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Article

Pathogenesis and Etiology of Hearing Loss in Children

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Abstract

Hearing loss in infancy leads to preventable speech, language, and cognitive developmental delay [1, 2].

Sensorineural hearing loss (SNHL) is caused by damages, problems, or issues related to the inner ear such as the cochlea with or without the auditory nerve; cranial nerve VIII, involvement.

There are three anatomic areas which include the outer ear: composed of the auricle and external auditory canal and the middle ear: which includes the tympanic membrane, ossicles, and the middle ear space, the inner ear: composed of the cochlea, semi-circular canals, and internal auditory canals.

The unique anatomical shape of the auricle catches the incoming sound waves to send them down the external auditory canal.

Hearing risk assessment should be part of all health visits while regular hearing screening checks are done for all children from 4 to 21 years [1, 2].

Assessment of hearing loss includes history, physical examination and specific hearing assessment tests.

Keywords: Hearing loos; conductive; sensorineural; outer ear; middle ear; inner ear; SNHL; Cochlear; auditory; physical examination; history

Introduction

Hearing loss in infancy leads to preventable speech, language, and cognitive developmental delay [1, 2]. Therefore, early detection of permanent (mostly sensorineural) or temporary (mostly conductive) hearing loss is the base for children's acquisition of communication skills [3, 4].

The incidence of clinically significant hearing loss is 0.1 to 0.2 percent in neonates while it is 0.2 percent in young children. This incidence does not include the transient hearing loss due to middle ear infections that

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occur in almost all children from birth to 11 years of age [5]. Identification of hearing loss etiology, especially the genetic ones, can help in genetic counselling and assist in other management [6].

Conductive hearing loss is related to external or middle ear conduction of sound to the inner ear from the external ear including the pinna, external auditory canal to the stapes, and oval window. Most conductive hearing loss in children is usually transient due to otitis media with effusion. However, rarely can maybe permanent such as in aural atresia or chronic adhesive otitis media.

The etiology of hearing loss is divided into conductive and sensory-neural hearing loss causes.

Sensorineural hearing loss (SNHL) is caused by damages, problems, or issues related to the inner ear such as the cochlea with or without the auditory nerve; cranial nerve VIII, involvement. Numerous congenital or acquired conditions related to the inner ear are associated with SNHL. Auditory neuropathy spectrum disorder, auditory neuropathy, neural synchrony disorder, neural dys-synchrony, and paradoxical hearing loss are synonymous terms of the same problem of a defect in sending the signal to the brain from an intact cochlea. In Auditory neuropathy spectrum disorder, there is an abnormal auditory brainstem response to normal otoacoustic emissions of a healthy outer hair cell function. The abnormal auditory brainstem response may be anatomically located from the inner hair cells of the cochlea to the cochlear nerve. Retro-cochlear hearing loss is related to lesions proximal to the cochlea. This type of hearing loss is caused by abnormalities of the auditory nerve. The most common lesion in this group is vestibular schwannoma. Sometimes, it is not easy to differentiate between retro-cochlear hearing loss and auditory neuropathy spectrum disorder due to overlap. Some articles use the retro-cochlear term broadly to include the auditory central nervous system abnormalities in general. Mixed hearing loss is a combination of both, conductive and sensorineural hearing loss.

Anatomy

There are three anatomic areas (picture)

1. Outer ear: composed of the auricle and external auditory canal
2. Middle ear: includes the tympanic membrane, ossicles, and the middle ear space
3. Inner ear: composed of the cochlea, semi-circular canals, and internal auditory canals

Physiology

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The unique anatomical shape of the auricle catches the incoming sound waves to send them down the external auditory canal. These sound waves vibrate the tympanic membrane which in turn moves the ossicles ending up in a movement of the stapes footplate. Then this movement is transmitted to the fluid of the inner ear thus these waves propagate in the 2 and ½ turns of the cochlea. This frequency-specific movement of the organ of Corti bends the stereocilia, leading to depolarization of the inner and outer hair cells to create electrical impulses transmitted to the brain through the auditory nerve. Finally, the brain organizes the received information into a complex sound perception.

Etiology of hearing loss in children

Conductive hearing loss

Caused by outer or middle ear mechanical defect affecting the sound conduction to the inner ear. It starts from the outer ear including the pinna or the external auditory canal to the stapes footplate and oval window. One of the common examples is cerumen impaction, middle ear fluid, and ossicular chain fixation by fibrous tissue due to chronic adhesive otitis media.

