could not be effected from the outside either by syringing or by introducing a sound through the Eustachian tube, nothing more would

[1] 'Observationes Medicæ,' Amstelod, 1672.

remain than trephining the mastoid process, in order by syringing to drive it *through the newly made opening* into the external meatus, or to seize it directly with forceps.

67. Very few instances are on record of foreign bodies that have found their way into the Eustachian tube either from the tympanum or pharynx. One such is related of a girl[1] who, after a pin had entered her ear, was attacked by extremely violent pain, inflammation and swelling of the entire corresponding half of the head and neck, which symptoms did not disappear until, after an emetic taken according to custom, she had vomited up the bent pin. That particles of food and other foreign bodies do not more frequently enter the Eustachian tube from the pharynx, especially during violent expiratory action, as sneezing and vomiting, arises from the fact that in these attacks the soft palate always contracts and separates the upper from the lower pharyngeal space like a valve, and that also a special closure of the pharyngeal orifice of the Eustachian tube by the levator palati muscle takes place.[2] This may account for the fact that hitherto—as far as I know—only one case is recorded of a foreign body having entered the ear from the pharynx.[3] A man complained for many years of a constant noise in the ear and of a very peculiar sensation in the pharynx, which he compared with the sensation produced by a hair accidentally present in the mouth or throat. On post-mortem examination a barleycorn (arista) was found protruding from the pharyngeal orifice, and extending from there into the osseous Eustachian tube.[3] At the present time such a condition might certainly in some cases be recognised during life by means of rhinoscopy and, perhaps, also relieved.

[1] Albers, in 'Loder's Journal,' B. i, p. 151; or in Linke's 'Sammlung,' H. ii, p. 182.

[2] See 'Archiv für Ohrenheilkunde,' B. i, H. i, p. 25.

[3] Fleischmann in 'Hufeland's and Osüann's Journal,' 1835, June, p. 25, and in Linke's 'Sammlung,' ii, p. 183.

# III.—THE INTERNAL EAR.

## CHAPTER XII.

68. The internal ear or labyrinth includes the peripheral terminations of the auditory nerve, and, therefore, the most essential part of the organ of hearing. As, however, the diseases of the nervous apparatus have very lately begun to be reduced to a practical, *i. e.* an anatomical, basis, and we therefore know very little of them, and as the internal ear also is completely removed from the direct operations of the physician and surgeon, we must speak of them here in very few words.

The internal ear or labyrinth consists of a series of communicating canals and saccules which, surrounded and filled by the fluid of the labyrinth, contain the variously shaped peripheral terminations of the auditory nerve. The vestibule with its two saccules forms the anatomical centre of the whole: the three semicircular canals open into it, and it is also in direct communication with the cochlea. The latter and its membranous spiral zone especially, with its wonderfully complex structure, appears from a physiological point of view to be the most important part of the labyrinth, and consequently of the whole organ of hearing. Towards the tympanum the vestibule is closed by the stapes and its surrounding membrane, the cochlea by the membrane of the fenestra rotunda (or the second membrana tympani). Towards the internal auditory meatus both cavities of the labyrinth have on their walls a series of cribriform perforated spots through which the radiating fibrils of the auditory nerve enter. The internal meatus itself, in which the auditory and facial nerves lie, must be considered as a lateral canal of the cranial cavity since it is lined by a prolongation of the membranes of the brain, and is also filled with cerebro-spinal fluid.

69. The characteristic and often described serous discharges from the ear after injuries to the head are explained by this relation. The fluid escaping in such cases, often in large quantity, was for a long time thought to be the serum of blood, which came either from some extravasation situated in the neighbourhood of the fracture of the skull or from some very slight rupture of the venous sinuses of the dura mater; others considered it fluid from the labyrinth until a careful anatomical examination of such cases and chemical analysis of the fluid escaping from the ear proved that it was certainly cerebro-spinal fluid. An abundant and continuous discharge of a clear watery fluid, of a saline taste, nearly devoid of albumen, and rich in chloride of sodium from the ear, after injury to the head has taken place, may, from previous observations, be considered a certain proof of fracture of the bone of the skull; it, moreover, implies that the fracture extends through the internal auditory meatus, the osseous labyrinth, and the tympanum, and that the dura mater in the internal auditory meatus, as well as the membrana tympani or the walls of the meatus, have at the same time been ruptured, or else no fluid from the cranial cavity could escape through the external meatus.[1]

An absolutely fatal prognosis is even yet often associated with this escape of cerebral fluid, and the fracture of the base indicated thereby, but falsely, since a large series of carefully observed cases is recorded in which the patient recovered, in spite of long-continued and

[1] The very extensive literature of this long discussed condition may be found collected in Bruns' 'Chirurgischen Handbuch,' i, p. 324, as well as in Luschka's 'Abhandlung über die Adergeflechte des Menschlichen Gehirnes,' Berlin, 1855, p. 78. As it appeared possible to me from the arrangement of these parts that a similar serous discharge might arise from the ear after fissured fractures of the roof of the osseous meatus, or the tegumen tympani, with simultaneous laceration of the soft parts situated on both sides, I applied on the subject to Herr Prof Luschka, at Tübingen, asking his opinion about it. His kind answer runs as follows:—"According to my views it can scarcely be supposed that a discharge of cerebro-spinal fluid will occur on fracture of the roof of the external auditory meatus, or of the tegumen tympani, even when all the soft parts are completely divided: for the spheno-temporal cerebral lobe is in contact with the cranial surface of those parts, and over this the visceral arachnoid is spread so tightly that the subarachnoid tissue here contains only a minimum of that fluid. It is, on the other hand, abundantly collected in the subarachnoid sinus, situated by the side of the medulla oblongata, between it and the cerebellum, and can easily escape from it on laceration of its walls, but is prevented by the tentorium from extending to the upper and inner side of the temporal bone.

abundant discharge of that kind,[1] just as complete recovery often occurred, even after incised wounds of the spinal cord and prolonged escape of spinal fluid; but it is true that much greater importance should be attached to such a serous discharge from the ear after an injury to the skull than to even a more protracted discharge of pure blood. The former always implies an injury to the dura mater and the base of the skull, while the bleeding may possibly arise only from laceration of soft parts situated quite superficially.

It must also be borne in mind that suppuration of the ear, such as not unfrequently occurs as the result of injuries to the head, extending at the same time to the ear, is often preceded by serous exudation, which secretion sometimes trickles from the ear in considerable quantity, even for a whole day, and might easily be mistaken for the other.

70. Deafness not unfrequently comes under our observation after injuries to the head, and the investigation of the cause is in some cases very difficult. For as the deafness may be central, arising in the brain or labyrinth, in spite of the most varied visible changes in the peripheral parts of the ear (*e. g.* rupture of the membrana tympani, or thickening and adhesions of it), so also it may arise solely from pathological changes within the tympanum, although the patient was unconscious for days and weeks together, and afterwards underwent the most varied sequelæ of cerebral injury or concussion. We should consider how easily the force of a blow or fall causing the lesion of the skull and brain may directly or indirectly produce in the hard or soft parts of the middle and external ear lacerations, separations of the normal connections, *e. g.* of the ossicula, and especially effusion of blood in the middle ear, which again may lead to suppurative otitis, to superficial thickening of the mucous membrane, *e. g.* of the fenestræ, or to adhesions of the membrana tympani with the promontory and the ossicula. All of these are conditions which present nothing characteristic of injuries of the head,

[1] The American naval surgeon Lockwood recently reported a case in which, after a fall, not only considerable hæmorrhage and abundant clear watery discharge from the ear occurred, but even removal of a portion of brain-substance through the external ear; and in spite of this the patient recovered. (See "Gurlt's Bericht," in 'Langenbeck's Archiv,' i, 3, p. 145.) A very similar case, which also recovered, was demonstrated in the summer of 1870, by Prof. Dehler, before the physico medic. Gesellschaft in Wurzburg.

and which, treated in proper time, may possibly be removed, or their effects on the hearing diminished.

In such cases examination with the tuning-fork will very often give very important indications as to the seat of deafness, at least when it occurs on one side only. When the sound of a tuning-fork placed on the middle of the forehead or on the upper teeth[1] of a patient is perceived principally or exclusively on the affected side, it follows that the difficulty of hearing has a peripheral cause, and arises solely from some impediment to the conduction of the sound, while in the opposite case a lesion of the labyrinth or inside the cranial cavity may be inferred with great probability.[2]

The foundation for "deafness after injuries to the head" is also not unfrequently laid during their treatment; from ice-water, the cold application being allowed to run unimpeded into the ear, where, as a rule, it does not fail to set up inflammation, and so add another to the previous sufferings of the patient. Not a few cases of deafness and suppurative discharge from the ear after injuries to the skull (and certainly also after typhus, &c.) may owe their origin to this cause.

[1] The teeth of the lower jaw, which are in more direct relation with the petrous bone, seem often preferable for this purpose, and seem to me to give much more reliable indications than the forehead.—Ed.

[2] On the significance of bone-conduction, see, especially, Politzer, 'Archiv für Ohrenheilkunde,' i, p. 318; and Lucae, ibid., p. 303, as well as 'Med. Centralblatt,' 1863, Nos. 40 and 41, and 1865, No. 13; further, 'Virchow's Archiv,' xxv and xxix.

# EXPLANATION OF THE ANATOMICAL PLATE.

FIG.

I.—Perpendicular section of the *osseous auditory meatus* (right), made near the membrana tympani. 1. *Inner surface of the squamous portion of the temporal bone.* The dura mater has been removed; the elevations and depressions (juga cerebralia et impressiones digitatæ) are seen, and also above, running horizontally, a vascular groove is shown. 2. *Articulating cavity for lower jaw.* 3. *External auditory meatus.* 4. *Mastoid process,* with the external series of cells. 5. *Fossa sigmoidea,* in which terminates the lateral sinus of the dura mater.

II.—*Left temporal bone* of a child, about three years old. Views of the gap in the ossification of the anterior wall of the meatus.

III.—Superficial view of the *labyrinth wall of the tympanum,* with part of the posterior wall. 1. *Promontory,* or most convex portion of the labyrinth wall, behind which is situated the external portion of the cochlea. 2. *Horizontal or anterior semicircular canal,* laid open at its most prominent part. 3. *Facial nerve,* as far as the knee-shaped curve of the *aqueductus Fallopii,* half of which has been removed. 4. *Stapedius muscle* in its osseous pyramid, for the most part laid open. Above, its tendon going to the head of the stapes. The letter itself on the *fenestra ovalis,* or *vestibular window.* 5. *Entrance to the fenestra rotunda,* or window of the cochlea. 6. *Cavity for the sinus of the internal jugular vein* (*jugular fossa*). 7. *Internal carotid artery* in its osseous canal, laid open. 8. *The superior part of the osseous Eustachian tube,* interrupted by the carotid canal, which has been laid open. 9. *Tensor tympani muscle,* section of its tendon near the facial.

IV.—*Perpendicular section of the tympanum,* through the membrana tympani and meatus (left). 1. *Section of the facial nerve,* directly after its knee-shaped curve. 2. *Section of the tensor tympani muscle,* just in front the origin of its tendon. The tendon of the same can be seen passing transversely across the tympanum to the malleus. Below it is seen the articulation between the incus and the stapes. 3. *Vestibule.* 4. *Cochlea,* and the membrana of the fenestra rotunda. In front of it the most convex portion of the promontory. 5. *Cavity* (*jugular fossa*) *for the sinus of the internal jugular vein,* with the floor of the tympanum. 6. *External auditory meatus,* at the end of which is the membrana tympani with the malleus. 7. *Squamous portion of the temporal bone.*

Fig. I.

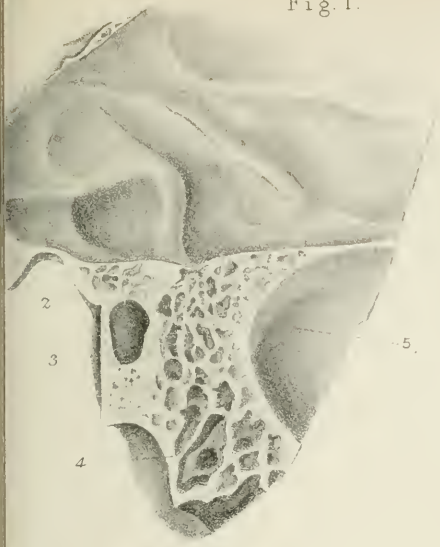



Fig. II.

Fig. IV


Fig. III

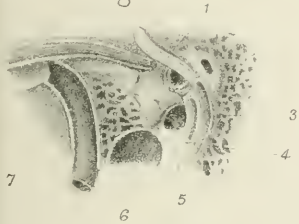
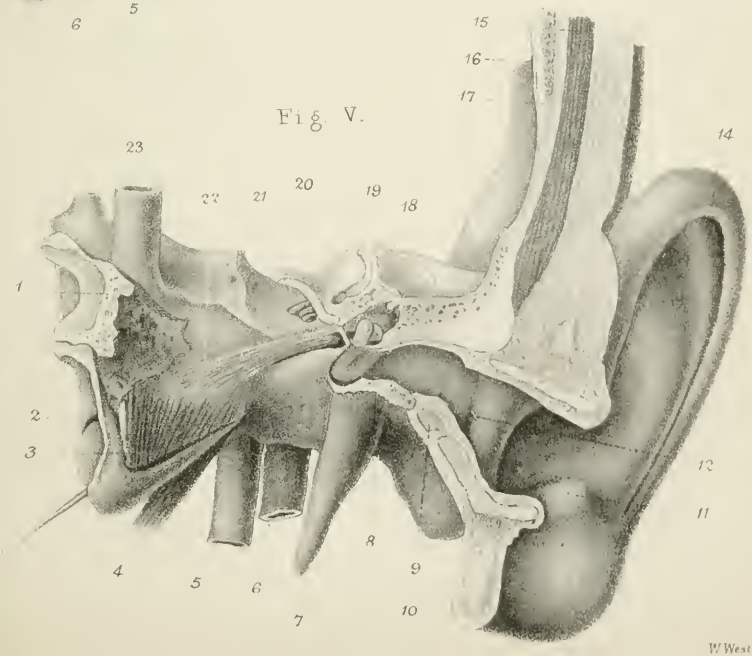



Fig. V.



EXPLANATION OF THE ANATOMICAL PLATE—*continued.*

FIG.

