Problems of conventional hearing aids (low fidelity, poor frequency response and feedback) and of hearing aids employing implanted piezoelectric elements (high power requirements and microtrauma) are eliminated or attenuated by implanting a coil and magnet in the ear after removal of the incus, the magnet being fastened to the head of the stapes and the coil being energized by electrical signals from a sound transducer and producing a magnetic field which, interacting with the magnetic field of the magnet, causes movement of the stapes in the same manner as it normally is moved by the incus.
IMPLANTABLE ELECTROMAGNETIC HEARING AID

This application is a continuation-in-part of Ser. No. 364,938 filed May 29, 1973, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to hearing aids. More particularly, this invention relates to hearing aids that operate electromagnetically and some of the components of which are implantable.

A conventional hearing aid consists of a microphone, an amplifier, batteries and a loudspeaker. All of these components are mounted externally on the user, and various attempts have been made to disguise of hide them, as by building them into the earpieces of eyeglasses for example.

There is a considerable number of people with severe sensorineural hearing losses who are not adequately served by the most modern hearing aids that are available. The reasons for this revolve around the distortion inherent in the individual's hearing loss as well as the superadded distortion in the hearing aid which may include low fidelity, poor low frequency response and feedback.

Many conventional hearing aids require an ear mould and ear tubing. These components must be custom made, which is expensive. Moreover, if they are not made perfectly, feedback and consequent distortion problems are likely to arise.

A number of attempts have been made to solve the aforesaid problems. Thus it is known to place a magnet on the eardrum with a coil in an externally located earpiece and energize the coil via a microphone and amplifier. A hearing aid of this type suffers from low efficiency because the coil is located too far from the magnet. In addition, such a system does not provide a permanent solution for hearing loss because the magnet on the eardrum will be displaced in a short time by migration of the epithelium. Epithelial migration commences at the eardrum. Only about six weeks is required for the epithelium to leave the eardrum, and only about five months is required for it to come out of the ear canal. Another disadvantage of this system is its high power requirements. This is due not only to the large distance between the externally located coil and implanted magnet, but also to the large mass (eardrum and ossicles) that must be moved, taking into consideration that all that really is required is movement of the stapes, and the area ratio of eardrum to stapes footplate is about 15:1.

In U.S. Pat. No. 3,594,514 dated July 20, 1971, Robert C. Wingrove, and U.S. Pat. No. 3,712,962 dated Jan. 23, 1973, J.M. Epley, there are described implantable hearing aids that utilize piezoelectric ceramic elements. From an electrical point of view such systems, as compared to the electromagnetic system to be disclosed herein, have a higher impedance and higher voltage requirements. In fact such systems probably will require about a 15 volt battery, which would be about 1 inch × 1 inch × ½ inch in size and hence not readily disguised or hidden. On the other hand the electromagnetic system to be disclosed herein will require only about 1.5 volts to operate it. A battery of this size would be about 10 mm. in diameter and 5 mm. thick, and a battery of this size can be hidden readily. What is even more serious, however, is the fact that the piezoelectric ceramic element will, as a result of its continually striking the bone (one of the ossicles) with which it cooperates, create microtrauma and erosion of that bone.

In accordance with my invention there is provided a hearing aid which eliminates or attenuates many of the disadvantages of conventional hearing aids of the type noted previously as well as those of hearing aids of the types noted in the two preceding paragraphs.

SUMMARY OF THE INVENTION

A hearing aid embodying my invention may include a microphone, amplifier and a battery or batteries (or other suitable sound transducer), as is conventional, all of which may be located in a small housing that may be hidden behind one ear of the individual and which may plug into a receptacle and socket implanted in the temporal bone behind the ear. The hearing aid further includes an implanted electromagnetic device that replaces the loudspeaker, tubing and earmold of a conventional hearing aid. This device consists of a magnet that is permanently attached to the stapes (one of the three auditory ossicles) and an implanted coil that is located in close proximity to the magnet and which receives electrical signals from the sound transducer. Also provided is a suitable support for the coil.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will become more apparent from the following detailed description, taken in conjunction with the appended drawings, in which:

