Multiple Intracochlear Electrodes for Rehabilitation in Total Deafness

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Proposed as early as 1957 by Djourno and Eyries[6] for the saccular nerve and then used by Simmons[18] for the cochlear nerve, electrical stimulation of the cochlea through implanted electrodes was recently resumed with the use of a single electrode and developed simultaneously by Michelson and Merzenich[12] in San Francisco and House and Urban[10] in Los Angeles.

For 15 years, working with Charles Eyries on neuroanatomical research, I had the opportunity frequently to hear about his own attempts to electrically stimulate the cochlear nerve. Consequently I took great interest in the lecture that these authors gave in May 1973 during the Tenth International ENT Congress in Venice.[7, 11, 14]

However appreciable the auditory gain thus offered to these patients, it nevertheless remains restricted by the paucity of frequency information. In order for these results to be improved, the implantation of several electrodes was deemed to be indispensable by all participants in the symposium held on this subject in San Francisco in June 1973.[13] Following that meeting I studied this problem with the help of Dr. P. MacLeod, Director of the Sensorial Neurophysiology Laboratory of EPHB in Paris.

By implanting multiple electrodes using a special surgical method, we succeeded in obtaining promising clinical results in cases of acquired total deafness, as well as in cases of congenital or childhood deafness. This surgical procedure involves the placement of several electrodes inside the cochlea and requires a transmitter device to bring to these electrodes the necessary electrical information. We partially resolved these difficulties, and this experience enabled us to gather some physiological observations. They appear to be worth reporting with an account of our technique and clinical results.

EXPERIMENTAL STUDY

Simmons and House were the first to carry out multielectrode implantation in humans. Simmons implanted four to six electrodes directly in the cochlear nerve through a transcochlear approach in six patients. He

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obtained good frequency discrimination, but he could not construct the necessary device to study speech intelligibility. Moreover the good results obtained did not last longer than 18 months. House, using the round window approach, implanted several electrodes of different lengths in the scala tympani, but failed to obtain better frequency discrimination than that obtained with a single channel.

These two attempts were instructive in guiding our own trials. In Simmons' study the deterioration in frequency discrimination probably resulted because the electrodes were implanted close to one another inside the nerve and because of their construction from silver. House's failure was obviously due to the diffusion of the electrical stimulus throughout the cochlear nerve via the cochlear liquids.

Therefore, because of the difficulty in effecting direct stimulation of individual fibers within the nerve trunk, we prefered to take advantage of their spreading along the lamina spiralis of the cochlea by implanting the electrodes at the level of the scala. Moreover, in order to obtain a good frequency discrimination, we decided to build an insulated compartment for each electrode along the cochlear keyboard, using small pieces of Silastic gently introduced inside the scala vestibuli.

Our three first cases were experimental patients, who received only one, two, and five electrodes. When it was obvious that lasting frequency discrimination was obtained, we proposed this measure of surgical rehabilitation to totally deaf patients. They used a device carried on a shoulder belt that was connected to the electrodes through Teflon plugs, insuring transmission between the internal and external media (Fig. 1). We obtained the good results in frequency discrimination, speech intelligibility, and voice improvement previously reported.[2] We implanted electrodes in 21 patients with this method, but it quickly became apparent that an apparatus transmitting the electrical information through the skin to each electrode was necessary in order to suppress the transcutaneous plugs and counter their inconvenience. This development was made possible through grants from the French Government (DGRST and DIELI), but more than two years was required, and our patients presented some instructive complications during this delay. We now report the results obtained with the two first models of this radio transmitter.

MATERIAL AND METHODS

Selection of Patients

We did not operate on a patient without ascertaining that he had at least a partially functional auditory nerve.

An electric square wave signal is supplied to the membrane of the round window; the cochlear liquids carry electrical impulses to the whole auditory nerve fibers and yield a sound sensation, provided some fibers are still functional. The number of fibers necessary to produce this sensation is still undetermined.

Contrary to the experience of House and Brackmann,[8] who found round window stimulation through the intact eardrum feasible, we find

Figure 1. Wires are connected to the external device through transcutaneous Teflon plugs.

that anatomical variations of the round window are so frequent that this diagnostic test must be performed surgically. The eardrum is removed at its lower edge and folded up. This gives a clear view of the round window, which often varies in shape and size, especially in deaf mutes who may have birth defects. The bare tip of an insulated electrode is placed in position against the membrane of the round window. In adult patients this test is performed under local anesthesia with all necessary instructions to the patient written on cue cards beforehand. In order to have some points of comparison we also carried out stimulation in five patients with conductive deafness directly through the eardrum perforation.