V.—*Topographical representation of the entire auditory apparatus* (left ear). 1. *Section of the body of the sphenoid bone.* 2. *Recessus pharyngis,* or *Rosenmüller's fossa,* between which and a sound introduced into the commencement of the cartilaginous Eustachian tube projects the posterior cartilaginous lip of the pharyngeal mouth of the tube. 3. *Tensor palati,* or *spheno-salpingo-staphylinus* (abductor or dilator of the Eustachian tube). 4. *Levator palati,* or *petro-salpingo-staphylinus.* Between the two divided muscles a portion of the membranous part of the cartilaginous Eustachian tube. 5 and 23. *Internal carotid artery,* before and after its passage through the petrous bone. 6. *Internal jugular vein.* 7. *Styloid process.* 8. *Section of osseous meatus.* At the end of the latter the external surface of the membrana tympani is seen. 9. *Section of cartilaginous meatus.* 10. Lobule of the ear. 11. *Antitragus.* 12. *External orifice of ear,* commencement of meatus, the anterior wall of which, with the tragus, has been taken away. 13. *Antihelix or opposite rim,* passing below or into *antitragus.* 14. *Helix, or rim of the ear.* 15. *Temporal muscle.* 16. *Dura mater,* lining the temporal bone internally. 17. *Squamous portion* of temporal bone. 18. *Head of the malleus;* near and behind it the body of the incus; above it the osseous roof of the tympanum, with its hollow spaces, and covered by dura mater. 19. *Inferior semicircular canal,* partly laid open, with one entrance to the vestibule. 20. *Facial nerve,* from the internal meatus, as far as its knee-shaped curve. 21. *Cochlea,* partly laid open. 22. *Tensor tympani muscle* (*Trommelfellspanner*), passing along and above the laid open osseous Eustachian tube, and giving off superiorly its tendon, which passes transversely across the tympanum.

## INSTRUMENTS.

Natural Size, except No. 4.

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Fig.

1.—Ear speculum, p. 12.

2.—Pincers (forceps) bent knee-like, with crossed blades, p. 14.

3.—Scalpel, with a scoop for abscesses of the ear, p 20.

4.—Ear catheter, p. 42.

5.—Tube for pharyngeal douche, p. 55.

6.—Caustic holder, p. 81.

7.—Polypus snare, p. 82.

THE

# MECHANISM OF THE OSSICLES

AND THE

# MEMBRANA TYMPANI.

BY

PROFESSOR HELMHOLTZ.

## NOTE BY THE TRANSLATOR.

In respect to the Mathematical portion of this Treatise, I beg to acknowledge my great obligations to Professor Smith, of Oxford, who, in the kindest manner, consented to revise my translation, so securing it against the inaccuracies to which it must otherwise have been liable.

J. H.

THE

# MECHANISM OF THE OSSICLES AND THE MEMBRANA TYMPANI.

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A PAPER lately published in the 'Zeitung für rationelle medicin' from among the scientific works of B. Riemann (too early lost to science) contains the product of his extraordinary power of penetration and indefatigable energy during the last months of his life. He treats of the problems of physiological acoustics, and the deficiencies of previous solutions; here too he perceived the point which forms the nucleus of all difficulties and which is the immediate object of scientific inquiry. He proposes, as the main problem of the mechanics of the ear, to explain how the apparatus of the tympanum is enabled to convey vibrations of the extraordinarily delicate degrees of gradation it actually does from the air to the labyrinth water. He calculates that the excursions of the stapes, in weak though distinctly audible tones, must in part be so small that they could not be rendered visible even under the highest powers of our present microscopes. For the sure and regular transmission of vibrations of this delicacy there is required an inexpressible precision and certainty in the movements of the conducting apparatus.

In many points he says that he will be obliged to disagree with me on the theory of the motions of the ear which I propounded in my 'Lehre von den Tonempfindungen.'

In this connection I must remark that I myself only considered the representation of the movements of the apparatus of the tympanum [in section 1, paragraph 6] as they had been previously described by others. It would have been impossible for me then to have prosecuted researches concerning these questions, although

I was very well aware of the necessity for fresh inquiries on that subject.

I have thus essentially followed the statements of Ed. Weber,[1] which constitute a material advance on the older theories, and which are certainly correct in their fundamental points, although ampler details and more exact application cannot be dispensed with.

The chief difficulty as it strikes me in this theory is connected with the existence of the malleo-incudal articulation. According to Weber's statement, the malleus and incus form together a firm angular lever, whose axis of rotation runs from the processus folianus to the top of the short process of the incus. But how could a very yielding joint, supported almost entirely by a weak and relaxed covering membrane, form a connection in the middle of this lever of the necessary fineness and delicacy?

As soon as the termination of my course of physiological optics left me leisure for other investigations, I took in hand the above-mentioned inquiry, and I had already obtained most of the following results before I received Riemann's paper.[2] The solution of the difficulties, as they appear under more rigorous examination of the mechanism of the joint and the fastenings of the ossicles, is certainly very different from what the celebrated mathematician appears to have believed. I must also oppose his formulisation of the rôle of the organs of the ear, inasmuch as I hold it to be in nowise proved by known facts. He states that the tympanic apparatus conveys instantaneously the difference of pressure of the air increased in a constant ratio, to the labyrinth water, yet the exactitude of perception only requires that every tone of a constant pitch should, whenever it occurs, produce a sensation of a similar kind and intensity, and it is already well known that tones of a certain height affect the ear very disproportionately. We shall find below fresh illustrations of such variations.

## § 1. *Consequences arising from the smallness of the organs of hearing.*

The most important advance made by Ed. Weber in the theory of conduction of sound in the ear, and one which, perhaps because

[1] "Berichte über die Verhandlungen der Königl. Sächs ges d. Wissenschaften zu Leipzig," 'Moth. Phys. Klasse,' 1851, Mai 18, S. 29—31.

[2] I have given a short preliminary explanation of the same in the Heidelberger 'Jahrbücher,' July 26 and Aug. 9, 1869.

it was rather briefly indicated than propounded, has not received so much attention as it deserved, seems to me to rest on the view that in the conduction of sound the ossicles and the petrous bone are to be considered as firm incompressible bodies, and the labyrinth water as an incompressible liquid. He asserts correctly that the question is not one of the conduction of waves of compression and rarefaction in these solids and fluids, but that the ossicles are to be considered as a firm lever, and the labyrinth water as a mass of liquid to be moved only as a whole. We will now enter into more particulars to verify this point which forms the foundation of the following researches.

If there be an elastic medium infinitely extended in all three dimensions, either solid, liquid, or gaseous, and in it regular waves are excited which answer to some simple tone, these will proceed with the velocity suitable to their manner of vibration, and will cause at different points in the mass, partly displacement of the particles, and partly also if they move in longitudinal vibrations, condensation of the mass. Take at any given time and point, particles which are at their utmost upward displacement, then others, distant half a wave's length from them, are at their utmost downward displacement. The same holds true for all other directions. Between these limits of extreme displacement upwards and downwards, which in the above-mentioned case are half a wave's length apart, we find in continual transition slighter degrees of displacement upwards till we come to a particle on its original level, and then slighter degrees of displacement downwards, so that the difference of the displacements of two oscillating particles, whose distance is infinitely small compared to the wave-length, is itself infinitely small compared to the whole amplitude of the displacement. Let us limit ourselves to the consideration of a small portion of the vibrating mass, whose dimensions are all infinitely small compared with the length of the wave. In this case the difference of the displacements of single points must be infinitely small in comparison with the amplitude of the whole vibration which itself always, in regularly transmitted vibration of sound, must be considered as infinitely small compared with the wave-length. These relative displacements of the separate points of this small portion as compared with one another are thus infinitely small quantities of the second order in comparison with the wave-length; infinitesimals of the first order in comparison with the amplitude of the vibration, and in comparison with the

linear dimensions of the small mass to which they belong. That is, this mass moves in the given case exactly as a rigid solid would do.

The relation remains unaltered if a great number of regular waves which belong to the same simple tone pass through the elastic mass, and also if circular waves with any centre of excitation passing through the mass spread themselves through it, except in the near neighbourhood of the point or line which is the centre of excitation. This is, however, rather a mathematical fiction than a practically occurring case. The same holds good for rigid elastic solids if their mass is not infinitely extended in all directions, but has limits, the waves of sound impinging on which are thrown back into the interior of the mass; provided only no one linear dimension of the vibrating mass be very small in comparison with the wave-length, or that every dimension is equally small in comparison with the wave-length, so that no one is very small in comparison with the others as is the case in plates, membranes, rods, &c.

As long as we consider only plane waves of simple tones in infinitely extended masses, the proof of this proposition becomes evident from the known propositions on the form and manner of vibration of plane waves.

On the other hand, the case of a limiting plane and the last-named conditions have been discussed by Kirchoff, in his treatise on the equilibrium and motion of an infinitely thin elastic rod. This treatise deals directly only with conditions of equilibrium of such elastic masses, and proves that forces which bear an infinitesimal ratio to the constant of elasticity of the body, and which act partly on the internal, partly on the external, portions of the mass, cause only infinitely small relative displacements of such points of the mass as lie at finite distances from one another, so that, in consequence, the differential co-efficient of the displacements taken along the co-ordinates also remain finite. This last case actually occurs. For if these differential co-efficients are of a finite magnitude, then in masses of infinitely small linear dimensions the relative displacement of their individual particles are infinitely small compared to the whole absolute displacements which such masses undergo. What Kirchoff,[1] as we have said, has proved for the conditions of equilibrium under the supposition of infinitely small forces may be, by means of

[1] 'Borchardt's Journal für reine und angewandte Mathematik,' lvi, in § T of the above-mentioned treatise.

D'Alembert's principle, transferred to the case of motion, inasmuch as we consider the accelerations which the small masses undergo in their motion as the displacing forces in elastic solids. Now, these are infinitely small if they appertain to vibrations of an infinitely small amplitude compared with the wave length,[1] and correspond to Kirchoff's assumption of infinitely small disturbing forces. The proposition proved by Kirchoff adapted to the case before us can be thus expressed:

Suppose we are dealing with solid elastic bodies in which either of the following two conditions holds (1) that all their linear dimensions are not infinitely small in comparison with the wave length, or (2) that at least none of them are infinitely small in comparison with the rest. In these cases, vibrations of a simple tone whose amplitude is infinitely small compared with the wave length of the same sort of vibration in infinitely extended masses behave thus. At two points of the elastic body, whose mutual distance also is infinitely small compared with the same wave length, relative displacements are produced, which are infinitely small compared with the whole amplitude of the vibrations.

That is to say, that within the above-mentioned limits masses, whose linear dimensions are all infinitely small compared with the wave lengths, behave as if they were absolutely solid bodies, *i. e.* that the changes of form which they undergo are to be neglected in comparison with the total amplitude of their movements.

If we now consider that in air the wave lengths of the tones of our

[1] Denote by A the amplitude of the vibration, and by $n$ the number of vibrations in a simple tone, $t$ the time, and $c$ a constant distinguishing the phase; then if $s$ is the varying displacement from the position of equilibrium we have

$$s = \mathrm{A} \sin \{2\pi n t + c\}.$$

If $\mu$ is the mass of the particle and $\kappa$ the force applied to the acceleration of the same

$$\kappa = \mu \frac{d^2 s}{dt^2} = -4\pi^2 n^2 \mathrm{A} \sin \{2\pi n t + c\}.$$

Now let $\lambda$ be the wave length and $a$ the speed of the transmission of vibrations of the sort considered in unlimited masses, then—

$$n = \frac{a}{\lambda}.$$

Thus for the maximum of $\kappa$ which occurs as often as the sine of the formula given to this end becomes equal to $\pm 1$

$$\frac{\kappa}{a^2} = \pm 4\pi^2 \frac{\mathrm{A}}{\lambda^2}.$$

Thus $\kappa$ is infinitely small in comparison with $a^2$ if A is infinitely small in comparison with $\lambda$, and $a^2$ multiplied into the density is equal to the constant of elastic resistence, which is assigned by the above mode of comparison.

musical scale between $C_1$ of 33 and $C_5$ of 4224 vibrations have values contained between the limits on one side of 1000 ctm., on the other of 8 ctm.; that the wave lengths are in water more than four times as large, in brass about eleven times, in copper twelve times, in steel and glass more than fifteen times as large as they are in air, and that, on the other hand, the dimensions of the ossicles and the labyrinth are in general small fractions of one centimetre, the important fact appears that the dimensions of the elastic solid and liquid masses which compose the hearing apparatus are in every case only small fractions of the wave lengths of those tones which usually occur and to which our ear is adapted.

We can hence draw these further conclusions. In the vibrations of the labyrinth, of the ossicles, and of the petrous bone, produced by the commonly audible tones, the parts of each of these small masses undergo relative displacements, which are infinitely small in comparison with the amplitude of the vibrations in question, *i. e.* they move approximately like absolutely rigid bodies.

The last ground of this peculiarity of movement lies in the extreme velocity with which the action of every force and impulse upon one of these little solid masses is transmitted. This velocity is so great that the time necessary to propagate the impulse can be considered as infinitely small compared with the duration of the sound waves, and hence the action can be looked on as instantaneously communicated throughout the whole mass.

An incompressible fluid also contained between solid walls is distinguishable from a compressible one in this: that every impulse which reaches any part of its surface communicates itself immediately throughout the whole fluid, and sets every part instantly in motion, while in a compressible fluid a wave proceeds from the spot of action, and travels with a certain velocity, setting in motion the several particles of the fluid consecutively. Thus, if the dimensions of the whole mass are infinitely small in comparison with the wave length (as it is in the labyrinth water), and if the walls of the petrous bone which enclose it are so solid that we can consider them as absolutely so when compared with the minute pressure under consideration, we deduce the following: The communication of action throughout the whole mass is practically instantaneous, and the labyrinth water, under the influence of the sound waves, moves virtually as a fluid absolutely incompressible, and therefore incapable of sound waves, would move under the same relations.

Finally, for the higher and middle tones of the scale at least, there must be an equality of pressure of the air within the meatus and that in the tympanum. In very high tones which correspond to the highest octave of the piano the length of the auditory canal is near a quarter of the length of the wave, and there occur the phenomena of resonance which I have described.[1] But the transverse diameter of the meatus is always too narrow for simultaneously existing, and distinct phases of condensation or velocity to enter at all or impinge on the separate portions of the membrane. Hence, without further consideration, we may always regard the pressure of the air as equal over its whole surface. This consideration is of great importance in the mechanism of the ear, because by it we exclude every possibility of a different local action on the membrane according to the position of the sounding body, and thus there remains in the sensation no other sign of the locality of the sound than the difference in its loudness, which can be noticed by altering the position of the head or by comparing the sensation of either ear.

The rule above laid down applies (as has been often noticed) to such solids as have none of their linear dimensions infinitely small compared with the rest, and, therefore, not to threads, membranes, rods, and plates. It is inapplicable also when some middle part of the body in question is very minute and compressed. Amongst the constituents of the organs of hearing it is only the membrana tympani which is thus excepted. In fact, such solids as are very thin in any direction, or at any spot, are capable of proportionately slower vibrations, for displacements of this sort—namely, to which the solid offers slight elastic resistance on account of its slight thickness—slowly equalise themselves and propagate themselves with a much smaller velocity than oscillations in thick masses of the same sort.

It is easily perceived that the ossicles are not included under these exceptions, when one compares them with the metallic rods or

[1] 'Lehre von den Tonempfindungen,' S. 175, 6. Helmholtz here refers to an especial loudness of several of the notes of the 4th octave, especially $c_4$ to $g_4$, which is most marked in the human voice, affecting the direct notes of the soprano and the harmonics of the lower scales. A distinct note may be recognised when attention has been drawn to it, especially in loud choral singing, due to the resonance of several consecutive notes of this octave, which are formed as harmonics. The phenomenon is due (as stated in the text) to the meatus being a resonator to notes of that pitch.—Ed.

tongues which we employ to obtain high tones. The tongues which are employed to produce the highest tones of the musical scale in a harmonium are relatively very long and thin compared to the dimensions of the ossicles, and to any one who has had any experience of the proper tone of such solid bodies there will remain no doubt that, if it were possible to set in continuous vibration such small masses as the ossicles, even the relatively thin stapes not excepted, they would produce enormously high tones which lie far beyond the superior limit of our musical scale, and would not be audible to our ear.

