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CLINICAL OBSERVATIONS ON BONE CONDUCTION*

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THE object of this research was to investigate bone conduction acuity in a series of patients in whom the presence of an intracranial lesion had been proved at operation or at *post mortem* examination. The patients examined were for the most part from the Montreal Neurological Institute, and we are greatly indebted to Dr. Wilder Penfield and his associates for placing at our disposal this excellent material.

A great difficulty in undertaking such a clinical investigation of hearing by bone conduction was the lack of uniformity in instruments, tests and methods for determining bone conduction. Much care was exercised in selecting the instruments. We were guided in our selection by the report of the Committee for the Consideration of Hearing Tests, of the Royal Society of Medicine, London, 1933, and by the report of the Committee on Tuning Forks and Tests of Hearing of the American Academy of Ophthalmology and Otolaryngology (1931). It was finally decided that the bone conduction of each patient should be tested by a variety of methods ; tuning forks, the monochord

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of van Struycken and by the audiometer bone conduction attachment, in order to compare the results from each method.

Tuning Forks

In selecting tuning forks most suitable for this investigation, much valuable assistance was given us by Professor W. Watson of the Department of Physics, McGill University. The vibrations of each fork were compared and checked against the General Radio Oscillator No. 222. The vibrations from the prongs and from the stem of each fork were tested separately. The following forks were tested by this method and were all found to be quite true both for the prong and the stem vibrations: Edelmann's forks c^1, c^2, and c^3, an aluminium-magnesium alloy fork c^2 (Riverbank Laboratories), and Hartmann's c^1, and c^2 forks.

In spite of the fact that all of the above-named forks proved to be accurate, they were not all equally suitable for carrying out bone conduction tests. When struck a standard blow, the Edelmann forks and the alloy fork gave off a considerable number of overtones which were quite misleading, and the vibrations from the prongs were so loud at the outset that they were easily heard by air conduction. Finally the vibration period of these forks was so long that both patient and examiner became fatigued after each test was repeated and checked a few times. The smaller Hartmann fork c^2 (512), which when tested proved to be accurate in its vibrations, was more suitable for our purposes in that it did not give off as strong overtones, nor did it have as strong an initial vibration, and finally the total length of vibration was not as long as in the larger forks and yet was long enough for accurate determination of the hearing both by air and bone conduction.

Two forks, c^1 and c^2, made according to the specifications of the Hearing Test Committee of the Royal Society of Medicine, London, were not found to be any more satisfactory for testing bone conduction than the Hartmann c^2 fork.

Considerable thought was given to the range of forks which should be used to test the bone conduction. The majority of otological writers now agree that forks below c (128 d.v.) and above c^3 (1,024 d.v.) are totally unsuitable for bone conduction tests, but there is considerable variation of opinion about the forks within this small bracket. See Clarke (1929), Hallpike (1930), and the Report of the Committee for the Consideration

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of Hearing Tests of the Royal Society of Medicine (1933). The majority of the writers favour either c^1 (256 d.v.) or c^2 (512 d.v.). With a c^1 fork, it is impossible to be sure that, at threshold strength, the patient is not actually feeling, rather than hearing the vibrations. On the other hand, for a c^3 fork the vibrations by air are so much more pronounced than the vibrations from the stem that it is possible that the sound may be heard more by air than by bone conduction. It was therefore decided that the fork c^2 (512 d.v.) was the most practical to use for routine bone conduction tests. This conclusion received support from the Report of the Committee on Methods of Testing Hearing by Bone Conduction of the American Otological Society, 1936.

The Weber test was recorded in each patient, but instead of reporting the bone conduction tests in terms of Rinne and Schwabach it was thought more satisfactory to examine separately and record the air conduction, the bone conduction and the absolute bone conduction times for each ear in each case. In order to do this a standard method of activating the fork had to be employed and the tests done under similar conditions each time.

A reasonably efficient method of activating the fork was adapted from the Physiology Laboratory, McGill University. A small brass clip (see Fig. 1) was made, which when applied to the prongs of the tuning fork held them in slight compression. When the clip was pulled off, the fork vibrated with a minimum of overtones, and always for the same length of time, the variation being a matter of only a few seconds. For the c^2 (512) Hartmann fork, thus activated, the duration of the vibration as heard by air conduction in a quiet room was about 70 seconds. This was found to be the average time for a number of normal examiners.

Care was taken to establish a routine method of handling the tuning forks in order to standardize such factors as the rate of decay from the damping effect of the cranial bones, etc., as pointed out by Clarke (1929) and re-affirmed by the Committee for the Consideration of Hearing Tests of the Royal Society of Medicine, London, 1933.

The Monochord

The van Struycken monochord used in these examinations was tested and accurately set by checking it with the General

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Radio Oscillator No. 222. Cotton wool saturated in methyl alcohol was used to stroke the wire. The longitudinal or double vibrations were the only ones tested. The monochord was used to test the upper tone limit of both air and bone conduction.

The Audiometer Bone Conduction Attachment

We used the bone conduction attachment of the 2A Western Electric Audiometer. The instrument was checked by the Northern Electric Company during the course of these experiments and was carefully examined before each test to assure its proper working. It was decided that on the audiometer, in addition to testing for the note c^2, we should also test for the note c^1 in every case in the hope of showing some variation between the two. Both ordinary or relative bone conduction and absolute bone conduction were tested by the audiometer. Knudsen and Jones (1931) used the bone conduction receiver of the audioamplifier and tested bone conduction over a range from 64 d.v. to 4,096 d.v., and they were of the opinion that this wide range of frequency facilitated the differential diagnosis between conductive and perceptive deafness.

Conditions During the Test

We were fully aware of the influence of the surroundings upon the accuracy of any hearing test. Because of the serious condition of many of these patients, they could not be removed from the wards so that the majority of the tests were carried out in a relatively noisy ward. When possible or where it seemed to be especially indicated, the test was repeated in a quiet room. The room used for re-testing was particularly quiet but was not sound-proof. As far as possible the results in each case have been interpreted in the light of the surrounding conditions as well as with reference to the age (see Fig. 2) and the physical and mental condition of the patient. Slight individual differences between the examiners and the variability of the test methods themselves were also considered. Every care was taken in carrying out the different tests to reduce the variable factors to a minimum. In almost every instance each examination was carried out in the presence of at least two and usually three of the examiners, and all abnormal findings were checked and re-checked by each examiner present. An impression of the case was recorded at the end of each examination.

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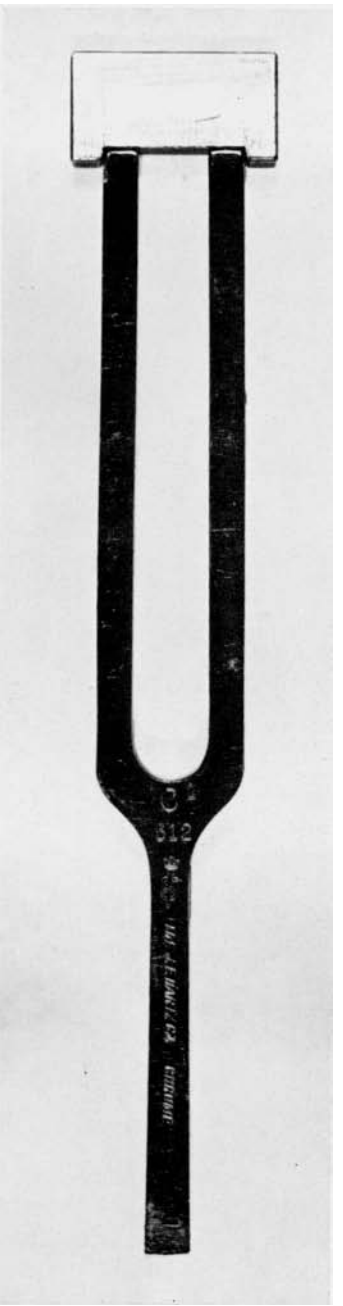


Fig. 1.
Hartmann Tuning Fork C^2 (512) with brass clip attached for activating the fork.

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Clinical Observations on Bone Conduction

It was felt from the outset that an examination of the bone conduction could not be properly interpreted unless it was accompanied by a very careful audiogram and by air conduction tests with the tuning forks and the monochord. The vestibular tests were also done as an added check and help in interpretation.

Because it is so difficult to standardize the voice and watch tests they were not included in the routine examination. At

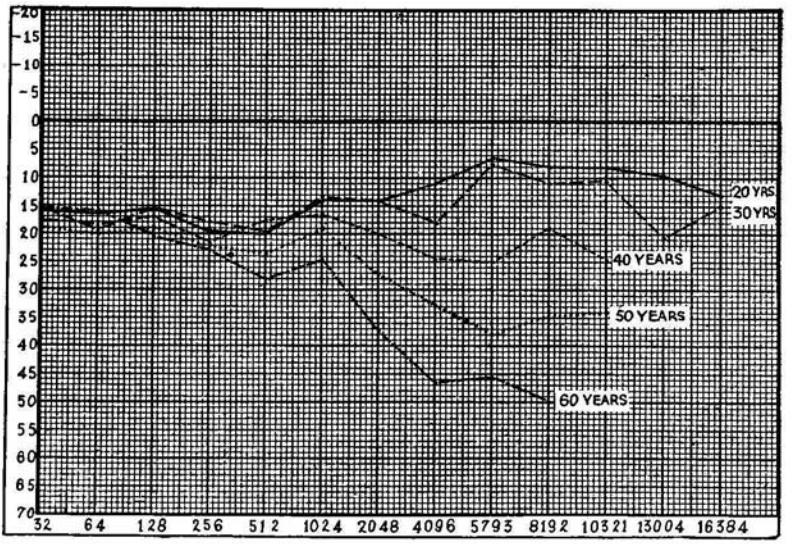


FIG. 2.
Audiogram showing the means for the different age groups (Bunch, 1929).

the end of the investigation, however, it was felt that had we included them this would have been an excellent opportunity of comparing their value in diagnosis with the more mechanical tests.

Method of Examination

A suitable routine examination was arrived at and was used in all cases except where the preliminary hearing tests had been done before this investigation was undertaken. In so far as possible a complete hearing test and vestibular examination were done before and after any operative procedure was carried out.

The complete examination consisted of :

(*a*) A careful history and inspection of the ears, nose and throat.

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(*b*) An audiogram (2A Western Electric Audiometer).
(*c*) Tests with the Audiometer Bone Conduction Apparatus of bone conduction and absolute bone conduction for the notes 256 d.v. and 512 d.v.
(*d*) Tests with a tuning fork (512 d.v.) of air conduction, bone conduction and absolute bone conduction.
(*e*) Tests with a von Struychen monochord of air conduction and bone conduction.
(*f*) A vestibular examination.
(*g*) Masking of the non-tested ear for any of the above tests when indicated.
(*h*) Impression of the case.

