Physiopathologic and Electrophysiologic Changes of the Inner Ear in Hearing Losses

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In this review the authors discuss the physiopathologic and electrophysiologic changes of the inner ear in Meniere's disease, otosclerosis, ototoxicity, acoustic neuroma, presbycusis, noise-induced hearing loss, metabolic hearing loss, perilymphatic fistula, syphilis, autoimmune inner ear disease, congenital genetic hearing loss, and viral labyrinthitis. The etiology and pathogenesis of hearing losses are generally not well established; and the significance of inner ear changes in hearing losses are not exactly known. The explanations provided are usually not satisfactory. The real answers are hidden within the mystery of the ear. [Journal of Turgut Özal Medical Center 1997;4(3):319-328]

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İşitme kayıplarında iç kulakta ortaya çıkan fizyopatolojik ve elektrofizyolojik değişimler

Bu çalışmada, Meniere hastalığı, otoskleroz, ototoksisite, akustik nörinom, presbiyakuzi, gürültü ve metabolik hastalıklara bağlı işitme kayıpları, perilenf fistülü, frengi, iç kulağın otoimmün hastalığı, konjenital genetik işitme kayıpları ve viral labirintit gibi iç kulağı tutan hastalıklarda iç kulakta görülen fizyopatolojik ve elektrofizyolojik değişiklikler derlenmiştir. Işitme kayıplarının etyoloji ve patogenezi kesin olarak henüz ortaya konamamıştır. İşitme kayıplarında iç kulaktaki değişikliklerin anlamı da tam olarak anlaşılamamıştır. Ortaya atılan hipotezler yeterli görünmemektedir. Doğru yanıtlar iç kulağın gizemi içinde saklıdır. [Turgut Özal Tıp Merkezi Dergisi 1997;4(3):319-328]

Anahtar Kelimeler: *Elektrofizyoloji, işitme bozuklukları, sensorinöral-iletim tipi-yüksek frekans-gürültüye bağlı-parsiyel işitme kaybı, labirint*

In this review we will discuss the physiopathologic and electrophysiologic changes of the inner ear in common hearing losses. Each disease or disorder will be handled separately. The etiology and pathogenesis of hearing losses are generally not well established; and the significance of inner ear changes in hearing losses are not exactly known. The explanations provided are usually not satisfactory. The real answers are hidden within the mystery of the ear.

Meniere's Disease

Basic pathologic finding of Meniere's disease is endolymphatic hydrops, which usually involves both scala media and otolith organs. Rarely, hydrops may involve segmentally only the vestibular part, but frequently the cochlear part is also involved. Cochlear hydrops is seen in every case, saccular hydrops in majority of cases, but utricular hydrops is rare. In half of the cases the endolymphatic space swells towards

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helicotrema; the saccule extends into the semicircular canal in one-third of the patients (1-3).

The symptoms and findings in Meniere's disease are explained on mechanical and biochemical grounds. According to the mechanical theory, there is an increased pressure in the endolymph; elimination of increased pressure after sac surgery is thought to cause the disappearance of clinical findings (1).

The principal problem in Meniere's disease is thought to be the disordered absorption of endolymph in endolymphatic canal and sac. Perisaccular fibrosis, loss of epithelial integrity and atrophy of the sac, hypoplasia of the vestibular aqueduct, narrowing of the lumen in the endolymphatic duct have been determined in temporal bone studies. A lack of periaqueductal pneumatization, a lack of pneumatization medial to the arcuate eminence, a short vestibular aqueduct, a narrow external aperture of the vestibular aqueduct, a reduction in size of the mastoid air cell system, and an anteriorly and medially displaced lateral sinus are the findings that are thought to be related to the Meniere's disease. Membranous ruptures have been described as a cause of all attacks of Meniere's disease, but some cases show no evidence of rupture. Ruptures are more often seen in the cochlear duct and not in the saccule or other vestibular structures. Saccular hydrops can be so severe as to extend into the semicircular canal; such distension can physically alter function of the crista ampullaris, causing instantaneous vertigo. In cases where ruptures do not heal, the membranous labyrinth is seen as collapsed. Leakage of potassium into the perilymphatic compartment as a result of Reissner's membrane rupture with subsequent contamination of the cortilymph through the canaliculae perforantes might be expected to produce symptoms of cochlear failure. As a result of fibrous tissue proliferation in the vestibule there may be adhesions between the footplate and utricle and saccule (1-5).

