Section of Otology with Section of Laryngology

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OTOLOGICAL SESSION

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(President of the Section of Otology)

The Anatomy of the Eighth Cranial Nerve in Man

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THE innervation of the otic labyrinth has been much studied in animals, and to a lesser extent in man, but in spite of this there are many problems connected with it which have remained unsolved. Interest has recently been rekindled in the finer points of its anatomy by the suggestion that the auditory nerve, which has long been regarded as wholly sensory, may carry an autonomic motor component. The function of such motor fibres, if present, might be to control either the secretion of endolymph by epithelial cells of the stria vascularis and perhaps other parts of the membranous labyrinth, or the calibre of blood vessels supplying it. It is well established that the vessels of the inner ear are supplied with nerve fibres, probably derived from the sympathetic plexuses accompanying the vertebral arteries. At the same time it is possible that the cranial parasympathetic outflow is not limited, as is usually supposed, to the third, seventh, ninth and tenth cranial nerves, but in addition contributes secretomotor or vasomotor fibres to the eighth nerve. Thus Garnett Passe (1951) has based a surgical treatment of Ménière's disease on the theory that the functional pathology of this condition is a sympathetic hypertonus which upsets the normal sympathetic and parasympathetic balance. It is difficult to prove anatomically the presence of motor fibres, or to map out their possible pathways and connexions, so long as there remains any doubt concerning the general innervation pattern. There is therefore a great need to reinvestigate the peripheral distribution of the auditory nerve in man.

The commonly accepted version of the innervation of the human labyrinth is illustrated by Fig. 1, which has been redrawn from an original diagram by de Burlet. The vestibular and cochlear ganglia and their branches are shown. The cells of both these ganglia remain bipolar throughout life, giving rise to peripheral and central processes which run in the nerve bundles to the labyrinthine end-organs and to the brain-stem respectively. The vestibular ganglion is situated within the internal auditory meatus and is double, being divided into an upper and lower part. The central processes of the superior vestibular ganglionic cells form the upper division of the auditory nerve. The peripheral branches of the superior vestibular ganglion run to the ampullæ of the superior and lateral semicircular ducts and to the utricle. In the diagram the superior ampullary fibres are shown leaving the ganglion below those to the lateral ampulla, but this is incorrect: they should in fact be uppermost. The inferior vestibular ganglion gives off the main nerve to the saccule and the nerve to the posterior ampulla. The spiral or cochlear ganglion occupies the spiral canal of the modiolus. Its central processes join those of the inferior vestibular ganglion to form the inferior division of the auditory nerve.

If this were the whole story, the representation of the acoustic receptor organs in the various groups of ganglionic cells would be quite clear-cut. But a number of connecting nerve bundles have also been reported of which only two of the larger are shown in Fig. 1. These more or less constant nervous reinforcements may be classed as (*a*) *supplementary nerves to the saccule*, which have been described as running to the macula from the superior vestibular and cochlear ganglia; and (*b*) *intrameatal anastomoses*, linking the various ganglia and nerve trunks as they lie in the internal auditory meatus. The geniculate and superior vestibular ganglia, the two vestibular ganglia, the inferior vestibular ganglion and the cochlear nerve, the facial and cochlear nerves, have all been said to communicate. Finally (*c*) *intraganglionic bundles* have been found within the substance of the ganglia themselves. Much difficulty has been encountered in determining where the parent cells of these various fibre bundles are located. An intraneural anastomosis may ultimately be derived from a remote ganglion on one of the nerves which it connects. An anastomosis which is topographically interganglionic may arise from the bodies of either cell group to which it runs.

On the other hand, the parent cells of all these connecting bundles of the labyrinth may be situated within the central nervous system, so that their fibres merely pass through the peripheral ganglia. They may in fact be, as some workers have believed, motor fibres. Before setting out the present findings a summary will be given of various views that have been held.