An effort was made in every case to determine the exact condition of the middle and internal ears in order that loss of hearing would not be attributed to an intracranial lesion when it could be explained by the presence of local ear disease.

The Absolute Bone Conduction Test

A valuable part of the bone conduction examination was the absolute bone conduction (ABC) test. In the present investigation it was done in connection with the fork tests and with the audiometer bone conduction tests. It consists of closing the external canal while the stem of the fork is held against the mastoid. When carried out on a normal person in an ordinary room absolute bone conduction is twice as long as ordinary (relative) bone conduction and is about half as long as air conduction. These ratios vary with the surrounding noise. The routine use of this test was advocated in a report of the Committee of Research of the Royal Society of Medicine, London, in 1917. However, it never received general adoption, and Hastings (1929) suggested that the reason may be that this report appeared during the War and may have been overlooked. Clarke (1929) states that the test was described as early as 1883 by Pomeroy. The test and its advantages were described in detail by Hastings (1929), Clarke (1929), Hallpike (1930), and by the Committee for the Consideration of Hearing Tests of the Royal Society of Medicine, London (1933). Very similar to the absolute bone conduction test, is a modification of the Weber test described by David-Galatz (1934).

Hallpike's explanation of the phenomenon is that closing the external canal shields the internal ear from room noises

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and allows the tuning fork against the mastoid to be heard for a much longer time, or for the same length of time that it would be heard in a quiet or sound-proof room. A patient who has a middle-ear lesion and a normal internal ear on the same side has a longer relative bone conduction than normal because the damaged middle ear shields the internal ear from the room noises just as closing the external canal would do. Hallpike (1930) found that the increased relative bone conduction of patients with middle-ear lesions was equal to the examiner's bone conduction if tested by the absolute bone conduction test, or if tested in a sound-proof room, if there was no internal ear lesion. See also Knudsen and Jones (1931) and Kobrak, Lindsay and Perlman (1935).

This test was particularly valuable in our experience when it was necessary to carry out an examination in the ward, because it offset the noise factor in both the patient and the examiner.

We found that when the ABC test was carried out in the following manner it gave additional information as to which ear was really hearing a bone conducted sound in the case of an asymmetrical hearing lesion. The fork was placed on one mastoid, both ear canals were closed simultaneously, and the ABC time was recorded. With the fork on the same mastoid, the ABC time was recorded while only the ear canal on the same side was closed. Finally the test was repeated while the ear canal on the opposite side was closed. This may be illustrated by considering a case with right-sided nerve deafness. The ordinary or relative bone conduction over the right mastoid may be normal or even lengthened. When both canals are blocked, bone conduction over the right mastoid may be equal to the examiner's absolute bone conduction. On the other hand, when only the right canal is blocked, the hearing for the fork is not increased above the time of relative bone conduction for this ear. At this point, the left ear canal is blocked and the time for hearing the fork on the right mastoid increases and may equal the absolute bone conduction of the better hearing left ear. In the absence of masking, this simple test is an indication that the apparent bone conduction over the right mastoid is really bone conduction being heard in the more normal left ear. The bone conduction is improved when the left ear is screened from room noises, but on the other hand bone conduction is not increased by closing the right or deaf ear.

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The accuracy of the test was checked by masking both ears alternately. We found that in such a case applying the mask to the right ear had no effect on the bone conduction time over the right mastoid, whereas, when the mask was applied to the left ear, bone conduction over the right mastoid was no longer heard. Examples of the value of this method of carrying out the absolute bone conduction are seen in Cases XLIII and XLVIII.

Masking

In selecting a suitable masking apparatus we were guided by an excellent description of masking by Bunch (1931). Occasionally a Bárány noise apparatus was used, but for the most part we used a continuous current of air or else an electrical buzzer of the door-bell type, a modification of that described by Bunch. A resistance was inserted to give variation in the loudness. Instead of having a telephone receiver the small buzzer itself was enclosed in a rubber sponge and was held in contact with the patient's ear.

As a source of a continuous current of air the stream from an ordinary compressed air circuit was used, and directed into the ear canal. The strength and noisiness of the current could be varied from the outlet valve. It was felt that when used with sufficient force to mask some sounds the air was so cold or so disagreeable as to be acting as an irritant rather than as a simple masker of the sound in the non-tested ear (see Case V).

Since we were testing bone conduction with the audiometer bone conduction attachment, with the forks, and with the monochord, masking was not quite the same problem in each case. The electric buzzer appeared to be very ineffective as a mask for the monochord. In fact, it was only with the strongest current of air that the monochord could be masked in a few cases where there was proved nerve deafness. In one case, for instance, where the right VIIIth nerve had been cut (Case XLVIII) the monochord BC on the right could not be masked with the electric buzzer and only with the very strongest current of air could it be eliminated. The monochord and especially monochord bone conduction in cases of unilateral nerve deafness may be most misleading and very difficult to check up even with masking. Possibly if a mask of somewhat similar high frequencies to the monochord itself were used masking might be more effective.

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Bunch (1931) refers to the fact that in some normal individuals masking occasionally increases hearing for some notes in the non-masked ear. The phenomena is probably similar to the crossed paracusis of Hastings and Scarff (1928). In this investigation it was noted in a few cases (Cases XLI and XLII) that attempting to mask the monochord actually increased the hearing by BC in the non-masked ear.

These results, however, support those of other workers in stressing the importance of masking in cases of asymmetrical or unilateral deafness. As pointed out by Bunch, discrepancy in the two ears, especially if there is a shadow curve audiogram, calls for masking (as shown by Cases XLII, XLIII, XLIV, XLVIII, and Figs. 11, 12, 16 and 17). Furthermore, where there is a high grade bilateral deafness, masking may bring out some unsuspected differences between the two ears (see Case XXXII and Figs. 7 and 8).

In doing the absolute bone conduction test, if blocking the opposite ear canal is more effective in prolonging the hearing by bone conduction, masking the opposite ear as previously mentioned will also support the idea of nerve deafness in the tested ear.

A word of explanation is in order with reference to certain abbreviations which have been used especially in the preparations of the tables in the case reports. Masking with a current of air is designated by " A.M.", masking by the Bárány noise apparatus by " B.M." and masking by the electric buzzer by " E.M.". In connection with the testing of bone conduction by means of the bone conduction attachment for the audiometer, " s.u." represents sounds units. For the tests with the monochord, " d.v." stands for double vibrations.

Clinical Material

During the present investigation fifty patients from the Neuro-Surgical Service were studied. The cases were chosen either because the intracranial condition had been determined by a previous operation, or because they were about to be operated upon, or else because they were to be subjected to some special procedure.

In order to make this survey of most use to those specially interested in the subject, it was decided to report the complete hearing examination in every case showing any hearing loss, and to include a brief description of the neurological diagnosis

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and operative procedures. However, in those cases in which the hearing was within normal limits, the tests will be described only briefly, in order to conserve space, and in such case reports the clinical examination of the ears, nose and throat, and the vestibular tests will not be mentioned unless they reveal some abnormality. If the hearing test was complete according to the standards of this investigation, it is reported as follows :

Audiogram, Subclass (?) each ear.

Audiometer B.C., Tuning fork and Monochord tests, are normal.

On the other hand, if the hearing test was performed prior to this investigation, or was not complete according to the present standards, the following phraseology is used :

Hearing Tests are normal to superficial examination.

We present our conclusions drawn from this material, but it is possible for anyone to review the material and make their own deductions.

Reproducing all the audiograms is unnecessary, but those not reproduced are described according to the excellent classification published by Guild (1932). In order to help the reader to visualize each audiogram, Guild's diagrams are reproduced for ready reference (Figs. 3 and 4). The audiograms in this series requiring special description or those of special cases have been reproduced. In these audiograms, circles joined with a continuous black line always indicate the right ear, while the left ear is always indicated by the letter X and an interrupted black line. When masking is used a filled-in circle represents the right ear when the left ear is masked, and a filled-in X represents the left ear when the right ear is masked. In order to avoid any misunderstanding the significance of each of these characters is given on the individual audiogram and the type of masking is specified in each case. When a note is not heard at the full strength of the audiometer, the character representing the deaf ear is shown on the audiogram at the point of maximum loudness of the machine with a down pointing arrow attached to the character (see Fig. 6).

The cases have been divided into the following six groups :

Group 1. Encephalography and Ventriculography, Cases I to XIII.

,, 2. Removal of Cerebral Tissue, Cases I and XIV to XXVI.

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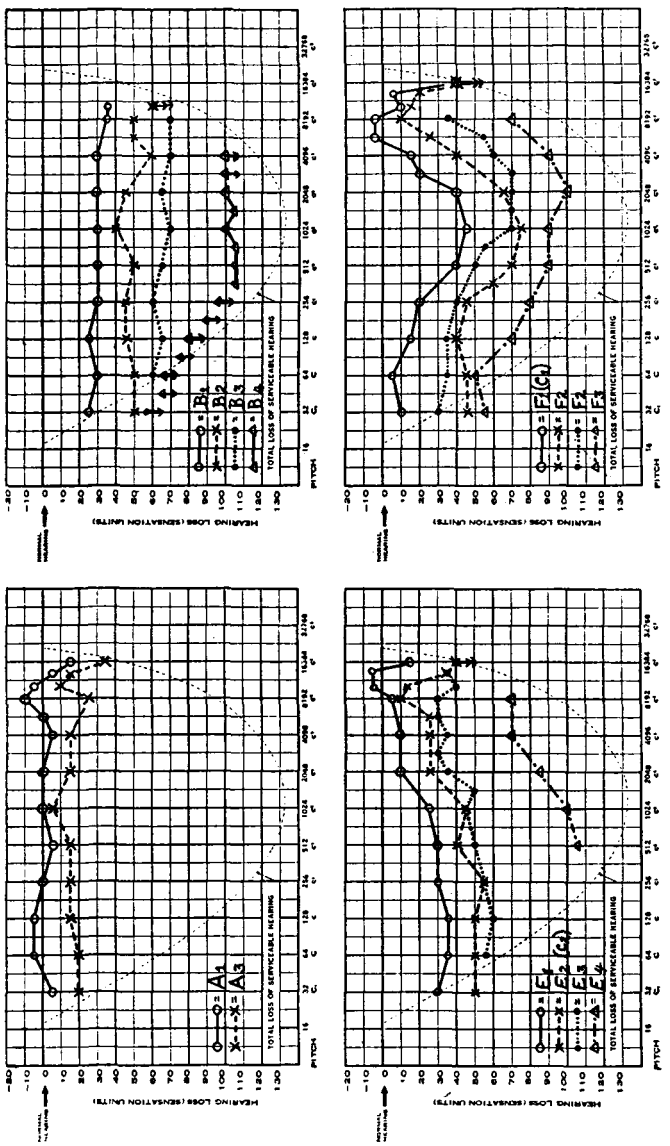


FIG. 3.
Examples of Audiograms classified by Guild (Guild, 1932).