With frightened subjects, such as children, the electrode can be placed under general anesthesia and tested on the following day. The auditory evoked responses may be registered on the scalp, allowing this test to be performed in very young deaf children (Fig. 2).[15] For the past few months we have also recorded brain stem evocated responses. In most cases of bilateral deafness we stimulated only one ear, usually the right one.

We performed this test in 158 cases of total deafness of various etiologies.[4] In 70 deaf mutes with major language problems the etiology was frequently unknown (Tables 1 to 3).

Table 1. *Preoperative Age Range (158 Patients)*

AGE (YEARS)	NO. PATIENTS
2 to 17	38
18 to 49	92
50 to 68	19
Over 69	9

Table 2. *Etiology in 70 Cases of Deafmutism*

NUMBER OF CASES	ETIOLOGY	RESULT OF ELECTRICAL TESTING *Positive*	*Negative*
59	Undetermined	55	4
4	Maternal rubella	3	1
3	Streptomycin before age 1 year	3	0
1	Pneumococcal meningitis	1	0
2	Bilateral otitis before age 1 year	1	1
1	Measles before age 1 year	1	0
	Total	64	6

Table 3. *Etiology in 88 Cases of Acquired Total Deafness**

NUMBER OF CASES	ETIOLOGY	NUMBER OF CASES	ETIOLOGY
1	Undetermined from childhood	2	Tertiary syphilis
11	Undetermined in adult	7	Chronic otitis
1	Meningococcal meningitis	12	Otosclerosis
8	Tuberculous meningitis with streptomycin	9	Petrosal fracture
2	Meningococcal meningitis	9	Progressive deafness
8	Undetermined meningitis	8	Vascular deafness
1	Kanamycin	1	Acoustic trauma
1	Mumps	1	Meniere's disease
1	Measles	1	Lobstein
		2	Operated acoustic neuroma

*Hearing has been normal during various periods. Speech problems are slight. All had a positive response to the electrical testing except two patients with acoustic neuroma.

Surgical Procedure

A Teflon coated microelectrode wire was used that was 10 per cent iridium and 90 per cent platinum with a 0.005 inch diameter. The reference electrode was a platinum-iridium wire (diameter 0.007 inch) whose insulation was removed for 3 cm. before being inserted in the temporalis muscle.

In our three first patients only one, two, and five electrodes were implanted. In the first, one electrode was inserted in the scala vestibuli

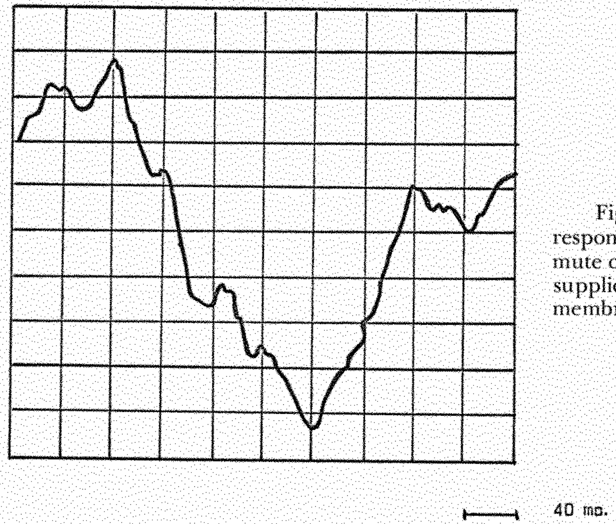

Figure 2. Auditory evoked response in a three year old deaf mute child to an electric stimulus supplied to the round window membrane.

through a hole in bone located just anterior to the round window. The second patient received two electrodes. One was in the same position as in the first patient and the other was in the apical portion of the cochlea, but small pieces of Silastic were introduced in the scala through each bone hole in order to insulate each portion of the cochlea stimulated by the electrode. The third patient received five electrodes, inserted and insulated in the same way. These first patients were experimental patients with facial paralysis and unilateral deafness. There was no indication for a suprapetrosal approach. We implanted only through the middle ear approach in the second turn and in the basal turn of the cochlea.