Most textbooks of gross anatomy mention a connexion between the facial and auditory nerves. Lorente de Nó (1926) demonstrated by histological methods in mice a *facio-cochlear anastomosis* which he believed carried sympathetic fibres to the cochlea from the internal carotid plexus via the petrosal nerves and the tympanic plexus. A *vestibulo-cochlear anastomosis* was first described by Oort (1918), running from the inferior vestibular ganglion to join the cochlear nerve in the region of the basal coil of the cochlea. Its position is indicated in Fig. 1. Opinion since has been divided

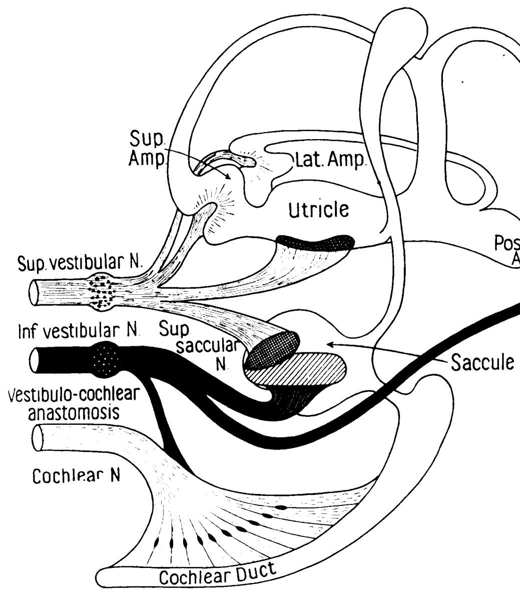

FIG. 1.—Standard diagram of the innervation of the mammalian labyrinth. Redrawn from "Textbook of Histology" by Maximow and Bloom, after de Burlet (W. B. Saunders, Philadelphia and London).

as to whether the bundle is formed by peripheral processes of vestibular ganglionic cells innervating the cochlea, or by aberrant central processes of cochlear ganglionic cells traversing the inferior vestibular ganglion. Lorente de Nó (1926) strongly urged the latter interpretation. Poljak (1927) on the other hand inclined to the former, and was also the first to raise the possibility that the fibres might be autonomic. G. L. Rasmussen (1946) approached the problem from an experimental angle. He found that in cats a myelin degeneration could be produced in Oort's bundle as a result of a lesion in the hind-brain between the facial colliculi. He therefore concluded that the vestibulo-cochlear anastomosis was not sensory, but consisted rather of preganglionic parasympathetic fibres to the cochlea. He was, however, unable to detect among the bipolar cells of the cochlear ganglion any post-ganglionic cells of motor type on which such fibres might relay.

Hardy (1934) discovered that the macula of the saccule in man was supplied at its posterior end by a small separate bundle which she named the *cochleo-saccular nerve* since its fibres could be followed to the region of the basal part of the cochlear ganglion. She believed that it was most probably derived from cochlear ganglionic cells. Rasmussen (1946), however, was able to show by means of microdissection, though not histologically, that a similarly placed bundle in cats could be traced back with the vestibulo-cochlear anastomosis to the inferior vestibular ganglion. In view of this association he suggested that the cochleo-saccular nerve might also consist of motor fibres, although it did not share the myelin degeneration of Oort's bundle following an experimental lesion in the hind-brain.

The innervation of the saccule is also supplemented at the anterior end of the macula, by the much more substantial *superior saccular nerve* originally described by Voit (1907). This bundle is commonly accepted as being a branch of the superior vestibular ganglion, as illustrated in Fig. 1. Nevertheless Poljak (1927) was able to trace Voit's nerve in cats down to the inferior vestibular ganglion through an anastomotic bundle. The precise function of the saccule, whether it acts as an organ of balance or of hearing, has been much debated. A correct interpretation of the relation of these nerves to the adjacent ganglionic masses will therefore be of prime importance in deciding whether the saccule plays a part distinct from the cochlea on one hand and the utricle on the other.

