Regaining BALANCE with Bionic Ears

Electronic implants in the inner ear may one day restore clear vision and equilibrium in some patients who experience disabling unsteadiness

By Charles C. Della Santina

KEY CONCEPTS

- Disorders of the vestibular system of the inner ear can cause vertigo and shaky, blurred vision.
- Three semicircular structures in the inner ear are responsible for measuring head rotation.
- Prostheses that would replace the function of the semicircular canals and thus restore balance are under development.

—The Editors

Ask friends to list the body's senses, and they will usually stop after five: taste, touch, sight, smell and hearing. Most do not even notice their sixth sense—the sensation of how one's head is oriented and moving. But losing this capacity can cause dramatic, disabling vertigo, followed by chronic unsteadiness and blurred vision when the head is in motion. Fortunately, good progress is being made toward the development of bionic ear implants to restore balance in people who suffer from damage to the vestibular labyrinth of the inner ear—the part that provides us with our sixth sense.

The availability of these prostheses cannot come too soon for Richard Gannon, a 57-year-old retired steamfitter, who has homes in Pennsylvania and Florida. Gannon lost much of his sensation of balance seven years ago after suffering an apparent viral illness. "Let me be the first to get a vestibular implant," he says. "I've been waiting for a call for five years. As soon as they can do it, I'll walk to the hospital if I have to."

"I moved to a house near the beach when I retired because I love the water. But since I lost my balance, I can't walk straight, especially on sand," reports Gannon, a formerly avid swimmer. "Now mothers pull their kids away from me, thinking I'm drunk. Standing in two inches of surf makes me feel like I'm going to fall. I barely drive now, and never at night, because for every headlight, I see 20."

Although he feels fairly comfortable during daytime driving, he remarks that the cometlike trails left by road lights as they streak across his eyes at night are "like a laser show. I'd give up my hearing if it would mean getting my balance back." The recent advances toward bionic ear implants offer hope for Gannon and tens of thousands like him who have sustained damage to the inner ear from certain antibiotics (such as gentamicin) or chemotherapy or from meningitis, Ménière's disease or other illnesses.

Staying Upright and Steady

Much like cochlear implants, which restore hearing by electrically stimulating parts of the auditory nerve, this new type of bionic ear will provide stability by electrically stimulating the vestibular nerve, which normally conveys signals from the vestibular labyrinth to the brain. The device's electrical connection to the nerve will bypass the defective vestibular system.

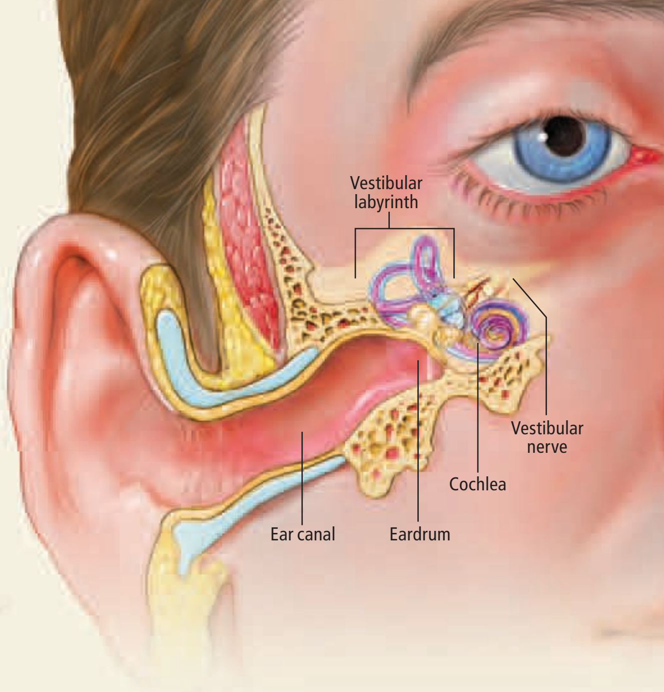
The healthy labyrinth performs two important jobs. One is measuring which way is up and which way you are heading. You need this information to stand and walk normally. The second is sensing how your head is turning. You need this information to keep your eyes on target. Whenever your head turns up, for instance, the