Both the longitudinal and radial flow of the endolymph is thought to be disordered in Meniere's disease. Excess production of endolymph in the stria vascularis and insufficient production of perilymph may be operational in hydrops (3).

Hair-cell populations in the organ of Corti, the maculae of the saccule and the cristae of semicircular canals and the neuron population of the spiral and the vestibular ganglia are normal under light microscope. Na^+, K^+, glucose and protein concentrations in the endolymph (a mixture of endolymph and perilymph) are within normal limits (3).

On pure-tone audiogram three main patterns may be found: a hearing reduction maximal in the low or high tones, or a flat loss. The rising type of curve is generally found in the earlier stages. As the disease progresses, the curve is seen to flatten out. Speech discrimination is impaired, although much less severely than in patients with a neural lesion. Recruitment, Metz phenomenon are found. The static impedance of the involved ear increases due to hydrops. On electrocochleography, widened AP/SP waveform due to enhanced negative SP is determined; the cochlear microphonic amplitude is very variable, though it tends to become smaller and more distorted with advanced disease; "after ringing" may be observed. Dehydration tests based on the use of glycerine and urea may be useful not only in the diagnosis of Meniere's disease, but also in the assessment for the suitability of diuretic treatment and in the selection of patients for operations on the endolymphatic sac. Vestibular investigations show either a simple canal paresis or sometimes a directional preponderance, but a normal response is by no means uncommon and does not rule out the presence of Meniere's disease (1-3).

Otosclerosis

Otosclerosis is a primary disease of the otic capsule. It causes the fixation of the stapedial footplate at the oval window, thus leading to conductive hearing loss. On-off phenomenon of the stapedial reflex and reversed reflex due to tensor tympani muscle contraction are observed in cases with early incomplete fixation of the stapedial footplate. First the contralateral then the ipsilateral stapedial reflex disappears. By decreasing the inertia of the inner ear fluids otosclerosis of the footplate causes a decrease in bone conduction, leading to the Carhart notch. The Carhart notch is a depression in the bone-conduction audiogram of patients with clinical otosclerosis. The middle frequencies from 0.5 to 2 kHz, which correspond to the resonance frequency of the middle ear, can be substantially improved following successful stapes surgery. Obstruction of the round window orifice by otosclerotic focus leads to a mixed type of hearing loss. Liberation of toxic metabolites from the otosclerotic focus into the fluids of the inner ear, the presence of proteolytic enzymes in the

perilymph and endosteal involvement by otosclerosis in the cochlea are possible causes of sensorineural hearing loss. Vascular compromise and hypoxemia of the inner ear due to vascular shunts between the otosclerotic focus and the vessels of the inner ear have been implicated as causes of sensorineural hearing loss. According to Otto Mayer's theory, venous obstruction caused by invasion of the root of the spiral lamina in the basal turn of the cochlea by otosclerotic bone gives rise to incompetence of the venous drainage of the anterior and middle spiral veins, leading to neuroepithelial degeneration of the inner ear. Otosclerotic foci producing end-organ and/or neural degeneration, biochemical changes in the perilymph, extensive capsular otosclerosis causing labyrinthine hydrops are causes related to changes in the inner ear. Na^+, K^+, glucose and protein concentrations in the perilymph are within normal limits (6-10).

Tinnitus is sometimes seen in patients without cochlear degeneration when it is the result of an abnormal degree of vascularity of the otosclerotic bone; more often, it is an indication of sensorineural degeneration. Vertigo is probably the result of the action of toxic enzymes, which are liberated by the otosclerotic lesion, on the vestibular labyrinth. The coexistence of Meniere's disease may be considered if vertigo is a very prominent feature (6,8).