Our patients with total and bilateral deafness received seven or eight electrodes. In order to reach the speech frequencies located in the hidden side of the cochlea, a middle ear approach and a transtemporal suprapetrosal approach are necessary for implantation. The cutaneous incision must be large. In our first patients the classic Y shaped incision was used for total decompression of the facial nerve. In order to insure a large cutaneous flap to re-cover the implanted device, we now use a long curved incision from the point of emergence of the superficial temporal artery in subcutaneous tissues to the nuchal region. This flap includes the posterior branch of this artery, the occipital and posterior auricular arteries, and the temporalis muscle. The two extremities of this incision must be low enough so that all the skin of the external auditory meatus can be folded back easily. An aponeurotic graft is removed from the posterior part of the temporalis muscle to strengthen the eardrum and skin of the ear canal postoperatively. Then a large mastoidectomy is performed by an antroaticotomy. The bony wall covering the third portion of the facial nerve is lowered in order to yield a better view of the round window. The incus is suppressed. The head of the malleus is cut to move the eardrum down. The anterior bony portion of the auditory meatus is removed in order to allow a view of the whole promontory and the eustachian tube. The skin of the meatus and the eardrum are progressively and carefully removed to the outside. The bony canal of the tensor tympani muscle is destroyed, special care being taken not to damage the second portion of the facial nerve, which lies just above. This muscle is displaced to expose the second turn of the cochlea. The promontory is drilled down until the dark shadow of the two turns of the scala tympani is visible. Then three holes are made in the basal turn and two holes in the second turn. This middle ear approach is slanting and tangential. It is difficult to drill the anterior part of the promontory just behind the carotid canal, but this step is important to reach the conversational frequency region of the cochlea.

Next a classic opening of the middle fossa is performed. The internal auditory meatus area and the petrosal nerve are exposed. The bone is drilled anterior to and inside the first portion of the facial nerve to reach the hidden facet of the first turn, in which only one hole can be created. Sometimes this approach necessitates stripping the facial nerve tangentially.

Cylindrical pieces of Silastic are prepared preoperatively in different sizes determined according to the dimensions of an injected cadaver model and do not exceed 2 mm. for the basal turn, 1.5 mm. for the first turn, and 1 mm. for the second turn. These Silastic mandrels are used both to fix the electrodes in the scala and to electrically insulate each compartment formed by the six fenestrations in the cochlea.

Two electrodes are inserted in the suprapetrosal hole and in the posterior hole of the second turn. Each electrode is fixed to the bone around the fenestration with methylmethacrylate. In order of their position in the cochlea the electrodes are connected to the corresponding channels of the apparatus. In our first patients two Teflon plugs were inserted in the scala in order to insure the transmission between the internal and external media. Now, however, the receptor device is implanted in the mastoid cavity under the retroauricular skin. Postoperative drainage is continued for 24 hours. This operation was performed in 24 cases of total bilateral deafness, 21 patients with Teflon plugs and three patients with an implanted receptor device (Figs. 3, 4).

Electrophysiological Procedure

PREOPERATIVE TESTING. The stimulus is a square wave of negative polarity. The reference electrode is a metal plate held in hand. We use a radio frequency insulation unit for maximal safety. The pulse duration is 0.3 ms., the amplitude varies between 0 and 5 and occasionally 10 volts, and the pulse frequency varies from 0 to 1000 Hz. The patient is instructed to describe every sound sensation he experiences. We have not had the opportunity to carry out electrical stimulation of the nerve and electrocochleography simultaneously.

POSTOPERATIVE TESTING AND CHRONIC STIMULATION. The procedure has differed since we began to use the radio transmitter device.

Use of Transcutaneous Teflon Plugs. Following the operation, in order to determine the threshold subjective frequency and the maximal stimulation amplitude for each implanted electrode, we use the same

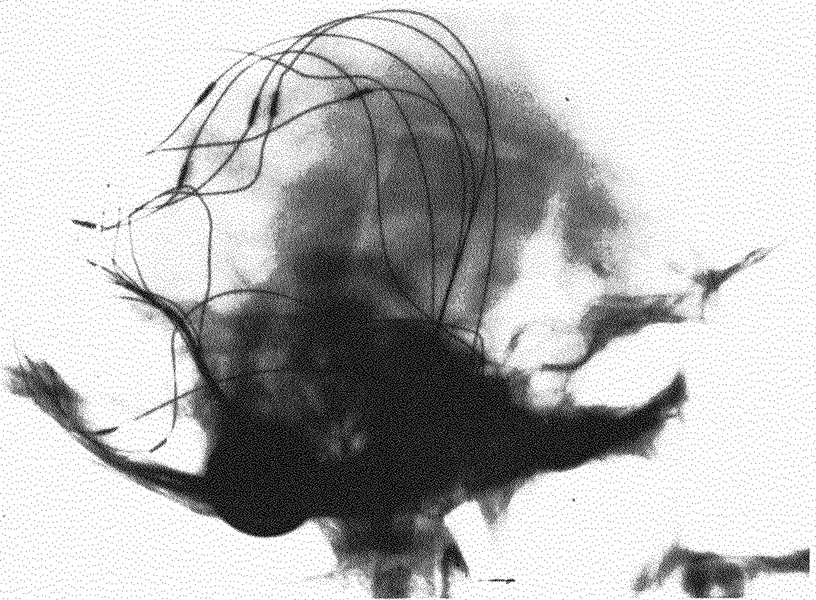

Figure 3. Skull x-ray view in a patient with the implanted receptor and the eight electrodes.