The nervous structures in the internal auditory meatus and the commencement of the facial canal can readily be displayed in the human cadaver by nibbling away extradurally with fine bone forceps that part of the petrous temporal bone which forms their roof. A facio-auditory connexion can usually be made out with the naked eye, leaving the pars intermedia of the facial nerve proximal to the visible swelling of the geniculate ganglion and running down in front of the vestibular portion of the auditory nerve to join the cochlear nerve. If, under the dissecting microscope, the upper division and the two parts of the lower division of the auditory nerve be gently separated from one another, two further connecting strands can be seen to leave the inferior vestibular trunk: the one running up to join the superior vestibular nerve, the other down to join the cochlear nerve. The latter is presumably the bundle of Oort. The limits of the vestibular ganglia are, however, not obvious, and the relation of the intrameatal anastomoses to the ganglionic cells can only be determined histologically. I am therefore greatly indebted to Professor J. D. Boyd for having given me, while working in his department, access to his series of human embryos which have been specifically stained for nervous tissue by de Castro's method. By this technique the embryo is fixed and decalcified simultaneously, and subsequently stained with silver in bulk. Nerve fibres are selectively coloured a dark brown, so that when the embryo has been serially sectioned the various bundles can be followed throughout their length from the ganglia centrally to the brain-stem and peripherally to the labyrinthine end-organs. The fibres can be seen to take their origin from the neurofibrillar cytoplasm of the ganglionic cells. In the nerve bundles, however, they become packed together so closely that it is usually difficult to trace with certainty individual fibres for any great distance, particularly in older embryos and when the bundle has been cut transversely. A nerve can be regarded as a true branch of a ganglion if some of the ganglionic cells can be seen to send their peripheral processes into its trunk. It may not be possible to decide whether or not all the fibres of a bundle arise from the cells of a ganglionic mass to which it is apparently related. For this reason the presence of motor fibres can only be detected by simple descriptive methods if multipolar motor-type nerve cells occur on their course.

The distribution of the vestibular nerve in the young embryo is similar to that of the adult, but the paths taken by its branches are more direct. On account of the relative simplicity of the innervation pattern the various anastomotic and supplementary bundles are then quite easy to identify, and by following their development back to its beginnings much can be gleaned of their true nature. The *vestibulo-cochlear anastomosis* on its first appearance stains rather feebly, in this respect resembling the intraganglionic spiral bundles of the cochlea. It forms as a result of the separation of the originally continuous inferior vestibular and cochlear ganglia. There is an intermediate stage of separation when an island of ganglion cells remains on the course of the anastomosis. This intermediate island is situated close to the basal portion of the cochlear ganglion, but remains topographically and morphologically distinct from it in embryos up to the 62 mm. stage. The neural processes of such island cells must necessarily form a great part at least of Oort's bundle: some are shown contributing to it in the 62 mm. embryo in Fig. 2. If the cells had happened to be of motor type, Rasmussen's missing parasympathetic synapse would have been found and his interpretation of the vestibulo-cochlear anastomosis as a wholly motor nerve could be accepted. But this is not so: they are definitely bipolar, resembling vestibular ganglionic cells. They have not yet undergone the maturation and reduction in size which characterizes the fully migrated cells of the cochlear ganglion. In the 92 mm. embryo they are no longer distinguishable from other cochlear cells. Oort's bundle therefore springs primarily from the last group of cochlear ganglionic cells to migrate to the basal coil. The central processes of these cells become caught up in the downward growth of the inferior vestibular ganglion, where it gives origin to the nerve to the posterior ampulla. These cochlear fibres are the main constituents of the anastomosis: it may possibly receive a few vestibular fibres of an aberrant nature; it could also provide a bridge to carry motor fibres to the stria vascularis or other parts of the cochlea.

Hardy's view of the origin of the *cochleo-saccular nerve* proves to be incorrect. Fig. 3 shows this nerve in the 62 mm. embryo lying in the cochlear recess close to the vestibulo-cochlear anastomosis. Distally it loops up to reach the posterior end of the macula of the saccule from below. Proximally it can be traced up to the inferior vestibular ganglion, from the cells of which it takes its origin. The younger the embryo the more direct is the course of the cochleo-saccular nerve, until at the 30 mm. stage it is represented by a bundle running straight from the inferior vestibular ganglion to the region where the cochlear duct is budding off as a diverticulum from the saccule. Later, when the loop has formed, fibres can sometimes be seen leaving the cochleo-saccular bundle near its origin to take the more direct route to the saccule via the main saccular nerve trunk. It seems then that Hardy's nerve, which is not constantly present, is merely a portion of the saccular innervation which gets caught and drawn down towards the basal coil of the cochlea during the formation of the vestibulo-

FIG. 2.—62 mm. human embryo. × 550. Bipolar ganglion cells on the course of the vestibulo-cochlear anastomosis (V.C.). Cochleo-saccular (C.S.) and cochlear (C.) nerve fibres also shown.