Ototoxicity

Aminoglycosides: Resorption in the stria vascularis is the probable mechanism by which the aminoglycosides are eradicated from the fluids of the inner ear. The stria itself may be damaged by the toxicity thus slowing the rate of resorption of the drugs which are, therefore, removed from the inner ear more slowly than the blood. The hair cells are therefore exposed to high levels for a long time. Damage has been observed in the stria vascularis as well as in the neuroepithelia of the cochlea and vestibular apparatus. Aminoglycoside exposure results in injury to the secretory and reabsorptive tissues of the labyrinth, thereby disturbing microhomeostasis, with subsequent injury to the sensory cells. The drug exerts an immediate physiologic effect on the transduction of sensory input by reversibly blocking calcium-sensitive potassium channels on the apical aspect of the receptor cell. Eventual degeneration of the sensory cell is believed to be due to inhibition of the synthesis of structural proteins and/or interference with cell membrane lipid metabolism. An influence on protein synthesis in mammalian hair cells exists. The drugs can reduce the membrane Na^+-K^+ ATPase and thus interfere with intracellular metabolic processes changing the ionic content of the endolymph leading to a fall in K^+ and a rise in Na^+ ions. Aminoglycosides inhibit polyphosphoinositide metabolism, which is essential for control of cell membrane permeability and maintenance of membrane structure. A reduction in the action potential and cochlear microphonic of electrocochleography and a decline in endocochlear resting potential was observed in patients under toxicity. A high frequency sensorineural hearing loss and/or a loss or decrease of labyrinthine function on caloric and rotational testing may appear (11-14).

Loop diuretics: Ethacrynic acid, frusemide and bumetanide lead to reversible sensorineural hearing loss by inhibiting cochlear Na^+-K^+ ATPase and cochlear adenylate cyclase. Permanent depression of cochlear activity and severe damage to the organ of Corti is seen when they are used in combination with aminoglycosides. They lead to a depression of the cochlear microphonic, endolymphatic potential and eight nerve action potential, as well as a decrease in vestibular nystagmus in response to caloric irrigation. These changes result from changes in the electrolyte composition of the endolymph and cortilymph, the perilymph being remarkably stable in its composition during intoxication (11-13).

Salicylates: Salicylates lead to reversible sensorineural hearing loss without demonstrable morphologic injury. They selectively reduce cochlear action potential, lead to a greater drop in N1 action potential than in the microphonic potential. There is no change in auditory evoked brain stem response. They lead to vasoconstriction of capillaries of the spiral ligament and stria vascularis by way of their effect on prostaglandin synthesis, thus leading to vasomotor disturbances and ischemia of the inner ear. Salicylates uncouple oxidative phosphorylation, inhibit various transaminases and dehydrogenase systems, and competitively inhibit NAD. There is a decreased electrical activity in the cochlea. This can reflect a decrease in metabolic activity of the stria vascularis and organ of Corti. Glucose levels are increased, reflecting a rise in blood glucose, but Na^+, K^+ and total protein concentrations remain unchanged. Salicylates interfere with the cochlea's ability to generate a neural action potential whereas the cochlear microphonic is

unchanged or if anything enhanced. The reversible effect on the action potential is greater in the higher frequencies. In transtympanic electrocochleography a recruiting biphasic action potential of the pattern associated with cochlear hair cell damage is noted. It is possible that salicylate produces its ototoxic effect by a temporary metabolic blockade at the synapse between hair cell and neuron (11,12,15).

Antimalarial agents: Quinine and chloroquine cause reversible or dose-dependent permanent sensorineural hearing loss, which is presumed to be due to vasoconstriction of the cochlear microvasculature with subsequent ischemia (11,12).

Cis-platinum: Cis-platinum leads to bilateral, irreversible, high frequency sensorineural hearing loss by causing degeneration of hair cells and wallerian degeneration of cochlear nerve (11,12).