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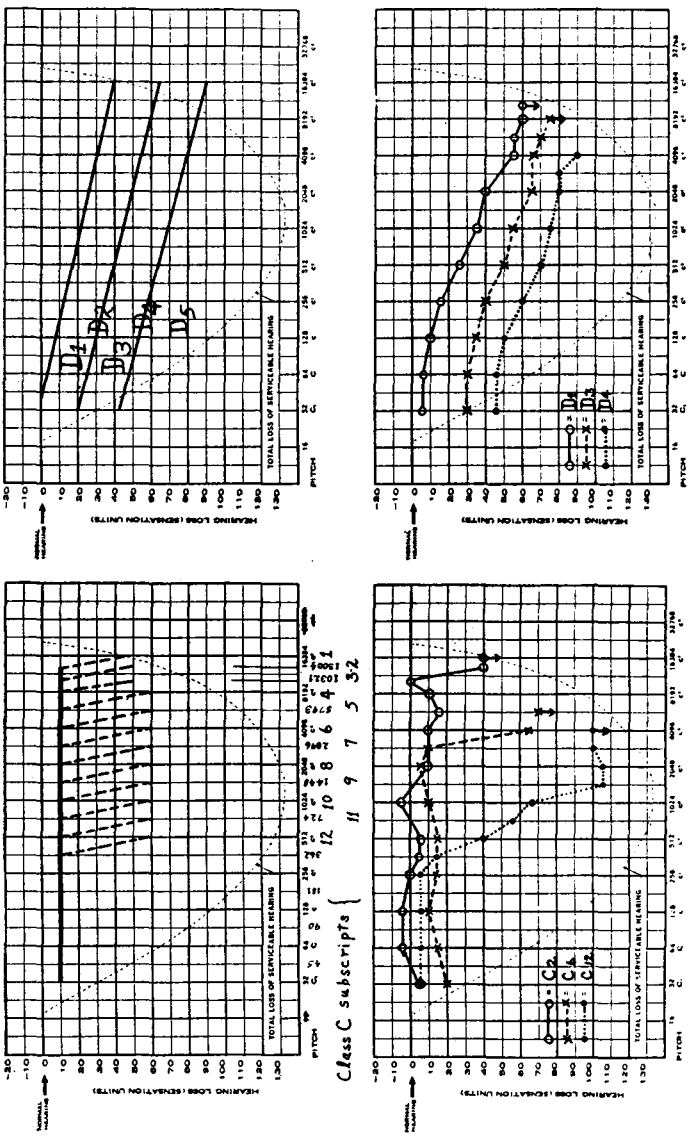


Fig. 4.
Further examples of Audiograms explaining Guild's method of classification (Guild, 1932).

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Group 3. Removal of Cerebral Tumours, Cases XXVII to XXXV.

,, 4. Removal of Cerebellar Tumours and Abscesses, Cases XXXVI to XLI.

,, 5. Removal of VIIIth Nerve Tumours, Cases XLII to XLV.

,, 6. Miscellaneous, Cases XLVI to L.

Group 1.—Encephalography and Ventriculography

When carrying out an otolaryngological examination in a patient suffering from possible intracranial disease, one is called upon frequently to estimate the possible influence of changes of intracranial pressure upon the hearing and vestibular mechanism. To obtain accurate information about the effect of intracranial pressure changes, a hearing test must be done immediately before and after a known pressure change. The present investigation afforded an opportunity to make some observations upon this question, because many of the patients in a neuro-surgical service have had either an encephalogram or a ventriculogram done as a diagnostic procedure.

Encephalography consists of the withdrawal of approximately 90 c.cm. of spinal fluid by lumbar puncture, while the patient is sitting up, and its replacement by approximately 110 c.cm. of oxygen. What happens to the intracranial pressure is not exactly known, but the air in the intracranial spaces remains for two or three days or more and the subjective disturbances persist for the same length of time. Usually when a second encephalography is attempted in twenty-four hours' time the pressure is found to be low.

Ventriculography consists in the direct replacement by ventricular puncture of 20 or 30 c.cm. of ventricular fluid with a similar quantity of oxygen.

From these procedures it is presumed that there is a very definite alteration of intracranial pressure relationships. Using various gases, Aird (1936) performed encephalographies on dogs and recorded the spinal fluid pressure changes. The injection was done as for encephalography. There was great variation, low as well as high pressures being recorded. He found that these changes occurred up to twenty-four to forty-eight hours after the injection of the various gases. The majority of the cases suggested a rise of spinal fluid pressure.

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From the above observations it would seem reasonable to presume that there are intracranial pressure changes within the first twenty-four hours following encephalography and ventriculography.

With these ideas in mind ten patients were examined immediately before encephalography and within twenty-four hours after, and three patients were examined just before ventriculography and the test repeated within twenty-four hours afterwards.

CASE REPORTS

In Case I the hearing tests are normal but the case is included in full as an example of the type of examination carried out in this series of patients. It also illustrates how slight variations do occur in the different tests from day to day, showing the necessity for a complete examination repeated on several occasions. In Group 1, there are five other cases in which the hearing tests before and after encephalography and ventriculography are within normal limits. These cases are included only in the most concise detail, as follows :

CASE II. Mrs. Y.B. Age 30. Diagnosis, Psychoneurosis, hysterical type.

CASE VI. Mr. C.S. Age 23. Diagnosis, Peripheral facial paralysis, right.

CASE VII. Mr. R.S. Age 20. Diagnosis, Epilepsy, grand mal, idiopathic.

CASE X. Mr. H.T. Age 48. Diagnosis, Post-traumatic headache.

CASE XII. Mr. R.S. Age 46. Diagnosis, Cerebral thrombosis, right middle cerebral artery. Internal hydrocephalus, cause undetermined.

The remaining patients in this group showed some slight hearing abnormality and are included in full.

CASE I.—Miss M.B., aged 30. Admitted March 17th, 1936.

Diagnosis : Jacksonian epilepsy, focal area of cortical atrophy.

NOTE : The epileptic seizures were characterized by micropsia, dizziness, tinnitus, pain in the left ear, and numbness in the right hand.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : March 18th, 1936.

Nose and Throat : Normal. Posterior cervical glands of both sides nodular.

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Otoscopy : Drums normal. Left ear canal narrower that the right. The patient has had some pain in the region of the left ear, which becomes a definite noise before an attack.

HEARING EXAMINATION :

Audiogram : Subclass A_3 each ear.

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	80 s.u.	80 s.u.
	ABC	50 ,,	55 ,,
c^1 (256)	BC	75 s.u.	75 s.u.
	ABC	50 ,,	50 ,,
Tuning Fork Tests :			
c^2 (512)	AC	65 seconds.	65 seconds.
	BC	15 ,,	18 ,,
	ABC	28 ,,	30 ,,

Weber : BC not referred while ABC tends to be referred to the left side.

Monochord :	AC	17,000 d.v.	17,000 d.v.
	BC	18,000 ,,	18,000 ,,

Vestibular Examination : Cold Caloric Test : Normal. (The patient stated that the dizziness which she experienced was exactly like that preceding her attacks. She became very much frightened, thinking she was about to have an attack.)

Operative Procedure : March 20th, 1936. Encephalography.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : March 21st, 1936.

Audiogram : Subclass A_2 each ear.

Bone Conduction Tests :

Audiometer BC.		*Right.*	*Left.*
c^2 (512)	BC	75 s.u.	75 s.u.
	ABC	55 ,,	55 ,,
c^1 (256)	BC	75 s.u.	65 s.u.
	ABC	45 ,,	45 ,,
Tuning Fork Tests :			
c^2 (512)	AC	65 seconds.	60 seconds.
	BC	22 ,,	22 ,,
	ABC	40 ,,	50 ,,

Weber : Slight tendency to be referred to the right when the fork is placed in the mid-line with both ears blocked, otherwise is not unusual in either BC or ABC.

Monochord :

	AC	16,000 d.v.	16,000 d.v.
	BC	17,000 ,,	17,000 ,,

Vestibular Examination : Cold Caloric Test : Normal reactions.

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April 9th, 1936. Operator, W. G. Penfield. Left posterior osteoplastic craniotomy and excision of cerebral cicatrix. Near the mid-line in the mid-parietal region, the convolutions were removed over an area of 3 by 3 cm. and down to a depth of 4 cm. to the falx.

May 6th, 1936. Thirty days after operation, the patient has recovered quite satisfactorily from the operative procedure. General condition excellent, and she is free from attacks.

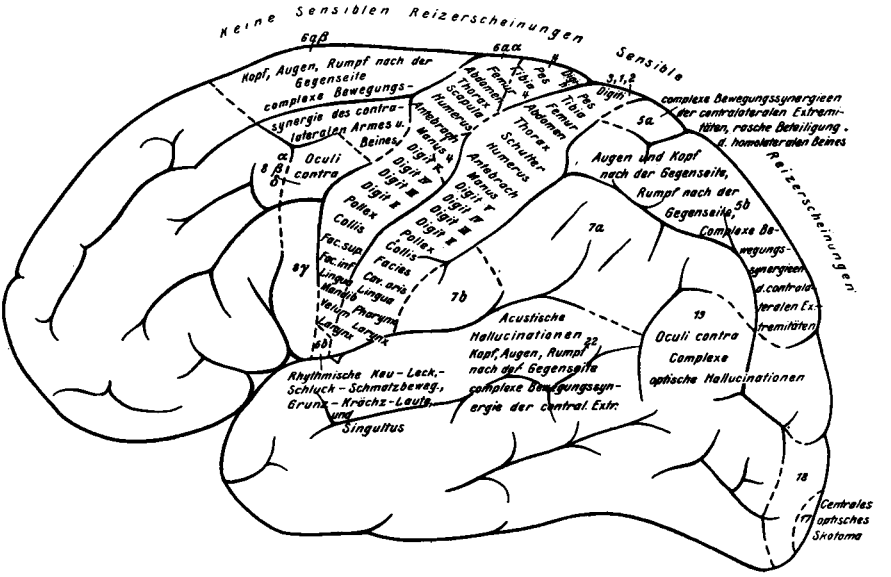


FIG. 5.
Diagram of the human cortex after Foerster and Penfield (Penfield and Gage, 1933).

