SURGICAL EXPERIENCES WITH ACOUSTIC TUMORS
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Acoustic tumors rank third in the statistics of brain tumors operated on in our clinic. Out of a total of 3,265 brain tumors verified to Dec. 31, 1946 there were 304 unilateral acoustic tumors, or 9.3 per cent. The total number of neurinomas is somewhat higher as there were 6 cases of bilateral acoustic tumors and 4 cases of neurinomas arising from the 5th nerve.

In previous communications from this clinic the early and late results up to 1930 and 1939 were reported. In the present paper we shall review the entire material of acoustic tumors from December 1922, when the first case was verified, until the end of 1946. Although the material is fairly homogeneous in that nearly every patient has been examined by the senior author and all except 21 have been operated on by him, a number of new factors have necessarily come into play during this period of 24 years. The technical equipment has been enormously improved since the early twenties by the introduction of suction, the electrosurgical unit, and long-handled silver clip holders, to mention only a few of the many new devices that have been added to our armamentarium. New methods of anesthesia, particularly the intratracheal method, and the unilateral approach introduced by Dandy have relieved the surgeon of a good deal of his burden, lessened the operative shock, and made the operation less of a Marathon procedure than it used to be. These factors all contribute to simplify the technique of operation and have made possible the extensive use of more radical procedures than those in vogue 20 years ago. The realization that in those cases where some considerable portion of the tumor has been left behind few patients survive more than 3–4 years, and that few of the survivors regain their capacity for work, has led to the adoption of radical removal as the method of choice in acoustic tumors. It should not be forgotten, however, that the radical removal of an acoustic tumor carries considerably more risk than the more conservative methods carried out under present day conditions by surgeons of great experience, as shown by Cushing’s latest figures. It should be realized, therefore, that our statistics covering the last 24 years reflect the conflicting influences of improved equipment and technique and an increasingly radical attitude towards these tumors.

A sad fact remains to be noted—the diagnosis or rather the ability of the non-specialist to recognize the acoustic tumors in their early stage, has not improved much. We still receive most of our patients with acoustic tumors in a very late stage of development, nearly all of them with choked discs and not a few of them blind or with vision much reduced. Almost without exception a large tumor is found at operation and our records contain only a single instance of a very early tumor where the only symptoms were loss of
hearing and an enlarged porus, and this patient came under neurosurgical observation only because he was fortunate enough to have had a few vertiginous attacks suggesting Ménière’s disease.

Among our 304 cases of acoustic tumors there was 1 in which operation was not performed. In 2 cases a suboccipital decompression was made. In 1 of these, where a reliable history could not be obtained, auditory perception was only slightly affected. Ventriculograms showed only a moderate degree of hydrocephalus. This patient died 3 weeks after the suboccipital decompression from pulmonary embolism. Autopsy showed an acoustic tumor on the side of the better ear. In the other case, where the tumor was thought to be too vascular to be attacked, death occurred 3 weeks later from pneumonia. In 1 case where the patient entered the clinic in a comatose condition only a subtemporal decompression was made. The patient died 3 weeks later from the effects of increased intracranial pressure.

The remaining 300 patients were all subjected to total or partial removal. In earlier communications the attempt was made to divide the partially removed tumors into 2 groups: the intracapsular enucleation and subtotal removal. However, on reviewing the case histories it was found that there was no significant difference in the subsequent course of the disease in the 2 groups, and since the division is an arbitrary one and apt to lead to confusion, especially when more than one operator is involved, the division of the incomplete removals into 2 groups was abandoned. All incomplete removals will therefore be treated as a single group regardless of the relative amount of tumor tissue removed. It is recognized, however, that this group is far from homogeneous. Especially in the early cases the intracapsular enucleation, which was the method of choice in those days, frequently amounted to little more than a suboccipital decompression, while with increasing experience relatively more tumor tissue was as a rule removed. It should also be pointed out that during the last 15 years an incomplete removal has rarely been deliberate; in most cases during this time radical removal was attempted, but had to be abandoned short of completion because of technical difficulties, complications occurring during operation and so forth. In many of these cases only a small part of the tumor was left behind. The unilateral approach used almost exclusively during the last 15 years also introduces another variable, as the decompression left after an incomplete removal probably is somewhat less effective than after a bilateral exposure. It is our impression, however, that the subsequent fate of the patient is less affected by the relative amount of tumor tissue removed and the size of the decompression than by the nature of the tumor and particularly its rate of growth.