stimulating apparatus as in preoperative testing. The reference electrode in this case is a platinium-iridium wire 0.007 inch in diameter, whose insulation has been removed for 3 cm. This reference electrode lies in the temporalis muscle. Using a resistor, we also measure the impedance of each electrode. These measurements are repeated monthly in order to record eventual changes.

In addition we constructed an apparatus that divides the sound message by means of filters into eight groups of frequencies at octave intervals, from 125 to 8000 Hz. Because of the narrow dynamic range of the acoustic nerve, drastic dynamic compression is necessary to prevent the patient from being disturbed by intense sounds. That is the reason the sinusoidal signal received in each channel is converted into impulses whose frequency varies with the intensity. This particular difficulty can be eliminated if constant-level impulses whose frequency increases with stimulus intensity are used as stimuli. Our first results were obtained with this procedure.

We also constructed a voice synthesizer in order to hear what our patients are hearing with our device and to improve its performance as its characteristics are changed. This voice synthesizer compresses the sound message and divides it into eight frequency groups whose limits may be changed by means of variable filters. Each channel is used to modulate different bands of white noise whose average frequency is determined by the position of the electrodes in the cochlea—approximately one octave from 125 to 8000 Hz. The frequency width of each band may also vary.

Figure 4. Deaf mute patient three weeks after implantation of the electronic device. Note cutaneous incision and outside transmitter.

Use of Radio Transmitter Device. The first results we obtained with the voice synthesizer allowed us to determine the characteristics of the radio transmitter prototype we had used since October 1976.[5] This device consists of an implanted receptor and an outside transmitter (Fig. 5). The implanted receptor, embedded in Silastic, is a cylinder 20 mm. in diameter and 11 mm. thick with eight electrodes. In order of their frequency these electrodes are operatively attached to the corresponding intracochlear electrodes by mean of small iron needles embedded in Silastic tubes to insure good insulation.

The outside transmitter consists of a metallic box connected to an antenna fixed on an eyeglass frame (Fig. 6). This box, 22 by 18.5 by 7 cm. and weighing 2.5 kg., is borne on the shoulder. It contains the power source, the microphone, the compressor, the filters, and the circuitry. The power source consists of a battery, which is recharged during the night. The compressor suppresses sounds lower than 40 dB. Its response is

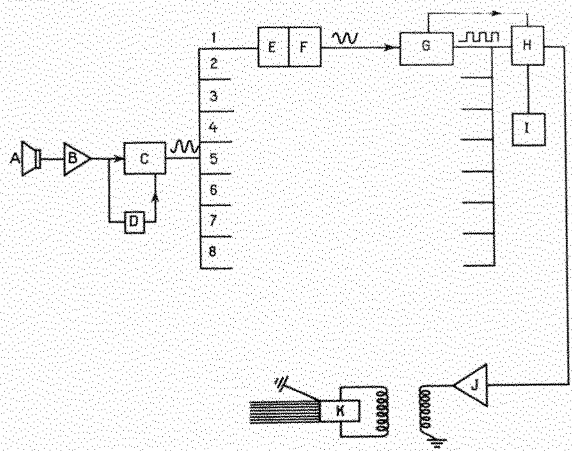

Figure 5. Diagram of radiotransmitter device. A, microphone. B, preamplifier. C, compressor. D, detection filter of compressor. E-F, passband filters. G, modulator. H, serializer. I, 3.2 mHz. J, amplifier. K, implanted recěptor.

rapid, less than 25 msec., but it remains active for ½ second in order to avoid the brief pauses in normal conversation. It is perfectly linear, without distortion, and the transcients are perfectly transmitted. The scale of the central frequency of the filters is a geometric progression from 300 to 2300 Hz. It contains the 250 to 3000 Hz. band containing speech information. The envelope for each canal is modulated in pulses whose duration and frequency vary with the intensity of the signal. This frequency varies from 300 to 1000 Hz. The variation of pulse duration is complex. Each pulse is not a continuous rectangular wave but consists of several elementary pulses. The number of these elementary pulses varies automatically from six to 12 with the intensity of the outside signal. The duration of each of these elementary pulses varies from 2 to 32 μsec. The duration is