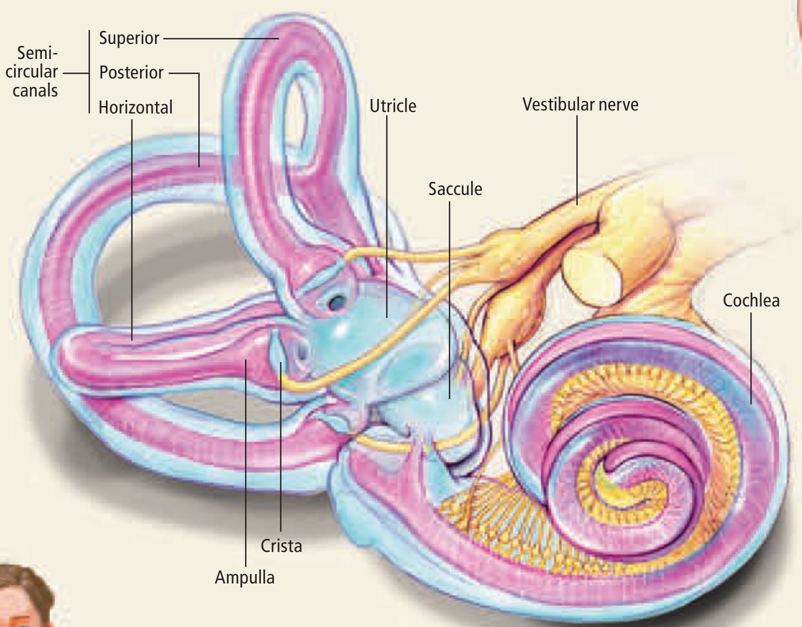
GERARD SLOTA

[REPLACEMENT PARTS]

A Device to Restore Balance

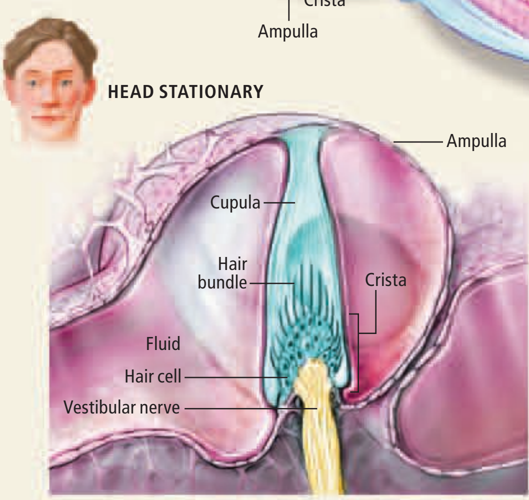
The intricately structured vestibular labyrinth of the inner ear is central to balance; damage causes unsteadiness and blurred vision. Researchers are making progress toward a prosthesis that can compensate for such damage, much as implants for hearing loss compensate for harm to the cochlea.

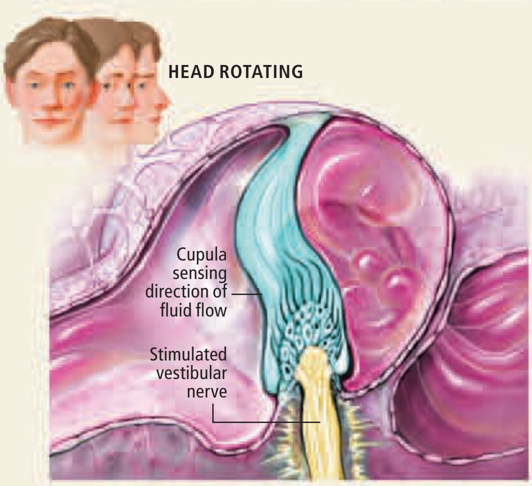




◂ INNER EAR: NOT JUST FOR HEARING

The vestibular labyrinth includes three fluid-filled, Hula-hoop-like structures called semicircular canals, each of which contains a structure termed an ampulla at one end. The ampullae sense head rotation in three dimensions and, like other sensors in the inner ear, rely on specialized cells that translate fluid movement into neural signals. Other structures in the labyrinth—the utricle and saccule—tell the brain how the head is oriented relative to the pull of gravity. The author's prosthesis would replace the function of the semicircular canals.