Altogether 83 cases belong to the group in which the tumor was incompletely removed, while in the remaining 217 cases all visible tumor tissue was extirpated. This latter group may be further subdivided into 2 groups, one where the anatomical continuity of the facial nerve was preserved at the end of the operation (69 cases) and one where efforts in this direction were either unsuccessful or the nerve was deliberately sacrificed (148 cases.)
The tendency towards more radical procedures in the treatment of acoustic tumors is clearly seen in Table 1. During the first period 1923–30, incomplete removal was used exclusively; in the period 1931–39, 30.5 per cent of the tumors were still incompletely removed; while during the last period, only 6.3 per cent were so treated. Among this last group there were 4 cystic tumors where for reasons to be discussed later an incomplete removal may be all that is necessary, and in 2 cases there was an urgent indication to save the facial nerve. In 2 cases only, the operation had to be abandoned short of completion because of technical difficulties or complications of some sort or other.

In Table 2 the operative mortality figures are presented. Taken at their face value these figures would seem to indicate that incomplete removal is the most dangerous method and that complete removal with saving of the facial nerve carries very much less risk than the other methods. In reality these conclusions are of course entirely wrong. The unfavourable showing of the incomplete removals depends largely upon the fact that during the early years, when the intracapsular method was used exclusively, the operator had very little experience and the mortality therefore naturally tended to be high. On the other hand, as experience grew, more radical methods were gradually adopted and the group of incomplete removals therefore tended to be composed of the most unfavourable cases, a considerable portion of them being cases where an attempted complete removal had to be abandoned because of technical difficulties, complications during operation and so forth. This group therefore is unduly weighted with unfavourable cases and the misfortunes of an inexperienced operator and there is little doubt that if the conservative method were to be rigorously adhered to, the immediate mortality could be reduced to an insignificant figure.

With regard to the mortality attending complete removal it is obvious

<table>
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<tr>
<th>No. of Cases</th>
<th>Operative Deaths</th>
<th>Percentage</th>
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<tr>
<td>Incomplete removal</td>
<td>88</td>
<td>24</td>
</tr>
<tr>
<td>Complete removal, facial nerve preserved</td>
<td>69</td>
<td>7</td>
</tr>
<tr>
<td>Complete removal, facial nerve not saved</td>
<td>148</td>
<td>44</td>
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that the group where the facial nerve was saved is composed largely of the more favourable cases while the other group contains many more unfavourable cases. To this group also belong many cases where prolonged efforts to save the facial nerve had failed with resulting increase of the operative trauma.

The cause of death in the complete extirpations was: pulmonary complications (pneumonia, embolism, usually 1 to several weeks after operation), 5 cases; subdural hematoma, lesion of the basilar artery, injury to the vagus nerve, shock and hemorrhage, each 1 case. In all the remaining 41 cases death was caused by a postoperative clot in the tumor bed or hemorrhagic softening of the pons. Nearly always, both a clot in the angle and hemorrhagic softening of the pons were combined, but in most cases one of these was dominating. In about half of the cases the extracerebral clot was regarded as the most important cause of death; in the other half, hemorrhagic softening of the pons was extensive enough to be regarded as the cause of death and a small clot in the tumor bed was considered to be of minor importance.

Among the incomplete removals, pulmonary complications were responsible for 4 fatalities, and meningitis was the cause of death in 2 cases (1 cerebrospinal fluid fistula, 1 originating from opened mastoid cells). Shock and hemorrhage caused death in 3 cases, and 3 fatalities were due to postoperative pressure associated with backward dislocation of the brain stem because of incomplete tumor removal. In the remaining 12 cases death was caused by a postoperative clot within, and usually also outside, the tumor capsule, nearly always combined with hemorrhagic softening of the pons.