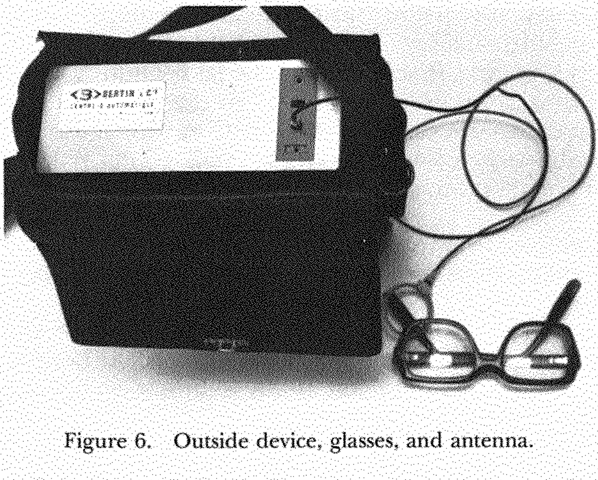

Figure 6. Outside device, glasses, and antenna.

manually selected for each canal in order to match the signal to the threshold level of each implanted electrode. The voltage of each elementary pulse is 6 volts.

Then the eight channels are multiplexed and injected in a high frequency oscillation. The antenna makes possible electromagnetic transmission supplying power and information through the skin to the implanted receptor.

RESULTS

Electrophysiologic Findings

PREOPERATIVE TESTING. In total deafness the threshold level averaged 1.42 volts with a standard deviation of 1.02. During a progressive increase in stimulating current intensity, the uncomfortable level was reached quickly above the perceptual threshold. With low perceptual thresholds the uncomfortable level was reached at approximately twice the threshold. Such a dynamic range of 6 dB. was seldom obtained and never exceeded.

We did not find any correspondence between the level of the audiometric curve, the etiology of the deafness, and the threshold level of the sound sensation. Even in five subjects with pure transmission deafness of 30 to 50 dB., with normal bone conduction the threshold level was within the standard deviation, provided the thick mucosa of the promontory had been removed.

The sound sensation depends on the frequency. With frequencies higher than 300 Hz. the result is a white noise in which high sounds are somewhat predominant, probably because the greater width of the scala at the beginning of the cochlea favors diffusion of the current in this area at the expense of the narrowed areas at the apex of the cochlea. This white noise is perceived irrespective of the frequency of the electrical stimulus, and only physiologically perceptible rhythms are present in this stimulus; i. e., frequencies under 300 Hz. are perceived. Thus, when the frequency of the signal is varied below this figure, a false impression of tonal discrimination results, analogous, for instance, to the noise of the explosions of a motorcycle engine, first idling and then accelerating until they give the impression of a continuous sound when the frequency of 300 Hz. is reached. But the analogy is not complete. Contrary to the sound shocks of an engine, electrical stimuli, when further accelerated, merely induce within all nerve fibers an increased intensity of the white noise obtained by fusion.

Registration of brain stem evoked responses is sometimes impossible. First, the electrical stimulus diffuses in the response for more than 2 msec. even if its duration does not exceed 0.1 msec. Moreover, for unknown reasons, in many cases the curve is without significance, even when the patient has a high intensity auditory sensation. Although meaningful diagrams are frequently obtained, this test cannot yet be used to measure the function of the cochlear nerve.

POSTOPERATIVE TESTING. If the cochlea is divided into several electrically insulated compartments, it is possible to stimulate only one compartment. Stimulating each electrode separately, we obtained for each the same values for threshold level and discomfort level. In five cases one of eight implanted electrodes did not yield any response. After three years our first patients now always have sound sensation by stimulating the electrodes, with a constant threshold.

For a stimulus over 300 Hz. applied in succession to each electrode, the sound perceived depends on the topography of the electrode. By experimenting on implanted patients with unilateral deafness it has been possible to equalize the sound perceived in the implanted ear and the sound perceived in the normal ear with an audiometric machine. Thus for the first time we were able to plot a frequency map of the human cochlea that corresponds closely to what one would expect in animal investigations (Fig. 7). By stimulating one of the electrodes with a stimulus whose frequency is less than 300 Hz., the same phenomena of frequency variation, acceleration, and fusion are obtained as with total stimulation except that the sound resulting from the fusion, instead of being a white noise, approximates a pure tone corresponding to the topography of the stimulating electrode. In fact, at a frequency of 1 Hz. the sound heard is similar to either a gong or a handbell stroke depending on the electrode concerned. When an electrode lying close to the apex of the cochlea is stimulated, beginning with a frequency under 300 Hz., the gradual acceleration of the stimulus produces a sound whose pitch increases up to a frequency of 300 Hz., a level at which the fusion of each sound results suddenly in a new, much deeper sound (a rumbling in the case taken as an example).

