A Chronic Implant for Recording of Cochlear Potentials in Primates [1]

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ABSTRACT A new technique for the continuous recording of peripheral bioelectrical activity in the auditory system of primates is described. Because of basic differences in the anatomy of the temporal bone, the approach to the round window of the cochlea is more difficult in most primates than in lower animals. A relatively simple surgical approach, which made possible the placement of an electrode into the perilymph of the inner ear via the well-demarcated horizontal semicircular canal was therefore developed and is described in detail. The bared tip of a Teflon-coated wire was cemented into the canal opening with carboxylate cement, and the wire attached to a permanent electrical connector on the skull. Cochlear microphonic and action potentials of 50 to 100 μV amplitude were thus recorded on a continuing basis at the same time that behavioral studies of primate auditory acuity were conducted.

In recent years, the body of knowledge concerning the sense of hearing in subhuman primates has grown significantly. These data have been obtained through anatomical studies, behavioral psychophysical experiments, and the recording, on an acute basis, of the bioelectrical potentials arising within the cochlea. Behavioral methods, while time-consuming and costly, have proven rewarding; they have permitted accurate assessment of primate auditory acuity in the waking state and have provided reliable serial measures of auditory function over long periods of time. Through the use of such techniques, the effects of overstimulation and drug ototoxicity are being examined in animal models closely akin to human beings (Stebbins, '70).

The value of bioelectrical potential measurements in the study of the physiology of the sensory cells of the cochlea is well-established (Wever, '66; Lawrence, Wolsk and Burton, '59). Cochlear potentials, recorded from the round window by acute methods, have provided valuable information on the sensitivity of the primates' peripheral transducing mechanism (Wever, Vernon and Lawrence, '58), as well as data of phylogenetic significance (Peterson, Wruble and Ponzoli, '68). The round window exposure, however, destroys the normal anatomical integrity of the middle ear cavity of the primate; and this factor must be taken into account when these data are examined. Furthermore, although chronic experiments of short duration have been performed with round window electrodes in cats (Marsh and Worden, '69), it is virtually impossible to maintain an electrode in a constant relationship to the primate round window membrane for any length of time after the initial placement. For these reasons, the present experiments were carried out to develop a long-term implant whose installation would preserve normal middle ear physiology.

The bony horizontal semicircular canal is a prominent anatomical landmark in clinical mastoid surgery. It was utilized by Lempert ('38) for the production of an artificial fenestra as a pathway for sound transmission to the cochlea in cases of otosclerosis. This canal is rather easily exposed through a mastoid approach, which does not disturb the middle ear cavity. The present study demonstrates the feasibility

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of obtaining very stable long-term bioelectrical measurements from a wire electrode implanted within the perilymph of the horizontal semicircular canal.

MATERIALS AND METHODS

Four male pigtail monkeys (*Macaca nemestrina*) and two rhesus monkeys (*M. mulatta*), ranging in weight from 4.0 to 6.5 kg, were used in this study. Anesthesia for the surgical procedure was conveniently carried out with intramuscular injections of Ketalar (Parke-Davis), 20 mg per kg, and Valium (Roche), 0.75 mg per kg. Atropine, in a total dosage of 0.2 mg, was also given initially to suppress hypersalivation. This regimen provides immobilization and relaxation of monkeys within two minutes, and surgery can be carried out safely over a period of several hours with only supplemental doses of Ketalar.

Figure 1 illustrates, in schematic fashion, the relationship of the external ear to the underlying middle and inner ear structures of these primates. The horizontal semicircular canal is seen to lie posterior to an imaginary line extending from the center of the tympanic membrane out through the external auditory meatus. Consequently, a surgical approach through the spongy mastoid bone posterior