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION: May 6th, 1936.

Nose and Throat: Normal.

Otoscopy: Normal as before operation.

HEARING EXAMINATION:

Audiogram: Subclass A_3 each ear.

Bone Conduction Tests:

Audiometer BC:	*Right.*	*Left.*
c^2 (512)	BC 70 s.u.	70 s.u.
	ABC 55 ,,	55 ,,
c^1 (256)	BC 70 s.u.	70 s.u.
	ABC 45 ,,	50 ,,

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Tuning Fork Tests :

c^2 (512)	AC	65 seconds.	65 seconds.
	BC	25 ,,	25 ,,
	ABC	45 ,,	42 ,,

Weber : ABC and BC equal.

Monochord :

AC	18,000 d.v.	18,000 d.v.
BC	20,000 ,,	19,000 ,,

Vestibular Examination : Cold Caloric Test : Normal reactions.

Impression : The Jacksonian attacks included dizziness and tinnitus, and yet removal of the cortical area which on stimulation reproduced these symptoms had no demonstrable effect upon the hearing and vestibular tests one month after the operation, although there may have been some effect immediately after the operation.

Cortical stimulation of the mid-line, mid-parietal area elicited dizziness from this patient (Foerster's area, Fig. 5).

Encephalography had no effect upon the hearing or vestibular tests twenty-four hours after the procedure.

CASE III.—Mr. T.H., aged 32. Admitted March 3rd, 1936.

Diagnosis : Epilepsy, grand and petit mal, ætiology undetermined.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : March 4th, 1936.

Nose and Throat : Normal.

Otoscopy : Drums normal.

HEARING EXAMINATION :

Audiogram : Subclass A_2 each ear, but with dip at 4,096 d.v. in left ear down 45 s.u. (Similar to Fig. 9.)

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	80 s.u.	80 s.u.
	ABC	55 ,,	50 ,,
c^1 (256)	BC	65 s.u.	65 s.u.
	ABC	40 ,,	45 ,,

Tuning Fork Tests :

c^2 (512)	AC	60 seconds.	60 seconds.
	BC	20 ,,	20 ,,
	ABC	40 ,,	40 ,,

Weber : not referred for BC or ABC.

Monochord :

AC	18,000 d.v.	18,000 d.v.
BC	19,000 ,,	19,000 ,,

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Vestibular Examination : Cold Caloric Test : Normal.
Operative Procedure : March 7th, 1936. Encephalography.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : March 8th, 1936.
Nose and Throat : Normal.
Otoscopy : Unchanged.

HEARING EXAMINATION :
Audiogram : Essentially the same as before operation.
Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	70 s.u.	65 s.u.
	ABC	50 ,,	50 ,,
c^1 (256)	BC	70 s.u.	60 s.u.
	ABC	45 ,,	45 ,,
Tuning Fork Tests :			
c^2 (512)	AC	65 seconds.	62 seconds.
	BC	23 ,,	20 ,,
	ABC	40 ,,	43 ,,

Weber : Not referred for BC or for ABC.
Monochord :

AC	18,000 d.v.	18,000 d.v.
BC	20,000 ,,	21,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.
Impression : Encephalography caused no change in hearing.

CASE IV.—Mrs. N.L., aged 37. Admitted March 10th, 1936.
Diagnosis : Epilepsy, grand and petit mal, ætiology not determined.

NOTE : Repeated encephalograms and one ventriculogram revealed nothing of localizing value. Duration of the symptoms, three years.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : March 11th, 1936.
Nose and Throat : Normal.
Otoscopy : Normal.

HEARING EXAMINATION :
Audiogram : Subclass A_3 right, A_2 left.
Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	75 s.u.	70 s.u.
	ABC	55 ,,	55 ,,
c^1 (256)	BC	60 s.u.	65 s.u.
	ABC	50 ,,	50 ,,

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Tuning Fork Tests :

c^2 (512)	AC	65 seconds.	65 seconds.
	BC	20 ,,	20 ,,
	ABC	25 ,,	25 ,,

(Under these conditions, BC=20 seconds, and ABC=45 seconds normally.)

Weber : The fork tends to be referred to the left when it is placed almost anywhere on the vertex. On the other hand if it is placed on the teeth or glabella, it tends to be referred to the right. When both ears are blocked, the fork tends to be referred to the left from the vertex, but if moved towards the right ear, it tends to be referred to the right.

Monochord :

AC	17,000 d.v.	16,000 d.v.
BC	18,000 ,,	19,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.

Operative Procedure : March 12th, 1936. Encephalography.

NOTE : This patient was examined twenty-four hours after the first encephalography, but not after any of the others.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : March 13th, 1936.

Nose and Throat : Normal.

Otoscopy : Normal.

HEARING EXAMINATION :

Audiogram : Subclass A_3 right, A_2 left.

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	75 s.u.	80 s.u.
	ABC	50 ,,	50 ,,
c^1 (256)	BC	65 s.u.	65 s.u.
	ABC	50 ,,	50 ,,

Tuning Fork Tests :

c^2 (512)	AC	70 seconds.	70 seconds.
	BC	23 ,,	23 ,,
	ABC	35 ,,	35 ,,

Weber : The fork was referred to the right ear from any point on the skull, even when placed over the left mastoid. When both ears were blocked, the fork was referred to the right ear from the midline, but if moved to the left of the midline, it was heard in the left ear.

Monochord :

AC	16,000 d.v.	17,000 d.v.
BC	17,000 ,,	19,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.

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Impression : A definite diagnosis of an intracranial lesion could not be established in this patient. The hearing tests carried out before and after encephalography were roughly within normal limits. We have no suggestion to offer in explanation of the slight diminution of absolute bone conduction for the fork c^2 (512). The peculiar reference of the Weber apparently has no explanation when considered in the light of all the other findings. It may serve in conjunction with many other examples to show how misleading this test may be.

CASE V.—Mr. C.S., aged 54. Admitted March, 1936.

Diagnosis : Cerebral thrombosis, middle cerebral artery, left, old standing. Bilateral chronic suppurative otitis media, right active, left healed. General arteriosclerosis.

NOTE : Patient had discharging ears in childhood.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : March 12th, 1936.

Nose and Throat : Large injected cryptic tonsils.

Otoscopy : Right Ear : Canal filled with foul-smelling discharge. Whole of the drum is destroyed except for Shrapnell's membrane. The mucosa of the middle ear is much injected.

Left Ear : Large central perforation occupying the whole of the posterior half of the drum. It has been healed over by a very thin membrane which is much retracted. The anterior part of the drum is intact though covered with a large calcium plaque. Healed chronic suppurative otitis media.

HEARING EXAMINATION :

Audiogram : Subclass right D_4 ; left F_1, C_6 down to 50 s.u. (On masking left ear with stream of air, right ear drops to D_5.)

Bone Conduction Tests :

Audiometer BC :		*Right.*		*Left.*	
c^2 (512)		No masking.	Operated ear masked with A.M.	No masking.	Operated ear masked with A.M.
	BC	60 s.u.	75 s.u.	65 s.u.	N.H.
	ABC	55 ,,		55 ,,	
c^1 (256)	BC	45 s.u.	60 s.u.	50 s.u.	75 s.u.
	ABC	40 ,,		50 ,,	

Tuning Fork Tests :

c^2 (512)	AC	7 seconds.		45 seconds.
	BC	23 ,,	23 seconds.	25 ,,
	ABC	27 ,,		30 ,,

Weber : Not referred for either BC or ABC.

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Monochord :

AC	0	12,000 d.v.
BC	14,000 d.v.	14,000 d.v.

NOTE : For Bone Conduction, masking the right or poorer hearing ear caused a marked lessening of hearing for bone conduction in the left or better ear, whereas, masking the left or better hearing ear had much less effect upon the hearing for bone conduction in the right or poorer hearing ear. The only explanation we could give for this was that the stream of cold air was more disturbing to the actively suppurating right ear. The discomfort so distracted his attention that he no longer heard with the left or better hearing ear.

Vestibular Examination : Cold Caloric Test : Normal.

Operative Procedure : March 14th, 1936. Encephalography.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : March 16th, 1936.

Nose and Throat : Unchanged.

Otoscopy : Unchanged.

HEARING EXAMINATION :

Audiogram : Subclass right D_4 ; left B_1, C_6 to 75 s.u.

(The effect of masking the left ear with a stream of air for note 2,048. Hearing in the right ear for this note dropped 35 s.u.)

Bone Conduction Tests :

Audiometer BC :		*Right.*		*Left.*	
c^2 (512)		No masking.	Operated ear masked with A.M.	No masking.	Operated ear masked with A.M.
	BC	50 s.u.		50 s.u.	
	ABC	45 ,,	70 s.u.	45 ,,	
c^1 (256)	BC	45 s.u.	45 s.u.	45 s.u.	70 s.u.
	ABC	40 ,,		40 ,,	

Tuning Fork Tests :

c^2 (512)	AC	10 seconds.		45 seconds.	
	BC	30 ,,	22 seconds.	37 ,,	8 seconds.
	ABC	50 ,,		25 ,,	
		43 ,,		32 ,,	
		35 ,,		30 ,,	

Weber : Not referred for BC or ABC.

Monochord :

AC	10,000 d.v.	N.C.	12,000 d.v.	N.C.
BC	14,000 ,,	N.C.	15,000 ,,	N.C.

NOTE : For the bone conduction tests, as noted before, masking the right ear caused a greater loss of hearing in the left than the reverse. At this examination, the fork tests are more in keeping

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with a double middle-ear lesion. BC is relatively increased and more nearly approximate ABC.

Vestibular Examination : Cold Caloric Test : Normal.

Impression : There has been very little change in the hearing tests before and after encephalography. There is an obvious bilateral middle-ear lesion. It is interesting to note that the audiogram would suggest a high grade nerve deafness in the right ear, whereas, the bone conduction tests and the monochord tests suggest very little nerve deafness in either ear.

A most difficult finding to understand is that masking with a stream of cold air when applied to the supposedly poorer hearing ear, caused a greater loss of hearing for bone conduction in the supposedly better hearing ear than the reverse. Presuming that this might be due to some type of pain phenomenon from the cold air douche acting upon the actively suppurating right ear, it was decided to repeat the tests using a graduated electrical buzzer as the masking apparatus.

CONTROL EXPERIMENT USING THE GRADUATED ELECTRICAL BUZZER : May 11th, 1936.