The reasons for this predominance of postoperative clots as the cause of death is, of course, that even a small clot, which would be of little consequence in a large cavity in one of the cerebral hemispheres, is very dangerous in the angle, especially when associated with more or less swelling of the adjacent structures. Hemorrhagic softening of the pons may sometimes be caused directly by the operative trauma but, in our opinion, more often by the obstruction by clips or coagulation of the petrous vein and other veins on the lateral side of the pons. The reason for this belief is that softening of the pons may often be seen even when removal of the tumor has been easy with practically no direct damage to brain stem during operation.*

Among the 59 survivors of the incomplete operation 5 have been lost track of, in most cases because the patients lived in central Europe. Twenty are known to be dead, the proven or probable cause of death in every instance being recurrence of the tumor. The average survival period in these cases has been a little more than 3 years after operation. In 9 cases the patients came back to the clinic with recurrence. In all these cases the tumor was completely removed, with 4 fatalities, 1 from pulmonary embolism, the cause of death in the remaining 3 cases being softening of the pons or a postoper-

*After completion of this paper the article by W. J. Atkinson (J. Neurol., Neurosurg. Psychiat., 1949, n.s. 12: 137-151) on the variations of the anterior inferior cerebellar artery came to our attention. This important paper gives a very good explanation of the hemorrhagic softening of the lateral part of the pons, so frequently observed after extirpation of acoustic tumors.
ative clot. In the cases terminating fatally the 2nd operation was performed on the average $5\frac{1}{2}$ years after the 1st. In the surviving cases the average time between operations was $4\frac{1}{2}$ years.

Altogether there were therefore among the 59 survivors 29 recurrences, or 50 per cent, the recurrence leading to death or to a 2nd operation between 3–4 years after the 1st operation. The mortality rate with and without secondary operation was 40 per cent of those surviving the 1st operation. The total mortality for incompletely removed acoustic tumors therefore is exceedingly high. Within 3–4 years 60 per cent of those so treated are dead either from the immediate effects of the operation or from recurrence. Even if this figure could be somewhat reduced by a lower primary mortality, the late mortality from recurrence would probably remain unchanged. This must be considered a strong argument in favour of radical removal of acoustic tumors.

The functional results in the survivors showing later recurrence after the incomplete operation are equally depressing. In none of the 29 recurrent cases was full earning capacity ever regained excepting those cases where the tumor was later successfully removed. Among these 5 cases, 4 regained full earning capacity, and 1 was much improved but died some years later from the effects of a second neurinoma in the brachial plexus. With 1 or 2 exceptions the other patients with recurrence were all invalids, although some of them were able to do light work at least for some time before recurrent tumor symptoms became manifest. Cerebellar incoordination was the dominant cause of inability to work in nearly all cases, although poor vision, headache, mental disturbance and so on were contributory in some instances.

If we now turn to those who are known to be still alive it is rather surprising to find that among these 25 patients surviving for an average period of 13 years, 12 consider themselves completely well with full earning capacity, 9 are in a fairly good condition with earning capacity ranging between 50–75 per cent and only 4 are complete invalids, 2 because of blindness and 2 because of cerebellar disturbances. Among those who are well, there are 5 cystic tumors, where nothing was done except evacuating the cyst and cauterizing its walls with Zenker’s fluid. These 5 patients have been under observation from 5 to 20 years, the average observation time being 12 years. Four with solid tumors have been followed for an average of 19\frac{1}{2} years. Since the technical procedure has been the same as in those cases recurring within a few years it is hardly possible to escape the conclusion that some acoustic tumors do not continue to grow after incomplete removal or at least grow so imperceptibly slowly that life and function are not endangered for many years or even decades. Unfortunately there is no way except in the case of the cystic tumors to decide at the time of operation how the tumor is going to behave in the future. In the case of cystic tumors, however, there is good reason to be conservative and even if some of these do recur, the time until recurrent symptoms manifest themselves is usually a long one and quite frequently 10–15 years or more elapse without any symptoms of recurrence.
After complete removal of the tumor there were 166 patients surviving the operation. Eighteen of these have not been heard from for some years and as most of them were Jews from Central Europe they are presumably dead. Nine patients are known to be dead, 1 from pneumonia 2 months after leaving the hospital, the remaining cases between 1–10 years later, all from intercurrent disease. In 1 case which came to autopsy a recurrent tumor the size of a pea was found. Otherwise no recurrences have been observed.