The relation between the ossicles and the vibrations of sound is practically the same as that between the vibrations of an iron bar hung so as to form a pendulum and the oscillations of the pendulum. Such a bar, too, is elastic, and can vibrate in many ways of its own. Of these vibrations many hundred occur in a second, whilst as a pendulum it oscillates, perhaps, only once in a second. If such a pendulum is put into oscillation by a periodic force whose periods last one or more seconds, or very large fractions of a second, each impulse which such a force imparts to a point on the bar can traverse the bar many hundreds of times before the corresponding impulse of the next period follows, and so spread its action completely through the whole mass of the bar before a small fraction of the period of oscillation is past.

Under these conditions the pendulum moves practically like an absolutely rigid body, that is to say, its actual movement is not observably distinguishable from such a one, even by the finest methods of observation. It is altogether different if we set the pendulum in oscillation by a tone whose pitch approximates to the bar's own tone. In this case it no longer moves according to the laws of the pendulum, but as a vibrating elastic rod.

The same holds good for the ossicles: as long as the periods of vibration of the conducted tones are very large in comparison with the proper tone of the ossicle, so long these must move practically as absolutely rigid bodies.

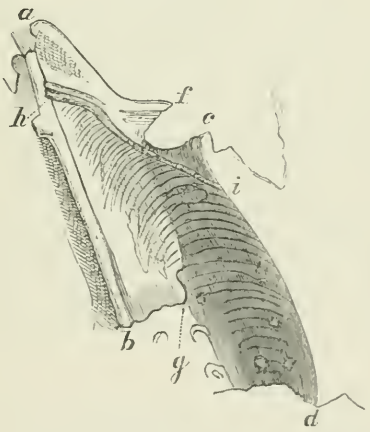
### § 2. *The anatomy of the membrana tympani.*

Before I can pass to the discussion of the mechanical action of the tympanic apparatus I must enter upon a few anatomical considerations, not because I have anything actually new to adduce, but

because in a thorough investigation of physiological relations a multitude of small details, glanced at only casually by anatomy, may help us to results of the highest importance, and on that account they must be partly recalled to the memory of the reader, and in part carefully corroborated.

The opening in which the membrane is inserted is, as is well known, formed by the squamous portion of the temporal bone, and by the remains of the tympanic ring, which, in the adult, is anchylosed, though not so firmly as not to break occasionally, on chiselling a preparation, just at that point where the union takes place, which constitutes a hindrance to the examination of the superior connection of the membrane. Even in the dried adult bone this separation is still indicated by the fact that at the borders of both parts, before and behind, spring bony projections, which separate a lower part of the opening, moderately oval in outline, and surrounded by the groove for the insertion of the membrana tympani from a superior section, more concave and irregular in form. The former belongs to the tympanic bone and the latter to the squamous bone.

Fig. 1.




In fig. 1 is represented the superior and anterior wall of the meatus of a temporal bone, of which a section is made parallel to this wall; *a b* is the plane of section of the anterior wall, which bounds the meatus on the side of the maxillary joint; *c d* is the line of section of the posterior wall; *b d* is the exterior opening of the

meatus. A shallow furrow, which, in the diagram, is somewhat more pronounced than is actually the case, indicates the line of insertion of the membrane. From the front (*f* to *g*) runs the line of the fissure, which, in the fœtus, separated the superior anterior edge of the tympanic ring from the squamous bone. The same fissure is also visible between *a* and *h* (fissura glaseri).

At *f* is a projecting point, which plays an important part in the attachment of the malleus. Henle calls this the posterior "spina tympanica," in contradistinction to another point distinctly pronounced in the fœtus at the anterior extremity of the tympanic ring and at its exterior anterior angle, which he calls the anterior spina tympanica, which might correspond to the point *g* in the much broader tympanic bone of the adult. The latter lies close by the corresponding surface of the squamous bone, and appears no more as a spine. On the other hand, we see somewhere between *c* and *i*, in fig. 1, at the posterior extremity of the above-mentioned segment, a blunt, less pronounced projection of the insertion edge of the membrane, which we shall have to mention very often.

In order not to occasion confusion by using Henle's name of spina tympanica posterior for the anterior *f* of these two points, I shall indicate *f* by the name of spina tympanica major, and the posterior *i* by the name of spina tympanica minor.

The neck of the malleus lies in the interval between *f* and *c*, so that the point *f* almost touches it. A somewhat shallow and less sharply bounded recess, which is visible between *f* and *i* in fig. 1, indicates also the insertion line of the membrane where it passes close in front of these points. Here this line is much less sharply indicated at this point than at the lower part of its attachment formed by the os tympanicum; for at this spot the membrane may be very easily displaced by means of a gentle pressure with a blunt instrument, and is really fastened to the skin rather than to the bone.

We will call this recess of the superior border the recess of Rivini, since it includes the position of the orifice described by Rivini—the last remnant of the first visceral cleft—though it does not exist in the majority of adults. If, as is normal, there is no opening, Rivini's recess is filled by a slack portion of the membrane, containing beneath the thin cutis merely loosely interwoven connective tissue, which is traversed by nerves and vessels (membrana flaccida of Shrapnell).

We will call the part of the membrane which occupies the recess Rivini's segment. On this account abscesses easily open here, and artificial openings are easily made in making preparations of the cutis layer. The difference in tension and consistence of this upper portion of the membrane, in comparison with the rest, is felt if the blunt end of a needle is allowed to pass over the surface in a preparation in which the attachments of the ossicles and the membrana are uninjured.

Between the spina tympanica major and the spina tympanica minor can be felt a pretty firmly stretched band of fibres, in which the short process of the malleus is inserted towards the anterior border. This band forms the upper boundary of the lower firm portion of the membrane. As soon as the needle passes over this it sinks suddenly in, as it presses back the loose cutis and connective tissue of Rivini's segment; also if the curvature of the external surface of the membrane is carefully observed with oblique illumination there is visible, as a rule, this band passing from the short process of malleus towards the spina tympanica minor. This, so far as I can discover, is formed by the peculiar fibres of the membrane. We will call this band the superior ligament (Befestegungsstrang) of the membrane. It forms the limit of the part of the membrane which is concerned with sound waves. On the inside, the membrana flaccida passes from its line of insertion into the fold of mucous membrane, which forms, according to Von Tröltsch, the posterior pocket of the membrane, and in the inferior free border of which the chorda tympani runs. The attachment lines of the membrane and of this fold meet at the bottom of the arch formed by Rivini's recess. They are here connected much more firmly with one another than with the bone. Posteriorly, the line of attachment of the fold of the mucous membrane does not run alongside the attachment of the membrane, but along the sharp edge of the wedge-formed, bony prominence which is indicated in fig. 1 by *e*. The outer surface of the process lies close within the membrane and almost parallel to it, and from without can be seen shining through its transparent tissue.

Further downwards, at its projecting edge, is found the opening for the exit of the chorda tympani. The little indentation which can be seen at *c* behind the projection in fig. 1 is the section of a funnel-shaped continuation of the canal of the chorda. The mucous fold of the posterior pocket of the tympanic membrane extends to the exit of the chorda. The nerve exactly bounds it inferiorly.

In front, from the highest part of Rivini's recess, runs the line of attachment of the fold of mucous membrane to the membrane itself, towards the short process of the malleus. This portion of the fold severs the small anterior from the larger posterior pocket. The attachment to the hammer will be described later.

The recess of Rivini lies towards the front and upper part of the membrane. Its greatest diameter runs down almost vertically from the posterior edge of the segment above the spina tympanica minor. I have measured its length in a number of preparations, and find, agreeably to Von Tröltsch, that it is from 9 to 10 mm. The least diameter lies almost horizontally, and starts somewhat below the spina tympanica major. I find its length to be from 7½ to 9 mm. These diameters have for the most part the same dimensions in the case of children as of adults.

The internal end of the meatus is turned inwards and a little downwards. The plane marked by the furrow of attachment of the membrane is again strongly inclined towards the axis of the meatus, so that it makes an angle with the latter of about 55°, whilst the two membranes together form an obtuse angle opening upwards of 130° to 135°. The membrane is not flat, but in the middle it is drawn strongly inwards by the attachment to it of the malleus, and on that account the membrane is shaped like a funnel, the point of the handle of the malleus corresponding to the apex of the funnel, and the meridian lines of the funnel are convex to the inside of the funnel. This form is very important in the mechanism of the conduction of sounds; so to render it more manifest I took a preparation from which the lower wall of the auditory canal had been removed, so that the membrane was left free, but otherwise undisturbed from its connections. From this I made a cast in stearin of the upper wall of the meatus and of the exterior surface of the membrane. An outline is given in fig. 2, which I had copied by the camera lucida:

Fig. 2.


*a b* is the upper wall of the meatus, *b c* the vertical outline of the membrane; the other portion is filled in from other preparations.

The convex arching (as regarded from the meatus) of the radial fibres thus put under tension is here very manifest. At the same time one sees how, in consequence of this drawing in of the umbo, the upper half of the membrane comes to be almost in the same direction as the upper wall of the meatus and how the lower stands almost vertically to the axis of this passage. This last circumstance is of importance in the examination of the ear by means of the speculum, because that portion of the membrane which is perpendicular to the axis of the meatus, and which, as a rule, lies close under the extremity of the handle of the malleus, reflects the light from outside back towards the opening of the meatus, and, in consequence, appears as a triangular shining spot.

The outer surface of the membrane is covered by a layer of epithelium, which is the continuation of the horny epidermis of the skin of the meatus, and acquires the power of reflecting light through being fatty. In the case of a very recent specimen, drops of water run off this fatty surface as from oiled paper.

The convexity of the meridians of the membrane is least in that meridian at which the handle of the malleus is attached to the membrane. In fig. 3 we have the outline of the above-mentioned stearine cast. The position of the malleus is indicated by dotted lines. In this diagram it is easily seen that the umbo lies somewhat beneath the centre of the membrane.

The meridian in which the handle of the malleus is fastened runs from the umbo of the membrane upwards and forwards towards the anterior border of Rivini's segment, so that the short process of the malleus, which bounds the superior extremity of the handle, lies close behind the external prominence which corresponds to the spina tympanica major that projects within. The malleus is fastened to this spine partly by a tense mass of fibres (ligamentum mallei anterius), partly by the so-called long process (processus folianus). The latter lies (as long as it exists) in a furrow on the inner edge of that process.

Whilst the point of the handle of the malleus pulls the umbo inwards, the membrane is known to be somewhat pushed out by the short process at the base of the handle.

The substance of the membrane consists of a peculiar fibrous membrane which is only about one twentieth of a millimètre thick, but very firm in proportion; on the outside it is covered by a thin continuation of the dermis of the meatus, on the inside by a con-

tinuation of the mucous membrane of the tympanum. These layers put together have a thickness of about 0·1 of a millimètre. The external dermoid layer consists chiefly of a continuation of the epidermis, which is borne on a thin layer of loose cellular tissue. It can be smoothly separated from the greater part of the surface of the membrane, except at Rivini's recess; and along the handle of the malleus, it clings firmly to the there thick and cartilaginoid tissue of the membrane.[1] From Rivini's recess there runs also on the upper wall of the meatus a line of firmer attachment of the skin with the bone, since the fibres of the cutis here bury themselves in the fissura glaseri—the old cleft which separates the tympanic from the squamous portion of the petrous bone.

The firm middle layer of the membrane is a fibrous skin which consists partly of radial, partly of circular fibres. The radial fibres lie externally. The end of the malleus handle forms the centre of radiation for those in the anterior half. On the posterior side they run more parallel, starting from the whole length of the handle of the malleus. The layer is thinnest along the edge, and becomes gradually thicker towards the handle of the malleus where the fibres are more closely packed.

The circular fibres form in the centre of the membrane a very thin layer which becomes gradually thicker towards the periphery, but (according to Gerlach) leaves the external periphery free, or, at least (according to Gruber), becomes much thinner than it is in the middle. At Rivini's segment the ring fibres are pretty strongly developed, shining like satin, and form here the ligament which bounds superiorly the firm portion of the membrane. Here they cut at a small acute angle the radial fibres, which at this point do not radiate from the umbo but from the short process of the malleus. Here also the entangled fibres of the cutis mingle with them.

The fibres of this layer are very firmly stretched bands, lying close to one another, and oppose a great resistance to any extension. They are distinguished by their great inelastic resistance from the much more yielding yellow elastic tissue. The substance of the membrane swells in acid and in caustic alkali, as tendon also does, but not the elastic tissue, and I found that, like tendon, it is quickly

[1] Gruber's obliquely ascending fibres of the membrane join here to the fibres of the cutis, as their deepest layer mechanically, even though they perhaps may be different in histological structure.

dissolved by boiling in alkali, so that only a small remnant of the elastic tissue remains, which is easily recognisable, as consisting partly of vessels, partly of a very thin continuous membrane, which apparently forms the basis of the mucous layer on the inner side of the membrane.

This constitution of the membrane is of great importance for its mechanical function, as what follows will prove. It is to be considered not as an elastic and yielding membrane, but as an almost inextensible one; its very slight extensibility is seen if either in its natural situation, or when removed, it is spread on a glass plate and torn with pins. It does not expand like caoutchouc, or like a moistened piece of animal bladder, but it opposes the stretching tension with considerable force, and forms folds around the torn spot like a collodion membrane.

### § 3. *The attachment of the malleus.*

The malleus is connected with the membrane in a manner described not long since by J. Gruber. The membrane is thickened at those points at which the bone is attached, partly by strong bundles of fibres of the cutis layer, which run from Rivini's recess to the points of attachment of the malleus, partly through an introduction of fibro-cartilaginous tissue. The periosteum of the malleus on both surfaces of the handle passes into this fibro-cartilaginous layer, and fixes the bone to its borders. In the neighbourhood of the lower end of the handle the union of the bone with the thickened tissue of the membrane is thoroughly firm. But towards the short process a more yielding layer is formed between the bone and the membrane, or even a sort of incomplete joint, which is fixed only on its two borders, through the connection of the periosteum of the malleus with the edges of the cartilaginous layer and the fibrous tissue of the membrane.

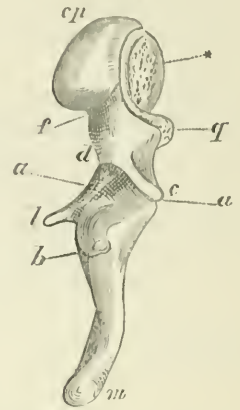
By the point of its handle the malleus draws the umbo of the membrane inwards, so that the union must here be very firm. At the short process the malleus presses against the membrane; thus a less firm union is sufficient; and at the same time there is allowed the possibility of slight displacements of the bone in respect to the membrane, of the conditions of which a more explicit account will be given hereafter.

The second and relatively firmest attachment of the malleus is that

with the spina tympanica major. The point of this spine reaches quite

Fig. 3.

