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Hearing Loss in Adults

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HEARING LOSS IN ADULTS IS ENCOUNTERED IN ALL MEDICAL SETTINGS and frequently influences medical encounters. This disorder constitutes a substantial burden on the adult population in the United States, yet screening for hearing loss is not routine,[1] and treatments are often inaccessible because of the high cost or perceived ineffectiveness.

BURDEN OF HEARING LOSS

The Global Burden of Disease Study[2] measured years lived with disability and found that hearing loss is the fourth leading cause of disability globally. In the United States, the prevalence of hearing loss doubles with every 10-year increase in age. Approximately half of persons in their seventh decade (60 to 69 years of age)[3] and 80% who are 85 years of age or older[4] have hearing loss that is severe enough to affect daily communication. Because of the aging population in this and other developed countries, hearing loss is likely to become an increasingly prevalent disability.

The primary effect of adult hearing loss is impaired communication, which can adversely affect relationships with family and friends and create difficulties in the workplace. Untreated hearing loss in adults also has indirect health, psychosocial, and economic effects and leads to social isolation and a reduced quality of life.[5–7] As compared with age-matched adults with unimpaired hearing, older persons with hearing loss have higher rates of hospitalization,[8] death,[9,10] and falls and frailty,[11,12] as well as higher rates of dementia[13–15] and depression,[16,17] even when known risks for these disorders are taken into account.[13] On a societal level, because of their hearing loss, persons with hearing loss achieve significantly lower levels of education than do those with normal hearing; they also have higher levels of unemployment or underemployment and lower levels of income than those with normal hearing.[18,19] Annual health care costs for middle-age U.S. adults with hearing loss are significantly higher than the costs of care for those without hearing loss.[19]

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TYPES OF HEARING LOSS

Peripheral hearing loss is typically categorized as conductive (caused by impairment of the outer or middle ear) or sensorineural (caused by dysfunction in the cochlea or spiral ganglion). Hearing loss that has both conductive and sensorineural components is categorized as mixed. Conductive hearing loss results from obstruction or disease of the outer or middle ear that prevents transmission of sound energy to the inner ear. The causes of conductive hearing loss range from cerumen impaction and otitis media to fixation of one or more of the middle-ear bones, mainly fixation of the stapes due to otosclerosis. Medical or surgical treatment of most types of conductive hearing loss often results in full restoration of hearing.

ASSESSMENT OF HEARING

Audiologic testing is performed to assess hearing thresholds across the range of frequencies that are important for human communication. Auditory thresholds are typically measured for air- and bone-conducted pure-tone stimuli in order to differentiate conductive from sensorineural hearing loss and to characterize the pattern of hearing loss at various frequencies. The term “threshold shift” refers to a change in hearing thresholds between sequential audiologic tests; it may reflect improvement or worsening of hearing. Testing the perception of speech signals of low redundancy (monosyllabic words) presented at a comfortable listening level in the absence of background noise is another method of assessing hearing in adults.

The broad term “sensorineural hearing loss” has been used by clinicians because, until recently, diagnostic tests could not determine whether a lesion was in the sensory or the neural portion of the peripheral auditory system. This distinction is now made by measuring optoacoustic emissions, performed by simultaneously presenting tones of different frequencies and sound pressures to the external canal and detecting sound emissions from the cochlea itself; the results reflect the functioning of outer hair cells of the cochlea. Auditory brain-stem responses also test the neural component of audition by recording synchronous neural activity of the auditory nerve and auditory brain-stem nuclei.

STRUCTURES OF THE EAR INVOLVED IN HEARING LOSS

The peripheral auditory system consists of the outer ear, the middle ear, and the inner ear (cochlea); the inner ear contains the mechanosensory hair cells that convert sound energy into neural signals (Fig. 1). Cochlear hair cells are innervated by neurons of the spiral ganglion, which project centrally to the auditory nuclei of the brain stem through the auditory nerve. Sensory hair cells are susceptible to damage from a variety of stresses, and since hair cells in the mammalian cochlea are not regenerated after they are lost, the resulting hearing loss is permanent. In many cases, the death of hair cells results in degeneration of spiral ganglion neurons, which complicates the treatment of hearing loss with cochlear implants because these devices directly stimulate the spiral ganglion neurons.