There remain therefore 139 patients who are still alive and whose subsequent fate is known. Among these, 63 or about 50 per cent are well with full or nearly full capacity for work; 54 are fairly well but their earning capacity is reduced, usually to about 50–75 per cent. There are 22 who are complete invalids, 7 of them because of blindness which was present already before operation. In the remaining cases cerebellar incoordination and general weakness, sometimes also associated with old age, were the chief causes of invalidism. The average observation time of the surviving cases is 7 years. In some of the recent patients who have been followed for only a year or so, and who have been classified as complete invalids, some recovery of function may be expected but probably none of them will ever regain full earning capacity.

Of the 62 survivors where the anatomical continuity of the facial nerve was preserved, 6 have not been heard from. Among the remaining 56, there was complete or nearly complete recovery of function in 19, partial recovery...
in 20, and no recovery in 17. In two-thirds of the cases, where the facial nerve has been saved, moderate to good recovery may be expected, while in one-third a complete facial paralysis persists. It should be noted that in every case the porus has been coagulated to destroy all remnants of tumor tissue. This naturally leads to complete loss of function immediately after operation and in a number of cases there is probably too much scar tissue for regeneration to be possible.

It has already been noted that the operative mortality in the group where the facial nerve has been saved is much lower than in the other groups. The results with regard to earning capacity also are considerably better. There are only 4 complete invalids, 2 because of amaurosis, among the 56 patients who could be followed, as compared with 18 (5 cases of blindness) among the 139 cases where the facial nerve could not be saved. The time of rehabilitation is also considerably shorter in this more favourable group, where the tumor as a rule is smaller and more easily handled.

A comparison between the final results in the incomplete and the complete removals shows, that in the former group 25 per cent are reasonably well and able to work after an average observation time of 13 years, while among the complete removals 55 per cent are well and working after an average observation time of 7 years. There is no mortality from recurrence where the tumor has been completely removed, while among the incomplete removals 40 per cent died within 3–4 years from recurrence or secondary operations.

A final word should be said about the influence upon the mortality rate of attempts to save the facial nerve. In our opinion the careful dissection of the facial nerve makes the operation infinitely more difficult, the operation is considerably prolonged thereby, and although the increase in the operative risk cannot be stated in figures, there is in our opinion no doubt that the danger of the operation is to some extent increased by efforts to save the
facial nerve. Although it is eminently desirable to save the facial nerve, this principle should not be carried too far and the cases should be carefully selected with due consideration to the age, sex and occupation of the patient. A serious effort to save the nerve should be made only when the anatomical conditions in the field of operation are reasonably favourable.

The general conclusion from our present experience with acoustic tumors is that they should be completely removed unless the tumor is cystic or there is a very urgent indication to save the facial nerve, and the anatomical conditions in the operative field are not quite favourable for saving the nerve.

TECHNIQUE OF OPERATION

We prefer local anaesthesia, especially because the function of the facial nerve can be watched during the operation. Pain may occur, particularly when the tumor is mobilized from the glossopharyngeal nerve and also as the tumor is dissected away from the trigeminal root. Pain from the glossopharyngeal nerve can nearly always be prevented by placing a pledget of cotton, wet in 5 per cent novocain solution, on the nerve as it leaves the brain stem. Pain from the trigeminal nerve may occur both during the intracapsular part of the operation, though this is usually slight, and particularly as the capsule is pulled away from the root and the brain stem. This pain is difficult to prevent as the 5th root is not accessible until the capsule has been mobilized from the brain stem to a considerable extent. A few drops of novocain may then be injected into the root as it emerges from the pons.