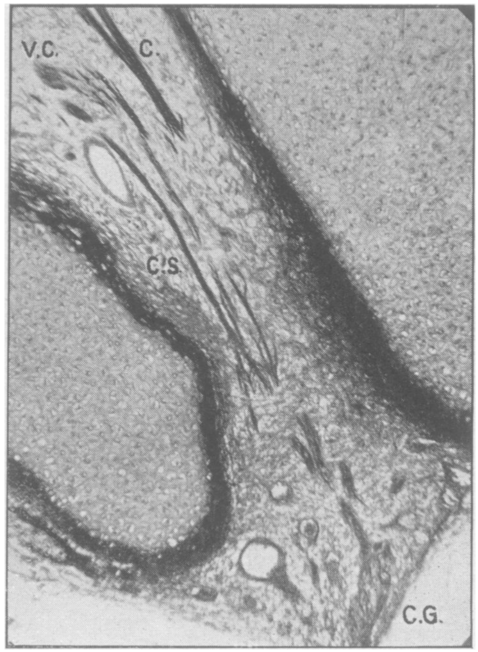

FIG. 3.—62 mm. embryo, preceding section to Fig. 2. × 100. Course of the cochleo-saccular nerve (C.S.) proximal to the cochlear ganglion (C.G.).

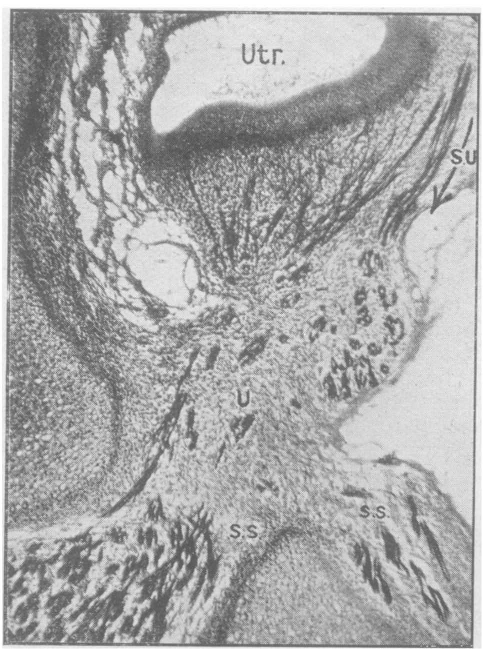

FIG. 4.—92 mm. embryo. × 60. Superior utricular nerve (S.U.) joining the utricular nerve (U.) from above and the superior saccular nerve (S.S.) leaving it below.

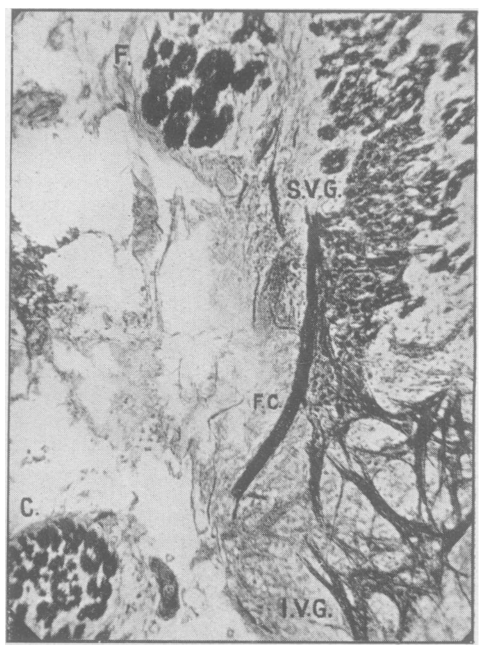

FIG. 5.—92 mm. embryo. × 80. Facio-cochlear anastomosis (F.C.) running from the facial nerve (F.) to the cochlear nerve (C.) close to the superior and inferior vestibular ganglia (S.V.G. and I.V.G.).