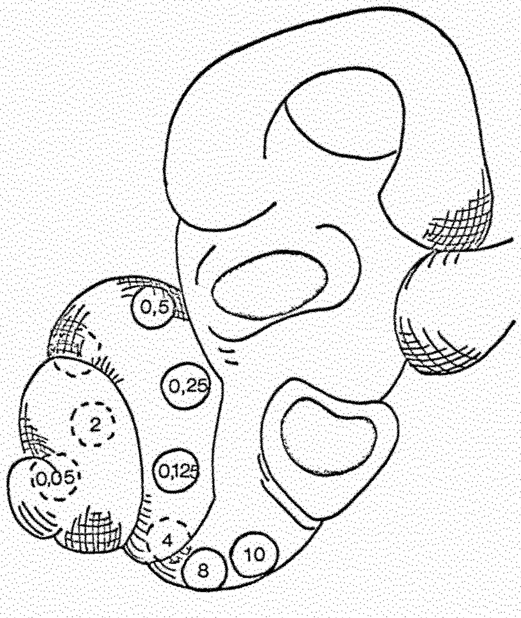

Figure 7. Map of frequency localization in the human cochlea.

There is one special difficulty with this procedure. During electrical stimulation of the cochlear fibers, there is a very narrow margin between the perceptual and uncomfortable thresholds. In terms of volts the latter is approximately twice as high as the former. The enormous dynamic compression effected by the tympano-ossicular system and increased by the cochlear fluids and Corti's organ is easily perceived. This difficulty can be overcome if pulsations of an adequate level are used as stimuli. The level of these pulsations must be between the threshold level and the discomfort level. Their frequency must vary between 300 and 1000 Hz. to warn the patient of the sound intensity. A frequency lower than 300 Hz. would give a crackling sensation.

The impedance of each electrode varies during the postoperative period. The day after the operation the impedance is generally low, about 2 kilo-ohms; a high voltage is necessary to obtain a sound sensation. The impedance increases up to eight or 12 kilo-ohms during the next few days and does not vary again after two or three weeks.

In four of our early patients some electrodes were allowed to emerge from the skin in the hair. For three years it has been possible to stimulate them easily every three or six months; the threshold level of each has not increased, and moreover the discrimination between each electrode has remained constant. Nevertheless, in cases of infection the impedance of an electrode may decrease until electrical stimulation becomes inefficient. All these factors were used to determine the parameters of our radiotransmitter device.

Clinical Findings

DIAGNOSTIC ASPECTS. Careful selection of patients for electrical stimulation of the round window through a surgical approach allows us to select those with bilateral total deafness in whom intracochlear implantation may be used.

With this preoperative test we obtained negative responses in only eight cases of total deafness. Two of the patients had bilateral acoustic neuromas. All the others were deaf mutes.

Although the number of patients we have tested is still small, our results to date suggest that in the majority of cases of acquired total deafness and childhood deaf-muteness, at least partial neural function is retained and that such patients therefore are eligible for implantation.

THERAPEUTIC ASPECTS. During the last three years we have implanted 24 patients with total deafness. Seven had been deaf from birth or early childhood and suffered major speech impairment. The youngest was 17 years old and the oldest, 70 years. Of these 24 patients, connections to the external device by transcutaneous plugs were established in 21. Probably because of movement of the outside wires under the earpacks, they suffered from suppuration of the skin around the plugs. This was treated after a few months and sometimes even after one year by elimination of the Teflon knob, making it necessary to temporarily hide the electrodes under the scalp until the definitive radiotransmission device could be built. In four cases of total deafness from chronic otitis, infection occurred with a severe decrease in the impedance of electrodes. In three cases one or several had to be removed.

None of these postoperative complications appeared in the last three patients who received the radiotransmission device. Two of them were deaf mutes 17 and 23 years old. One, a 29 year old, had acquired total deafness 12 years previously following streptomycin therapy. These patients have been implanted for more than six months.

In all these cases clinical results have been very satisfactory. As early as one day after the electrode positioning, discrimination of frequencies and the understanding of a few words are possible. These early results imply the continued use of lip reading, especially when the patient has been deaf for a long time. In any event these results are always superior to those obtained when a single electrode is stimulated. Melody recognition is variable from patient to patient; patients who had normal hearing before they became totally deaf are able to recognize popular melodies in almost 100 per cent of the cases if they are stimulated by only two electrodes, provided these electrodes are located at the two ends of the cochlea and are not too close to each other (Table 4). In tone deaf patients the recognition of popular melodies decreases and does not improve if all the seven electrodes are stimulated. As a consequence, complex melodies such as symphonies or concertos were neither identified nor appreciated. In all cases, however, music or songs could be distinguished from speech.