Fig. 4.




close to the neck of the malleus at the point *d*, fig. 4, close over the root of the processus folianus. In this view the malleus is seen from the outer side; *cp* is its head, *b* the short process, *m* the handle, * the surface of articulation with the incus. The processus folianus lies along that edge of the spina that is turned towards the tympanum (the edge *fa* in fig. 1). Thus the edge of the spina and the above-mentioned edge of the malleus run alongside, separated only by a very small interval of about one third millimètre in breadth, from the point *l* to the furrow at *d*. This interstice continues from *d* upwards to the depression at *f*, where an edge of bone running upwards from the upper surface of the spina stands over against the malleus. The whole of this interstice is bridged over by short tense fibres. Longer fibres of the same sort run from the surface of the spina, and from that edge of it that runs downwards, converging towards the point *d* of the malleus. They surround the under edge as well as the external surface of the processus folianus, so that it lies altogether hidden in the mass of fibre which forms the ligamentum anterius mallei and in the folds of mucous membrane which cover it. Here I must remark that in children the processus folianus is for the most part a long elastic strip of bone, extending to the fissura glaseri. Concerning its proportions in adults, I must follow those anatomists who describe it as a short shrunken stump. I remark that I have in many preparations of the temporal bone been particularly cautious lest this process should be broken

by the attempt to remove the hammer. With this view, before the malleus was at all loosened, I have introduced a fine needle as a probe between the bundles of fibres of the ligamentum mallei anterius, and tested the processus folianus with it. I was able to follow it for a short space, then it stopped suddenly in the middle of the aforesaid ligaments, and I could not feel any kind of continuation of the stump of bone, which must have been present if the process had only been broken off.

I must also remark, the remaining stump of the aforesaid process does not throughout join directly and firmly to the spine, but is everywhere united to it only by a short fibrous band. Consequently, in a preparation in which the connections of the malleus are all perfectly preserved, and in which it retains its natural position, if we lay a needle on the root of the processus folianus we can somewhat displace the malleus from above downwards as well as from within outwards; that is, as much as the short connecting bands of the ligamentum anterius allow. Neither of these movements is opposed by the contact of bone with bone. Thus the anterior ligament is mainly (apart from the superficial longer strengthening fibres) a very short and broad band, whose line of attachment to the malleus runs from *l* to *f* (fig. 4); and it is closely opposed, from *l* to *d*, to the inner edge of the spina tympanica major at *d*, to its point, and from *d* to *f* to a ledge of bone which runs upward from the spine. I observe here that the ligament expands upwards and downwards in the form of a fold of mucous membrane. Upwards the fold runs nearly along the contour line of the bone as in fig. 4, remaining always thin and falcated all the way, since the external wall of the tympanum is, all along, very near the head of the malleus. It terminates above on the head of the malleus, and on its border lies the short round ligamentum mallei superius, which descends obliquely to the head of the malleus outwards and downwards, and thus forms a limiting band for its outward movements.

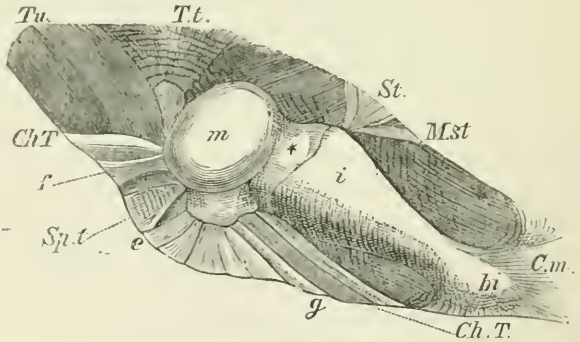
Inferiorly, the ligamentum anterius is prolonged downwards from *l* through two mucous folds, one of which runs from the root of the processus folianus towards the point *b* of the short process. The opposite line of attachment lies on the membrane. This is the fold which separates the anterior and posterior pockets of the tympanum from one another, so that the space over the short process *b* belongs chiefly to the posterior pocket.[1]

[1] In 'Archiv für Ohrenheilkunde,' iii, Bd., S. 255—266. Dr. Prussak has

The second downward prolongation of the anterior ligamentum is a small fold with a free border which descends to the lower edge of *l*, and, enwrapping this process, descends somewhat along the contour line of the bone in fig. 4 as far as the tendon of the tensor tympani, *i.e.* to the point where the dotted line from *b* cuts the contour of the bone. The last-mentioned fold bounds the anterior pocket towards the tympanum.

The line just described, of ligaments and folds of mucous membrane, runs from *b* in fig. 4 to *cp* all along the contour line of the bone. From it, precisely at *d*, where it is strongest and shortest, there starts a second ligament, which I will call the ligamentum mallei externum. This springs from the malleus, from *d*, along a pronounced ridge of bone which runs to *c*, fig. 4. On the other side it is attached to the sharp edge of Rivini's recess, while posteriorly it follows the line of attachment of the posterior pocket of the membrane. (In fig. 1 it runs along the contour from *f* to *c*). This ligament consists of a multitude of distinct satiny fibres which radiate from the short crest of the malleus between *d* and *c* to a much broader and more curved line of attachment on the temporal bone.

Fig. 5.




In fig. 5 this series of bands is represented, as seen from above; *e.g.* in its line of attachment to the temporal bone. In this prepara-

given a different description of the pocket of the membrane. According to him the space over the short process forms an upper pocket separated by a partition wall from the posterior one. I have never been able to find it. The supposed opening of this pocket leads upwards over the head of the malleus to the space over the ligamentum mallei externum, and so no more to the membrane.

tion the tympanum was opened from above, and its superior external wall was cut away, so as to afford a view between this wall and the corresponding surface of the ossicles. *M* is the head of the malleus, *i* the body of the incus to the point of its short process. *Tu* the entrance to the tube. Deeper are observed a portion of the stapes (*St*), and the tendon of its muscle. Further, the tendon of the tensor tympani and the bony funnel (*Tt*) from which it comes. *Ch. t* is the chorda tympani, which indicates the free edge of the folds of the mucous membrane which bound the pockets; *f* is the uper fibres of the ligamentum mallei anterius which rise above the spina tympanica major. *Sp. t*, the sharply projecting crest at the neck of the malleus, from which the diverging bundles of the ligamentum externum radiate, is plainly visible.

Of these bundles the strongest and most tense is the hindermost, which is attached at *g*. Its direction, if prolonged, would go towards the point of the spina, and this band it is which principally represents the rotation axis of the malleus. I might on this account call these most posterior bands of the ligamentum externum by the special name of ligamentum mallei posticum, because, in fact, they have mechanically a special importance.

The extreme tension of these fibres is very evident in a preparation in which the attachments of the ossicles are intact, if one tries them with a pin-point, while the border of the mucous fold in which the chorda lies is always slack, and also the anterior portion of the ligamentum externum at *e*, fig. 5, is not very tense, unless the tensor tympani is contracted, or the membrane pushed outwards. If one pushes with a needle strongly against the ligamentum posticum the malleus inclines itself noticeably, and, further, when the membrane moves backwards and forwards, this last-named band is that which moves the least of all the attachments of the malleus. We shall afterwards discuss whence comes the small movement which they make.

If we suppose the direction of the ligamentum posticum prolonged through the malleus the prolongation coincides with the central and strongest fibres of the ligamentum anterius, which proceed from the spina tympanica major. These two bundles of fibres together, which are separated, indeed, from one another by the body of the malleus, yet considered mechanically form one band, which we call the axis band of the malleus. This band suffices to hold the malleus in its natural position; even when the incus is carefully removed. As long as the tension of the tendon of the tensor tympani is maintained

its position is quite firm. In fig. 4 the approximate position of the axis of the malleus is shown by the dotted line *a*, *a*.

The other fibrous strands in the fore part of the ligamentum externum are shorter filaments, reaching directly outward towards the attached edge of the membrane in the base of Rivini's recess; since they lie above the axis they are antagonistic to an outward motion of the malleus handle and membrane towards the meatus. They are thus essentially bands limiting the rotation of the handle of the malleus externally. We see this clearly in suitable preparations, such as that of fig. 5. They relax as we press the membrane inwards or the head of the malleus outwards. They allow of only a trifling rotation of the handle of the malleus outwards, even though the tendon of the tensor tympani, the articulation of the stapes, and the ligamentum superius of the malleus have been previously loosened. The membrane is drawn still more inwards if the above-mentioned bundle of fibres is pressed from above by the point of a blunted needle, and thereby stretched. Finally, we have to observe that on a powerful pull of the tensor tympani, when the handle of the malleus is by the stretching of the membrane prevented from being pushed further in, and the above-mentioned bundle of fibres of the ligamentum externum prevent the axis band of the malleus from being pushed beyond a certain degree from within outwards; that movement can only take place till these fibres become stretched, and they are evidently seen to become tense on making the experiment. Then the traction of the tensor tympani is transferred to them, and can no longer act on the axis-band. Just as the ligamentum externum protects the axis-band of the malleus from a too violent inward traction, so do the upper and lower bundle of fibres of the ligamentus-anterius shield the axis-band from being drawn too strongly upwards or downwards. If the malleus turns on its attachment to the end of the spine, its head backwards, its handle forwards, the upper fibres of ligamentum anterius are stretched; if a rotation in the opposite direction takes place, the lower ones. Hence it is that even if the incus is removed, the hitherto described ligaments remaining, the malleus still resists such inclinations pretty well, and remains pretty steadily in its natural position. The uppermost fibres of the ligamentum anterius generally (as shown in fig. 5) approach the head of the malleus in a direction inclined somewhat inwards, and, consequently, are stretched, like the ligamentum superius and externum, on an outward motion of the membrane.

The tightness of these ligaments is, under natural conditions, still further increased by the elastic tension of the relatively strong muscle, the tensor tympani, whose tendon is inserted at the beginning of the handle of the malleus, on the anterior half of its surface, which is turned mediumwards and faces the tube, a little lower down than where the short process projects from its side at the upper part of the handle, a little below the short process. Fig. 9 shows the somewhat oblique line of attachment of the tendon running from above downwards and backwards.

The muscle lies, as we know, in a peculiar canal of bone, which runs over the Eustachian tube, through which the tympanum communicates with the throat. The further end of the muscle arises outside this canal from the under surface of the pyramidal portion of the petrous bone, and from the cartilaginous portion of the Eustachian tube. Thence it proceeds through its canal, the end of which, opening on the tympanum, forms a hook-shaped prominence, round which the tendon winds, so as to run finally across the tympanum to the malleus. The direction of the tendon is nearly perpendicular to the plane in which the edge of the membrane lies, so that its line of action only deviates from it slightly downwards and forwards. On the other hand, it forms a pretty acute angle with the lower part of the handle of the malleus, and with the anterior portion of its axis of rotation. The tensor tympani is a feathered muscle; it springs from the periosteum of the upper surface of the bony canal in which it lies. Its tendon lies on its under side, and turns a smooth free surface towards the smooth periosteum. The muscle-fibres are pretty short, and the tendon, therefore, contracts as far as the lower end of the canal. The tube of the periosteum which encloses the muscle is prolonged also over the free portion of the tendon that runs through the tympanum, externally covered by its mucous membrane. Toynbee gives the name of tensor ligament of the membrane to this sheath of the free portion of the tendon. The isolation of the tendon and its sheath from one another appears to be more or less perfect when one compares different accounts. I myself have found, in a preparation in the anatomical collection at Bonn, a perfectly smooth and free tendon inside the sheath, as Toynbee describes.

On the contrary, Henle has seen in microscopic sections the tendon and sheath blended together by moderately strong connective tissue. In consequence of the very small space for move-

ments of the malleus there is no necessity for much mobility of the tendon.

The tensor tympani draws the handle of the malleus and with it the membrane inwards, and so stretches the latter. This action is easily seen in a preparation in which the canal of the muscle and the tympanum are opened from above. If one takes hold of the tendinous strands of the muscle still within the canal and draws upon them, the membrane is stretched.

As the attachment of the muscle lies only a little lower than the axis ligament of the malleus, this is also stretched medianwards, especially its posterior portion (the ligamentum mallei posticum), which most nearly corresponds to the direction of the tensor tympani. A very moderate tension of the tendon gives a very tense poise to the malleus.

We must here consider that a slight tension, which is exerted transversely upon a tense inextensible band, is able to increase the tension of that band very considerably, and that the living muscles in their natural state must be considered as very yielding, yet always slightly stretched, elastic bands, which tension becomes very considerably increased by their active contraction. For the rest, since the tensor tympani is, on account of its feathered structure, equivalent mechanically to a muscle of much greater section and less length of fibre, we must regard its elastic strain, even without any active contraction, as a considerable force. In this way it is evident that the malleus, although held only by pliant bands, yet as long as its natural fastenings remain, has, even after disarticulation of the stapes, but a very slight mobility, and this in the way of turning on its axis as above described; and it is also evident that it opposes a very considerable resistance to any attempt to force it in a different direction. Its axis is fastened in front by the ligamentum anterius, and by the processus folianus, which lies in it. Posteriorly it is fastened by the hindermost strands of the ligamentum externus. These two we have classed together as the axis-band of the malleus. This ligament is always somewhat tense, even if the tendon of the tensor tympani is severed; but so long as this muscle exerts its strain transversely upon the axis-band, the tension of the latter is kept at a high point.

The malleus thus attached possesses, further, the above-described limiting bands against outward motion of the handle; these are, besides the tendon of the tensor tympani, (1) the central and ante-

rior fibres of the ligamentum externum; (2) the ligamentum superius; (3) the upper fibres of the ligamentum anterius.

The membrana tympanica itself forms a limiting band for its inward motions.

As far as the slight extensibility of the axis-band and of the upper and relatively lower fibres of the ligamentum anterius will admit, the head of the malleus can move forwards and backwards, or revolve round a vertical axis; but the latter movements are yet further limited by its connection with the incus. Yet we shall see that the movement of the malleus, together with the incus, demands a certain yielding of the axis-band.

### § 4. *The attachment of the incus.*

The body of the incus is united by an articulation to the malleus. Its long process we will call the handle of the incus, in analogy with the similarly directed handle of the malleus. It stretches downwards, and has at its end, which is slightly turned towards the median line, a small articulating surface for the stapes. The other, or "short," process looks backwards, and rests by its point, which has on its lower corner a small imperfectly formed articular surface, in a slight depression of the bony wall of the tympanum, where the tympanum prolongs itself into the cells of the mastoid process. The capsule of this articulation has, especially at its upper side, firm tendinous fibres (indicated at *b i* in fig. 5), which pass partly inwards and partly laterally and backwards. In the same figure *i* is the body of the incus, and * the capsule of the malleo-incudal articulation.