Sensory hearing loss is the result of damage to the organ of Corti (the sensory organ within the cochlea that houses the hair cells) or the stria vascularis, a portion of the inner ear that

provides metabolic support for the organ of Corti and generates the electrochemical (endocochlear) potential that is the driving force for transduction of sound by sensory hair cells.[20] In contrast, neural hearing loss is the result of loss or dysfunction of spiral ganglion neurons or of more proximal auditory structures. Auditory neuropathy is characterized by normal (or nearnormal) sensory hair-cell function coupled with abnormal neural responses and, usually, poorer word recognition than is typical in sensory hearing loss[18,21]; this type of hearing loss is caused by damage to the synapses that connect hair cells to spiral ganglion neurons or to asynchronous neural firing within the auditory nerve. For this reason, patients with auditory neuropathy may benefit less from hearing aids than those with sensory hearing loss.

CAUSES OF HEARING LOSS

Hearing loss can be caused by damage to any portion of the peripheral and central auditory systems. The main causes of sensorineural hearing loss are degenerative processes associated with aging, genetic mutations, noise exposure, exposure to therapeutic drugs that have ototoxic side effects, and chronic conditions.

AGE-RELATED DEGENERATIVE PROCESSES

The leading cause of adult onset hearing loss is he effects of aging on the auditory system. Hearing loss in older persons is caused not only by the degenerative effects of aging on the cochlea but also by the accumulated effects of exposure to noise and ototoxic drugs. Age-related hearing loss (presbycusis) is usually bilateral and symmetric and is most pronounced at higher frequencies (≥2000 Hz).[19] A prominent feature of this type of hearing loss is reduction in the ability to understand speech,[22,23] even if the sounds are loud enough. Sensory presbycusis refers to death or damage of the cochlear sensory hair cells with aging, and metabolic presbycusis refers to decreased functioning of the stria vascularis through age-related mechanisms that have not been fully determined.[24,25]

GENETIC MUTATIONS

More than 100 genes have known mutations that result in hearing loss that is not associated with disorders of other organs or with dysmorphic features (nonsyndromic hearing loss). Mutations in approximately 30 of these genes are associated with adult-onset or progressive hearing loss that is inherited as an autosomal dominant trait.[26] In addition, more than 500 syndromes that include hearing loss have been described. Hereditary hearing loss is relatively common among newborns, affecting approximately 1 in 1000 live births,[27] but it is difficult to estimate the heritability of adult-onset hearing loss, since genetic and environmental factors are not easily separable. Estimates of the heritability of adult-onset hearing loss range from 25 to 55%.[28] The majority of monogenetic causes of hearing loss involve mutations in genes that are required for normal functioning of the cochlea, and several of these genes specifically affect the functioning of sensory hair cells.[29] In addition, the genetics of susceptibility to age-related and noise-induced hearing loss are beginning to be understood.[30] The identification of genetic modifiers that enhance or reduce susceptibility to acquired hearing loss will be important for the development of therapies to preserve hearing.

NOISE EXPOSURE

Approximately 104 million people in the United States are exposed to levels of noise that can cause hearing loss,[31] and 1 in 4 adults in the United States has measurable hearing loss caused by exposure to harmful noise.[32] Even among people who report that their hearing is "excellent" or "good," nearly 20% have audiometric evidence of noise-induced hearing loss.[32] Workplaces such as factories and certain jobs in the military are associated with exposure to high noise levels; however, even people who do not work in these environments have a risk of noise exposure in daily life that they often underestimate. Loud sounds are pervasive in modern life, and noise exposure can occur in a variety of seemingly innocuous settings, such as concerts, movie theaters, and fitness classes with loud music, and through engagement in a range of activities, such as listening to music at home, participating in power sports (e.g., those involving motorcycles, all-terrain vehicles, speed boats, or snowmobiles), shooting, and using power tools.