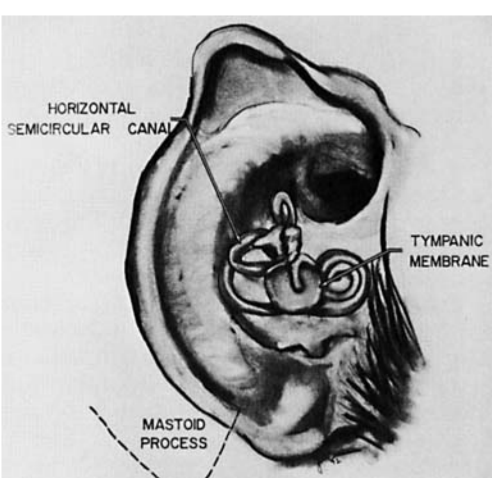

Fig. 1 Positional relationship of external ear to underlying middle and inner ear structures. The bony cochlea lies anterior to the center of the tympanic membrane, while the horizontal canal is clearly posterior.

to the external ear is favored. Following shaving of the surgical area, several important anatomical landmarks may be palpated. The bony occipital ridge continues in the temporal bone as a line passing just superior to the external auditory meatus into the zygomatic arch. This delineates the superior border of the dissection. Inferiorly, the tip of the mastoid process may be palpated; it is advisable to remain at least 5 mm above this structure. The cartilaginous external auditory meatus serves as the anterior border of the dissection.

An incision is made 3 mm posterior to the pinna, and parallel to it, from the temporal line to 5 mm superior to the tip of the mastoid process. The mastoid bone is exposed, and the pinna retracted forward as in figure 2. Drilling is carried out with a medium dental burr within the boundaries described above, posteriorly to a distance of a few centimeters from the wall of the external auditory meatus. At a depth of approximately 1.5 to 2.0 cm, the spongy, pink pneumatized mastoid bone gives way to a very different marble-like white bone. At this point, the bony horizontal semicircular canal is being exposed. Dissection may proceed with a curette, which will separate the air cells from the very hard petrous bone.

The canal is exposed for about one centimeter of its length, as shown in figure 2. The opening into the mastoid antrum is seen anteriorly; care is taken not to disturb the incus, which may be seen within at its articulation with the malleus. Posterior-inferior to the bony horizontal canal is the bluish prominence of the sigmoid sinus, which is also left undisturbed. A 1 mm diameter opening is made into the bony wall of the exposed horizontal semicircular canal with a fine dental burr. Perilymph is observed to form a meniscus within this aperture. The bared tip of a 30-gauge Teflon-coated, platinum-iridium wire is then carefully inserted 2 mm into the canal opening, anteriorly, and is sealed permanently in place with carboxylate dental cement. Before closure of the surgical incision, the remaining length of wire is passed subcutaneously to the top of the head where it is attached to a permanent electrical connector.