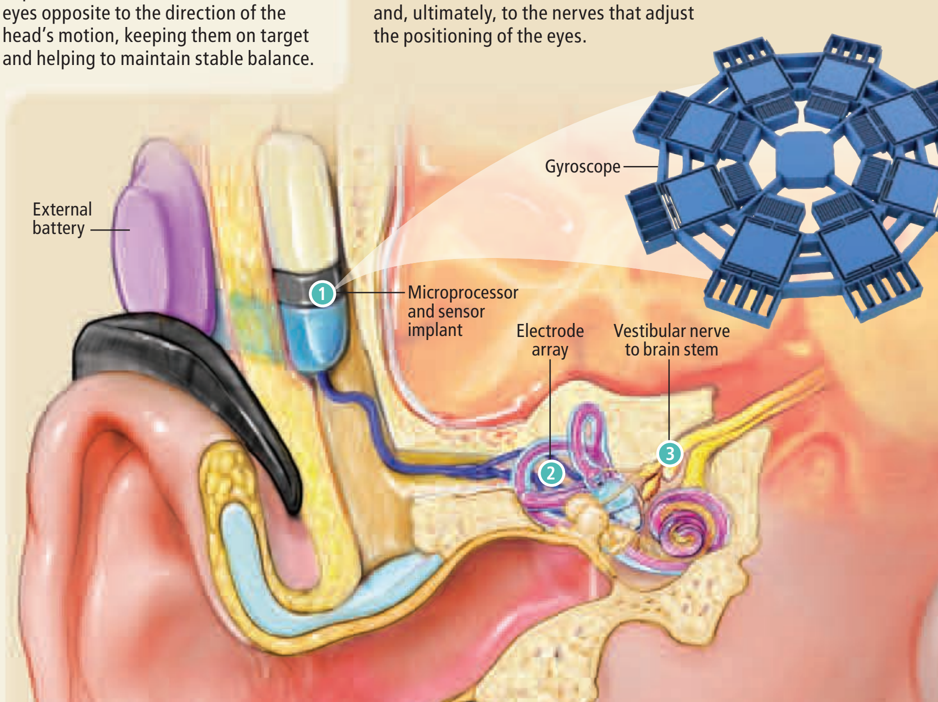


◂ GOING WITH THE FLOW

When the head is stationary, fluid in each semicircular canal remains still and vestibular nerve fibers fire at a constant rate (*top*). During head rotation (*bottom*), fluid in each horizontal semicircular canal bends a cupula (a flexible membrane across the canal). Hair cells translate this motion into electrical signals that are relayed by the fibers to other parts of the brain. These impulses drive reflexes that turn the eyes opposite to the direction of the head's motion, keeping them on target and helping to maintain stable balance.

▾ BALANCE AID: AN ELECTRONIC BYPASS

The planned prosthesis would use a miniature gyroscope to sense head rotation, taking over for defective structures in the ear. The gyroscope sits within a unit implanted behind the ear and consists of a vibrating microelectromechanical wheel (machined using the kind of photolithography that etches computer chips). The wheel deflects slightly when the head moves, changing the voltage on nearby capacitors housed within the hardware 1. A microprocessor in the gyroscope detects this change and sends signals to electrodes inserted in the inner ear 2, which relay the information to the vestibular nerve 3 and thus to the brain stem and, ultimately, to the nerves that adjust the positioning of the eyes.



labyrinth instructs your eyes to rotate down at exactly the same speed, thereby keeping images stable on the retina. Without this vestibulo-ocular reflex, the world would look as if you were watching a movie made by a shaky, handheld video camera. This reflex is the one that would be replaced by the planned prostheses, restoring much but not all of the lost equilibrium.

The vestibular labyrinth measures head rotation using three fluid-filled structures called semicircular canals, so designated because of their Hula-hoop-like shape. The semicircular canals reside in each ear at right angles to one another so that they can register head rotation in three spatial dimensions.

One canal in each ear measures rotation in the horizontal plane, for example. When you turn your head to the left, say, fluid inside the canal exerts pressure on a membrane that stretches across one end of the duct, bending hairlike projections, or cilia, on cells embedded in the base of the structure. The bowing of the cilia triggers signals in vestibular nerves that reach the brain stem and cerebellum, the centers for sensory perception and motor control that send messages to muscles that rotate the eyes opposite to the direction of the head movement.

A Balance Bypass

My colleagues and I at the Johns Hopkins Vestibular Neuroengineering Lab have developed and tested in animals one of the implants of so much interest to Gannon. It contains a miniaturized (micromechanical) gyroscope that measures head movement in all three dimensions, and its microprocessor sends signals to electrodes that stimulate three branches of the vestibular nerve. Electronics and sensing techniques pioneered for the more than 120,000 cochlear implants during the past 25 years will supply some of the technological underpinnings for this new generation of neural implants, easing the transition from research to clinical use.

FIRST VOLUNTEER for a prosthesis is a former steamfitter, Richard Gannon, who became disabled after an illness seven years ago.

We typically implant on only one side, because we would like to limit the surgical risks—such as the possibility of damaging structures in the inner ear involved in hearing—to just one ear. From our animal experiments, we believe a prosthesis that supplants the function of one set of semicircular canals will provide sufficient stability and balance to a patient with a vestibular disorder. Restoring function of structures in the inner ear that serve as gravity sensors might also be possible but should not be necessary to correct the visual blurring that most annoys those who have lost inner ear function.

Beyond the work at Johns Hopkins, other researchers are also developing vestibular implants. Daniel Merfeld, Wangsong Gong and their colleagues at the Massachusetts Eye and Ear Infirmary (MEEI) in Boston reported on the first prosthesis in 2000, a device that served as a replacement for one of the three semicircular canals, and they have shown that animals can adapt to inputs from the implant. Richard Lewis, also at the MEEI, is studying whether that device can stabilize posture.

More recently, a group led by James O. Phillips of the University of Washington has created a pacemakerlike device in an attempt to overcome the abnormal nerve firing that occurs during an attack of vertigo caused by Ménière's disease. Andrei M. Shkel of the University of California, Irvine, and Julius Georgiou of the University of Cyprus are working on integrated circuits to support the effort. Yet another group, led by Conrad Wall of the MEEI, is developing external devices to serve as aids to maintaining stable posture.

Mindful of the disability Gannon and similarly affected patients suffer, our group at Johns Hopkins hopes to begin clinical testing as soon as remaining technical and regulatory hurdles are overcome. If research proceeds as planned, bionic ears that restore the missing sixth sense will finally enable patients like Gannon to regain a sense of balance. ■

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➥ MORE TO EXPLORE

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Johns Hopkins Vestibular Neuroengineering Laboratory: **www.hopkinsmedicine.org/otolaryngology/research/vestibular/VNEL**