The form of this last articular surface is commonly described as saddle-shaped, only it is to be observed that not only the concave, but also the convex curve of this saddle, forms an almost sharp angle, in which two almost plane surfaces meet. To make the mechanical action of this articulation evident, it will be best to use another comparison than that of a saddle surface. It is an articulation like the ratchet joints of watch keys commonly are, in which the handle cannot be turned in one direction unless the steel case move with it; in the other direction it can be turned backwards with little resistance. Like such a watch-key joint, the articulation between the malleus and the incus allows a rotation, though but a small one, round an axis running through the head of the malleus towards the short process of the incus, which rotation, if directed to the inward dis-

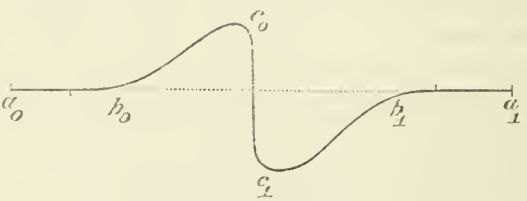
placement of the handle of the malleus, is opposed by a pair of cogs, whilst the malleus, on the contrary, can be pushed outwards without carrying the incus with it.

In order to make such an articulation of metal, screw surfaces are employed. A hollow cylinder, cut away as in fig. 6, on which the piece B, denoted by the dotted lines, fits, would represent the normal form of such an articulation. It is clear that if A and B are turned opposite ways in the direction of the two arrows, they must resist one another with their two cogs *a* and *b*, and so such a rotation is necessarily prevented, while the opposite rotation is free, with a gradual separation of the cylinders from each other. The mechanic who executes such a joint makes the cylinder hollow, because near the axis there would be a difficult steep ascent, like the inner wall of a spiral staircase. The articular surfaces of the bones, which are covered with elastic cartilage that easily fills their interstices, exhibit the corresponding geometrical forms only approximately, with rounded angles, and so on.

Fig. 6.


The periphery of the malleo-incudal articulation is not a regularly formed screw line. If we suppose the cylindrical circumference of the articulation to be spread out on a plane, it would have somewhat

Fig. 7.



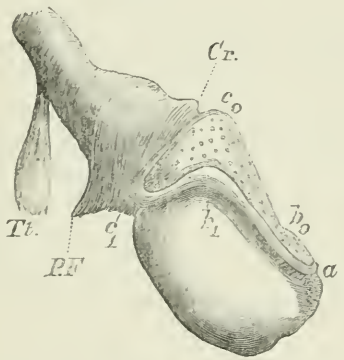

the form of fig. 7, so that the ends $a_0$ $a_1$ are continuous. Further, regarded from the axis of the joint there is not presented the form of a perfect spiral like a spiral staircase, but rather that of a conical surface. If we suppose straight lines drawn from a point in the axis

of the cylinder to all points in the periphery (running as $a_0\ a_1$), we obtain about the form of the articular surface. And, indeed, for the malleus we must place the apex of the cone thus arising somewhat lower than the straight part of the periphery $b_0\ a_0\ a_1\ b_1$, so that the hither directed portion of the conical surface is concave to the malleus; to the incus, on the contrary, it is convex.

Such an articulation consists of four pretty level surfaces, which meet in its centre, and at the border show the edges (1) $c_0\ c_1$, (2) $c_0\ b_0$, (3) $c_1\ b_1$, (4) $b_0\ a_0\ a_1\ b_1$; the superior surface of the articulation will (like a saddle-formed one) display two projecting edges, namely, those which proceed from $c_0$ and $b_1$; and two receding, those which proceed from $b_0$ and $c_1$.

In fig. 8 the malleus is represented as seen from above and from

Fig. 8.




within; the letters $a\ b_0\ c_0\ b_1\ c_1$ have the same meaning as in fig. 7, the flat portion of the articular surface is just seen foreshortened. P F is the origin of the process folianus; *c r* the beginning of the ridge of bone from which the ligamentum mallei posticum springs; *t t* is the tendon of the tensor tympani. As we see here, the point $a_0\ a_1$ (*a* in fig. 8; $a_0$ and $a_1$ joining on together) lies at the upper side of the joint; on the other hand, the opposing edges of the cogs lie below, at $c_0\ c_1$, between the malleus handle and the long process of the incus. The cog $c_0$ of the malleus lies on the side of the articulation which is turned to the membrane; that of the incus on the median side. An inward motion of the malleus handle is thus

not possible without carrying the incus with it. Its outward motions, however, have so much play as the ligaments and the cartilages will allow.

The point $a_0\ a_1$ lies, on the articular surfaces of both bones, further from the axis than the cogs $c_0\ c_1$, so that the almost level portion of the surfaces is more developed than are the surfaces of the cogs. Corresponding to this the whole surface of the articulation is elliptic, with the vertical axis the longer. We must further remark that the apex of the conical surface, which we have taken as the type of the articulation, is not sharp, but is rounded off saddle-wise.

A conical surface, such as may be constructed by means of fig. 7, cannot move upon its counterpart with complete contact, for if the two portions of the spiral line $b_0\ c_0$ and $b_1\ c_1$ slide on one another at the periphery of the joint, the middle of the joint and the level portion must part from one another, whilst the two bones rest on one another only by means of the two above-mentioned spiral lines. But in a fresh articulation this interval, which is really very slight, is completely filled by the swelling cartilage.

The described action of the articulation can also be very well perceived in dry preparations if small matches are fastened as handles (with sealing wax), one to the malleus above and in the direction of the processus folianus, and the other to the incus, at the top and in the direction of its short process; and if then the bones are placed with their articular surfaces against one another, and the match fastened to the malleus is rotated, whilst the other is held with a light friction.

If one turns the malleus in the direction from the head to the short process and handle, it grasps the incus completely, and carries it with its motion. If it is rotated backwards the articular surfaces are separated from each other and the incus remains stationary.

The peripheries of both articular surfaces are joined by a capsular ligament, which is inserted into a slight depression. The capsular ligament is not very firm; it tears on comparatively slight jerks of the bone. The fibres which proceed from the cog of the malleus are the firmest. Hence start also a few fibres of the ligamentum externum of the malleus to the incus.

The excursion-distance of the malleo-incudal articulation, measured at the lower end of the long process of the incus, amounts to only half a millimètre, and since this point is about six millimètres from

the point of rotation of the joint, the rotation of both bones upon one another does not amount to five degrees.

As long as malleus and incus are in their natural connection with one another and with the petrous bone, but the incus separated from the stapes, they can pass through motions together, in consequence of which the handle of the malleus and that of the incus (ambosstiel) move outwards or inwards simultaneously with the membrane. The malleus taken alone would revolve around its axis-band as an axis of motion; through its connection with the incus its rotation is somewhat altered. The attachment of the short process of the incus *b c* (fig. 5) lies pretty considerably inwards from the lengthened axis-band of the malleus. But on a simple movement round a firm axis it is only the points of the axis of rotation itself that can remain fixed—no others. Further, the distance of single points lying on the outside of the axis of rotation of the moved body from an external fixed point (in this case the point of attachment of the short process of the incus) cannot remain undisplaced by the rotation. From this, in the case of infinitely small rotations, are only excepted such points of the rotated body as lie in a plane passing through the axis of rotation and the external fixed point. This last is not the case with the head of the malleus, which, since it lies above the axis of rotation, must become more distant from the point of attachment of the short process of the incus on an inward rotation of the handle. But since the incus is held tight between the malleus and the above point of attachment by short and but slightly yielding ligaments, and the distance of these two points does not vary; it follows that as its handle moves inwards the malleus-head must make a slight inclination backwards towards the incus, and the handle a similar turn forwards. That such an inclination occurs in fact is evident by the tension which we see to be thus caused in the capsule ligament on the upper side of the malleo-incudal articulation, in the uppermost strands of the ligamentum mallei anterius, and in the tendinous strengthening fibres of the incudal tympanic articulation. Both the capsular ligaments may be seen by a lens to stretch when the membrana tympani is pushed inwards by the head of a pin.

Further, if under these conditions the short process of the incus is pushed from above by a needle, we feel and see that it does not lie in contact with the floor of the depression in which its point is inserted, but can still approach perceptibly nearer, in which case the

satin-like ligaments of the articulation relax into folds. On the other hand, the point of the short process of the incus lies on the wall of the tympanum which rises on its outer side, and externally rests on this, while it is capable of a slight gliding movement vertically. The incus is thus, as it were, free from the malleus, and held suspended in the air, so that in its normal position the point of its short process touches the bone only on its outer side; but if the malleus and membrane are pushed outward the point of the short process of the incus slides a little downwards and rests upon the bone below at the bottom of the hollow of its articulation. There must also take place a small displacement of the incus towards the malleus, at this articulation, when the malleus handle is pushed inwards. Suppose, for a moment, that the incus were joined firmly to the malleus, and that the latter turned on its axis-band, then the point of the short process of the incus which lies in front of the axis-band would be raised by an inward motion of the membrane. For the point to return to its place of attachment, the incus must execute a rotation towards the malleus, by which motion the point of the short process is lowered.

A small motion of this kind is rendered possible by the saddle shape of the malleo-incudal articulation; and simultaneously the long process of the incus somewhat approaches the malleus handle. This last movement can be recognised in preparations in which the incus and stapes are separated, but all the other articulations remain. Now this is exactly the position of the two bones (as can be seen in fig. 8) when the lower, cog-bearing, portions of the articular surfaces press against each other. This is plainly felt if one tries, as above, to place the dried bones in the positions in which they pack closest.

Another small displacement of the malleus is effected by this connection. Its head cannot be inclined towards the incus without forcing the axis-band somewhat out of a straight direction. The anterior side of the neck, with the processus folianus and the ligamentum anterius, would rise; and the posterior side of the neck, with the hinder strands of the ligamentum externum, would sink. The former can hardly take place, since the spina tympanica posterior lies close above the processus folianus, and would forbid its upward movement. The more decided, therefore, must be the sinking of the posterior side of the neck, and with it of the whole of the malleus, in consequence of which the fibres of the ligamentum

mallei posticum, which are directed backwards, and somewhat upwards, must become more tense.

These considerations agree with a thesis recently put forward by Politzer.[1] He attached threads of glass as levers to the ossicles, so as to determine with greater accuracy the axis of movement of the particular bones. He put the membrana tympani in motion by a pressure of air in the meatus. He found that the axis of the malleus passes through the root of the processus folianus; that of the incus through the point of the short process; but that both axes are not fixed but movable.

The small changes in the axis-movement of the malleus, which are occasioned by the peculiar attachments of the incus, appear to me to have great influence in determining that the umbo of the membrane always moves in a direction normal to its plane of insertion. As the axis-band of the malleus is directed obliquely to the plane of insertion of the membrane, each inward movement of the malleus handle would cause also a backward movement of the umbo. But at the same time the malleus head would be drawn backwards by the incus, and so the handle receive an opposing motion forwards. As the umbo of the membrane lies farther from its plane of insertion than the axis of the malleus (excepting, at most, its foremost end at the spina tympanica) each inward motion of the malleus handle will cause a small upward displacement of the umbo (*i.e.* in a direction towards the head of the malleus). This motion and that which we have just explained, namely, that the malleus as a whole is drawn somewhat downwards by the incus, act in opposite directions. Thus both deviations in the movement of the umbo are compensated, and thus there only remain the movements which take place perpendicular to the plane of insertion of the membrane.

It is evident, at the same time, that the short process of the malleus must slide a little on the membrane in these movements, which is rendered possible by the peculiar connection between them described by J. Gruber.

I would further remark that the traction of the tensor muscle of the membrane renders tense all these ligaments, which fix the ossicles in their position. Primarily, it draws the malleus handle inwards, and with it the membrane; but, at the same time, it acts on the axis-band of the malleus, which it draws inwards and stretches. Thereon

[1] 'Wochenblatt der k. k. Gesellschaft der Aerzte,' Wien, 1865. Jan. 8.

the head of the malleus, as we have shown, is moved away from the incudo-tympanic articulation, and the ligaments of the incus are stretched, as well those towards the malleus as those at the point of its short process, which last is raised from the bone. The incus, in consequence, comes into the position in which the cogs of the malleo-incudal articulation grip one another the tightest. Finally, its long process is forced to accompany the inward motions of the malleus handle, and it is urged, as we shall see further on, upon the stapes, and presses it into the fenestra ovalis upon the labyrinth water.

In reference to this, the construction of the ear is very remarkable. By the traction of this one elastic mass of fibres (the tensor tympani), whose tension, besides, is variable, and can be adapted to the requirements of the case, all the inelastic ligaments of the ossicles can simultaneously be placed in active tension.

The only ligament that is relaxed is the ligamentum mallei superius, which acts in the same direction as the tensor muscle. Hence in a recent preparation, in which the tensor tympani is still rigid, all the contents of the tympanum are tense and firm, while later on, if the different parts are taken separately, almost all the ligaments of the ossicles, both those of attachment and interconnection, are relaxed and slack, so that, without an exact scrutiny of these relations it cannot be perceived how they are united with one another.[1]

### § 5. *The motions of the stapes.*

The articulation of the stapes with the incus has the shape of a shallow segment of a sphere which is convex on the side of the stapes. The capsule is delicate, more interwoven with elastic fibres than are the two other articulations.

[1] In respect to the occasions on which the tensor tympani contracts, I can confirm Politzer's observation, that it takes place in yawning. Before I knew his experiments I had observed that when I depress the lower jaw in yawning I hear, first, the well known 'knack,' which indicates the opening of the tube; then, at the acme of the yawn, there occurs in me, with a feeling of tension in the ear, a loud muscular murmur, louder than I ever hear with open meatus (and almost than with closed) when I make the strongest contractions of the muscles of mastication. At the same time external sounds are much dulled. I conclude from this that a muscle is set in contraction whose oscillations are much more completely conveyed to the ear than those of any other; that is, the tensor tympani.

On the under side there are compact fibres, which, when the incus is drawn upwards, are stretched and carry the stapes with them. On the opposite movement, however, they fold together, so that the stapes does not follow so implicitly.

The basis of the stapes is surrounded by an elastic fibrous cartilaginous lip, like those of larger articulations, which has a breadth of 0·7 mm.

The connection between the base of the stapes and the wall of the labyrinth seems to be established only by means of the periosteum of the vestibule, which is continued over the basis of the stapes (Henle).

The fibrous lip of the stapes is not attached to the edge of the oval fenestra. On the outer side the mucous membrane of the tympanum also covers the joint. The attachment of the base at its under side (along its straighter edge) is somewhat closer than at the upper side. It is firmest at the posterior end. Hence if one pushes the basis of the stapes outwards by means of a blunt needle introduced into the vestibule, it makes (even if it has been separated from the incus) a lever motion, so that its head is displaced downwards and backwards. If a fine needle is pushed into the basis, to act as an indicator, the lever motion is seen still better; but, on the whole, the mobility of the basis of the stapes is very small.

I have estimated it partly directly, partly by calculation, from the movement of the labyrinth water. For the direct estimation, a preparation is taken in which the tympanum and the vestibule are opened from above, and a very fine needle is inserted into the membrana obturatoria of the stapes near the anterior crus. The preparation should then be placed so that the basis of the stapes looks downwards, and be fastened in a $\gamma$ vice in this position.

The needle has, as its second point of support, the sharp edge of the section of the bony wall between the tympanum and the labyrinth. This point is distant 3·8 mm. from the point of the needle in the ligamentum obturatorium, and serves as a fulcrum for its lever motions. The free horizontal remaining part of the needle forms the second and longer arm of the lever, 23 mm. in length. The point of this longer arm moves 0·20 mm. up and down when a needle placed against the basis of the stapes is moved out and in; it moves 0·15 mm. if alternate compressions and rarefactions of the air are produced in the external meatus, so that the motion of the membrane is conveyed to the stapes through the other ossicles.