Acoustic neuroma

Degenerative changes in the cellular structures of the inner ear and biochemical alterations in the ear fluids secondary to the presence of an acoustic neuroma may account for the fact that the audiological picture may appear to be cochlear or exhibit mixed cochlear and retrocochlear features. Cochlear changes may result from interference with the arterial blood supply of the inner ear. Venous backpressure on the cochlea from meatal obstruction is unlikely to be responsible for inner ear changes. Atrophy of the organ of Corti, most frequently in the basal turn, vacuolisation of the stria vascularis, extensive or total loss of spiral ganglion cells are the inner ear changes secondary to acoustic neuroma. Protein concentration of perilymph is increased, but Na^+ and K^+ concentrations are within normal limits. There appear to be no correlation between the degree of hearing loss and the extent of perilymph protein elevation. An exudate may even be seen in the perilymphatic spaces (16-19).

On pure-tone audiogram, a unilateral high frequency loss is most frequent, but any pattern of neurosensory loss is possible, including normal audiometric findings. Word discrimination is reduced out of proportion to pure-tone loss, but any pattern is possible including normal. Retrocochlear findings on ABR include ipsilateral absolute wave V, I-V, I-III and III-V interpeak latency prolongation, contralateral wave V latency prolongation in large tumors with brainstem shift ("offside" abnormality). Ipsilateral increased latency and decay of stapedial reflex are observed. On ENG ipsilateral marked hypofunction or absent response is most common; positional nystagmus is occasionally seen (16,20).

Presbycusis

Sensory presbycusis is due to the atrophy of the organ of Corti, most prominent in the basal turn; it is manifest clinically by an abrupt high-tone hearing impairment; it does not impair hearing for speech frequencies. Neural presbycusis is related to the degeneration of the spiral ganglion cells starting at the basal end, and of the neurons of the higher auditory pathways; there is high tone hearing loss with disproportionately severe impairment of speech discrimination. Metabolic presbycusis is due to defects in the physical and chemical processes of energy production in sense organs; the underlying pathologic change is atrophy of the stria vascularis resulting in a flat audiogram. Mechanical presbycusis is characterised by a slowly progressive hearing loss for high frequencies without any abrupt descent; it is believed to be due to a disorder in the mechanics of the cochlear duct, such as thickening of the basilar membrane in the basal turn, increased number of fibrils and accumulation of an amorphous osmiophilic material. Not only the cochlea, but also the cochlear nuclei are involved in the degenerative processes associated with ageing (21-23).

Noise-induced hearing loss

Acoustic trauma: Immediately after exposure to short, intense, uninterrupted sound, the anatomic changes range from a moderate disarray of stereocilia of inner and outer hair cells to complete absence of the organ of Corti and rupture of Reissner's membrane. No changes are ordinarily found in the bone, nerves, blood vessels, stria vascularis, spiral ligament or limbus, although the endolymph may contain debris from destroyed hair cells and other structures. Pronounced swelling of various structures occurs within a few minutes and edema of the stria vascularis appears shortly thereafter. Much of the swelling observed is caused by an increase in potassium content of the perilymph, due to invasion of endolymph into the perilymphatic space when rupture of structures that

separate the two fluids occurs. With destruction of the hair cells, secondary degeneration takes place; ganglion cells and nerve fibers will also be missing in a region where hair cell destruction is complete (24,25).

Habitual exposure: Long-term noise induced hearing damage may represent a gradual accumulation of noise microtrauma, or it may be the outcome of a slowly accumulating exhaustion of metabolites at the cytochemical or enzymatic levels not involving direct gross tissue destruction. These biochemical changes eventually produce widespread hair cell destruction only indirectly or auditory fatigue is the precursor of noise induced hearing damage. A loss, first, of outer hair cells, then inner hair cells and supporting cells, followed by degeneration of nerve fibers and the spiral ganglion (24,26).

Noise stimulation produces a decrease in the oxygen tension in the cochlear duct. After the sound level reached 120 dB SPL, blood flow in the cochlea increases immediately. This implies that the decrease in oxygen tension associated with moderate exposure indicates only an increase in oxygen consumption, not necessarily a decrease in oxygen supply. Alterations in concentrations of RNA, DNA, succinic and lactic dehydrogenase, ATP, GABA, glutamate, various enzymes and metabolites involved in maintenance of cochlear integrity, and changes in membrane permeability and transport processes occur in the fluids and tissues of the cochlea in response to noise exposure (24-26).