Nose and Throat : Unchanged.

Otoscopy : Unchanged.

HEARING EXAMINATION :

Audiogram : Subclass right D_4 ; left B_1, C_6 down to 65 s.u.

(Masking either ear with electric buzzer at full strength caused very little reduction in the opposite ear.)

Bone Conduction Tests :

Audiometer BC :		*Right.* No masking.	*Right.* Operated ear masked with E.M.	*Left.* No masking.	*Left.* Operated ear masked with E.M.
c^2 (512)	BC	55 s.u.	65 s.u.	60 s.u.	65 s.u.
	ABC	55 ,,		55 ,,	
c^1 (256)	BC	45 s.u.	60 s.u.	45 s.u.	60 s.u.
	ABC	40 ,,		45 ,,	

NOTE : Masking the homolateral ear gave roughly the same results as those in which the contralateral ear was masked.

Tuning Fork Tests :

c^2 (512)	AC	10 seconds.		40 seconds.	
	BC	32 ,,	25 seconds.	37 ,,	23 seconds.
	ABC	42 ,,		40 ,,	

Weber : Not lateralized for BC or ABC.

Monochord :

AC	11,000 d.v.	10,000 d.v.	12,000 d.v.	11,000 d.v.
BC	15,000 ,,	15,000 ,,	15,000 ,,	15,000 ,,

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Vestibular Examination : Cold Caloric Test : Not repeated.

Final Conclusion : Masking the left ear on the audiometer with an electrical buzzer confirms the presence of a nerve deafness in the right ear, but the drop in the right ear is less than that caused by the use of a stream of air. Use of the electrical masker in connection with the bone conduction tests would suggest a bilateral middle-ear deafness, bone conduction being well preserved in both ears and ABC approaching BC.

In spite of the great loss of air conduction in the right ear as compared with the left ear (bone conduction being equal in both), the Weber test has not been referred to the right ear as one would expect.

Whereas, masking either ear with a current of air eliminated hearing for the monochord in the opposite ear—masking with an electric buzzer had no effect upon the monochord.

CASE VIII.—Mr. A.S., aged 47. Admitted March 7th, 1936.

Diagnosis : Anxiety neurosis. Chronic suppurative otitis media, right, healed.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : March 10th, 1936.

Nose and Throat : Normal.

Otoscopy : Right Drum : Shows a thinly healed central perforation involving the whole of the postero-inferior quadrant. The postero and antero-superior quadrants are each covered with calcium plaques. The membrane of Shrapnell's area is retracted, but intact. There is no evidence of active disease in this ear. X-rays show the mastoids to be small and sclerosed, and the sinuses appear clear.

Left Drum : Normal.

HEARING EXAMINATION :

Audiogram : Subclass A_2 each ear.

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	65 s.u.	65 s.u.
	ABC	55 ,,	55 ,,
c^1 (256)	BC	55 s.u.	55 s.u.
	ABC	50 ,,	55 ,,
Tuning Fork Tests :			
c^2 (512)	AC	65 seconds.	65 seconds.
	BC	23 ,,	25 ,,
	ABC	35 ,,	37 ,,

Weber : From practically all points it is referred to the right ear including teeth and glabella. ABC from the midline is not referred. From either side including the left mastoid, it is referred

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to the right. Blocking the left ear refers all sounds to the left, including the right mastoid.

Monochord :

AC	15,000 d.v.	14,000 d.v.
BC	15,000 ,,	16,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.

Operative Procedure : March 13th, 1936. Encephalography.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : March 14th, 1936.

Nose and Throat : Normal.

Otoscopy : Unchanged.

HEARING EXAMINATION :

Audiogram : Subclass A_3 each ear.

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	75 s.u.	80 s.u.
	ABC	65 ,,	65 ,,
c^1 (256)	BC	60 s.u.	70 s.u.
	ABC	50 ,,	55 ,,
Tuning Fork Tests :			
c^2 (512)	AC	60 seconds.	60 seconds.
	BC	20 ,,	18 ,,
	ABC	30 ,,	35 ,,

Weber : Is not consistently referred to either ear. When both ears are closed ; the fork in the midline is referred to the left ear, but if moved to the left about two inches it is referred to the right ear. If the fork is placed over the left mastoid and the ears not blocked, it is referred to the right ear ; if the ears are blocked it is referred to the left ear.

Monochord :

AC	13,000 d.v.	14,000 d.v.
BC	17,000 ,,	17,000 ,,

Watch Test : 20/30 in each ear.

Whispered Voice : Repeated at 20′ in each ear.

Vestibular Examination : Cold Caloric Test : Normal.

Impression : Encephalography has had no pronounced effect upon the hearing tests. It is worthy of note that even though the audiometric and fork tests of bone conduction show very little if any change from normal, and show very little difference on the two sides, the Weber does tend to be referred to the right, which is the side of the old middle-ear disease. On the other hand, the Weber test itself is not consistent in that from the vault, the fork was not referred to the right ear, whereas, from the left mastoid, it was referred to the right. As has been previously stated none of these

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findings was constantly present. This is another instance pointing to the great care necessary in attempting to assess the clinical value of the Weber test. Any slight hearing loss in this patient may be explained by the old middle-ear disease.

CASE IX.—Mr. T.S., aged 50. Admitted March 5th, 1936.
Diagnosis : Psychoneurosis, anxiety type.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : March 9th, 1936.
Nose and Throat : Normal.
Otoscopy : Normal.

HEARING EXAMINATION :
Audiogram : Subclass A_3 each ear, but with a dip at 4,096 d.v. left ear down to 40 s.u. (Similar to Fig. 9.)
Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	70 s.u.	70 s.u.
	ABC	45 ,,	50 ,,
c^1 (256)	BC	70 s.u.	70 s.u.
	ABC	40 ,,	45 ,,
Tuning Fork Tests :			
c^2 (512)	AC	70 seconds.	60 seconds.
	BC	25 ,,	20 ,,
	ABC	50 ,,	50 ,,

Weber : Not lateralized for BC or ABC.
Monochord :

AC	15,000 d.v.	15,000 d.v.
BC	16,000 ,,	16,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.
Operative Procedure : March 13th, 1936. Encephalography.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : March 14th, 1936.
Nose and Throat : Unchanged.
Otoscopy : Unchanged.

HEARING EXAMINATION :
Audiogram : Subclass A_3 each ear, but with a dip at 4,096 d.v. left ear down to 40 s.u. (Similar to Fig. 9.)
Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	70 s.u.	70 s.u.
	ABC	45 ,,	45 ,,
c^1 (256)	BC	65 s.u.	65 s.u.
	ABC	45 ,,	50 ,,

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Tuning Fork Tests :

c^2 (512)	AC	75 seconds.	75 seconds.
	BC	25 ,,	25 ,,
	ABC	50 ,,	50 ,,

Weber : Not lateralized for BC or for ABC.

Monochord :	AC	14,000 d.v.	14,000 d.v.
	BC	16,000 ,,	16,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.

Impression : Encephalography has not caused any alteration of hearing.

CASE XI.—Mr. R.F., aged 21. Admitted March 29th, 1936.

Diagnosis : Not yet determined. Posterior fossa tumour suspected but not confirmed.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : March 30th, 1936.

Nose and Throat : Normal.

Otoscopy : Otorrhœa in childhood ; side not known. Right drum : thickened in posterior half. Left drum : shows narrow band of thickening concentric with periphery in the postero-inferior quadrant.

HEARING EXAMINATION :

Audiogram : (Similar to Fig. 10.) Subclass right A_1, C_6 down to 50 s.u. ; left A_1.

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	65 s.u.	65 s.u.
	ABC	50 ,,	50 ,,
c^1 (256)	BC	60 s.u.	60 s.u.
	ABC	45 ,,	45 ,,

Tuning Fork Tests :

	AC	70 seconds.	70 seconds.
	BC	35 ,,	35 ,,
	ABC	45 ,,	45 ,,

Weber : Not referred for BC or ABC.

Monochord :	AC	17,000 d.v.	17,000 d.v.
	BC	18,000 ,,	18,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.

Operative Procedure : April 2nd, 1936. Ventriculography.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : April 3rd, 1936.

Nose and Throat : Unchanged.

Otoscopy : Unchanged.

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HEARING EXAMINATION :

Audiogram : (Similar to Fig. 10.) Subclass right A_1, C_6 down to 50 s.u. ; left A_1.

(Masking left ear with air caused further drop of 20 s.u. at 4,096 and 8,192 d.v. in the right ear.)

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	65 s.u.	65 s.u.
	ABC	45 ,,	45 ,,
c^1 (256)	BC	60 s.u.	60 s.u.
	ABC	45 ,,	45 ,,
Tuning Fork Tests :			
c^2 (512)	AC	75 seconds.	75 seconds.
	BC	35 ,,	35 ,,
	ABC	50 ,,	50 ,,

Weber : Not referred for BC or ABC.

Monochord :	AC	17,000 d.v.	17,000 d.v.
	BC	18,000 ,,	18,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.

Impression : Ventriculography caused no change in hearing. The dip for the high notes of the audiometer in the right ear may possibly be explained by the history of old middle-ear disease. On the other hand, it may have been caused by an undiagnosed intracranial lesion. An exploratory suboccipital myoplastic craniotomy April 7th, 1936 after the last hearing examination did not reveal any evidence of a neoplasm.

CASE XIII.—Mr. A.W., aged 38. Admitted February 17th, 1936.

Diagnosis : Multiple fractures of the skull with left peripheral facial paralysis.

NOTE : This injury occurred in November, 1935. There was bleeding from both ears.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : February 20th, 1936.

Nose and Throat : Normal.

Otoscopy : Some evidence of injury to both drums.

HEARING EXAMINATION :

Audiogram : Subclass right B_1 ; left A_3.

Bone Conduction Tests :		*Right.*	*Left.*
Tuning Fork Tests	Rinne	Negative.	Negative.
	Schwabach	Normal.	Normal.
	Weber	Not referred.	
Whispered Voice :		8′.	6′.
Normal Voice :		25 ,,	25 ,,

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Vestibular Examination : Cold Caloric Test : Normal.

NOTE : Above tests not done by present investigators.

Operative Procedure : (1) February 26th, 1936. Spinal subarachnoid insufflation. (2) March 7th, 1936. Bilateral trepanation and subdural insufflation.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : March 9th, 1936.

Nose and Throat : Normal.

Otoscopy : As previously reported.

HEARING EXAMINATION :

Audiogram : Subclass right B_1 ; left A_3.