Noise damages the sensory hair cells of the inner ear through the direct mechanical stress of intense sound pressure and by activation of stress-induced molecular pathways, including generation of reactive oxygen species and calcium overload.[33] Noise-induced hearing loss can be temporary or permanent, depending on the intensity and duration of exposure. The term "temporary threshold shift" is used to describe objective changes in hearing acuity that can be measured on audiometry immediately after an episode of exposure to loud sounds (e.g., attendance at a concert) and that revert to preexposure levels after a few days to 2 weeks. Temporary threshold shifts are characterized subjectively by decreased hearing sensitivity, a feeling of fullness in the ears, tinnitus (ringing), and a perception that sounds are muffled. Prolonged or repeated exposure to noise can cause the death of sensory hair cells and permanent hearing loss, referred to as a "permanent threshold shift." Death of hair cells can be followed by a slower loss of spiral ganglion neurons over a period of months or years.[34]

In the past, temporary threshold shifts were not thought to be associated with permanent damage to the auditory system; however, recent data indicate that noise exposures that result in temporary threshold shifts may cause permanent damage to the cochlea. In animal models, noise exposures that result in temporary threshold shifts lead to permanent loss of hair-cell ribbon synapses,[34,35] specialized synaptic structures that release neurotransmitters from hair cells in response to sound. Although our understanding of this type of synaptic loss is incomplete, it has implications for hearing function and for recommendations regarding safe noise levels.[36] It is not known whether synaptic loss is necessarily permanent, since in some animal models, there is partial recovery of the functioning of these structures.[37,38] A reliable, noninvasive clinical measure of cochlear synaptic damage has not been developed, although this is an area of active research.[39–41]

EXPOSURE TO THERAPEUTIC DRUGS

Various chemicals and drugs adversely affect the auditory system; the main ones in clinical use are aminoglycoside antibiotics and cisplatin, both of which are toxic to sensory hair cells. Hearing loss develops in approximately 20% of patients receiving aminoglycosides,[42,43] and the prevalence is as high as 56% among patients with cystic fibrosis,[44,45] a

population exposed to repeated courses of aminoglycoside therapy. Among adults who have received cisplatin, clinically significant hearing loss develops in approximately 60% of patients with testicular cancer[46] and 65% of patients with head and neck cancer.[47] Susceptibility to cisplatin-induced hearing loss depends on the cumulative dose of the drug, the age of the patient (children are more susceptible than adults), and status with respect to concurrent cranial irradiation.[48] Patients who have severe hearing loss caused by ototoxic drugs are likely to be identified and referred for follow-up auditory testing, but many more patients with mild-to- moderate drug-induced hearing loss are not identified and hence do not receive treatment for their hearing loss.[46]

SMOKING, ADIPOSITY, AND CHRONIC DISEASES

Strong associations between hearing loss and cigarette smoking, adiposity, diabetes mellitus, and other risk factors for cardiovascular disease are supported by epidemiologic studies, but causality remains uncertain. For example, in the Beaver Dam Eye Study, involving persons between the ages of 43 and 84 years, smoking, central adiposity, and poorly controlled diabetes mellitus were associated with hearing loss in later life, suggesting that vascular changes may contribute to age-related hearing loss.[49] On the basis of data from the National Health and Nutrition Examination Survey for the years 1999 through 2004, a study of patients with diabetes who were 20 to 69 years of age showed that low-density and high-density lipoprotein levels, as well as status with respect to coronary disease, peripheral neuropathy, and general health, were correlated with hearing impairment, whereas glycemic control, number of years since diagnosis, and type of hypoglycemic medication were not.[50] These putative associations with chronic systemic diseases suggest that some contributors to hearing loss may be modifiable.