On a pure tone audiogram there will be a notch of sensorineural hearing loss due to a threshold shift at 3000-6000 Hz region. With continued exposure the notch becomes deeper and wider, with a temporal plateau at about 60 dB HL. High frequency perception may be completely gone. After this, the low frequencies are more and more affected, until a state of near-deafness exists. There will be recruitment and diplacusis (24,25).

Metabolic hearing loss

Renal disease: The hearing loss in patients on dialysis does not appear to be correlated with the level uremia or the degree of electrolyte abnormality, but it does correlate somewhat with the number of dialysis. Ototoxic antibiotics and diuretics, infection, diabetes mellitus, hypertension, arteriosclerosis, hemodynamic changes associated with renal dialysis and/or transplantation may be the conditions associated with hearing loss. Alport's syndrome (chronic nephritis, hematuria, progressive renal failure associated with hearing loss) may be related to an abnormality of a structural gene at a locus governing the composition of basement membrane in the glomerulus, inner ear and lens capsule; histologically there are degeneration of the stria vascularis, a loss of cochlear neurons, atrophy of the spiral ligament, loss of hair cells and deposits of basophilic substances in the stria vascularis, which are not specific for any particular disease (27-29).

Hypoxia: In the hypoxic cochlea the oxygen tension falls first in the tunnel of Corti, then along the cochlear duct. The endolymphatic potential falls progressively along the cochlear duct, and a decrease in the endolymphatic K^+/Na^+ ratio occurs, as does a decrease in the cochlear microphonic potential. The stria vascularis is more sensitive to oxygen lack than the organ of Corti. Spontaneous nerve fiber activity and the response to sound are lost during anoxia. Drugs (salicylates), hypercholesterolemia, arteriosclerosis, hyperlipidemia, hypercoagulability, and inflammation (viral, allergic) all may result in hypoxia of the cochlea (27).

Calcium and phosphorus metabolism

Osteogenesis imperfecta: Osteogenesis imperfecta is an hereditary disorder of collagen synthesis, and it leads to a conductive and/or sensorineural hearing loss. Tympanometry shows a tendency to high normal or raised compliance values. Although fixation of the stapes is invariably present in cases with a conductive loss, hypermobility of the tympanic membrane due to reduced stiffness of the fibrous layer, or fracture or aplasia of the stapedial crura may coexist (27,28,30).

Paget's disease: Paget's disease is a disease of bone characterised by bone resorption and compensatory increase in bone formation. The type of hearing loss most frequently encountered is progressive and mixed with both conductive and sensorineural components. The otic capsule is spared until advanced changes are present. Involvement of the labyrinthine capsule begins in the outer periosteal layer; the middle enchondral layer is more resistant and the greatest resistance is present in the endosteal layer. The stapedial reflex is often present. Changes

are rarely present in the stapes footplate. Pagetic changes in the other ossicles and the formation of bony spurs in the epitympanum interfering with incudomalleal mobility are the common findings accounting for a conductive hearing loss. Pagetoid osteitis involving the endosteal layer of the otic capsule results in degenerative changes in the stria vascularis with atrophy of both the cochlear duct and vestibular labyrinth. The basal turns of the cochlea are most severely affected and it is suggested that a local toxic effect caused by pagetic disease of bony labyrinth leads to hearing loss. Secondary endolymphatic hydrops of the cochlear duct and saccule, and atrophy of the membranous semicircular canals have been described. The inner ear loss is mainly sensory with relatively well preserved speech discrimination, but later secondary neuronal degeneration occurs. Bony softening and deformity of the skull base can lead to acquired basilar impression and possibly sensorineural hearing loss by torsion of the eight nerve or its associated vasculature. The medial ends of the petrous pyramids become tilted upwards due to acquired basilar impression (31,32).

Fibrous dysplasia: In this disease, normal bone is replaced by fibrous tissue and poorly formed trabecula of immature woven bone. The commonest presenting otologic symptoms are progressive conductive, rarely sensorineural hearing loss, localised swelling of the temporal bone and progressive bony occlusion of the external auditory meatus. About 15 % of the patients with hearing loss have total or profound sensorineural deafness and the remainder have an early conductive loss. Labyrinthine involvement, facial nerve paralysis, blockage of Eustachian tube leading to middle ear effusion, and rarely bony narrowing of the internal auditory meatus with progressive impairment of function of the seventh and eighth cranial nerves may occur (31,33).