It must be admitted, however, that the operation under local anaesthesia is not as free from discomfort for the patient as one would wish. The alternative to local anaesthesia is intubation with ether and oxygen. It is important, however, that the anaesthetist be very experienced, as even comparatively slight obstructions of the airway might cause considerable venous stasis and swelling of the cerebellum. As it is necessary to have all the room possible in this narrow field of operation, even
slight or moderate degrees of venous stasis might greatly increase the difficulties and hazards of operation. Needless to say, shoulder supports are absolutely essential, especially if general anaesthesia is used. The face-down position with complete muscular relaxation induced by general anaesthesia, may during a prolonged operation place such a load on the heart, especially in elderly patients, that circulatory failure may occur.

In our clinic the face-down position is always used. It is important to place the patient with the neck well flexed and the head rotated somewhat away from the lesion. The head is fixed in this position with strips of adhesive tape. The table should be so constructed that it may be tilted around its long axle. During removal of the tumor the table is tilted this way, whereby a good exposure of the cerebellopontine angle is assured. The unilateral exposure proposed by Dandy is always used and the bone over the cerebellar hemisphere on the side of the lesion is removed. It is important to remove enough bone to expose the sigmoid sinus. Sometimes the mastoid cells extend behind the sinus, but unless there is a history of mastoid infection, the cells are opened to allow sufficient removal of bone. The opened cells are filled with penicilln solution and plugged with wax. After tapping the lateral ventricle, the dura is opened in stellate fashion. After retracting the cerebellum, the tumor is usually easy to expose and after incising the arachnoid covering the tumor, as much as possible on the surface of the tumor is exposed by pushing away the cerebellar cortex covering the neoplasm. After coagulating all superficial blood vessels visible in the capsule, the tumor is incised and as much as possible of the contents evacuated with a spoon and sucker, as in an ordinary intracapsular enucleation. During this procedure and until the end of the operation, a special nurse is watching the face of the patient. If the intracapsular enucleation is carried too close to the facial nerve, twitchings occur in the face, indicating that further progress of the enucleation in this direction should be stopped. From time to time the patient is asked to move the face on the affected side.

When the intracapsular enucleation has been carried sufficiently far, hemorrhage from the cavity is stopped by temporary packing with cotton strips, wet in 3 per cent hydrogen peroxide solution.

When a reasonable degree of hemostasis has been obtained, a de Martel automatic brain spatula is inserted, retracting the cerebellum from the lower pole of the tumor. The lower pole is now mobilized by retracting it upwards with a brain spatula. It is usually easy to separate the lower pole from the 9th 10th, and 11th nerves, which are usually elongated and pushed downwards by the tumor. Frequently, there are 1 or 2 fairly large branches from the vertebral artery coming from below and running up to the ventral part of the tumor or between the tumor and the brain.
stem. These arteries are doubly clipped and divided. A search is then made for the facial nerve, which always runs on the ventral side of the tumor. Usually, the nerve is most easily seen as it runs as a flattened band on the lateral surface of the brain stem. After the nerve has been seen, its identity is confirmed by faradic stimulation. One should then try to follow the nerve in the lateral direction as far as possible. This is rarely possible to any great extent, because the nerve is always pushed away in the cranial direction and usually can be followed for only about 2 cm. from the brain stem. The nerve is usually somewhat adherent to the capsule of the tumor and should be freed by careful blunt dissection. If the tumor is small, it is sometimes possible to follow the nerve all the way to the porus, but in most cases the facial nerve crosses over the trigeminal nerve about 15 mm. from the porus to enter the porus at its anterior margin, about mid-way between the superior and inferior quadrant.

After the facial nerve has been dissected free as far as possible, the upper pole of the tumor, which is usually wedged in between the brain stem and the margin of the tentorium, is mobilized, if possible, so far that the trigeminal nerve can be seen at its emergence from the pons. If necessary, a few drops of novocain are injected into the nerve.