Speech recognition improves quickly with training. Tone reeducation is necessary. These patients must relearn how to hear. After one month, although the intelligibility of words remains poor, nearly 50 per cent of the usual conversation can be understood without lip reading. After two months, recognition of 30 dissyllabic words, produced at random by a machine, becomes possible. The criterion of 80 per cent intelligibility is usually reached provided the patient is young and not fatigued.

Table 4. *Melody Recognition*

		RESPONSES			
TITLE OF SONG	SONG CODE	*Device with Lip Reading*	*Device without Lip Reading*	*Device without Lip Reading and without Low Frequencies*	*Device without Lip Reading and without High Frequencies*
Il pleut bergère	1	1	1	Nothing	Nothing
J'ai du bon tabac	2	2	2	2	2
Au clair de la lune	3	3	3	3	0
J'ai un problème	4	4	4	Nothing	Nothing
Auprès de ma blonde	5	5	5	5	5
Tiens voilà du boudin	6	6	6	6	6
Papa les p'tits bateaux	7	7	7	5	Nothing
Fais dodo Colas mon p'tit frère	8	8	8	Nothing	8
La Marseillaise	9	9	9	4	9
Ils ont des chapeaux ronds	10	10	10	Nothing	Nothing
Results		10/10	10/10	4/10	4/10

In our seven patients whose long standing deafness had resulted in voice changes, the voice improved dramatically as early as the first few weeks following treatment (Fig. 8).[1]

DISCUSSION

Experimental Patients

The justification for the experimental part of our work must be mentioned first. We were obliged to use experimental patients in order to

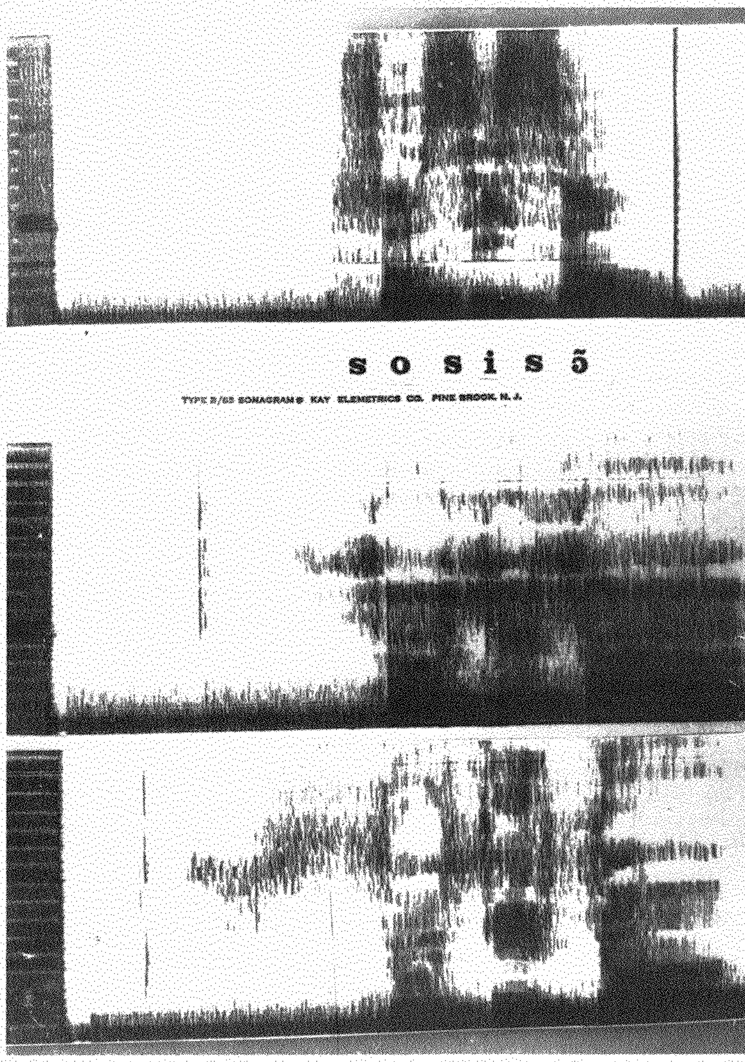

Figure 8. Sonagram. Top, normal voice. Middle, preoperative voice of a 17 year old deaf mute patient. Bottom, voice of same patient one month after implantation.