Now, the movements of the stapes, as observed at the free end of the needle, are increased about $\frac{3}{4}$ or $\frac{4}{5}$, so that the displacements of the stapes itself amount to only 0·033 and 0·025 mm. After frequent repetitions of the experiment, however, by which the ligaments were well stretched, the displacement rose to about 0·056 mm.

In another experiment (as practised by Politzer) only the upper semicircular canal was opened, and a fine glass tube was introduced, whose transverse section was found, through calibration by quicksilver, to be equal to 0·228 of a $\frac{1}{4}$ square mm. The vestibule and a portion of the glass tube were filled with water.[1]

Movements of the ossicles consequent on forcing the air into the meatus caused the liquid to mount about 0·9 mm. in the tube. Now, since the diameters of the fenestra ovalis equal 1, 2, and 3 mm., the surface of the fenestra ovalis is about 12·4 times as large as the section of the glass tube, and the mean amplitude of the excursions of the base of the stapes must, therefore, be $\frac{1}{12\cdot4}$ of that of the fluid in the tube, which gives 0·0726 mm. The largest values, therefore, that we have found for the excursions of the stapes are thus $\frac{1}{13}$ and $\frac{1}{17}$ mm.

The relation of the stapes to the incus is such that if the handle of the malleus is pushed inwards the long process of the incus presses firmly against the head of the stapes, even if the capsular ligament between the two is severed. If, on the other hand, the malleus handle is moved outwards so far as the ligaments of the malleus allow, then, if the capsule is severed, the long process of the incus moves away from the stapes about $\frac{1}{4}$ to $\frac{1}{2}$ mm. If in this position of the malleus the long process of the incus is pushed again towards the stapes, it remains there without springing back; the cogs of the malleo-incudal articulation are separated, and there is no force there sufficient to draw the incus back. With the malleo-incudal articulation perfect, the incus remains naturally in contact with the stapes; but it follows, from the above described facts, that when the malleus handle is pushed outwards the incus exerts no traction on the stapes, for even when the articulation is severed the incus will remain in

[1] To make it air-tight I first well dried the bones with blotting paper, then touched the opening of the canal with a red-hot iron-wire, and on the dried and seared spot was placed a drop of warm resin (Wachharzkett) in which the tube was fixed; then the preparation was placed in a cup of water, so that the end of the tube was covered, and brought under the air-pump. On exhausting the pump, the air escapes from the vestibule and water enters.

contact with the stapes, without being drawn outwards with the malleus.

This arrangement has evidently the important consequence that the air in the tympanum may be compressed, or the pressure diminished in the meatus, and so the membrane forced outwards, without the stapes incurring the risk of being torn away from the fenestra ovalis. For the reverse motion of the malleus inwards, the membrana tympani itself forms a very efficient check.

As the point of the long process of the incus, regarded from the axis-band of the malleus, is directed still more backwards than the point of the malleus handle, it is, on an inward motion, raised still more than the latter, and this elevation is not entirely compensated by the above described slight sinking of the malleus. Thus, an inward motion of the membrane causes the point of the incus to be pushed inwards and a little upwards simultaneously. This accords with the corresponding motion of the stapes, whose head rises a little when it is pushed inwards, in consequence of its above described unequal attachment to the upper and lower edges of the fenestra ovalis. This lever motion of the stapes has already been described by Henke,[1] Lucae,[2] and Politzer.[3] As to the first, I have only to remark that the lever motion is by no means simple, one wall of the base moving inwards while the other moves outwards. By observation of the stapes from the vestibule it can be ascertained that both walls are simultaneously moved in and out, only the upper more, the lower less.

Drs. Lucae and Politzer do not agree as to the action of an increase of pressure in the air in the tympanum upon the stapes and the labyrinth. The explanation may be that Lucae has observed the lever motion of the stapes, Politzer the fluctuations of the labyrinth water subsequent on an inward motion of the stapes. These do not necessarily entirely correspond, especially in this particular case, since the pressure of the air can increase the pressure in the labyrinth through the fenestra rotunda.

### § 6. *The united action of the ossicula.*

If we suppose the malleus and incus to be brought into contact,

[1] 'Der Mechanism der Gehörknochelchen in der Zeitschrft für rationelle Medicin,' 1868.

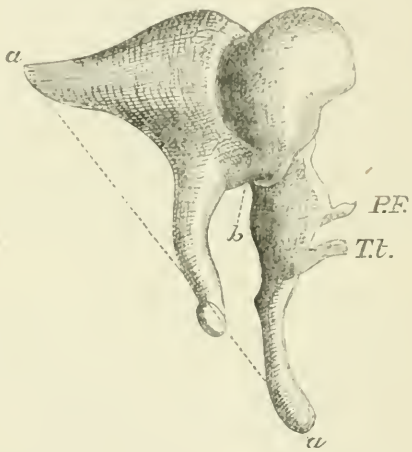
[2] 'Archiv für Ohrenheilkunde,' iv, S. 36-7.

[3] 'Wochenblatt der k. k. Gesellschaft der Aerzte.' Wien, 1868.

so that their cogs grip one another, and they move as one rigid body, and then suppose a pressure to act on the point of the malleus handle, so as to push it inwards, and then to be conveyed to the stapes from the incus, we may consider the system of the two bones as a one-armed lever, whose fulcrum lies where the point of the short process of the incus rests against the wall of the tympanum.

The point of the malleus handle indicates the point of application of the power, the point of the incus the point which acts on the weight. These three points lie, in fact, very nearly in a straight line, so that the incudo-stapedial articulation deviates only a very little inwards from the line which unites the point of the malleus handle and the outer side of the incudo-tympanic articulation. Of this it is easy to convince oneself on preparations in which the natural connections of the bones are still retained. Fig. 9 shows the two bones in

Fig. 9.




the position in which their cogs meet, seen from the tympanic side: *a a* is the straight line drawn through the above three points; P F the stump of the processus folianus; T *t* the tensor tympani. At *b* is seen the cog of the incus.

In the preparation here drawn I found the entire length of this lever to be about $9\frac{1}{2}$ mm; the short arm between the two extremities of the incus about $6\frac{1}{3}$ mm., so that it amounts to about two thirds of the longer. Hence it follows that, if the malleus and incus lie firmly together, each excursion of the point of the incus will amount to only two thirds of that of the malleus handle. But the force of the pres-

sure which it transmits to the stapes will be one and a half times as large as the power which acts on the extremity of the malleus handle.

As the three points of the lever under consideration lie in a straight line, this pressure is quite independent of the position of the other portions of the ossicles, provided only that they maintain such a position that the articular surfaces are firmly in contact.

This position is attained because on an inward motion of the membrana tympani the malleus, as above mentioned, turns round an oblique axis, inclined to the plane of attachment of the membrane at about 30°, and its head moves away from the incudo-tympanic articulation, and so the capsular ligament of the malleo-incudal articulation is rendered tense, and as now every attempt to turn the bones on each other in such way as to make their cogs press on one another immediately produces a considerable gaping between the articular surfaces, any such motion is sufficiently resisted by the already tense fibres of the capsular ligament.

Reversely, if the membrane is forced outwards, the capsular membrane of the malleo-incudal articulation relaxes to such a degree that it allows the small separation of the articular surfaces, which is required by a motion which parts the cogs from one another.

In the remaining displacements which the malleo-incudal articulation, as an imperfect saddle-form articulation, easily allows, the above three points of the lever still remain in a straight line. One axis of the saddle-formed joint passes through the point of the malleus handle, the second is perpendicular to the plane which passes through the three points and the articulation, and thus divides the long process of the incus from the malleus handle.

In the experiments hitherto described the stapes is mostly set in motion by means of the malleus or the membrana tympani, by which means, as we have seen, the amplitude of the excursions must be a little diminished; namely, by about a third.

In order to investigate the firmness of the mechanism, I made the reverse experiment, and sought to measure the excursions of the malleus on moving it by force applied to the basis of the stapes. These motions, of course, can be estimated only when it is firmly in contact with the incus. To this end I took the above-mentioned preparation (with the tube introduced into the vestibule), and I cemented to the head of the malleus a thread of glass about 59 mm. long. I then tried what amplitude of oscillation I could produce in the malleus by first introducing liquid into the glass

tube and then exhausting it. The excursion at the end of the glass thread amounts to a movement of only about $\frac{1}{4}$ mm. (of the malleus).

If we reckon the distance from the axis of rotation to the point of attachment of the thread at 4 mm., the length of the lever is 63 mm., and the above-mentioned excursion of $\frac{1}{4}$ mm. corresponds to a rotation of about half a degree. For the point of the malleus handle, on the other hand, whose distance from the axis-ligament amounts, to $4\frac{1}{2}$ mm., this gives an excursion of only $\frac{1}{32}$ mm., a magnitude which is somewhat corresponding to the smaller value found above for the average excursions of the basis of the stapes. In theory we should expect a somewhat larger value for the excursion of the malleus handle; but in consequence of the diminution of tension that takes place after death in animal textures, and the lack of elasticity, especially in the tensor tympani, we may well expect not to find the same precision in the connection of the ossicles to one another that exists in the living ear; and thus the conveyance of the small motions of the incus to the malleus may be impeded.[1]

These different measurements, however, agree in indicating that the oscillations of the stapes and malleus, so long as they are compact, are limited to amplitudes which are less than a tenth part of a millimètre.

On the other hand, if the malleus is set in oscillation by alternate pressure and exhaustion of the air in the meatus, the glass thread used as a multiplying lever indicates a much larger amplitude of excursion. Its point moves 5 mm. to and fro, whilst by force applied to the stapes it can be moved only about half a millimètre.

Thus the excursion which the malleus can make without the incus is almost nine times as great as it undergoes together with it. This kind of movement, however, is not conveyed to the labyrinth water, apart from the alterations of pressure—small in any case—which, perhaps, the altered tension of the articular ligaments or the friction of the articular surfaces of the malleus and incus on one another

[1] In reference to this I may observe also that the conveyance of the motions of the membrane to the fluid of the vestibule was also strikingly diminished on the day on which I made the above experiment. I obtained only 0·4 millimètre rise in the vestibule-manometer, while on the day before, when I had filled the vestibule with water, under the air-pump, it rose 0·9 millimètre. One could wish that these experiments should be frequently repeated by an anatomist who had at command an abundant supply of recent preparations.

may suffice to cause when the cogs of the articulation are not in contact.

When a person forces air into his tympanum he hears weak tones of the middle and upper parts of the scale nearly or quite as well as ordinarily. On the other hand, it is very remarkable that the same tones, if they are loudly pronounced, are heard much better on equalisation of pressure in the tympanum than when it is increased.

This appears to me to find its explanation in the fact that through friction the surfaces of the malleus and incus may be made to adhere and hold fast a little to one another, as is shown in an anatomical preparation by severing the stapedio-incudal articulation and drawing the malleus outwards by means of a rarefaction of air in the meatus. The incus moves outwards with it; but if one turns it with a needle, so that its long process touches the stapes again, it remains, as we have before seen, in this position also. Thus friction can retain it in any position, as to the malleus, once given it against the tension of the ligaments, or any other weak force; and this it can effect also in opposition to weak vibrations of sound. Stronger forces or oscillations, however, will cause the bones to slide over one another, and thus strong vibrations of sound will be perceptibly deadened by such a position of the ossicles.

In these experiments I have partly employed the high tick of a watch, partly tuning-forks, which I struck lightly, and held so far from the ear that I could just detect the variations which turning the forks around their long axes produces. One hears them, as before stated, with the membrane distended, as well as otherwise, when they belong to the upper octaves of the scale, almost as well in the middle octaves, but markedly weaker in the deeper tones. On the contrary, the higher forks, when they were struck hard and held before the ear with the tympanum distended, gave very audible increase of sound, when the equilibrium of the air was restored by swallowing.

I would here notice another phenomenon, which I believe owes its explanation to the mechanism now described; namely, if I bring near to my ear, so that I hear it quite strongly, a well-struck tuning-fork, which consists of one solid piece of steel so that there can be no rattling, its timbre becomes somewhat shrill, and I hear distinctly rattling sounds, such as one hears in a musical instrument when something is loose, or in a tuning-fork which has not been fastened quite firmly to a sounding-board. Such rattling sounds are

produced by the little collision of a vibrating body against one which is at rest or vibrating differently. These collisions are regularly repeated, and thus appear as sound, but as they correspond to a discontinuous periodical motion, this sound has very many high harmonics and a very shrill timbre. Such rattling tones are occasioned evidently in the ear itself by a strong sound, and in a B fork of 116 vibrations I hear the rattling in my ear distinctly as a rumble in separate shocks.

This rattling is very perceptible and strong if the pressure of the air in the tympanum is equal to or less than that of the atmosphere, and so the cogs of the malleus and incus are closed on one another, but it vanishes if I force air into the tympanum, and thereby separate the cogs from one another.

I believe that we may conclude from this that the rattling arises from the cogs. In very large excursions of the membrane the incus is not drawn outwards with sufficient force during the outwardly directed phase of vibration, or is in some way unable to follow completely the excursion of the malleus, so it lets it part from that bone and receives a blow from its return motion.

I would also recall that this mechanism is a very suitable one for the production of combination-tones;[1] and it may be that to the concussions between the malleus and incus may be referred the peculiar sensation of buzzing in the ear which is felt in the combination-tones of two powerful soprano voices in a passage of thirds.

This phenomenon appears also to be full of significance as to the natural sensibility to harmony of the ear; for thus powerful tones, even if before they reach the ear they are without harmonics, must develop harmonics in the ear itself, and so tones with musical harmonics which correspond to regularly periodic vibrations acquire a natural advantage over those with unmusical harmonics. Hence, too, the whole doctrine of concords (conferenzen) becomes, through this condition, more independent of external harmonics.

The rattling tones may be much deeper than the exciting tone if the raised body falls again only after several vibrations, and so produces a new impulse. Of this kind are, as I conclude, certain deep rough noises, which I hear when the shrill tones of the fourth octave, to which the meatus resounds, are very loudly sounded. In this case, probably, the surface of the membrane comes into unusually

[1] 'Lehre von den Tonempfindungen,' S. 233—236.

strong vibration, which betrays itself by a tickling, buzzing sensation in the depth of the ear. The apparatus of which fig. 10 (see p. 147) is a sketch is very suited to the production of such tones.

I may here mention, also, that in order to put the completeness and accuracy of this explanation of the mechanical construction of the ear to the test, I have constructed a model of the tympanic apparatus on a large scale. The ossicles are made of wood, the membrane cut out of glove leather, so that a seam fastened to the malleus holds it along the malleus-handle; by this means its concave conical form can be given. An opening of suitable form, cut in a small board with oblique edges, on to which the edge of the artificial membrane is glued, represents the inner end of the meatus. Externally a cylinder of tin is fastened to the board, encircling this opening, and over it is fixed a cover of tin with a caoutchouc border, as is now done to keep preserved fruits air-tight. If we apply this cover so that a movable portion of the caoutchouc border remains between it and the ring of tin, it is possible to compress the air on the outer side of this artificial membrane, and allow it to act on the ossicles.