Autoimmune forms of ear disease are characterized by progressive, fluctuating hearing loss with a variable time course. Although typically bilateral, symptoms may be more prominent in one ear, and one possible cause of sudden, unilateral sensorineural hearing loss is an autoimmune disorder. Ear disease may be associated with rheumatoid arthritis, systemic lupus erythematosus, Cogan’s syndrome, sarcoidosis, or other autoimmune disorders.[51] Glucocorticoids are the main treatment and are often used for long periods. The complications of this prolonged treatment led to a trial in which prednisone and methotrexate were compared with prednisone and placebo; the trial failed to show a benefit from the addition of methotrexate.[52]

SUDDEN HEARING LOSS

The prevalence of sudden, idiopathic hearing loss is 5 to 20 cases per 100,000 population, with approximately 4000 new cases per year in the United States. Sudden sensorineural hearing loss, defined as the onset of hearing loss over a period of 72 hours or less in one or both ears, is considered an otologic emergency because of evidence, albeit uncertain, that there is a benefit of early treatment with glucocorticoids. The audiometric criterion for diagnosis is a decrease in hearing of at least 30 dB, affecting at least three sound frequencies. The cause of sudden hearing loss is not known but is presumed to be viral, vascular, or autoimmune. The diagnostic workup involves testing to exclude identifiable

causes of sudden hearing loss, such as acoustic neuroma and rare tumors of the internal auditory canal.

A clinical practice guideline from the American Academy of Otolaryngology-Head and Neck Surgery[53] recommends that physicians evaluate patients presenting with a sudden onset of hearing loss in order to distinguish between sensorineural and conductive impairment, initially with a physical examination and tuning-fork tests, followed by audiometry when possible. Although high doses of oral glucocorticoids (typical dose, 1 mg per kilogram of body weight) and of intra-tympanic glucocorticoids have been used in the treatment of sudden, idiopathic hearing loss, spontaneous recovery in many patients and the lack of data from placebo-controlled trials make these treatment recommendations tentative. Nevertheless, most otolaryngologists recommend some form of glucocorticoid treatment for sudden hearing loss.[53]

PREVENTION OF HEARING LOSS

An epidemiologic study[54] has shown that the age-adjusted prevalence of hearing loss is declining in the United States. Possible explanations for this decrease include a reduction in exposure to occupational noise as a result of fewer manufacturing jobs and more widespread use of hearing protection, cessation of smoking, and better management of cardiovascular risk factors. Although the prevalence of hearing loss increases with age, it is not inevitable. Adults should be made aware of the potentially damaging and slowly cumulative effects of exposure to loud sounds such as the common sources of exposure noted above. Hearing protection includes using ear protectors (earmuffs or earplugs), avoiding or limiting time spent in loud venues, and using personal music systems at moderate volumes, and wearing noise-canceling headphones or earphones.

Despite the high prevalence of hearing loss among older adults, routine auditory screening is not currently recommended for asymptomatic persons. A review of data on primary care screening for hearing loss, performed for the U.S. Preventive Services Task Force,[1] concluded that additional research is needed to understand the potential effects of such screening on health outcomes but acknowledged that common screening tests, such as validated hearing-Ioss questionnaires and the whisper, finger-rub, or watch-tick test, or screening audiometry[55] can identify patients at risk for hearing loss. Primary care physicians are often the first to suspect and identify hearing loss, and they can play a role in referring patients for hearing evaluation and management.[56]

TREATMENT OF SENSORINEURAL HEARING LOSS

Despite increasing knowledge of the biology of the inner ear, hearing restoration is not currently available for most cases of hearing loss.[57] A review of novel therapies included 22 active clinical drug trials registered on the National Institutes of Health ClinicalTrials.gov website.[58] Most of these proposed treatments address cell-death pathways and mitigate the effects of oxidative stressors on inner-ear hair cells. Commercially sponsored trials of antibiotic and chemotherapeutic medications for the treatment or prevention of ototoxicity are planned or are under way (e.g., ClinicalTrials.gov number, NCT02819856). One study

uses a viral vector to deliver gene therapy to the inner ear.[59,60] Pre-clinical studies in animal models suggest that viral-vector gene therapy may be valuable in treating monogenetic hereditary hearing loss. Restoration or partial restoration of hearing and balance functions have been achieved with the use of gene therapy in mouse models of human deafness, including models of some forms of the Usher syndrome.[61–66]