Causes of conductive hearing loss

1. Outer ear problems such as congenital anomalies, infections, and trauma to the pina and or external auditory canal.
2. Obstruction of the external auditory canal by cerumen or bony growths. The commonest examples are
    A. Cerumen impaction: which is the most common cause of external auditory canal blockage. Obviously, because of this, the external auditory canal should clean off cerumen for better audiologic testing.
    B. Bony exostoses: which are benign broad-based osseous pathologies mostly occur after a history of chronic cold-water exposure such as in those who like to swim in cold water. They are usually multiple, more bilateral than unilateral, and commonly seen in male adolescents and or young people.
    C. Osteomas: They are benign solitary, smooth, and round osseous lesions presented at the tympano-squamous and tympano-mastoid suture lines inside of the bony part external auditory canal. Commonly occur in middle age, but sometimes in children.

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D. Trauma: especially penetrating ones in the external auditory canal or the meatus may lead to mild to severe conductive hearing loss.

3. Infection: one of the leading causes of external auditory canal obstruction is the otitis externa (OE) from the accumulation of debris, presence of edema, or inflammation. OE may result from bacterial (occasionally fungi) infection of local trauma or impacted cerumen, swimming, or exposure to a hot and humid environment. The canal is usually seen filled with squamous and purulent debris, with significant edema of the external auditory. OE usually presents severe ear pain (otalgia), pruritus, discharge, and hearing loss.
4. Congenital malformations of the external auditory canal: they can occur anytime during developmental embryonic development between 8 and 28 weeks of gestation. These can range from a microtia to the absence or malformation of the auricle with or without mild to moderate conductive hearing loss. However, atresia or significant stenosis of the external auditory canal on the other hand can cause moderate to conductive hearing loss up to 60 decibels (dB). The defect is more common as unilateral, can affect the canal with normal auricle, and can be isolated or associated with syndromes (Table 1).

Table 1 Genetic disorders & syndromes associated with external auditory canal congenital malformation [7]

Genetic disorder or the syndrome	**Gene(s) involved**	**Inheritance**
Ablepharon-macrostomia syndrome	*TWIST2*	AD
Antley-Bixler syndrome	*POR, FGFR2*	AR
Auriculocondylar syndrome	*GNAI3, PLCB4, EDN1*	AD, AR
Branchiooculofacial syndrome	*TFAP2A*	AD
Branchiootic syndrome, otofaciocervical syndrome	*EYA1, SIX1, SIX5*	AD
CHARGE syndrome	*CHD7*	AD

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Congenital deafness, with inner ear agenesis, microtia, and microdontia	*FGF3*	AR
Even-plus syndrome	*HSPA9*	AR
Hemifacial microsomia (Goldenhar syndrome)	Variable	Sporadic, AD
Klippel-Feil syndrome	*GDF6*	AD
Treacher Collins syndrome	*TCOF1*	AD
MFD, guion-almeida type	*EFTUD2*	AD
Mandibulofacial dysostosis with alopecia	*EDNRA*	AD
Diamond-Blackfan anemia with MFD	*TSR2*, *RPS26*, *RPS28*	XLR, AD
Meier-Gorlin syndrome	*ORC1*, *ORC4*, *ORC6*, *CDT1*, *CDC6*, *CDC45L*, *GMNN*	AR
Microtia, hearing impairment, and cleft palate	*HOXA2*	AD, AR
Oculoauricular syndrome	*HMX1*	AR
Townes-Brocks syndrome	*SALL1*, *DACT1*	AD
Van Maldergem syndrome	*FAT4*	AR
Walker-Warburg syndrome	*POMT1*	AR

5. Middle ear conductive hearing loss: caused by infection, congenital anomalies, perforation tympanic membrane, or tumours.

A. Acute otitis media (AOM) is the commonest cause of conductive hearing loss in children. Almost all children within the age of 3 years experience at least one AOM episode up to three episodes or more. The hearing defect results from the fluid in the middle ear space which prevents adequately tympanic membrane vibration which in turn limits the ossicular chain movement. It may lead to a median loss of up to 25 dB. Even

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after adequate treatment of the OM, the effusion persists in the patients leading to otitis media with effusion (OME) or serous otitis media. However, the OME usually recovers spontaneously within 6 weeks.