cochlear anastomosis. The ridge of the otic capsule separating the cochlear and spherical recesses forms between it and the main saccular nerve. The cochleo-saccular nerve is always small, and becomes increasingly attenuated at later stages as its loop lengthens. It is not greatly augmented during development by further outgrowth of neurones, and its importance in the transmission of vestibular impulses must be negligible. The cochlear ganglion makes no contribution whatsoever to the innervation of the saccule. If, as many have thought, the saccule plays a part in the appreciation of sound, perhaps that transmitted by bone conduction, the evidence of its nervous connexions suggests that the hearing must at least be of a different order from that effected by the cochlea.

Fig. 4 is of a section in the coronal plane through the anterior end of the left utricular macula in the 92 mm. embryo. The *superior saccular nerve*, on its way to innervate the front end of the macula of the saccule from above, has been cut across in two places, the right-hand portion being more distal. The proximal portion is applied to the trunk of the main utricular nerve, close to its origin from the superior vestibular ganglion. Most of the superior saccular fibres, however, can, in this and other embryos, be traced down to the inferior vestibular ganglion, where they take origin from the uppermost ganglionic cells. This proximal portion of the superior saccular nerve accounts for the anastomosis connecting the superior and inferior vestibular ganglia. It appears that at an early stage of development the upper fibres to the saccule become hitched up with the nerve to the utricle in much the same way as the cochleo-saccular nerve is drawn downwards with the vestibulo-cochlear anastomosis. A bridge is thus provided along which further "aberrant" neurones can grow from superior vestibular ganglionic cells to the saccule and from inferior vestibular cells to the utricle. A criss-cross innervation of this sort, however, occurs only to a limited extent, so that the macula of the saccule is almost wholly represented in the inferior vestibular ganglion.

Fig. 4 also shows nerve fibres supplying the macula of the utricle. The trunk of the utricular nerve is joined from above by a strand which can be traced back to the nerve to the lateral ampulla. Distally it contributes to the innervation of the lateral border of the utricular macula. This bundle has not been described by previous workers, but it is present in all the embryos and ends on hair cells of the utricular neuro-epithelium. I have called it the *superior utricular nerve* on account of its position in early stages up to 48 mm., while the macula of the utricle is still applied to the wall of the otic capsule. Later the utricle rotates so that its macula comes to lie horizontally above the perilymphatic space of the vestibule. The superior utricular nerve is considerably smaller than Voit's nerve, and is unlikely to have much functional significance. It could be looked upon as consisting of fibres of the main utricular nerve which have been caught up with the common ampullary trunk, and thereby comparable to the nerves of Voit and Hardy. But perhaps a more important factor is the early proximity of the common ampullary nerve to the macula of the utricle. Some neurones growing out with those destined for the lateral crista may be induced to diverge and make contact with adjacent utricular hair cells.

The superior utricular nerve provides a proof that the macula of the utricle is represented with its lateral margin uppermost in the superior vestibular ganglion. In some embryos the nerves to the ampullæ form aberrant bundles which leave the main trunks and run to the cristæ separately. When this has occurred, it has been possible to see that the superior crista is also represented with its lateral end uppermost in the superior vestibular ganglion, and the posterior crista in a similar position in the inferior vestibular ganglion. From the point of view of their innervation the vestibular end-organs are orientated from above downwards as follows: superior crista, lateral to medial; lateral crista, superior to inferior; utricular macula, lateral to medial; saccular macula, anterior to posterior; posterior crista, lateral to medial. In origin this sequence is developmental, but it may have some functional implications.