Inside, near the anterior superior border of the opening, is fixed a strip of wood with a projecting point to represent the spina tympanica major. The axis-band is represented by a hempen thread, which starts from this point and passes through and round the malleus, and then proceeds to the posterior superior edge of the opening, pierces the board, and is made fast by an iron screw, which regulates its tension. Other suitably fixed threads, with their screws, represent the strands of the ligamentum externum, and those strands of the ligamentum anterius mallei that run upwards from the spina. Finally, a thread of silk that passes through an iron ring, fastened to a small pillar of wood, and then is fastened to a stretched elastic band, represents the tensor tympani.

My method of forming the articular surfaces of the malleus and incus was as follows: first, I spread warm sealing wax over the surface of the malleus, and attempted to give it, while soft, the required form as well as I could. Then the articular surface of the incus was also covered with hot sealing-wax and pressed upon the articular surface of the malleus, which had been covered with tinfoil. The tinfoil attached itself to the incus. Then, before the sealing-wax was quite cool, I made such rotating movements with the incus, as occur in the natural connection of the bones, in order to give the

second surface the capability of gliding over the first. After the surface of the incus was quite cool it served as a mould on which the malleus surface, when warmed and covered with tinfoil, could be shaped and made able to slide. This was done alternately with each surface until both slid on one another easily enough. Of course precautions had to be taken against the execution of any sliding motions which the cogs would have arrested. I thus attained a good articulation. The capsular ligament was represented by thin elastic bands which were fastened to the incus, and which could be drawn over the malleus by means of small hooks formed of the stumps of needles, so as to hold the bones together by a slight elastic pressure.

The articular ligament of the short process of the incus consisted only of a loop of silk threads, which passed through a hole in the incus. This ligament may be lax, but it is essential that the point of support of this part of the incus on the outer wall of the tympanum should be accurately copied. The union between the long process of the incus and the stapes may be limited to one of simple contact, or be imitated by a noose of silken threads. The former suffices for the propagation of the impulses.

The fenestra ovalis is cut in a small board which is supported parallel to the larger board by small wooden pillars. This little board consists of two plates screwed together, between which is clamped a thin plate of caoutchouc which represents the membrane of the fenestra ovalis. The base of the stapes is also double and formed of two plates screwed together, the plate of caoutchouc above mentioned being inserted between them.

Such a model is very useful, partly for demonstration, partly for the ready exhibition of the significance of the particular ligaments and articulations in the attachment of the ossicles, as it is possible to take all the parts separately away from one another and make any of the ligaments tighter or looser. Besides, this model conveys with great precision to the stapes any small impulses which impinge either immediately upon the malleus handle or upon the external air-tight cover. This can be felt partly by laying the finger on the base and the plate in which it is inserted, partly also by the motions of light bodies laid on it.

The diameters of my artificial membrana tympani are eighty and 120 millimètres. The other parts are in proportion. In this model I have put to the test all the details of the foregoing description of

the motions and the method of attachment of the ossicles, and have found them confirmed.[1]

### § 7. *The mechanics of the membrana tympani.*

The membrana tympani is to be considered as a tense membrane, but it differs from those membranes that have hitherto been investigated and employed in acoustics in this respect, that it is curved. Its tension is conditioned by the handle of the malleus, which draws it inwards, and which is itself maintained in position by its ligaments and by the elasticity of the tensor tympani.

Were the radial fibres of the membrane alone in existence and not joined with transverse fibres they would extend in straight lines. In fact they do not do this, but assume a curved form, convex on the side of the meatus, whence it is to be inferred that they are drawn to each other by the ring fibres, and that these latter are also put on the stretch. In fact, in the quiescent membrane there is no other force that can maintain the radial fibres in their curved form besides the tension of the ring fibres.

On the impact of sound vibrations, the pressure of the air at one time acts against the convex surface of the membrane, at another against the concave, according as it is alternately greater or less in the meatus than it is in the tympanum. In each case it acts in a direction perpendicular to the surface of the membrane—thus perpendicularly also to the arching of the radial fibres which it tends alternately to increase and diminish.

As the curves which the radial fibres of the membrane form are pretty shallow, there arises, through this arrangement, as will be explained directly, the same mechanical action as if the pressure of the air acted on the end of a very long lever arm, whilst the point of the malleus handle forms the extremity of a very short lever arm. A relatively considerable displacement of the surface of the membrane in the direction of the pressure of the air necessitates a proportionately small displacement of the malleus point and *vice versâ*.

From this it follows further, according to the known general laws of virtual velocity, that a comparatively small amount of air

[1] Copies of this model are constructed by the assistants at the Physiological Institute of this place, the Messrs. Sittel.

pressure will be equivalent to a comparatively great force bearing on the handle of the malleus, and so might replace such a force.

In order to look closely into the matter we can limit ourselves to the consideration of a single curved radial fibre. We can suppose it under the pressure of the air changed into arcs of constant length, but varying curvature, and thus of varying radius. If $l$ is the length of the fibre, $r$ the radius of the circle to which a particular arc appertains, and if $\lambda$ is the chord which appertains to the arc $l$ then $\frac{1}{2}\frac{\lambda}{r}$ is the sine of the semi-angle subtended at the centre by the arc $l$. Thus,

$$l = 2r \sin^{-1}\left(\frac{\lambda}{2r}\right),$$

$$\text{or } \lambda = 2r \sin\left(\frac{l}{2r}\right);$$

and the difference between chord and arc

$$l - \lambda = 2r\left\{\frac{l}{2r} - \sin\left(\frac{l}{2r}\right)\right\}.$$

Suppose now the curvature to be very small, and so $r$ very large as compared with $l$, we can then consider the sine of this formula as expanded in powers of its circular measure, and limit ourselves to the first two terms of this expansion, as the terms quickly become very small.

$$\text{We have } \sin\frac{l}{2r} = \frac{l}{2r} - \frac{1}{6}\left(\frac{l}{2r}\right)^3,$$

which gives

$$l - \lambda = \frac{1}{24} \cdot \frac{l^3}{r^2} \quad \ldots\ldots\ldots\ldots\ldots (1).$$

The bulging of the arc, or the perpendicular distance $s$ of its middle point from the middle point of the chord, is given by the equation—

$$\frac{r - s}{r} = \cos\left(\frac{l}{2r}\right),$$

$$\text{or } s = r\left(1 - \cos\frac{l}{2r}\right).$$

Expanding the cosine we get

$$s = \frac{1}{8}\frac{l^2}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2),$$

or, on elimination of $r$ from (1) and (2),

$$l - \lambda = \frac{8}{3}\frac{s^2}{l}.$$

Now the difference or the left $l$—$\lambda$ is the shortening of the chord which arises from the curvature of the arc, or from the distance by which, in this case, the ends of the fibre approach one another.

Again, $s$ is the displacement of the middle point of the fibre. If now $s$ is infinitely small in comparison with $l$, the length of the fibre, the quantity $l$—$\lambda$ of the last formula denotes an infinitely small quantity of the second order compared with $s$.

Conversely, it is clear that if the fibre is to be considered as inextensile, the very small elongation of the fibre by the magnitude $l$—$\lambda$ cannot happen, except inasmuch as the fibre is stretched, and thus its middle point undergoes the proportionally much larger displacement $s$.

To calculate the relations of the forces, on the other hand, we have the known mechanical formula if the tension of the fibre be $t$, and the pressure on each unit of area is $p$,

$$t = pr.$$

The correctness of this formula is most easily seen in an elementary manner, if we suppose the fibre to be equally curved throughout its length, and equidistant from the equally curved neighbouring fibres, and so prolonged into a semicircle.

Then the forces which stretch the two ends of the fibre, that is $2t$, maintain equilibrium with the pressure which is exerted throughout the entire diameter of the semicircle on such breadth as the fibre has. So the forces at the ends of the fibres must be equal to $2rp$. Hence we get, corresponding to the last equation,

$$2t = 2rp.$$

Thus, the larger $r$ is, *i. e.* the less the fibre bends under the action of the pressure of the air, the greater will be the alteration of tension produced in the fibre through the pressure of the air. But it is the alteration of tension in the radial fibres of the membrane which

convey the vibrations of sound to the handle of the malleus. Thus, when the radial fibres of the membrane are stretched nearly straight, the alterations of tension can attain, on relatively small alterations of pressure of the air, very considerable magnitudes. Indeed, it is self-evident that, in proportion as the action of the force increases, the excursions of the malleus handle which take place under the influence of this force become less, just as the distance is diminished on the increase of the intensity of a force by means of a lever. On the other hand, we must remark that these alterations of tension, which are produced by the pressure of air, can always appear as increments or decrements of the tension maintained by the elastic fastenings of the membrane, and by the elasticity of its own radial fibres.

Large increments of the tension, produced by pressure of the air from inside outwards, cannot affect the stapes immoderately, because then the malleo-incudal articulation yields. On the other hand, pressure on the outside of the membrane can at most only push the malleus handle into the position which would result from the straightening of the radial fibres. Were the pressure to become still greater, it would bend them again, and thus make them shorter, and again pull the malleus outwards; that is, supposing the circular fibres, as appears to me improbable, could yield so much without tearing. Thus, the labyrinth remains, in any case, shielded from extremes of pressure, whilst the action of small fluctuations of pressure can be made extraordinarily efficient by means of the relations described.

It can be shown that the excursions of the portion of the membrane between the malleus handle and the border are considerably larger than those of the malleus itself, by introducing a manometer into the meatus (as done by Politzer). Only I found it preferable, in the anatomical preparations I used, to fill the meatus entirely with water, rather than to oppose the air contained in it by a drop of water only in the manometer tube. Such a drop resists, in some degree, small displacing forces, since it adheres to the glass with both its capillary bounding surfaces, and thus it often does not move when it should. But if one fills the whole auditory canal with water, and introduces into it a manometer, fastened in a well-fitting stopper of sealing-wax, but so that some water makes its way into it at the same time, then the upper surface of the fluid in the tube will indicate very exactly the movements of the membrane. Into the vestibule of the labyrinth,

in the same preparation, a little tube, as before described, was introduced, and by pressing in or drawing out the fluid the stapes and malleus could be moved. It has already been shown that the point of the handle of the malleus is thereby only moved to and fro about $\frac{1}{10}$ mm. On the other hand, the fluid in the manometer moved 1 mm. The internal diameter of the little tube was found by co-libration with quicksilver to be 1·37 mm., the diameters of the membrane were 7½ and 9 mm. Thus, the mean movement of the membrane amounts to a little more than $\frac{1}{9}$ mm., three times as much as the simultaneous movement of the point of the malleus. Now, as the external edge of the membrane remains firm, it follows that the middle free portion of the membrane must have moved relatively much more than the mean movement, and thus, in any case, more than three times as much as the point of the malleus.

In this elementary examination no consideration has been given to the facts that the meridian arcs of the membrane are connected together; that the distances between them increase towards the attached edge of the membrane; that they are bound together by the circular fibres, and cannot move without stretching them; indeed, that the curved natural form of the membrane cannot exist without every force which presses the malleus handle inwards also stretching and expanding the circular fibres. On account of the irregularly proportioned form of the membrane no full analysis of the mechanical action of these relations can be given. For that purpose the tension and the grade of the elasticity of the circular fibres must first be known. But a mathematical formula, somewhat better corresponding to the real proportions may be constructed, if one imagines, instead of the real, an ideal membrane, which is drawn in conically in the centre, but for the rest is circular and is formed symmetrically around the centre, thus forming a rotation surface. The radial fibres which traverse the meridians of such a surface may be considered as inextensile, but the circular fibres must have a certain degree of elasticity in order to remain stretched. In the mathematical appendix I have dwelt on the theoretical relations of such a mechanical action and the best form for the membrane. Here the following remarks are sufficient.

If the curvature of the membrane is slight, the pressure of the air produces most effect when the membrane has already, in consequence of its own elasticity, taken the form which the pressure of itself tends to give it. This form of the membrane is that which

makes the volume on its concave side, *i. e.* the volume of the tympanum, a maximum, and the volume on its convex side a minimum, when the lengths of the radial fibres are unaltered, and the position of their centre is not disturbed. If the membrane had not such a configuration from the commencement, the pressure of the air must first change it to such an one, through an altered tension of the circular fibres, before the total force can act on its centre.

The shape of the membrane here demanded can be calculated. In fig. 10 we have the section of a form which somewhat corresponds to the relations of the membrane. It is evident that this form agrees well with that of its lower relatively free portion. Let us denote by $\alpha$ the angle which the tangent to the membrane at its central point makes with the axis (drawn in the plane of the meridian which is that of the diagram); by $\beta$ that which the corresponding tangent at a border point of the membrane makes with the axis; by R the radius of the circle made by the border; by $p$ the pressure of the air; then if we denote by K the force which must be applied to the centre of the membrane to maintain equilibrium with the pressure of the air, we have—

$$K = \frac{p\pi R^2 \cos \alpha}{\cos \alpha - \cos \beta}.$$

In this equation it is evident again that the smaller the difference between the two angles $\alpha$ and $\beta$ is, *i.e.* the more flatly stretched the radial fibres of the membrane lie, the greater does this force become. Further, the force increases as $\cos \alpha$ if the angles $\alpha$ and $\beta$ become smaller, while the difference, $\cos \alpha - \cos \beta$, remains the same; *i.e.* if the vertex of the membrane is pushed forcibly inwards.

Hitherto the acoustic properties of such curved membranes have not been practically investigated; perhaps the most that can be said is, that I have seen use made of a curved piece of leather as a sounding-board on an Arabic percussion instrument, which was played on in the Tunis café in the last Exposition in Paris.

It is possible to prepare a membrane, formed like the membrana tympani, by taking a damp piece of pig's bladder and stretching it over the opening of a glass cylinder, setting the cylinder upright so that the bladder is at the upper end, and then placing a rod loaded with bits of metal perpendicularly on its middle point, so that the lower end of the rod presses the moist bladder firmly downwards. In this position the bladder should be dried; and it will keep a

shape like the membrana tympani, with an indrawn umbilicus and a meridian line convex externally.

In order to prove the acoustic reaction of such a membrane under similar conditions to those which the membrana tympani presents, I took a cylinder of forty-four millimètres internal diameter and fastened it on a strong horizontal slab of wood (fig. 10). In the

Fig. 10.

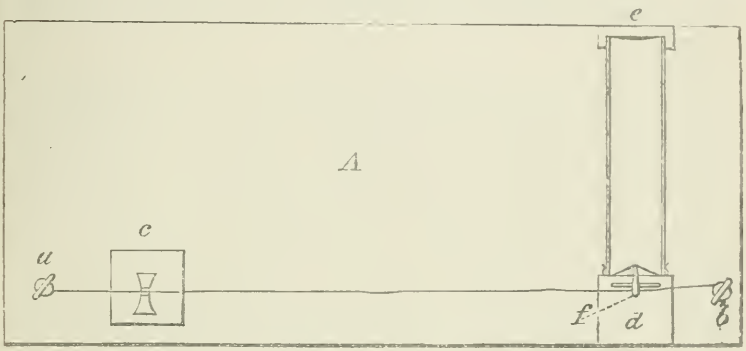



figure it lies between *e* and *f*, and is represented as cut through the middle. It is firmly bound to the board, its open end being supported at *e* by a suitably shaped piece of wood, which at the same time prevents it from slipping towards *e*. A small rod *f* of light wood is supported at the indrawn centre of the membrane, and this acts as a bridge for a violin string which can be stretched by the screws at *a* and *b*. At *c* the string runs over a bridge which is placed on the middle of a heavy block of lead, and bounds the vibrating string at the other end. A second block of lead lies at *d*, and between it and the small rod *f* there is introduced a thin piece of board like the bridge of a violin, which supports the small rod from underneath, but opposes no obstacle to the impulses given by the string which traverse the small rod *f* in the direction of its length.