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	65 s.u.	65 s.u.
	ABC	55 ,,	55 ,,
c^1 (256)	BC	55 s.u.	60 s.u.
	ABC	45 ,,	40 ,,

Tuning Fork Tests :

c^2 (512)	AC	60 seconds.	60 seconds.
	BC	20 ,,	25 ,,
	ABC	40 ,,	45 ,,

Weber : Not definitely referred for BC or ABC.

Monochord :

AC	13,000 d.v.	14,000 d.v.
BC	15,000 ,,	15,000 ,,

Vestibular Examination : Cold Caloric Test : Normal.

NOTE : There has been a slight improvement in hearing since February 20th, 1936 (eighteen days), which may be due to healing of the middle-ear condition since the previous examination or it may be due to variation in the examination methods. The slight loss of hearing, probably due to a middle-ear lesion, is further manifested by a shortening of the interval between BC and ABC in the audiometer.

Impression : Encephalography has not made any essential change in the hearing tests.

Summary.—Group 1

There was no appreciable change in hearing noted in any of these patients examined within twenty-four hours following encephalography or ventriculography. Some of the patients did have hearing losses before the procedure but these remained unchanged. One must conclude, therefore, that in thirteen

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patients these procedures which presumably cause changes in intracranial pressure have not caused any effect upon the hearing.

An approach to the problem with accurate measurements of pressure changes would be of great value, or an examination made before and after the dura had been opened without brain injury, as for a simple decompression, would be more definite but such opportunities are rare. The difficulty of making a more definite post-operative check upon this conclusion when dealing with patients is very great. Once the dura is opened and brain tissue is removed, it is no longer possible to say what changes in hearing, if any, are due to change of intracranial pressure as distinct from any effect that removal of the brain tissue might have.

Group 2.—Removal of Cerebral Tissue

This group comprises fourteen patients, all of whom had an intracranial operation for the removal of cerebral tissue. Twelve of the patients had epilepsy and the operations were to remove cerebral cicatrices. In two patients the brain removal followed a recent skull fracture with brain damage. The amount of cortical and subcortical brain removal varied in each case, but an approximate estimate is given in each report. Five of the patients showed some hearing loss.

CASE REPORTS

CASE I is a member of this group because cerebral tissue was removed. The complete case report is included in Group 1 because the hearing was also tested before and after encephalography.

CASE XIV.—Miss F.F., aged 19. Last admission August 28th, 1935.

Diagnosis: Epilepsy, Jacksonian (motor), right. Multiple cerebral cicatrices, right hemisphere.

PRE-OPERATIVE HEARING TESTS: August, 1935. Normal to superficial examination.

Operative Procedure: November, 1932. Encephalography. October, 1934. Encephalography. November 6th, 1934. Operator, W. G. Penfield. Myoplastic subtemporal craniotomy and separation of adhesions, left. March 20th, 1935. Operator,

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W. G. Penfield. Right parietal osteoplastic craniotomy and removal of cerebral cicatrix of the temporal lobe. Tissue removed measured 3×4 cm. on the surface and was 1 cm. in depth. September 11th, 1935. Operator, W. G. Penfield. Right parietal osteoplastic craniotomy and removal of cerebral cicatrix from the anterior part of the right post-central gyrus (area 7b, Fig. 5). Tissue removed measured 3×3×2 cm. and weighed 7 gm. December 16th, 1935. Patient unimproved, still having attacks.

POST-OPERATIVE HEARING EXAMINATION : December 16th, 1935.

Audiogram : Subclass A_2 each ear.

Audiometer BC : Tuning fork and Monochord tests are normal.

Impression : Multiple intracranial operative procedures have not caused any significant loss of hearing.

CASE XV.—Mr. G.G., aged 19. Last admission November 12th, 1931.

Diagnosis : Epilepsy and meningo-cerebral cicatrix of the right frontal lobe.

PRE-OPERATIVE HEARING TESTS : October 27th, 1931. Normal to superficial examination.

Operative Procedure : November 13th, 1931. Operator, W. G. Penfield. Right fronto-parietal craniotomy and amputation of the right frontal lobe. The right frontal lobe was cystic and was amputated, including the tip of the lateral ventricle. The tissue over an area of 4×4 cm.×4 cm. deep weighing 34 gm., was removed. It is noted that there is some suggestion of a lesion in the left frontal pole, but this area was not removed. December 16th, 1935. The patient is in good general health and has had no return of the seizures.

POST-OPERATIVE HEARING EXAMINATION : December 16th, 1935.

Audiogram : Subclass A_2 each ear.

Audiometer BC : Tuning fork and monochord tests are normal.

Impression : The removal of the right frontal lobe has not caused any significant loss of hearing.

CASE XVI.—Miss I.H., aged 15. Admitted June 24th, 1932.

Diagnosis : Traumatic meningo-porencephaly. Multiple cysts of left frontal lobe. Cranial defect. Jacksonian epilepsy.

PRE-OPERATIVE HEARING TESTS : June 24th, 1932. Normal to superficial examination.

NOTE : December 5th, 1932. Patient had grippe and otorrhœa right and left.

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Operative Procedure : (1) June, 1918. Aspiration of fluid from cyst of left frontal eminence. (2) November, 1919. Ventriculography. (3) June 25th, 1932. Operator, W. V. Cone. Left frontal exploratory craniotomy, removal of cerebral cicatrix and plastic repair of skull defect. A depressed bone fracture was removed leaving a bone defect in the skull of 8 cm. in diameter. All the lateral portion of the left frontal lobe was removed over an area of 7 cm. together with the enlarged anterior horn of the left ventricle. A celloidin plate was inserted in bone defect. (4) December 20th, 1932. Operator, W. V. Cone. Plastic repair of cranial defect.

POST-OPERATIVE HEARING EXAMINATION : December 19th, 1935.

Audiogram : Subclass A_2 each ear.

Audiometer BC : Tuning fork and Monochord tests are normal.

Impression : The removal of the left frontal lobe has not caused any definite loss of hearing. The fact that the patient was such a poor witness may have been due to her brain lesion.

CASE XVII.—Mr. D.K., aged 23. Admitted January 4th, 1936.

Diagnosis : Extensive depressed fracture left frontal region and base of the skull. Laceration of the dura and left frontal lobe.

NOTE : Ophthalmoplegia of the right eye except for the external rectus.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : January 4th, 1936.

Nose and Throat : Both nares contained crusted blood, but passages not obstructed.

Otoscopy: Both canals filled with old and recent blood. Fresh bleeding in each ear from the wall of the canal near the drum ; both drums dusky purple in colour, appearing to have blood behind them.

HEARING EXAMINATION : Not done. Patient stuporous.

Vestibular Examination : Cold Caloric Test : Not done.

Operative Procedure: January 4th, 1936. Operator, W. V. Cone. Removal of depressed fracture of the skull ; debridement of the left frontal lobe ; removal of mucous membrane of frontal sinuses. Suture of lacerated wound of the dura. Brain tissue filled the frontal sinuses. The comminution of the left frontal region and base was most extensive, and the roof of the orbit was in many pieces. Many comminuted fragments as far back as the sphenoid. Tip of frontal lobe entirely destroyed to a depth of 3 cm.

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POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION: March 2nd, 1936.

Nose and Throat: Thickened exudate more or less crusted on the posterior wall of the nasopharynx. Otherwise negative.

Otoscopy: Normal.

HEARING EXAMINATION:

Audiogram: (See Fig. 6.)

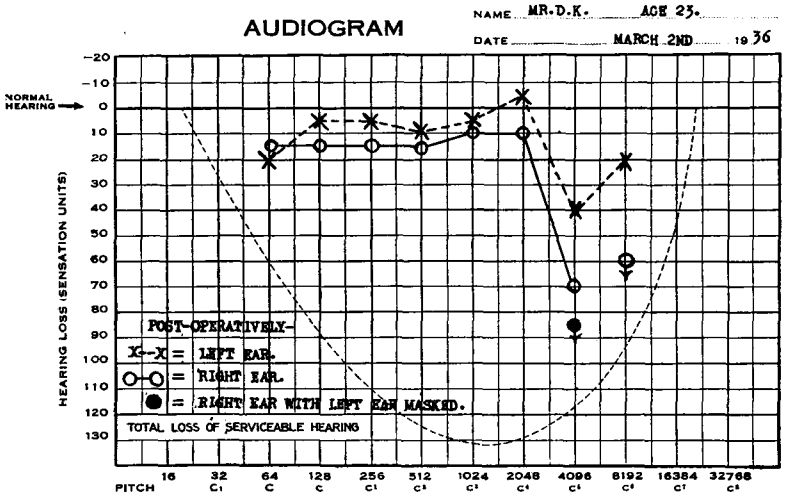


FIG. 6.

Audiogram from Case XVII. Following a skull fracture there was damage to brain tissue and to both ears. The high tone loss in the right ear was confirmed by the Monochord.

Bone Conduction Tests:

Audiometer BC:		*Right.*	*Left.*
c^2 (512)	BC	55 s.u.	60 s.u.
	ABC	45 ,,	45 ,,
c^1 (256)	BC	55 s.u.	45 s.u.
	ABC	35 ,,	35 ,,

Tuning Fork Tests:

c^2 (512)	AC	65 seconds.	70 seconds.
	BC	30 ,,	30 ,,
	ABC	45 ,,	45 ,,

Weber: Referred to the right ear by BC. Not referred for ABC.

Monochord:

AC	9,000 d.v.	16,000 d.v.
BC	16,000 ,,	19,000 ,,

Vestibular Examination: Cold Caloric Test: Stimulation of the horizontal and vertical canals of each ear elicits a normal

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nystagmus from the left eye, and an occasional atypical nystagmoid movement of the right eye.

Rotation Test: (Head to one side so that the turning is about a bi-temporal axis)—normal response from the left eye, and an atypical response from the right eye, the vertical canals being stimulated.

Impression: Hearing for low tones and for bone conduction normal in both ears. The audiogram shows a high tone loss, marked on the right side, which was partly confirmed by the monochord. This would suggest partial nerve deafness on the right side. Both vestibules are reacting normally. At the time of the injury, there was bleeding from both ears suggesting bilateral middle-ear trauma, which might be sufficient to account for the hearing lesion noted. The normal vestibular reactions are opposed to a traumatic internal ear lesion at the time of the fracture. There was evidently extensive trauma in the left frontal region, and the right-sided ophthalmoplegia would suggest extensive trauma in the right frontal basal region. It is impossible to say whether these frontal lesions or the middle-ear lesions at the time of the accident are responsible for the hearing loss.

CASE XVIII.—Mr. T.L., aged 41. Admitted August 2nd, 1930.