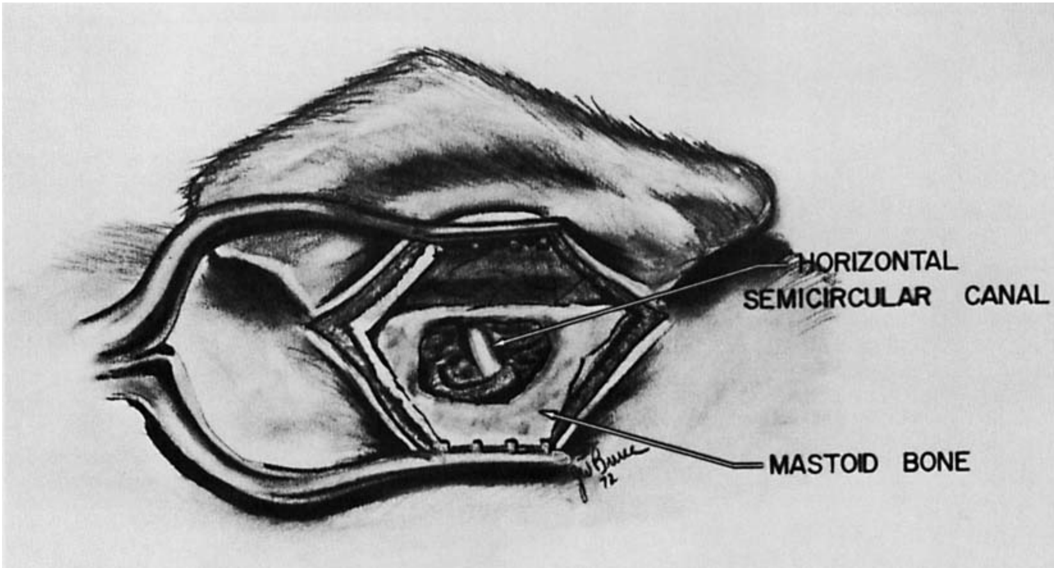

Fig. 2 Postauricular surgical exposure of bony horizontal semicircular canal within the dissected mastoid bone. The darkened area superior and to the right of the canal represents the opening of the antrum into the middle ear cavity.

Postoperatively, the monkeys demonstrate a horizontal nystagmus to the side opposite the operated ear; this subsides within 24 to 36 hours. In addition, there is a period of ataxia and postural unsteadiness that invariably disappears completely within six to ten days. During this period, central mechanisms apparently develop to compensate for the now-functionless horizontal semicircular canal; and no residual gross motor incoordination has been observed.

The four pigtail monkeys (*M. nemestrina*) used in this study were conditioned to hold down a key, then to release it in response to sounds delivered by closely-fitted earphones. Details of the procedures involved are given elsewhere (Stebbins, '70). Approximately eight weeks of daily conditioning were required to train each monkey to provide reliable hearing thresholds. Variations at particular testing frequencies were no more than three dB on a day-to-day basis. Two of the subjects were fully trained prior to the surgical procedure, and they were able to resume their sessions within ten days after the implantation. The other two subjects were trained after the successful implant procedures. Electrical recording was carried out in a shielded soundproof room, with the monkeys under light sedation. Responses to acoustic clicks were amplified and relayed to a PDP-12 computer for averaging, and on-line computer plots were obtained.

RESULTS AND DISCUSSION

Successful implants were achieved in all of the six subjects. In three of the four behaviorally-trained monkeys, no deficit in auditory acuity resulted from the procedure. Figure 3 demonstrates the lack of any deleterious effect on cochlear function resulting from the implant. It should be noted that fluid accumulation in the middle ear cavity, secondary to surgery, may cause some slight change in hearing threshold at lower frequencies, but this has in all cases subsided from two to four weeks post-operatively. In the fourth monkey, the incus was inadvertently involved in the carboxylate cementing operation, and an average 30 dB hearing loss resulted in that ear, as detected by behavioral and electrical measures.

Electrical potentials recorded immediately after surgery are generally small, eighth-nerve action potentials reaching a

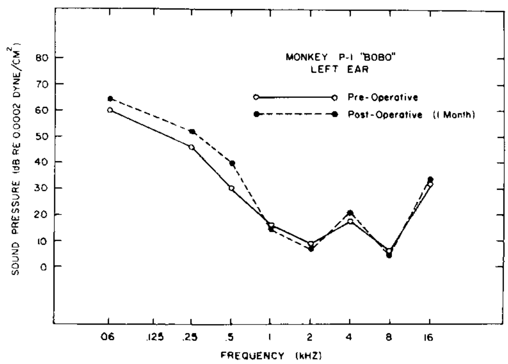

Fig. 3 Representative behavioral pure tone threshold curves of one subject before and after the horizontal canal implant procedure. The small hearing deficit at lower frequencies subsequently disappeared.

maximum of 10 to 20 μv. This small response is undoubtedly caused by the large amount of serous fluid in the middle ear cavity at this time and also by a temporary disturbance in cochlear bioelectrical conditions as a result of some loss of perilymph. However, within one week, the maximum electrical potentials are attained. Cochlear AC potentials of up to 40 μv and eighth-nerve action potential responses to clicks of up to 100 μv have been recorded. Most importantly, although the maximum voltage output differs among animals, the output voltages for individual animals remain stable with time. Eighth-nerve action potential voltages at specific click intensities varied no more than 5 to 10 μv for as long as four months.