The blocks of lead serve to impede the conduction of the vibrations of the catgut to the board A, and through this to the air, so the sound of the violin string (when excited with the violin bow) is heard with greatly diminished intensity as soon as the little rod *f* is removed from the curved membrane, or the string be held tight near

$f$ on the side of $e$. But as soon as the vibrations of the string can be conveyed to the curved membrane by means of the small rod, the membrane, notwithstanding its smallness, supplies a powerful resonance almost like a violin. The string can be easily shortened by clamping it between two fingers of the left hand, whilst the right hand applies the violin bow, and best applied near to the fingers of the left hand. Then it becomes evident that the resonance extends over a very large portion of the scale, and especially in high notes in the middle of the fourth octave becomes so powerful as scarcely to be borne.

The relations here are so far like those of the membrana tympani that the curved membrane effects the conduction of vibrations between the air and a rigid body of moderate weight and relatively small amplitude of vibration; in the one case the labyrinth water, in the other the ends of the string. But if the conduction of the sound is easy from the string to the air, reciprocally the conduction of the sound from the air to the string must be easy also, according to a general law of reciprocity for vibrations of sound in perfectly elastic bodies. We can also easily convince ourselves of this by experiment with the above-described apparatus. If light scraps of paper or thin shavings are placed on the string, and the note of the string be sung before the aperture of the tube, the bits of paper begin to dance, as in the case of the strings of a violin, or a pianoforte with an extended sounding board.

Likewise the note of a tuning fork which stands on a resonance box, and which has been brought into unison with the string, causes the string to sound along with it very easily, and the slips of paper to dance even at the distance of a foot.

In addition, the tuning of the glass tube has an influence exactly as is the case with an ear furnished with a resonator. If the string has such a length that its lowest note is in concord with the proper note of the tube, the sound of the string becomes remarkably full and powerful.

## § 8. *Mathematical supplement concerning the mechanism of curved membranes.*

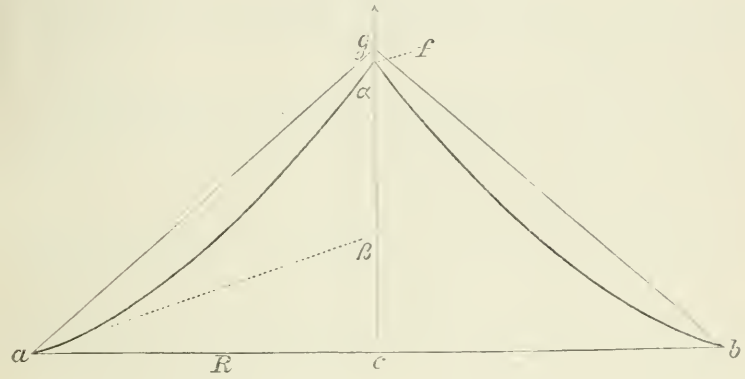
In the following we assume a membrane of circular form with inextensile meridian lines. Besides, let there exist elastic circular fibres and let the pressure of the air $p$ act on one of their faces; on

its centre, on the other hand, let there act a force $g$ in the direction of its axis of symmetry.

To demonstrate, as explained before, that in the case of a slightly curved membrane the pressure of the air produces the greatest resultant on its centre when, through the action of its elastic circular fibres, the membrane has assumed the form that the pressure of the air would have given it if there had been no elastic tension of the circular fibres, we may have recourse to the following considerations:

In fig. 11 let $a\ b$ be a diameter, $c$ the middle point of the

Fig. 11.




attached border, and $f$ the centre of the membrane, which centre is drawn in direction of its axis by the force $f\ g$. The membrane might under the influence of the tension of its circular fibres alone have taken the form indicated by the dotted lines, and be in this position in one of stable equilibrium. Let us suppose that there is no difference in the pressure of the air on its two surfaces. Now it is a well-known law in mechanics that in all cases, in which the law of the conservation of energy can be applied, stable equilibrium only occurs if in all the neighbouring positions into which the movable system can pass continuously the position of equilibrium is that in which the work performed by the forces applied inside and outside is a maximum.

This law is applicable to the membrane in question, and hence it follows that in its position of equilibrium the sum of the work performed by the contraction of its elastic circular fibres must be a maximum compared with that in all the other forms which the mem-

brane can continuously assume, the position of the point $f$ being unaltered. Thus, should any other force alter the shape of the membrane while the position of the point $f$ is unaltered, it must perform positive work, as the quantity of force of tension exerted by the membrane must be increased by this transition.

The same holds good if the membrane is brought into the position $a, f, b$, not by means of its elastic forces, but through the pressure of the air compressed above it, and a force $(f, g)$ acts on its centre $(f)$. In this case the membrane must take such a shape that the work done through the expansion of the compressed air above it may be a maximum. Now, this last would be the case if the volume of the air contained between the membrane and the plane $(a, b)$ produced was a maximum.

Hence it follows, again, that if another force be applied, so as to alter the form of the membrane in any way, the volume of the compressed air above must be diminished, and thus positive work must be performed by the additional force.

If, now, the form of $b$, which is produced by the elastic forces, is exactly the same as that which the pressure of air brings about, and the force $g$ in the first case, $\gamma$ in the second, maintains equilibrium, the membrane will be in equilibrium in the same form, beneath the simultaneous action of the elastic circular fibres and the pressure of the air, and the force $g + \gamma$, which acts at the point $f$, will preserve equilibrium.

But if the position of equilibrium $l$ (the centre of the membrane being at $f$) under the elastic forces differs from that which is demanded by the pressure of the air, the position of $f$ remaining the same, the membrane must, under the common influence of the two forces, come to rest in a position differing from either of these two positions. But, in this position, neither the elastic forces nor the pressure of the air performs the maximum of the work which they can perform when the centre of the membrane is at $f$.

Thus, if we proceed from that form of the membrane which it maintains when the force $g$ is infinitely great, and in which the radial fibres must be stretched straight, and the force $g$ be continually diminished until the centre of the membrane is brought back to $f$, the membrane performs work which increases from the value $o$ to $g$, and whose value is dependent on the position of the point $f$. Let $g_0$ be this work when the elasticity is alone operative, $g_1$ when the pressure of the air acts solely, $g_2$ when these two forces act together.

We have thus always $g_2 < g_0 + g_1$, except in that case in which the pressure of the air on, and the elasticity of, the membrane give the same form.

If we proceed from the initial position in which these quantities are equal to zero, we must always have on denominating the lengths $gf$ by $h$ during the first periods

$$\frac{dg_2}{dh} < \frac{dg_0}{dh} + \frac{dg_1}{dh},$$

for otherwise one would have from the beginning—

$$g_2 \geqq g_0 + g_1.$$

But now the above differential coefficients are equal to the resulting forces with which the membrane tends to advance its centre towards $c$.

For the force $g$, with which the elasticity of the membrane acts when taken alone, we have—

$$g = \frac{dg_0}{dh}.$$

For the force $\gamma$, with which the pressure of the air taken alone acts, we have—

$$\gamma = \frac{dg_1}{dh};$$

And for the force with which the pressure of the air and the elasticity together act, and which we will denote by $g + \gamma_0$, we have—

$$g + \gamma_0 = \frac{dg_2}{dh}.$$

From the above equation it follows that for small curvatures of the membrane,

$$g + \gamma_0 < g + \gamma,$$

$$\text{or } \gamma_0 < \gamma.$$

if the equilibrium-form is not the same for the elasticity and the air-pressure separately. Q. E. D.

*Determination of the form of a Membrane stretched only by the pressure of the Air, the Radial Fibres being inextensible.*

Let $z$ be a distance measured along the axis of the membrane, and $r$ the radius of the circle in which a plane perpendicular to the axis, through a variable point near the extremity of $z$, cuts the membrane.

The volume which lies between two such planes, which correspond to the infinitesimally differing values $z$ and $z + dz$, is therefore

$$\pi r^2 dz.$$

The whole volume $v$, between the membrane and the plane of its circle of attachment is therefore

$$v = \int_0^a \pi r^2 dz,$$

if for the centre of the membrane $z = o$ and for its edge $z = a$.

Let us denote the excess of the pressure of the air on the upper side of the membrane over that on its lower side by $p$, and let $g$ be the work performed by a force parallel to the axis which acts on the centre of the membrane, then the work performed by this force and the pressure of the air is equal to $g - pv$.

The condition of equilibrium is that this quantity be a maximum, whilst the length of the radial fibres remains unaltered. Their element of length $ds$ is given by the known equation

$$ds^2 = dr^2 + dz^2.$$

Let us take $r$ as the independent variable, thus we must have,

$$g - p\pi \int_0^R r^2 \frac{dz}{dr}\, dr = \text{max.};$$

or, according to the principles of the calculus of variations, if we cause $z$ to vary,

$$\frac{dg}{dz}\,\delta z - \pi p \int_0^R \left( r^2 \frac{d\delta z}{dr} - \frac{\lambda \frac{dz}{dr} \frac{d\delta z}{dr}}{\sqrt{1 + \left(\frac{dz}{dr}\right)^2}} \right) dr = o.$$

Partial integration gives, if we presuppose $\delta z$ to be zero at the edge of the membrane, and equal to $\delta z_0$ at its centre,

$$-\left\{ \frac{dg}{dz} + \pi p \lambda \frac{\frac{dz}{dr}}{\sqrt{1 + \left(\frac{dz}{dr}\right)^2}} \right\} \delta z_0$$

$$+ \pi p \int_0^R \delta z \frac{d}{dr} \left( r^2 - \lambda \frac{\frac{dz}{dr}}{\sqrt{1 + \left(\frac{dz}{dr}\right)^2}} \right) dr = o.$$

Thence it follows, as $\delta z_0$ and $\delta z$ are arbitrary quantities, independent of each other, that the quantities multiplied by them are equal to zero separately, thus (1) for the centre point of the membrane,

$$\frac{dg}{dz} + \pi p\lambda \frac{\frac{dz}{dr}}{\sqrt{1+\left(\frac{dz}{dr}\right)^2}} = 0$$

(2) for its surface,

$$r^2 - \lambda \frac{\frac{dz}{dr}}{\sqrt{1+\left(\frac{dz}{dr}\right)^2}} = C;$$

where by C a constant is to be understood.

At the central point of the membrane

$$r = 0 \text{ and } \frac{dz}{dr} = \text{cotangent } a,$$

in which $a$ denotes the angle so named in fig. 10. Hence the equation (2) for this point reduces to

$$C = -\lambda \cos a,$$

and the equation (1) gives for the same point

$$\frac{dg}{dz} + \pi p\lambda \cos a = 0.$$

If we, on the other hand, denote the value of $r$ at the edge of the membrane by R, and just there suppose

$$\frac{dz}{dr} = \cot \beta,$$

as in fig. 10, at this point by equation (2)

$$R^2 - \lambda \cos \beta = C = -\lambda \cos a.$$

Thus

$$R^2 = \lambda (\cos \beta - \cos a),$$

and the force $g$,

$$g = \frac{dg}{dz} = -\frac{\pi p R^2 \cos a}{\cos \beta - \cos a},$$

and is given in the foregoing paragraph.

Further, it follows from equation (2),

$$(r^2 + \lambda \cos a)^2 \left[ 1 + \left(\frac{dz}{dr}\right)^2 \right] = \lambda^2 \left(\frac{dz}{dr}\right)^2;$$

or

$$\frac{r^2 + \lambda \cos a}{\sqrt{\lambda^2 - (r^2 + \lambda \cos a)^2}} = \left(\frac{dz}{dr}\right).$$

This is an elliptic integral, which we bring to the normal form if we put

$$r = \sqrt{2\lambda} \sin \frac{a}{2} \cos w,$$

$$dr = \sqrt{2\lambda} \sin \frac{a}{2} \sin w \, dw;$$

thus

$$dr = -\sqrt{\frac{\lambda}{2}} \frac{1 - 2 \sin^2 \frac{a}{2} \sin^2 w}{\sqrt{1 - \sin^2 \frac{a}{2} \sin^2 w}} \cdot dw,$$

or, if we use Legendre's notation,

$$\mathrm{F}w = \int_0^w \frac{dw}{\sqrt{1 - \kappa^2 \sin^2 w}}$$

$$\mathrm{E}w = \int_0^w \sqrt{1 - \kappa^2 \sin^2 w} \, dw;$$

and put

$$\kappa^2 = \sin^2 \frac{a}{2};$$

then

$$z = \sqrt{\frac{\lambda}{2}} \{2\mathrm{E}w - \mathrm{F}w\} + \text{const}$$

$$r = 2 \sqrt{\frac{\lambda}{2}} \cdot k \cos w.$$

Simultaneously, we easily find the length of the arc of the radial fibres,

$$s = \sqrt{\frac{\lambda}{2}} \mathrm{F}w.$$

By means of Legendre's tables which give the values of $Ew$ and $Fw$ for all values from $\frac{a}{2}$ and $w$ which correspond to all the angular degrees, we can most easily construct the form of this curve.

For the rest the values of $Ew$ and $Fw$ may be calculated by the known methods for any particular values of $a$ and $w$.

Fig. 12.

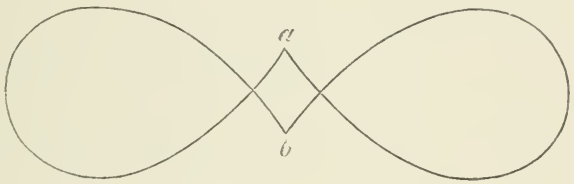



Fig. 12 shows a curve of this sort drawn completely from one point of its axis to the other, in which the form of the membrana tympani, corresponding to the angle $a$, is given of the value of $180° - 40° = 140°$.

The axis point $a$ may represent the centre of the membrane. Each point of the branch of the curve running from $a$, to those points where proceeding towards $b$ it cuts itself again, can correspond to the edge of the membrane.

The membrana tympani itself corresponds to only a small portion of this curve.

I delay for the time the more detailed description of the experiments on resonance in the living ear, mentioned in my above-cited monograph of August 9th, 1867, because I hope to supply myself with better means of producing deeper and purer notes than I have had hitherto, and so to conduct the experiments with better hope of success.

*Extract from a letter of Prof. Helmholtz.*

"Berlin, 30th September, 1873.

. . . . "As for the function of the stapedius muscle I have to add no remarks. I have always supposed that it is used to diminish the intensity of the oscillations when these become too violent, but I have not special facts which prove that hypothesis."

# INDEX.

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