The next step is to mobilize the tumor from its attachment to the porus. There is always a projection of neoplastic tissue into the porus and the capsule of the tumor is always firmly adherent to the margins of the porus. A knife must be used to separate the tumor from the margins of the porus. Before doing this, it might be advisable to coagulate the petrous vein which lies on the superior surface of the tumor. It may be quite large and may be troublesome, unless coagulated before the tumor is separated from the tentorium.

The dissection of the tumor away from the porus must be done very carefully.
to avoid injury to the facial nerve. As already pointed out, the usual point of entry of the nerve into the porus is in the anterior-inferior quadrant. Frequently, the nerve is separated from the capsule by a thin sheath of arachnoid, and, if existing, this sheath of arachnoid should be carefully preserved. As soon as the nerve is seen, it is identified by faradic stimulation. The neoplastic tissue present in the porus can usually be removed by blunt dissection without injury to the nerve. Nearly always there is troublesome bleeding from the porus which should be temporarily stopped by packing the porus with a small cotton pledget. When the facial nerve has been identified at its point of entry into the porus, it is carefully dissected away from the capsule. Usually the adhesions are quite firm between the lateral part of the nerve and tumor, and sometimes it is necessary to use a knife to separate these adhesions. If possible, the nerve should be dissected free from the capsule of the tumor in its entire course from the brain stem to the porus. When this has been accomplished, the removal of the tumor is a comparatively simple matter, provided the capsule is sufficiently tough to allow some pull to be exerted on it. If this is the case, the part of the capsule that has been attached to the ventral part of the porus is grasped with a Brüning nasal clamp and the capsule pulled away from the trigeminal and facial nerves. The medial part of the capsule is usually deeply embedded in the pons and several small arteries may be encountered, running from the lateral surface of the pons to the tumor. These are clipped and divided as they are seen and the pull on the tumor in a posterior-medial direction continued until the tumor is delivered from its bed in the cerebellopontine angle. A few veins on the lateral surface of the pons are usually torn in the process, but hemorrhage from this source usually stops by itself after temporary packing with strips of cotton, wet in hydrogen peroxide. The function of the facial nerve is now tested—in most cases the nerve has been so traumatized that voluntary function is lost, but response to faradic stimulation is usually retained, unless the nerve has been torn. The porus is now examined for remaining fragments of tumor. It is always advisable to coagulate thoroughly the porus both to destroy remaining tumor cells and to control hemorrhage, which may be quite troublesome from small arteries perforating the bone in the porus. During this process, any remaining function of the facial nerve is of course lost, but provided the anatomical continuity of the nerve is preserved, regeneration will take place in 2/3 of the cases. The pack in the angle is now removed and the lateral surface of the pons inspected for bleeding points. Arterial bleeding should be stopped by clipping the artery or by coagulation. One should be very careful, however, in coagulating blood vessels on the lateral surface of the pons. Venous oozing which has not stopped by itself or by temporary packing is best controlled by small pieces of gel foam pressed against the bleeding point for a short while.

After all hemorrhage is under control, the cavity is flushed out with 3 per cent hydrogen peroxide solution and normal saline. It can not be too strongly emphasized that control of hemorrhage must be absolute, as a fatal outcome of an operation for acoustic tumor is nearly always due to postoperative hemorrhage. The dura is carefully closed as watertight as possible.

SUMMARY

The immediate and late results in 300 operations for acoustic tumors are presented. In 83 cases the tumor was incompletely removed. In the remaining 217 cases all visible tumor tissue was extirpated. In 69 cases, or about 30 per cent, the anatomical continuity of the facial nerve was pre-
served. The mortality in the incompletely removed tumors was 29 per cent. In the completely removed tumors the mortality was 23.5 per cent. In two-thirds of the cases, where the facial nerve was saved, good or satisfactory regeneration occurred.

Among the survivors of the incomplete operations, recurrence of the tumor was observed in 50 per cent, the recurrence leading to death or to a 2nd operation 3–4 years after the 1st operation. The mortality rate with and without a 2nd operation therefore was 40 per cent of those surviving the 1st operation.

Among the completely removed tumors no recurrences were observed. The technique of operation is described.

REFERENCES