Osteopetrosis: In this disease there is a failure of resorption of cartilage and excessive formation of immature bone leading to thickening of the cortex and narrowing or obliteration of the medullary cavity. In the malignant recessive form there is sensorineural hearing loss. In the benign dominant form the hearing loss is usually conductive, but occasionally is mixed and is caused by impaired ossicular mobility by osteopetrotic bone. Recurrent facial palsy is a frequent manifestation (27,31,34).

Bilirubin metabolism: The hearing loss of kernicterus appears to be associated with a cochlear lesion. Degenerative changes have been demonstrated in cochlear nuclei and central auditory pathways. The pigment in the cochlear nuclei is deposited tonotopically so as to cause a high-tone hearing loss. No pathologic changes have been demonstrated in the temporal bone (27).

Diabetes mellitus: Diabetes has been claimed to cause a fluctuating hearing loss. The mechanisms of hearing loss include small vessel disease causing hypoxia of the inner ear, primary diabetic neuropathy, Neuropathy due to involvement of vaso nervorum, or alterations in inner ear glucose levels. A deposition of PAS(+) material occurs in the capillary walls of stria vascularis, with aneurysmal dilatation of the capillaries and a decreased number of cells in the spiral ganglion. The primary diabetic neuropathy may be due to the accumulation of sorbitol within the nerve tissue. The secondary neuropathy is due to a decrease in the blood flow of the vaso nervorum. The neurons show a thickened basement membrane of the Schwann cells, segments of demyelinization, and changes in the biochemistry of the lipids. Changes in the glucose concentration in the inner ear may alter hearing. Didmoad syndrome consists of diabetes insipidus, insulin dependent juvenile diabetes mellitus, optic atrophy and progressive high-tone hearing loss (27,28,35).

Adrenocortical insufficiency: Adrenocortical insufficiency may be associated with the symptoms of Meniere's disease. There may be an increased sensitivity to sound, decreased pure-tone thresholds, decreased discrimination, and a loss of sound localisation, but there is no recruitment. Adrenoleukodystrophy also includes hearing loss with preservation of the caloric response of the vestibular system (27).

Hypothyroidism: A progressive mixed hearing loss appears. There are deformities of the malleus and incus, incomplete ossification of the stapes, distortions of the round and oval window, poorly developed mastoid process, thickened middle ear mucosa and tympanic membrane, Eustachian tube obstruction and hyperostosis of the promontory and occasional closure of the round window. In the inner ear there are loss of hair cells, loss of cochlear potentials, changes in the spiral ganglion cells, and a general degeneration of organ of Corti, including the tectorial membrane (27,28,36).

Perilymphatic fistula

Perilymphatic fistula leads to sudden, fluctuating or progressive sensorineural hearing loss by distorting the Na^+/K^+ ratio of the perilymph. Fistula test may or may not be positive. The audiometric pattern may be rising, flat, or down-sloping, and may give a positive response to dehydration with glycerol or urea. An elevated SP/AP ratio may be present on electrocochleography and revert to normal with dehydration. Tympanic membrane compliance, electronystagmography are usually normal. ABR reveals normal absolute latencies and interwave intervals (1,28).