Some examples of *aberrant fibres* have already been mentioned. It is not generally recognized how commonly they occur in the human labyrinth. They may or may not make contact with end-organs. Whether those that succeed in doing so are functional presumably depends on the adaptability of their central connexions. It is possible that aberrant fibres from the pars intermedia of the facial nerve account for the *facio-cochlear anastomosis.* This small bundle is commonly though not constantly present: its appearance in the left ear of the 92 mm. embryo is illustrated by Fig. 5. The photograph indicates the closeness of the bundle to the vestibular ganglia, although in fact none of its fibres enter them. It is notable that the facio-cochlear anastomosis invariably leaves the mixed facial nerve trunk at the site of the most proximal ganglionic cells of the geniculate group. During its development the geniculate ganglion migrates outwards, but this occurs as a gradual process. Even at a late embryonic stage there is an extension of ganglionic cells of sensory type centrally along the course of the facial nerve as far as where it winds round the superior vestibular ganglion. The nerve processes of some of these cells can be seen to run to the facio-cochlear anastomosis.

It seems probable, therefore, that this bundle is formed by sensory fibres, aberrant peripheral processes of unmigrated geniculate cells, which have become caught up in the cochlear nerve. This apparently happens at an early stage of development, before the cochlear ganglionic cells have migrated outwards with the expansion of the cochlea, since the facial and cochlear ganglia are then in close relation to one another. The fibres of the facio-cochlear anastomosis proceed to grow out in a direction contrary to that of the centripetal cochlear fibres; they are soon lost sight of in the substance of the cochlear nerve. Unless this bundle also carries motor fibres it is difficult to imagine that it has any function.

Fig. 6 has been constructed to show the innervation of the labyrinth as revealed by the present work. This diagram represents the right ear—seen from the medial side. The ampullary cristæ, the maculæ of the utricle and saccule, and the organ of Corti have been stippled. The geniculate (G.G.), superior (S.V.G.) and inferior vestibular (I.V.G.), and cochlear (C.G.) ganglia have been given a ringed outline. Nerve trunks formed by central processes of the cells of these ganglia have been shaded. Of these, the cochlear nerve and the vestibulo-cochlear anastomosis (V.C.) are hatched vertically; the inferior and superior vestibular nerves and the sensory root of the facial nerve horizontally. The peripheral processes of the ganglionic cells group themselves into the bundles which have been blacked in. These include the two supplementary nerves to the saccule: namely, the cochleo-saccular nerve (C.S.) from the inferior vestibular ganglion, and the superior saccular nerve (S.S.) which, although apparently a branch of the utricular nerve, also has most of its cells of origin in the inferior vestibular ganglion. In addition there are the superior utricular nerve (S.U.), which is a constant supplementary nerve to the utricle from the common ampullary nerve trunk; and the facio-cochlear anastomosis (F.C.), which probably consists of aberrant fibres from the geniculate ganglion. Whether there is a motor component to the auditory nerve in man remains an open question.

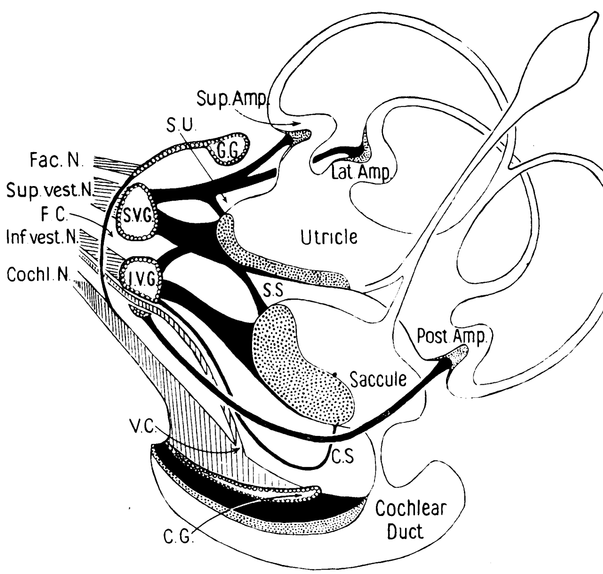

FIG. 6.—Diagram of the innervation of the human labyrinth according to the present findings.

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The following papers were also read:

The Gain in Hearing after the Fenestration Operation, and its Influence upon the Surgeon's Choice of Case.—Mr. WILLIAM MCKENZIE.

Some Problems of the Fenestration Operation.—Dr. I. SIMSON HALL.

(It is hoped that these papers may be published later in the *Journal of Laryngology and Otology*.)