HEARING AIDS AND OTHER DEVICES

A hearing aid is defined by the Food and Drug Administration (FDA) as a "wearable sound-amplifying device that is intended to compensate for impaired hearing." The goal of treatment with well-fitted hearing aids is to improve the audibility of even soft speech or music and other sounds while ensuring that sounds do not become uncomfortably loud. Hearing aids can be sophisticated instruments with a variety of customizable features that contribute to their high costs; whether performance improves with higher-cost devices is uncertain.[67] A variety of noncustomized devices, termed "hearing assistive technologies," are also available; they include amplified telephones, visual technologies such as captioning, video conferencing, and visual or vibrotactile alerts.[68] Hearing aids are regulated by the FDA, and state laws may restrict access to them. The devices are sold through audiologists and hearing-aid dispensers. The costs of services related to hearing-aid fitting are often bundled with the cost of the device, so the specific costs of the services and the technology are not transparent.[68]

The frequency of use of hearing aids by adults with hearing loss is low.[68] In a survey published in 2012, only 14.2% of adults with hearing loss reported wearing hearing aids.[69] Although the cost of the devices, typically $1,400 to $2,200, is probably a factor, other deterrents to the adoption of hearing aids include stigma, perceived ineffectiveness, ongoing costs (for batteries and maintenance), lack of comfort, and cosmetic appearance.[68] The United States is one of the few developed countries that does not offer government assistance for the purchase of hearing devices.[68] However, even in countries where assistance is provided, hearing-aid use is not universal among candidates; for example, the rate of use is less than 15% in Finland and is 50% in Denmark.[68] Efforts to increase use will therefore have to address multiple impediments.

COCHLEAR IMPLANTS

Persons with severe or total sensorineural hearing loss do not typically benefit from hearing aids, since inner-ear hair cells are not able to stimulate the auditory nerve in response to sound. In such cases, cochlear implants, which are surgically implanted devices that bypass the cochlear hair cells to electrically stimulate the auditory nerve, permit partial restoration of hearing and have been shown to improve speech perception and vocational, social, and psychological functioning,[70–72] as well as the quality of life for adults, including older adults.[73] Details of the function and use of cochlear implants can be found at https://www.nidcd.nih.gov/health/cochlear-implants.

The cost-effectiveness of cochlear implants has been established in developed countries[71] and in some developing countries.[71,74–77] These analyses have evaluated the lifetime costs of cochlear implants, including the costs of the device and of surgery and rehabilitation,

versus the benefits, as determined on the basis of health-preference measures. Measures of cost-effectiveness have also been used to compare cochlear implants with other treatments, such as educational programs for deaf persons, and these assessments have shown that cochlear implants compare favorably with other treatments.

INCREASING ACCESS TO HEARING AIDS

Hearing loss is increasingly being viewed as a public health problem.[68] In October 2015, the President's Council of Advisors on Science and Technology recommended that the FDA create a new regulatory class for hearing aids that can be sold over the counter for persons with mild or moderate hearing loss.[78] This recommendation was endorsed by the National Academies of Sciences, Engineering, and Medicine in their report titled "Hearing Health Care for Adults: Priorities for Improving Access and Affordability," released in June 2016.[68] They recommended that the FDA create a category of over-the-counter, wearable hearing devices that would be regulated to meet specific safety and quality standards and labeling specifications; the new FDA classification would preempt current state laws and regulations in order not to limit access to affordable hearing aids. Legislation has recently been signed into law that requires the FDA to create and regulate a category of over-the-counter hearing aids for adults who have mild to moderate hearing loss.[79,80] Opening the market to these devices should increase the options available to patients, decrease costs, and increase access.[81] Bulk purchasing by government agencies provides another opportunity to decrease costs. The Department of Veterans Affairs, for example, purchased approximately 20% of hearing aids on the U.S. market in 2013,[82] at an average cost of $369 per hearing aid as compared with $1,400 to $2,200 on the open market.[68]

CONCLUSIONS

Hearing loss is a major source of disability in adults, associated with serious communication and psychosocial problems and high health care costs, with economic implications at the societal and individual levels. Technologies exist to ameliorate hearing loss, but cost, health policies, and regulations limit access to these therapies. Efforts are under way to improve access to auditory health care for adults. Recent advances in our understanding of the underlying causes of hearing loss have led to efforts to develop drugs and therapies that can prevent or reverse hearing loss.