Syphilis

The temporal bone and other otic structures may be involved in virtually any stage of either congenital or acquired syphilis. Treponemes gain access to the ear and temporal bone via hematogenous dissemination from a regional or distant primary site. The histologic changes include a mononuclear inflammation, obliterative endarteritis, dense fibrosis common in the periosteal region, and gumma, a focus of granulomatous inflammation, characterised by a central area of coagulation necrosis. In the inner ear, the histologic picture is often dominated by inflammation of the otic capsule, with or without gumma formation. Secondary resorption of the otic capsule is common and is often accompanied by some degree of endolymphatic hydrops. Atrophy of the organ of Corti, stria vascularis and spiral ganglion, degeneration of the macula of the utricle and saccule, atrophy of the cristae of the semicircular canals and atrophy of the cochlear and vestibular branches of the eighth cranial nerve are inner ear changes encountered during syphilis infection. Productive periostitis with associated periosteal new bone formation may produce irregularity of inner ear margins of the bony labyrinth. In severe cases, the lumina of the labyrinth may be obliterated by new bone formation. Submucosal fibrosis in the middle ear, deformities of the middle ear ossicles, notably the crura and footplate of the stapes, fusion of the incudomalleal and incudostapedial joints, fusion of the head of the malleus with the lateral wall of the attic and perforation of the tympanic membrane complicated by secondary cholesteatoma are the middle ear changes encountered during syphilis (31,37,38).

Involvement of the ear is not, in general, a prominent feature of early congenital syphilis. In contrast, otic involvement may be a striking feature of the late congenital form of the disease. In those cases occurring early in childhood, the deafness is characteristically of sudden onset, bilaterally symmetrical, and profound. Among those cases occurring in adolescence or adulthood, the symptoms may begin abruptly or gradually, are often asymmetrical, and fluctuate. Hearing loss is characteristically of the sensorineural type secondary to labyrinthine involvement, with the most striking deficit in the lower frequencies; poor speech discrimination and loudness recruitment are typical. A conductive auditory deficit in cases with middle ear involvement, features of the endolymphatic hydrops, positive Hennebert's sign and Tullio phenomenon may be encountered (31,39).

Involvement of the inner ear may be encountered in both early and late acquired syphilis. Patients with acute syphilitic meningitis may develop bilateral profound sensorineural deafness as a result of extension of infection of the vestibulocochlear nerve. Inner ear involvement is well documented (31,37).

On transtympanic electrocochleography an enhanced summating potential with a small cochlear microphonic is found. Secondary neuronal degeneration associated with more profound degrees of hearing loss, alterations of the stapedial reflex to a retrocochlear pattern with elevated thresholds and decay, a relative greater impairment of speech discrimination are audiological changes associated with syphilis. The pattern of pure-tone audiometry then becomes flattened or high-tone in character (31,37,39).

Continuous antigenic stimulation resulting from a persisting low-grade syphilitic infection, either locally in the temporal bone or elsewhere, may lead to continuous and excessive immune complex production with secondary pathological changes including inner ear involvement. The precise role of immune complexes in the pathogenesis of sensorineural hearing loss remains to be defined (31,37-39).

Autoimmune inner ear disease

The autoimmune inner ear disease is an uncommon, quite well defined, but poorly understood entity. The immunologic mechanisms, either

independently or possibly synchronously, may contribute to the development of autoimmune inner ear disease. It may occur as a primary autoimmune disorder or may appear as an occasional local manifestation of a major systemic disorder due to an underlying immune system defect. The presence of a rich network of lymphatic capillaries and venules surrounding the endolymphatic sac and duct in guinea-pigs, and the interaction between macrophages and lymphocytes within the sac lumen suggests that the main site of antigen processing may be the endolymphatic sac. The finding of autoantibodies towards inner ear antigens, beneficial response to steroids and immunosuppressives of some inner ear diseases further supported the concept of autoimmune inner ear damage (31,40,41).

The labyrinth barrier analogous to the blood-brain barrier existed with respect to immunoglobulin equilibrium. The hypothesis of an inner ear immunodefence system primarily located in the endolymphatic sac was supported by further studies which indicated free and tissue-bound IgA and IgG immunoglobulins restricted to the endolymphatic sac region in human ears (31,40,42).

The otologic features consist of progressive sensorineural deafness, often bilateral and asymmetric, reduced vestibular responses, symptoms of pressure and tinnitus and very occasionally disruption of soft tissue of the middle and external ear with facial paralysis. It is disorder of young people in their 30s and 40s. The deafness progresses over weeks to months. Audiometric curves may be up- or downsloping, and the discrimination scores may be disproportionately poor in relation to pure tone thresholds (31,40,41).