FIG. 1 is a perspective view showing the aforesaid housing located behind the ear of an individual;

FIG. 2 is a horizontal section through a normal human ear but with the outer tissue folded over on itself;

FIG. 3 is a view similar to that of FIG. 2 but with the incus removed, a necessary step in the operative procedure for implanting certain components of a hearing aid embodying my invention;

FIG. 4 is a view similar to that of FIG. 2 but showing these components in place;

FIG. 5 is a side view of an individual's right ear with the tissue removed and showing the same components as are seen in FIG. 4;

FIGS. 6 and 7 are top and side views respectively showing the stapes and the components illustrated in FIGS. 4 and 5;

FIG. 8 is a view similar to that of FIG. 7 but with the coil and its support removed;

FIG. 9 is a view similar to FIG. 8 but showing another embodiment of my invention;

FIG. 10 is an exploded view of certain components of a hearing aid embodying my invention; and

FIG. 11 is a schematic diagram of a hearing aid embodying my invention.

Referring to FIG. 1, a hearing aid embodying my invention includes a housing 10 (see also FIG. 10) in which, as shown in FIG. 11, may be located a microphone 30, an amplifier 31 and a battery 32. This housing is very small and can be located behind the ear tissue of an individual. It has three male terminals 33 (FIG. 10) projecting therefrom adapted to plug into three female terminals 34 in a receptacle 11 (FIGS. 6 and 10). As best shown in FIG. 10, receptacle 11 fits into and externally threaded socket 35. The lower part 36 of socket 35 is permanently implanted by an opera-
tive procedure into the temporal bone of the patient. This procedure requires tapping a hole in the temporal bone immediately behind the ear to accommodate the lower part 36 of socket 35, this part being screwed into the tapped opening. Once housing 10 has been plugged into receptacle 11, an internally threaded cap 37 (FIGS. 1 and 10) is threadably engaged with the upper part 38 of socket 35 to hold housing 10 and receptacle 11 in position. A cap (not shown) similar to cap 37 but with its top end closed may be provided and used in place of cap 37 when the individual is showering or swimming. Illustratively socket 35 may be about 1 cm. long and have a maximum diameter of about 1.3 cm.

Housing 10, receptacle 11 and socket 35 are fabricated of a material that is non tissue toxic. One suitable material is "TEFLON" (trade mark). Cap 37 also may be fabricated of this material or stainless steel, for example.

Two of the three terminals 33 are, in fact, the output terminals of amplifier 31, the latter being powered by battery 32 and serving to amplify sounds picked up by microphone 30. The third terminal is for stability and location. The microphone, amplifier and battery may be of a conventional type. A suitable microphone is a condenser microphone model No. BL1680 made by Knowles Electronics Inc., Franklin Park, Illinois. Amplifier 31 preferably is a logarithmic amplifier. Two suitable amplifiers both manufactured by Robert Bosch Electronic Company of Berlin, West Germany are "STAR 6" (trade mark) dynamic range compression (DRC) amplifier and "OMNITRON II" (trade mark) DRC amplifier. The battery may be an "EVEREADY" (trade mark) model E675 1.4 volt mercury battery. Terminals 33 and 34 preferably are gold plated. It should be understood, of course, that microphone 30, amplifier 31 and battery 32 individually or in total may be located elsewhere than behind the ear.

The other part of a hearing aid embodying my invention consists of a magnet 12 (FIGS. 5, 6, 8 and 12), which, in the embodiment shown, is cylindrical in configuration, and which is secured to the stapes 13; a coil 14 located in close proximity to magnet 12; a support or holder 15 for the coil; and two lead-in conductors 16 connected between terminals 34 of receptacle 11 and coil 14. All of these components are surgically implanted.