B. Tympanic membrane perforation: is a common cause of hearing loss; however, the degree varies with the size and location of the perforation. If the perforation is small or anteriorly or inferiorly potions, it causes a mild degree of conductive hearing loss. Nevertheless, near-total or posteriorly positioned perforations can lead to severe significant hearing loss. Self-induced trauma by cotton-tipped applicators or other objects, blast trauma, foreign body, barotrauma, fractures of the temporal bone, infections of the ear, and a hollow after Gourmet tubes fall out are examples of tympanic membrane trauma. More than ½ of the injuries occurred in children less than 6 years old [8]. Foreign bodies, such as cotton-tipped applicators are the most common cause in children below 12 years. However, the leading cause in children between 13 and 18 years is water trauma such as forced pressure of water to the head during diving or water skiing, barotrauma related to scuba diving, or injury to the otitis externa during swimming. The ear has to be followed up until the perforation settles without cholesteatoma development.

C. Trauma: such as blunt trauma mostly by a blow to the temporal-parietal region may lead to a fracture of the temporal bone. It is usually a conductive hearing loss related to perforation of the tympanic membrane and to the blood in the middle ear or due to ossicular injury as a result of include-stapedial disjoining and/or incus dislocation. However, sensorineural hearing loss is usually associated with otic capsule fractures, facial nerve injury, or cerebrospinal fluid leak.

D. Tumors like squamous cell carcinoma and proliferative disorders such as Langerhans cell histiocytosis are rare causes of conductive hearing loss compared to non-malignant causes such as cholesteatoma or otosclerosis. cholesteatoma is a benign stratified-squamous epithelium full of desquamated cells and keratin coming from the epithelial lining of the developing sack that slowly increases in size until it erodes through the ossicular chain, mastoid air cells, and external auditory canal. It is usually developed after the retraction sack appears in the posterior or superior quadrant of the tympanic membrane, commonly related to defects in Eustachian tube function. However, it might appear after tympanic membrane preformation whether is traumatic, inflammatory, or iatrogenic. Rarely, the cholesteatomas may be congenital which usually occur at the anterior superior portion of the middle ear space looking like a whitish pearl behind an intact tympanic membrane.

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Otosclerosis is an abnormal remodelling that produces an overgrowth of sclerotic and hypervascular bone. It favours the stapes's footplate. As the overgrowth develops, stapes motion is impaired and ossicular vibrations are not effectively transmitted to the inner ear from the bone. This leads to gradual loss of conductive hearing up to 60 dB over years and in the end might involve a significant sensorineural element. It is an uncommon problem in children and extremely rare to recognize in the first decade of life.

E. Congenital malformations of the middle ear including the ossicles may lead to conductive hearing loss mostly as a part of syndromes such as Beckwith Wiedemann, Treacher Collins, Stickler, Branchio-oto-renal, and Velocardiofacial (DiGeorge). However, it may be an isolated event with or without external auditory canal malformation. The most common abnormalities of the ossicles are fixation of the malleus and/or incus, incudo-stapedial discontinuity, and stapes fixation. Its effects on hearing loss can range from minor to maximal of up to 60 dB with its consequence on communication and learning. Osteogenesis imperfecta is a syndrome that may develop conductive hearing loss due to ossicular dislocation, stapes fixation, or fracture of the ossicles.

Sensorineural hearing loss (SNHL)

SNHL is related either to the pathology of the eighth cranial nerve and/or outer hair cells or inner hair cells of the cochlea and/or pathology of the central nervous system. Auditory neuropathy or auditory dys-synchrony is caused by a pathology of the eighth cranial nerve or the inner hair cells and the function of the outer hair cells remains intact. Mixed hearing loss is sensorineural or neural hearing loss with conductive hearing loss. SNHL can be divided into congenital and acquired. Congenital hearing loss, which is identified in 2 to 3 cases per 1000 newborns, is the most frequently occurring birth defect [9]. Congenital hearing loss can be subdivided into genetic and environmental. Genetic causes account for at least 50 % of cases of permanent hearing loss in childhood [10]. Genetic causes of SNHL can be further divided into non-syndromic (70%) and syndromic (30%) [11]. Syndromic congenital SNHL: such as Waardenburg syndrome, Usher syndrome, Pendred syndrome, Alport syndrome, Jervell Lange and Nielsen syndrome and Branchio- otorenal syndrome.

a. Waardenburg syndrome is the most common syndromic cause of SNHL. It is autosomal dominant, with pigmentation anomalies of eyes and skin.

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b. Usher syndrome is one of the most common causes of autosomal recessive causes of SNHL. It is characterized by progressive hearing loss and vision loss due to retinitis pigmentosa.

c. Pendred syndrome is one of the common autosomal recessive causes of congenital sensorineural hearing loss. It is characterized by profound sensorineural hearing loss and euthyroid goitre.

d. Jervell Lange Nielson syndrome is also inherited as autosomal recessive. There is SNHL along with prolonged QT interval on ECG. It may present with SIDS.

e. Alport syndrome can be inherited as X-linked or autosomal recessive. It is due to a defect in Type IV collagen and presents with glomerulonephritis, end-stage renal disease, and eye abnormalities like lenticonus and myopia. There is usually a high-frequency hearing loss.