Figure 4 illustrates a typical response to a 100 microsecond-duration acoustic click at 40 dB sensation level. With the aid of a PDP-12 computer for on-line averaging, such responses to clicks are used to generate input-output functions for the whole eighth-nerve potentials, as shown in figure 5. These curves resemble quite closely those obtained from human beings by Portmann and Aran ('70). Correlation of input-output functions thus obtained for the eighth-nerve when varying stimulus parameters are used with the behavioral audiograms is being carried out at present. This work, it is hoped will provide some insight into the most favorable stimulus conditions for clinical testing of human beings with hearing disorders.

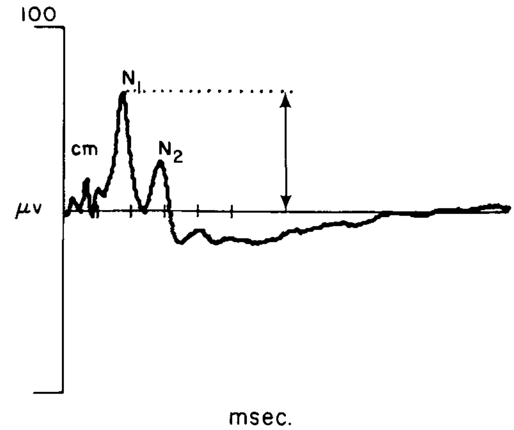

Fig. 4 Computer plot of a typical recording from the horizontal canal implant, in response to an acoustic click 40 dB above threshold (average of 100 responses). N_1 and N_2 designate the first and second negative action potential deflections, respectively. Arrows indicate the amplitude measurement of N_1.

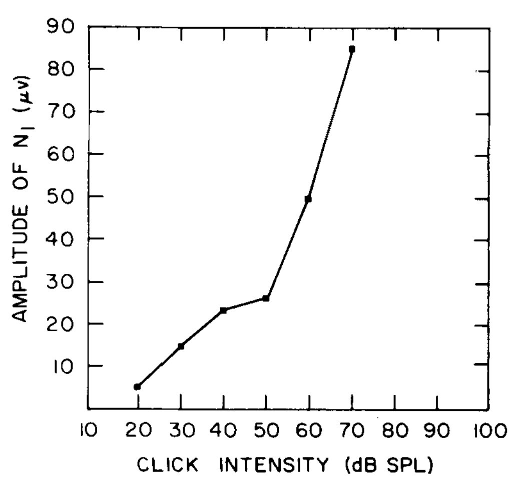

Fig. 5 A plot of the growth of amplitude of N_1 of the eighth nerve action potential in response to increasing intensities of acoustic click stimuli. Levels of sound intensity are given in decibels referred to average monkey click threshold.

The input-output function of cochlear AC response may also be determined by using a variety of pure-tone frequencies. A study is currently under way with these implanted animals, measuring both cochlear AC and eighth-nerve potentials in serial fashion, to determine the short-term and long-term effects of overstimulation on cochlear function.

CONCLUSION

1. The present study has demonstrated the technical feasibility of implanting a fine wire electrode into the horizontal semicircular canal of pigtail monkeys (*M. nemestrina*) and rhesus monkeys (*M. mulatta*).
2. A mastoid surgical approach permits the implantation to be accomplished without a disturbance of middle ear physiology.
3. No reduction in auditory acuity results from the implant, although fluid accumulation may temporarily impair low-frequency reception.
4. Nystagmus, ataxia, and other symptoms of vestibular imbalance are transient and invariably disappear completely within six to ten days.
5. Bioelectrical potentials recorded via this implant are stable for periods of several months.
6. Investigations of the effects of external factors, such as overstimulation, on hearing may now be studied in serial fashion, with cochlear electrical activity and behaviorally-obtained thresholds recorded simultaneously. In this manner, a clearer picture of the pathophysiology of the sensory cells and nerve endings may be obtained.

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