As shown in FIGS. 4, 6, 7 and 8, a holder 17 for magnet 12 is provided. This holder may be fabricated of "TEFLON" (trade mark), for example, and is designed so as to be readily attached to stapes 13. Magnet 12 may be encased in the material of the holder. In another embodiment of the invention shown in FIG. 9 magnet 12 is firmly secured to the head of stapes 13 by a non tissue toxic cement such as "SILASTIC" (trade mark) or "CRANIOPLAST" (trade mark). In this embodiment, unless magnet 12 is encapsulated in a non tissue toxic material, it itself must be non tissue toxic. Thus, it may be made of "VITALLIUM" (trade mark), for example. However, a superior magnet is one made of cobalt symareum and available from the General Electric Company, Schenectady, New York. Such a magnet requires encapsulation in a non tissue toxic material.

Regardless of how magnet 12 is secured to stapes 13, it must be firmly fastened thereto so that the magnet and stapes move as a unit without relative movement there-between in order to avoid microtrauma. This poses no problem where cement is used. Where holder 17 is mechanically secured to the stapes without cement, the inherent springiness of the holder material may be relied upon to provide the required connection or, depending on the holder material, it may be crimped in position.

Magnet 12 is very small, typically about 1 mm. in diameter and 1 mm. long. Coil 14 must be sufficiently small to fit in the middle ear space and should have an input impedance that matches the output impedance of amplifier 31. Strictly by way of example, coil 14 may consist of 1,600 turns of insulated 50 gauge copper wire embedded in a suitable non tissue toxic material such as "SILASTIC" (trade mark). It may be about 1.5 mm. internal diameter (core), 4 mm. outside diameter and 1 mm. long.

In order to implant components 12 and 15 to 17 a mastoidectomy is performed, the "facial triangle" bone is removed from the posterior bony ear canal wall and the incus 18 (FIG. 2) is removed. Magnet 12 then is firmly secured to stapes 13. In the embodiment shown in FIGS. 4, 7 and 8 this is accomplished by fastening holder 17 to stapes 13, but it also may be accomplished by cementing the magnet or its encapsulating material to the stapes using a suitable cement as shown in FIG. 9. By means of a tool 19 (FIG. 4) which threadably engages a connector 20 (FIG. 4) secured to holder 15, coil 14 and holder 15 are positioned in place and holder 15 is permanently cemented in position using a suitable non tissue toxic cement 40 (FIG. 4) such as "CRANIOPLAST" (trade mark). This operation is performed using a suitable micromanipulator. Tool 19 then is removed.

Coil 14 is located in close proximity to magnet 12. In the embodiment of the invention shown in FIGS. 4, 6 and 7 it is positioned just above magnet 12 with the core of the coil and the magnet arranged coaxially. The coil could be arranged to surround holder 17 if desired. In other words, magnet 12 then would be in the core of the coil. The important thing, however, is that coil 14 and magnet 12 are so arranged that the interaction of the magnetic field of the magnet and that of the coil then energized results in movement of the stapes in the same manner as it normally would be moved by the incus.

Holder 15 performs the important function of supporting coil 14 in a fixed position in the middle ear space. It may be a silver wire approximately 0.2 mm. in diameter. It may be flattened at one end and this flattened end then wrapped around coil 14, the flattening being for the purpose of providing a greater surface area of contact. The other end of holder 15 is cemented to bone within the mastoid bowl.

After tool 19 has been removed, wires 16, which preferably are made of gold, are led into socket 35 through a small opening in the bottom wall thereof, are passed through and out of the socket and then are soldered to terminals 34. Socket 35 then may be screwed into the previously tapped opening in the mastoid tip of the temporal bone behind the patient's ear and components 11, 10 and 37 located in position as previously explained herein.

When coil 14 is energized by electrical signals from amplifier 31, the interaction of the magnetic field of coil 14 thereby created and the magnetic field of magnet 12 causes stapes 13 to function in its normal way.
like a piston causing vibration of the inner ear fluids in response to sound pick up by microphone 30. It should be understood that my invention also may be practised using an implanted receiver and an external microphone and transmitter as disclosed in aforementioned U.S. Pat. No. 3,712,962, the piezoelectric element disclosed in this patent being replaced with the electromagnetic system disclosed herein.