The most common inheritance pattern of congenital non-syndromic SNHL is autosomal recessive approximately 75% to 80%. Autosomal dominant SNHL represents nearly 20%, X-linked in less than 2%, and mitochondrial 1% [12]. More than 60 autosomal recessive genes are present, the most common being the gap junction beta 2 (GJB2) gene, which accounts for almost half of the causes of non-syndromic hearing loss. GJB2 gene encodes connexin 26 which is required for the proper functioning of cochlea's potassium channels. SNHL can also be due to environmental causes like infections (toxoplasmosis, CMV, Herpes and rubella, ototoxic drugs), prematurity, hypoxia and neonatal jaundice.

The most common contributor to SNHL in NICU graduates is hypoxia. Children who have been treated with ECMO and children with PPHN are at increased risk for late-onset SNHL and need special monitoring [13].

The medications frequently used in the NICU may be associated with SNHL include aminoglycosides, such as gentamycin and kanamycin, and diuretics, such as furosemide. Aminoglycosides cause hair cell death resulting in permanent hearing loss and balance dysfunction. With the progress of hair cell damage, the hearing loss initially affects the higher frequencies and then progressively affects the lower frequencies. Loop diuretics affect the stria vascularis and cause acute but reversible effects.

Bacterial meningitis has been the leading cause of acquired SNHL in children but its incidence has reduced after the introduction of vaccines. Hearing loss after meningitis is caused by cochlear damage by ototoxic drugs used to treat meningitis or to direct damage to the cochlea by meningitis. Treatment early in the course of meningitis with dexamethasone is associated with decreased hearing loss and neurologic sequelae.

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Streptococcus pneumoniae, Neisseria meningitidis, and H. influenzae are common causes of meningitis leading to hearing loss. Congenital infections like CMV, Herpes simplex, congenital rubella, congenital syphilis, and congenital toxoplasmosis are associated with hearing loss. [14] The overall incidence of hearing loss in CMV is 12.6% [15]. Significant hearing loss has been reported in 10% to 15%of children with congenital toxoplasmosis [16].

Hyperbilirubinemia and hypoxia are the most frequent factors associated with sensorineural hearing loss in babies discharged from NICU. Preterms are more prone to neurologic insult as it is the peak time for neural circuit formation in the brain. Sensory pathways myelinate earlier and at a faster rate than motor pathways. Areas affected are Cochlear nuclei > Auditory nerve > Higher neural centers. Auditory Neuropathy Spectrum Disorder consists of auditory dyssynchrony and absent or abnormal BSAERs with normal tests of the inner ear function. Tests of the mechanical integrity of the inner ear (otoacoustic emissions) or of the outer hair cells of the inner ear (cochlear microphonics) are normal but there are absent BSA

In Prenatal Toxic Syndromes, hearing loss has been described in association with prenatal exposure to alcohol, trimethadione, and methyl mercury, as well as prenatal iodine deficiency.

1. Fetal alcohol syndrome includes growth retardation, dysmorphic facial features, and developmental and behavioral disorders, including mental retardation, attention deficit hyperactivity disorder, and language delays.
2. Severe iodine deficiency during gestation has been shown to result in fetal iodine deficiency, which is characterized by mental deficiency, SNHL, spastic diplegia, strabismus, and nystagmus.
3. Prenatal exposure to trimethadione is associated with mental deficiency, prenatal onset growth deficiency, facial dysmorphology, septa1 defects of the heart and tetralogy of Fallot, and hearing deficits.
4. The sources of methyl mercury exposure during pregnancy can be due to the ingestion of fish from contaminated water. Prenatal exposure usually leaves permanent sequelae of varying severity. The fetus may exhibit poor growth, microcephaly, aberrant muscle tone, hearing loss, and blindness [18].