Patients who warrant detailed investigation for autoimmune sensorineural hearing loss are those with progressive or fluctuant bilateral disease that does not respond to conventional medical therapy, coexistent autoimmune disease of other systems, abnormal otologic immune profile (complete blood count with differential, urinalysis, ESR, FTA-ABS, ANA, RF, C1q-binding, CH50, Raji cell assay, cryoglobulin count). There is no known specific immunologic test for autoimmune hearing loss (31,40,42).

Congenital genetic hearing losses

Michel's aplasia: Michel's aplasia is characterised by total lack of development of the inner ear. In some cases even the petrous portion of the temporal bone is not developed, whereas in others it is present but is underdeveloped at the usual site of the labyrinth. The external and middle ears may be normally formed and apparently capable of functioning (43,45).

Mondini's aplasia: Mondini's aplasia has been described as a flattened cochlea with development only of the basal coil. There may be only one and one-half turns. The agenesis is rarely symmetrically bilateral, but the other ear always shows some degree of malformation. The vestibular structures and their associated neural elements may be similarly underdeveloped. An enlarged endolymphatic duct and sac and a deficient utriculoendolymphatic valve are commonly found associated with collapse of Reissner's membrane or an absence of endolymphatic hydrops. It may be associated with an absence of the oval and round windows along with other aplastic lesions of the middle. Auditory function ranges from marked deafness to normal hearing (43,45).

Scheibe's aplasia: Scheibe's aplasia is the most common form seen in inherited congenital hearing losses. The bony labyrinth is fully formed, as are the membranous utricle and semicircular canals. The saccule and cochlear duct is represented by mounds of undifferentiated cells. The tectorial membrane is reduced in size. The scala media is collapsed. A few hair cells can usually be seen histologically, and there may be some hearing remaining (43,45).

Alexander's aplasia: Alexander's aplasia is characterised by aplasia of the cochlear duct. The organ of Corti and adjacent ganglion cells of the basal coil of the cochlea are most affected, resulting in a high frequency hearing loss. Hearing remains in the low frequencies (43,45).

Viral labyrinthitis

Congenital rubella: Most cases of fetal infections with rubella in the first trimester are symptomatic, with the major triad of cataracts, heart disease and deafness. The incidence of hearing loss among those infants with symptomatic congenital rubella is about 50 %. Infants infected with rubella during the second or third trimester are usually asymptomatic; about 10 to 20 %

of these are later found to develop a hearing loss. Most of these children have a bilateral hearing loss that may be asymmetric, with an audiometric configuration that tends to be flat or gradually sloping downward from low to high. In addition to damage to inner ear cerebral involvement may be associated. A partial collapse of Reissner's membrane and the saccular wall and strial degeneration are found histopathologically; the utricle, semicircular canals, vestibular neuroepithelia, and nerves are usually unaffected. The hearing loss resulting from congenital rubella may be severe or mild, unilateral or bilateral, but is permanent (44,45).

Cytomegalovirus (CMV): Fetal CMV infection most commonly leads to mental retardation, microcephaly, hepatosplenomegaly, and deafness. CMV infected the epithelial cells of the cochlea, saccule, utricle, and semicircular canals. Hydrops of the cochlea, and saccule and collapse of Reissner's membrane have been observed. The incidence of sensorineural hearing loss in those infants who are symptomatic at birth is about 30 %. Normal appearing infants who shed the virus in their urine are also at risk to develop hearing loss. The pattern of hearing loss is rather inconsistent. Hearing loss can be symmetric, with impairment greater in the high frequencies. An asymmetric or unilateral hearing loss has also been reported (44,45).

Mumps: Mumps is probably the most common cause of unilateral acquired sensorineural hearing loss in children. Atrophy of the stria vascularis and organ of Corti, with partial collapse of Reissner's membrane mainly in the basal turn and decreased cochlear ganglion cells are found in the temporal bone (44,45).

Measles: The hearing loss is usually symmetric, bilateral, and moderately severe, with high tones more affected than the low. Pathologic findings in the temporal bone include atrophy of the organ of Corti and vestibular organs, distortion of the tectorial membrane, strial atrophy and saccular collapse; these changes were most severe in the basal turn (44,45).

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