test our two fundamental hypotheses: that dividing the cochlea into electrically insulated compartments is feasible, and that this allows for speech discrimination. We could not use animals for this experiment, because even after long conditioning, animals are not yet able to communicate on a high enough level to yield sufficient information about the intelligibility of the message received. Neither could we use totally deaf patients, because in such psychologically fragile patients, there could be no risk of failure. On the other hand, it would have been too severe a test to perform such trials in patients with unilateral deafness who generally do not require surgery. However, when unilateral deafness is due to a skull fracture and is associated with facial paralysis, it is necessary to operate in order to save the facial nerve; in such a case the surgical approach allows one to reach the cochlea. Thus, with preoperative patient agreements it became possible to carry out without further damage the human experiments we required. Under these conditions the results obtained in three patients enabled us subsequently to operate on patients with total and bilateral deafness.[3]

Round Window Stimulation

Because of the anatomical variations of the round window we believe that a surgical approach is necessary to perform this important diagnostic test. Thus the differences between our results and those reported by House and Brackmann[8] can be explained.

There is no relation between the threshold level producing a sound sensation and the level of the audiometric curve or the etiology of the deafness. We think that the variations in the threshold level in our 158 cases were due to the differences in the round window membrane as they relate to its margins.

The positive results obtained in such widely varied afflictions seem paradoxical. Positive results do not signify that the cochlear nerve is normal in every case. They mean only that there are enough fibers to produce a sound sensation when all of them are electrically stimulated at one time. These clinical results are in accordance with the findings of Schuknecht.[17]

In most cases this diagnostic test was performed on one side only in order not to hurt the patient. Because of patient choice, the right ear was more frequently stimulated than the left one.

Frequency Map of the Cochlea

The frequency map of the cochlea we propose is only an approximate diagram. The frequencies we obtained by stimulating the electrodes of our unilaterally deaf patients individually were approximately as shown on the diagram. It is not possible to determine precisely the distance of each fenestration from the round window. Moreover, we cannot accurately know the exact length of the portion of the cochlea subjected to stimulation.

On the other hand localizations of the speech frequencies are only deductions. Our experimental patients suffered from traumatic labyrinth destruction with facial paralysis. The translabyrinthine approach to the facial nerve allowed us to reach the basal turn, the second turn, and the apex of the cochlea. But we had no justification for use of a suprapetrosal approach, which would allow us to reach this higher part of the first turn, in which by deduction we believe these conversational frequencies lie.

Tolerance

Implantation may be accused of destroying the few cochlear fibers remaining. Spoendlin[19] pointed out that such iatrogenic secondary degeneration may be late in occurring. Schindler[16] emphasized that the Michelson bipolar electrode implantation did not produce any nerve degeneration, and Schuknecht[17] showed that a hole made with a needle in the scala tympani did not produce any nerve deterioration. Moreover, in some of our first patients whose electrodes protruded from the scalp, there was no change for about four years in the impedance or the frequency discrimination. It is reasonable to hope that a longer tolerance will be easily obtained.

Indications for Implanting

Not only is a positive response to electrical stimulation of the round window necessary to decide upon implantation in cases of total deafness, but in order to have good results it is also important to consider, especially in elderly patients, the adaptation ability and the will for rehabilitation. Thus the indicators seem to point to young patients as the most promising candidates for implantation. Although we have not yet implanted in children (the youngest of our patients was 17 years old), we think that after a few months of postoperative re-education their residence in special schools for the handicapped will be unnecessary.

Electrode Sites

Because there is transmission from the radiotransmitter device frequency range to the frequency site of each electrode inside the cochlear keyboard, we believe that exact anatomical positioning is not indispensable. Moreover, if strict correspondence is necessary between the device channel frequency order and the frequency topography of the eight electrodes in cases of recent acquired deafness, it seems to be less important in cases of birth deafness.

Clinical Results

We have not described the training techniques we use for postoperative rehabilitation, because we are trying to improve them and we have not yet determined the best one. The clinical results we obtained with the radiotransmitter device seem better and occur more rapidly than those we obtained with Teflon plugs. The frequency scale of our first device ranged from 125 to 8000 Hz., whereas that of our new device is now the same as telephone bands, between 250 and 3000 Hz. Moreover, this apparatus is easier to wear and to use, and our patients live with it throughout the day.

Our results remain incomplete. Prolonged training is perhaps necessary. Because the cochlear nerve in these patients is rarely completely normal, perfect rehabilitation will probably never be possible.

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