Diagnosis: Depressed fracture of the skull, right temporal region. Laceration of the dura with softening of the brain. Intracerebral hæmorrhage.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION: August 2nd, 1930. Examination could not be completed because patient was unconscious.

Nose and Throat: Not examined.

Otoscopy: Not examined. Blood clot in the right canal (not disturbed).

Hearing Examination: Not tested.

Vestibular Examination: Cold Caloric Test: Not done.

NOTE: At the time of the accident there was profuse bleeding from the nose and the right ear.

Operative Procedures: August 4th, 1930. Operator, W. V. Cone. (1) Elevation of depressed fracture of the skull and removal of bony fragments. (2) Subtemporal decompression, right. Aspiration of damaged brain. Removal of two intracerebral blood clots. The softened brain involved almost the entire right temporal lobe. March, 1936. General condition is very satisfactory.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION: September 7th, 1930.

Nose and Throat: Not examined.

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Otoscopy: Right drum. Blood clot in the right canal. After removal the right drum was slightly dull and thickened but apparently intact. Left drum. Normal.

HEARING EXAMINATION:

Audiogram: Subclass right A_3, C_4 down to 45 s.u. (somewhat similar to Fig. 18); left A_2.

Bone Conduction Tests:

Tuning Fork Tests:		*Right.*	*Left.*
c^2 (512)	Rinne	Positive.	Positive.
	Weber	Not referred.	

Vestibular Examination: Cold Caloric Test: Not done.

NOTE: Examination not done during this investigation.

Impression: The slight hearing loss in the right ear is characterized by a dip at 8,192 d.v. to 45 sensation units. Unfortunately this test did not include the monochord. The slight hearing loss in the right ear may be due to ear damage at the time of the accident, or it may be due to the intracranial lesion.

CASE XIX.—Mr. M.McK., aged 21. Admitted June 12th, 1934.

Diagnosis: Jacksonian epilepsy. Cicatrix, following left frontal lobe abscess.

NOTE: In August, 1931, following an acute frontal sinus abscess and osteomyelitis, the patient developed a left frontal lobe abscess, which was drained through the frontal sinus. The following year he began having definite Jacksonian attacks.

PRE-OPERATIVE HEARING TESTS: June 12th, 1934. Normal to superficial examination.

Operative Procedure: June 13th, 1934. Operator, W. V. Cone. Left frontal osteoplastic craniotomy and amputation of the left frontal lobe. The left frontal lobe was completely removed back to the beginning of the corpus callosum at the midline and back to the tip of the left lateral ventricle. The size of the specimen removed was $7 \times 4 \times 5$ cm. and weighed 44 gm. December 12th, 1935. No recurrence of seizures and the patient is in good general health. He is able to carry on his medical studies.

POST-OPERATIVE HEARING EXAMINATION: December 12th, 1935.

Audiogram: Subclass A_2 each ear.

Audiogram BC: Tuning fork and monochord tests are normal.

Impression: Removal of the left frontal lobe has not caused any significant loss of hearing.

CASE XX.—Mr. F.R., aged 20. Admitted October 22nd, 1935.

Diagnosis: Epilepsy, Jacksonian, motor. Cerebral cicatrix left frontal lobe.

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PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : October 22nd, 1935.

Nose and Throat : Normal to superficial examination.

Otoscopy : No note.

Hearing Examination : Normal to superficial examination.

Vestibular Examination : Cold Caloric Test : Not done.

Operative Procedures : October 25th, 1935. Encephalography. October 30th, 1935. Operator, W. G. Penfield. Left osteoplastic craniotomy and removal of cerebral cicatrix. A section 3 cm. anterior to the pre-central gyrus was removed, in size $9 \times 4 \cdot 5 \times 3 \cdot 5$ cm., and weighing 87·3 gm. It extended down to the ventricle. February 20th, 1936. Improved but not free from attacks.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION : February 20th, 1936.

Nose and Throat : Normal.

Otoscopy : Normal.

HEARING EXAMINATION :

Audiogram (similar to Fig. 9) : Subclass right A_1 with dip 4,096 to 50 s.u. ; left A_1 with dip 4,096 to 50 s.u.

Bone Conduction Tests :

Audiometer BC :		*Right.*	*Left.*
c^2 (512)	BC	80 s.u.	75 s.u.
	ABC	55 ,,	55 ,,
c^1 (256)	BC	65 s.u.	65 s.u.
	ABC	45 ,,	45 ,,
Tuning Fork Tests :			
c^2 (512)	AC	80 seconds.	80 seconds.
	BC	30 ,,	30 ,,
	ABC	50 ,,	50 ,,

Weber : Not referred for BC or ABC.

Monochord :

AC	15,000 d.v.	15,000 d.v.
BC	16,000 ,,	16,000 ,,

Vestibular Examination : Rotation Test : Normal.

Impression : Removal of left frontal lobe has not produced any significant loss of hearing except for a bilateral dip in the audiogram at 4,096 d.v. This case will be discussed with other cases showing a similar audiogram.

CASE XXI.—Mr. D.R., aged 18. Admitted June, 1932. Encephalogram. Admitted May 2nd, 1935.

Diagnosis : (1) Focal atrophy of the brain, left temporal region, post-traumatic. (2) Epilepsy, Jacksonian, motor (epilepsy, focal cortical seizures).

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NOTE: In October, 1923, the patient was knocked down by a car. He was taken to the hospital, where a bilateral subtemporal decompression was done, and a subdural hæmatoma found on the right side. Attacks of epilepsy began within six months of the accident.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION: May 2nd, 1935.

Nose and Throat: Normal to superficial examination.

Otoscopy: Normal.

Hearing Examination: Normal to superficial examination.

Vestibular Examination: Cold Caloric Test: Not done.

Operative Procedures: June 13th, 1932. Encephalography. May 14th, 1935. Operator, W. G. Penfield. Left parieto-temporal osteoplastic craniotomy and removal of cerebral atrophy. A localized area of atrophy was removed from the posterior part of the superior temporal convolution measuring $1 \times 1 \cdot 5 \times 1 \cdot 5$ cm. April 7th, 1936. The patient is well, no attacks, continues to take luminal.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION: April 7th, 1936.

Nose and Throat: Normal.

Otoscopy: Normal.

HEARING EXAMINATION:

Audiogram: Subclass A_2 with peak 4,096, right and left to — 10 s.u.

Bone Conduction Tests:

Audiometer BC:		*Right.*	*Left.*
c^2 (512)	BC	65 s.u.	65 s.u.
	ABC	55 ,,	55 ,,
c^1 (256)	BC	60 s.u.	60 s.u.
	ABC	45 ,,	45 ,,
Tuning Fork Tests:			
c^2 (512)	AC	75 seconds.	75 seconds.
	BC	22 ,,	25 ,,
	ABC	50 ,,	50 ,,

Weber: Not lateralized for BC or ABC.

Monochord:	AC	17,000 d.v.	16,000 d.v.
	BC	18,000 ,,	17,000 ,,

Vestibular Examination: Cold Caloric Test: Normal.

Impression: Removal of brain tissue from the left parieto-temporal region has not produced any abnormality of hearing.

CASE XXII.—Mr. F.S., aged 38. Admitted April 28th, 1935.

Diagnosis: Right frontal meningo-cerebral cicatrix. Epilepsy, Jacksonian.

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NOTE: Seizures for six years. No history of trauma was obtained.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION: April 18th, 1935.

Nose and Throat: Normal.

Otoscopy: Normal.

Hearing Examination: Normal to superficial examination.

Vestibular Examination: Not done.

Operative Procedures: April 23rd, 1935. Operator, W. G. Penfield. Right parietal-osteoplastic craniotomy and excision of cerebral cicatrix. An area of brain situated immediately in front of the pre-central gyrus and extending down to the falx was excised. Measurements $5 \times 3 \times 4$ cm. March 17th, 1936: Patient well, and has had no major seizures but recently has had a return of epigastric aura.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION: April 9th, 1936.

Nose and Throat: Normal.

Otoscopy: Normal.

HEARING EXAMINATION:

Audiogram: Subclass right, A_3, C_6 down to 55 s.u. (somewhat similar to Fig. 18); left A_3, C_4 down to 60 s.u. (somewhat similar to Fig. 10).

Bone Conduction Tests:

Audiometer BC:		*Right.*	*Left.*
c^2 (512)	BC	75 s.u.	75 s.u.
	ABC	60 ,,	60 ,,
c^1 (256)	BC	65 s.u.	75 s.u.
	ABC	50 ,,	55 ,,

Weber: Not lateralized for BC or ABC.

Tuning Fork Tests:

c^2 (512)	AC	55 seconds.	55 seconds.
	BC	20 ,,	15 ,,
	ABC	30 ,,	30 ,,
Monochord:			
	AC	15,000 d.v.	15,000 d.v.
	BC	16,000 ,,	16,000 ,,

Vestibular Reactions: Cold Caloric Test: Normal.

Impression: The abrupt high tone loss in the audiogram and the shortening of the times for air conduction of the fork and slight lowering of the monochord are the three definite departures from normal shown post-operatively in this case. Such a high tone loss is frequently associated with cochlear damage (nerve deafness).

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CASE XXIII.—Mr. W.S., aged 27. Admitted February 11th, 1931.

Diagnosis : Epilepsy, Jacksonian. Cerebral cicatrix and atrophy in the left parieto-occipital area.

NOTE : Head injury at the age of nine years and attacks since the age of 11.

PRE-OPERATIVE HEARING TESTS : February 11th, 1931. Normal to superficial examination.

Operative Procedure : February 13th, 1931. Encephalography. February 20th, 1931. Operator, W. G. Penfield. Left parietal osteoplastic craniotomy with removal of cerebral cicatrix. There was a moderate amount of atrophy of the whole left hemisphere and a very deep fissure of Sylvius. At the upper and posterior end of this (left parieto-occipital area) one convolution was so much atrophied that it was only about 2 mm. wide. A surrounding area of about 8 cm. diameter showed less severe atrophy and was situated directly behind the motor gyrus on a level with the arm area. The extent of the tissue excised was about $4 \times 4 \times 4$ cm. and its weight about 15 gm. It extended down into the ventricle, about 2 or 3 cm. of whose roof was excised. December, 1935. Patient well, no seizures.

POST-OPERATIVE HEARING EXAMINATION : December 19th, 1935.

Audiogram : Subclass right E_1 ; left A_3.

Audiometer BC : Tuning fork and monochord tests are normal.

Impression : The removal of the cerebral cicatrix from the parieto-occipital area has not caused any significant hearing loss, apart from slight falling off of the lower tones as shown by the audiogram, but not confirmed by any of the other tests.