What I claim as my invention is:

1. A hearing aid having certain components thereof that are implanted in the ear of the user, said hearing aid comprising sound transducer means for converting audio signals to electrical signals and electromagnetic transducer means for receiving said electrical signals and converting said electrical signals into mechanical movement of the stapes bone of the ear of the user, said electromagnetic transducer means being implantable in the ear of the user and comprising a magnet, means for firmly securing said magnet to the head of the stapes bone of the user such that said magnet and said stapes bone move as a unit without relative movement therebetween when said magnet is attracted by a magnetic field and a coil of a size that permits it to be implanted in the middle ear space of the ear of the user, said coil being adapted to be implanted in the middle ear space of the ear of the user in close proximity to said magnet, said coil when energized by said electrical signals producing a magnetic field in which said magnet is located, said coil and said magnet being positioned with respect to each other such that upon energization of said coil said stapes bone moves as a result of the interaction between the magnetic field of said magnet and said magnetic field of said coil in the same manner as said stapes bone normally is moved by the incus bone, said hearing aid also including implantable support means for said coil, said support means being adapted to be secured to a bone that holds said coil in a fixed position in said middle ear space.

2. A hearing aid according to claim 1 wherein said sound transducer means comprises a microphone, an amplifier and a battery.

3. A hearing aid according to claim 2 further including a socket having electrical terminals therein, means electrically connecting said sound transducer means and said coil, said means electrically connecting said sound transducer means and said coil including implantable conductors connected to said terminals and to said coil for supplying said electrical signals to said coil, said socket being adapted to be located behind the ear of the user and secured to bone of the user thereof, a housing for said microphone, amplifier and battery, said housing having output terminals for said electrical signals, said housing being adapted for reception by said socket with said terminals of said socket electrically contacting said output terminals of said housing.

4. A hearing aid according to claim 3 wherein said socket is externally threaded to threadably engage in a tapped opening in said bone behind the ear of the user.

5. A hearing aid according to claim 1 wherein said means for securing said magnet to the head of the stapes bone of the user comprises a non tissue toxic cement.

6. A hearing aid according to claim 1 wherein said means for securing said magnet to the head of the stapes bones comprises a holder for said magnet, said holder being adapted for attachment to the head of the stapes bone of the user.

7. A hearing aid according to claim 1 including means for securing said support means to a bone that holds said coil in a fixed position in said middle ear space.

8. A hearing aid according to claim 7 wherein said means for securing said support means comprises a non tissue toxic cement.

9. A hearing aid having certain components thereof implanted in an ear of the user from which the incus has been removed, said hearing aid comprising sound transducer means for converting audio signals to electrical signals and electromechanical transducer means adapted to receive said electrical signals and convert said electrical signals into mechanical movement of the stapes bone of said ear of said user, said electromechanical transducer means being implanted in said ear of said user and comprising a magnet, means for firmly securing said magnet to the head of said stapes bone such that said magnet and said stapes bone move as a unit without relative movement therebetween when said magnet is attracted by a magnetic field and a coil implanted in the middle ear space of said ear in close proximity to said magnet, said coil when energized by said electrical signals producing a magnetic field in which said magnet is located, said coil and said magnet being positioned with respect to each other such that upon energization of said coil said stapes bone is moved as a result of the interaction between the magnetic field of said magnet and said magnetic field of said coil in the same manner as said stapes bone normally is moved by the incus bone, said hearing aid also including implantable support means for said coil, said support means being adapted to be secured to a bone that holds said coil in a fixed position in said middle ear space.

10. A hearing aid according to claim 9 further including a socket having electrical terminals therein, said socket being implanted in bone behind the ear of said user, implantable conductors connected to said terminals and to said coil for supplying said electrical signals to said coil, and a housing for said sound transducer, said housing having output terminals for said electrical signals and being received by said socket with said terminals of said socket electrically contacting said output terminals of said housing.