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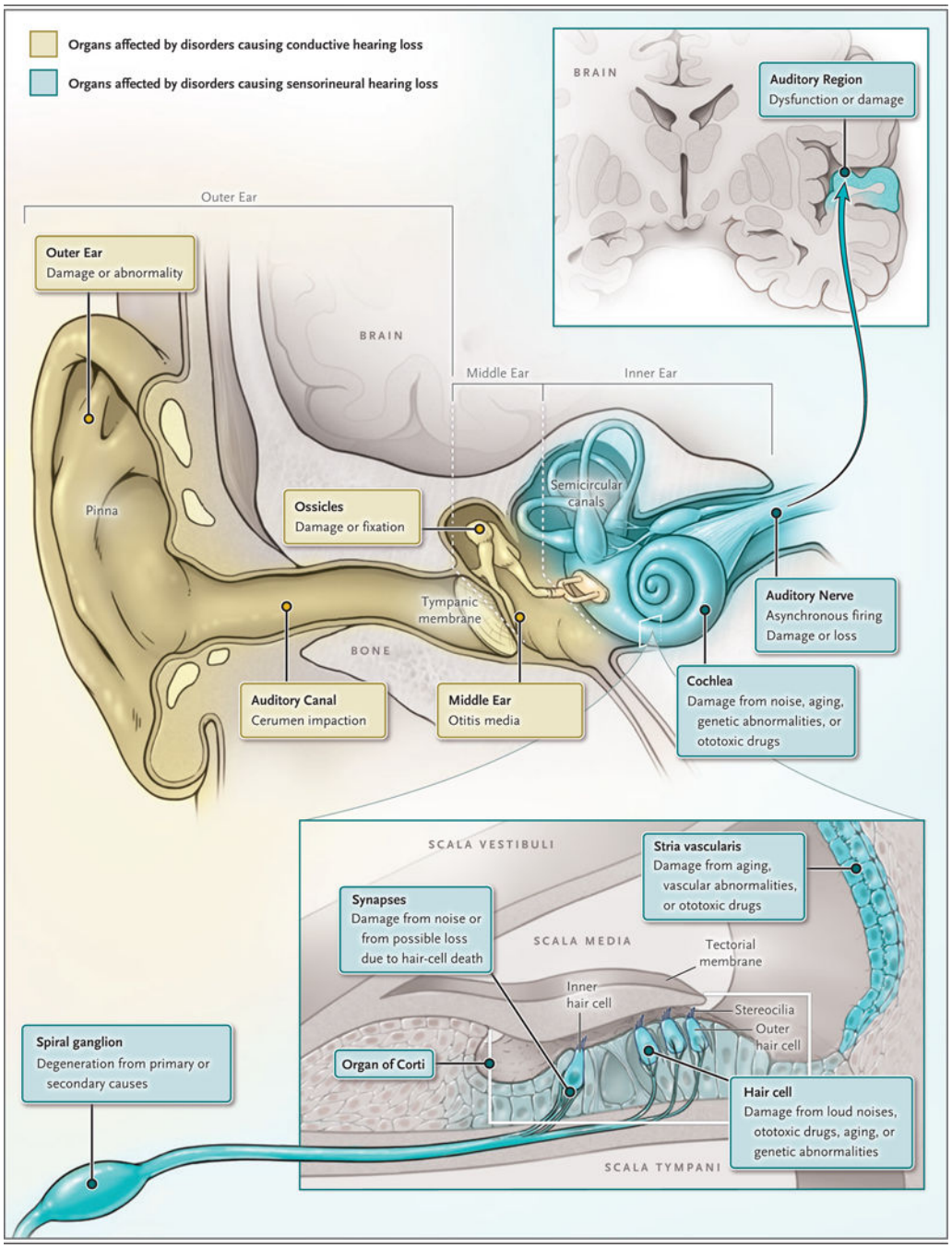

Figure 1. Diseases Affecting the Auditory System.

Shown are the auditory system and diseases affecting each component of the system, including the ossicular chain of the middle ear, the cochlea, the organ of Corti and hair cells, and the auditory nerve.