CASE XXIV.—Miss M.S., age 22. Admitted February 17th, 1933.

Diagnosis : Jacksonian epilepsy. Meningo-cerebral cicatrix, occipito-parietal region.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION : February 17th, 1933.

Nose and Throat : Normal.

Otoscopy : Normal.

Hearing Examination : Normal to superficial examination.

Vestibular Examination : Not done.

Operative Procedure : February 23rd, 1933. Operator, W. G. Penfield. Right occipito-parietal osteoplastic craniotomy, with removal of cerebral cicatrix of the occipito-parietal region, about 7×5 cm. in area, and complete unroofing of the lateral ventricle over an area of 4×2 cm.

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NOTE: December 12th, 1935. Patient well and has had no major attacks. However, she has had some minor sensory phenomena.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION: December 12th, 1935.

Nose and Throat: Not examined.

Otoscopy: Normal.

HEARING EXAMINATION:

Audiogram: Subclass right B_1; left B_1.

Bone Conduction Tests:

Audiometer BC:		*Right.*	*Left.*
c^2 (512)	BC	70 s.u.	75 s.u.
	ABC	60 ,,	55 ,,
Tuning Fork Tests:			
c^2 (512)	Rinne	AC greater than BC	AC greater than BC
	Schwabach	Normal	Normal
	Weber	Not lateralized for BC or ABC	
Monochord:			
	AC	17,000 d.v.	17,000 d.v.
	BC	18,000 ,,	18,000 ,,

Vestibular Examination: Not done.

Impression: The hearing apparently was not affected by the lesion in the occipito-parietal region.

CASE XXV.—Miss J.R., aged 13. Admitted April 24th, 1933.

Diagnosis: Jacksonian epilepsy. Cerebral cicatrix, in small pre-central gyrus, right, near the midline.

NOTE: No history of trauma.

Pre-operative Hearing Tests: April 24th, 1933. Normal to superficial examination.

Operative Procedure: May 2nd, 1933. Operator, W. G. Penfield. Right osteoplastic craniotomy and excision of cerebral cicatrix. A small, hard gyrus just anterior to the pre-central gyrus near the midline, was removed, with some of the gyrus in front and behind. The excision was not carried into the ventricle. December 19th, 1935. No further seizures, and the patient is in excellent general health.

POST-OPERATIVE HEARING EXAMINATION: December 19th, 1935.

Audiogram: Subclass A_2 each ear.

Audiometer BC: Tuning fork and monochord tests are normal.

Impression: The removal of a small area of brain tissue from the right frontal lobe has not caused any loss of hearing.

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CASE XXVI.—Mr. F.W., aged 17. Last admission April, 1936.
Diagnosis: Epilepsy, combined form, grand and petit mal, idiopathic.

NOTE: Attacks since August, 1934. History of trauma at the age of 11 years.

PRELIMINARY OTOLARYNGOLOGICAL EXAMINATION: June, 1935.
Nose and Throat: Normal.
Otoscopy: Normal.
Hearing Examination: Normal to superficial examination.
Vestibular Examination: Not done.

NOTE: Superficial hearing examinations were done on the previous admissions and were normal.

Operative Procedures: October 3rd, 1934. Encephalography. October 6th, 1934. Encephalography. March 15th, 1935. Encephalography. June 1st, 1935. Operator, W. G. Penfield. Left parietal craniotomy and excision of leptomeningeal cicatrix. Removal of cicatrix from the left frontal adversive field near the Pacchionian body. The cicatrix measured 1 × 1 × 2 cm. April 7th, 1936. Unimproved. Attacks continue.

POST-OPERATIVE OTOLARYNGOLOGICAL EXAMINATION: April 7th, 1936.
Nose and Throat: Normal.
Otoscopy: Normal.

HEARING EXAMINATION:
Audiogram: Subclass right A_2, C_4 down to 55 s.u. (somewhat similar to Fig. 18); left A_3.
Bone Conduction Tests:

Audiometer BC:		*Right.*	*Left.*
c^2 (512)	BC	65 s.u.	65 s.u.
	ABC	55 ,,	55 ,,
c^1 (256)	BC	70 s.u.	70 s.u.
	ABC	45 ,,	45 ,,
Tuning Fork Tests:			
c^2 (512)	AC	65 seconds.	70 seconds.
	BC	25 ,,	30 ,,
	ABC	40 ,,	45 ,,

Weber: Tendency to lateralize BC to the left when the fork was placed in the midline, but it was not lateralized for ABC.

Monochord:

AC	11,000 d.v.	16,000 d.v.
BC	16,000 ,,	16,000 ,,

Vestibular Examination: Cold Caloric Test: Normal.

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Impression: The audiometer and the monochord show a high tone loss by air conduction in the right ear. It is unlikely that such a small lesion in the frontal lobe would cause such a hearing loss when much more extensive lesions have had no effect upon the hearing.

Summary.—Group 2

In this group of fourteen patients, the removal of cerebral tissue was from the following regions:

Frontal Lobe. Right. Cases XV, XXII, XXV.
Frontal Lobe. Left. Cases XVI, XVII, XIX, XX, XXVI.
Parietal Lobe. Right. Case XXIV.
Parietal Lobe. Left. Cases I, XXI, XXIII.
Temporal Lobe. Right. Cases XIV, XVIII.

The hearing was normal in nine of the patients. In two of the five patients showing slight departures from normal hearing, there had been bleeding from the ears following skull fracture. Considerable evidence is accumulating to show that a middle-ear lesion may be accompanied by a loss of high tones (see Ciocco, 1932, and Gottlieb, 1933).

In the three remaining patients it is difficult to ascribe the high tone hearing loss to the brain lesion because the lesions in Cases XVI and XIX in which the hearing was normal were apparently just as large, and also from the left frontal lobe area, as in Cases XX and XXVI which showed a hearing loss. The lesion in Case XXV in which the hearing was normal was anterior to the pre-central gyrus, just as in Cases XX and XXII which showed a hearing loss. Furthermore the two patients of Group 2 with temporal lobe lesions had normal hearing, yet these lobes are thought to be more concerned with hearing than are the frontal lobes.

The five patients with hearing loss are later discussed in detail under the following headings:

Case XVII. Abrupt High Tone Loss.
Cases XVIII, XXII, XXVI. Gradual High Tone Loss.
Case XX. Audiogram " dip " at 4,096 d.v.

. . . .

Der Gegenstand dieser Arbeit bildete die Feststellung der Hörschärfe durch die Knochenleitung in einer Anzahl von Patienten, bei denen intrakranielle Verletzungen während der Operation oder

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bei postmortaler Untersuchung festgestellt wurden. Die grosse Schwierigkeit solcher klinischen Untersuchungen des Gehörs durch Knochenleitung war das Fehlen einheitlicher Instrumente, Prüfungen und Methoden zur Bestimmung der Knochenleitung. Wie aus den beschriebenen Fällen hervorgeht, wurde jeder Patient mit verschiedenen Methoden geprüft und die dabei erhaltenen Ergebnisse miteinander verglichen.

. . . .

L'objet de cette recherche est l'étude de la l'acuité de la conduction osseuse sur une série de malades chez lesquels l'opération ou la nécropsie avait montré la présence d'une lésion intracranienne. La grande difficulté que comporte l'étude clinique de l'audition par conduction osseuse, vient du manque d'uniformité des instruments, des tests et des méthodes employés dans la détermination de la conduction osseuse. Comme on le verra par les observations, chaque malade a été soumis à diverses methodes d'étude et les résultats sont comparés.

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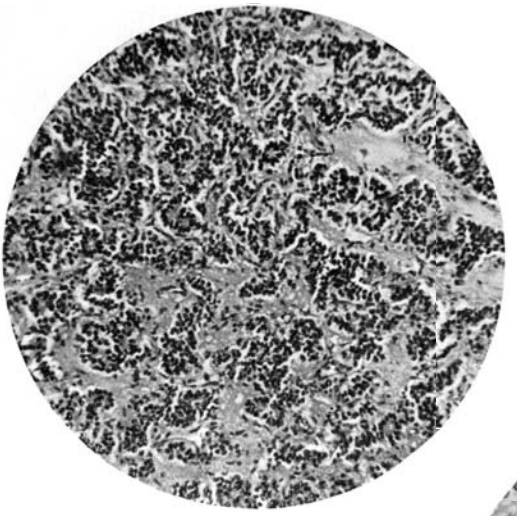


FIG. 1.
Case I. Low power.

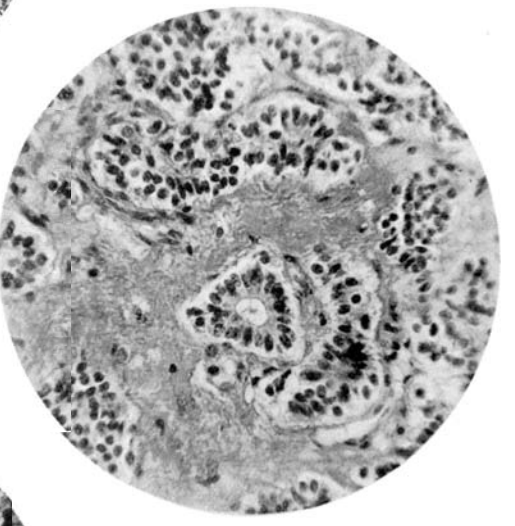


FIG. 2.
Case I. Glandular portion with high power. Fibrous interstitial tissue.

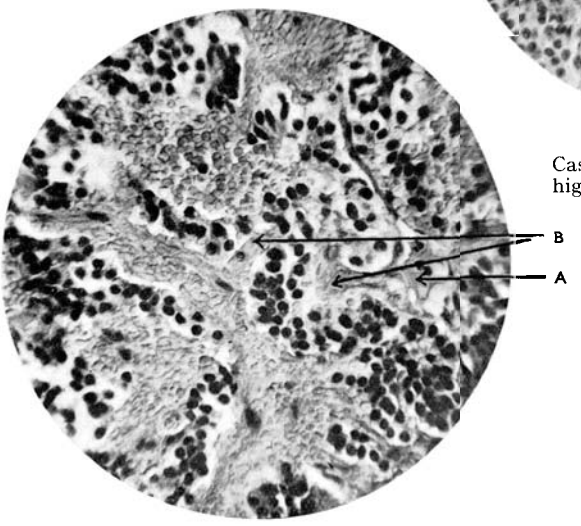


FIG. 3.
Case I. Vascular portion. Blood in tumour spaces and capillaries.
A. Capillary vessel.
B. Capillaries with open ends amongst the tumour cells.

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