Noise-induced hearing loss NIHL is a preventable cause of hearing loss in children. The audiometric configuration defines NIHL as decreased sensitivity of at least 15 dB at any or all of the frequencies 3000, 4000, or 6000 Hz and an improved threshold of at least 10 dB at 8000 Hz. There is a classical finding of a notched appearance at 4 kHz, which appears to start recovering at 8 kHz on a pure tone audiogram. This is

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known as the Carharts notch. It may not be present in all cases of NIHL. With continued exposure to loud sounds, the classic notch-type configuration evolves into a nonspecific high-frequency hearing loss with the gradual disappearance of the characteristic audiometric notch with continued exposure to loud sounds. Exposure to hazardous sounds may lead to a temporary threshold shift (TTS), acoustic trauma, or NIHL. Moderate exposure to potentially damaging sounds may initially cause TTS with associated subtle anatomic changes, such as swelling of hair cells and the afferent fibers under the inner hair cells, vascular spasm, and metabolic exhaustion. TTS can progress to NIHL with repeated exposure over time. A period of exposure to an intense, short-duration noise greater than 140 dB peak sound pressure level, such as an explosion may produce an immediate, severe, and permanent hearing loss exemplifying acoustic trauma. With acoustic trauma, the organ of Corti may get displaced from the basilar membrane, and swollen degenerating hair cells and nerve fibers may be seen at the edges of the lesion [18].

There have been reports that conductive, sensorineural, and mixed hearing losses may follow head trauma in children. Otic capsule fractures cause a severe SNHL due to disruption of the membranous labyrinth, hemorrhage into the cochlea, perilymph fistula, and avulsion or trauma of the cochlear nerve.

Other diseases in which the complication of SNHL has been reported include mumps, infectious mononucleosis, Kawasaki disease, pertussis; and scarlet fever. Hearing loss from tuberculosis may be a complication of the tuberculous middle ear and mastoid disease or meningitis. Measles with acute encephalomyelitis may lead to SNHL.

Congenital hypothyroidism also increases the risk of hearing loss in children. It may be associated with conductive, sensorineural, and mixed hearing loss. Incidence has reduced now due to newborn screening [19]. Antenatal exposure to maternal TPOaAb during the third trimester of pregnancy is associated with impaired auditory development [20].

Screening of hearing loss in children

Hearing risk assessment should be part of all health visits while regular hearing screening checks done for all children from 4 to 21 years [21]. Pure tone audiometry, tympanometry, or otoacoustic emission (OAE) testing may be performed by the primary care provider.

Hearing screening beyond the newborn period is necessary to identify children with hearing loss that is acquired (eg, from meningitis, trauma, noise exposure), progressive (eg, secondary to certain neurodegenerative syndromes), has delayed onset (eg, intrauterine

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infection with cytomegalovirus), or was not detected on newborn hearing screen (eg, some forms of genetic nonsyndromic hearing loss) [22]. Hearing loss of at least 16 decibels (dB) in either the low- or high-frequency range occurs in approximately 15 percent of children aged 6 to 19 years [23]. Screening the newborn for hearing loss is discussed separately.

- **Timing of screening:** Although most children with hearing impairment are identified before they begin school [24], some cases are missed [25]. Children with identified risk factors for hearing loss (listed below) should have at least one diagnostic audiology assessment by 24 to 30 months of age and ongoing developmentally appropriate hearing assessments [26]. Guidelines from the American Academy of Pediatrics suggest audiology screening for all children at ages 4, 5, 6, 8, and 10 years [26]. For children and adolescents >10 years old, the American Academy of Pediatrics guidelines suggests audiometry screening that includes 6000 and 8000 hertz (Hz) frequencies once between 11 and 14 years, once between 15 and 17 years, and once between 18 and 21 years [26]. These suggestions place a high value on the potential for improved outcomes with early detection and intervention (compared with the cost, inconvenience, and lost time necessary for follow-up of a potentially false-positive result).
- **Risk assessment:** Hearing risk assessment consists of auditory skills monitoring, developmental surveillance, and assessment of parental concern [27]. Additional risk factors associated with an increased risk of permanent congenital, delayed-onset, or progressive hearing loss in childhood include [28]:
    - Caregiver concerns regarding hearing, speech, language, or developmental delay
    - Family history of permanent childhood hearing loss (however, because hereditary hearing loss often has an autosomal recessive inheritance pattern, many children with hereditary hearing loss do **not** have affected relatives)
    - Neonatal intensive care unit stay of ≥5 days
    - Neonatal intensive care unit stay (regardless of duration) requiring extracorporeal membrane oxygenation, assisted ventilation, exchange transfusion for hyperbilirubinemia, or exposure to ototoxic drugs or loop diuretics
    - Congenital or central nervous system infections
    - Chronic or recurrent otitis media with effusion (OME; also known as serous otitis media or middle ear effusion)
    - Ototoxic drug exposure, including chemotherapy

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- Head trauma (particularly basal skull and temporal bone fractures)
- Syndromes associated with hearing loss
- Neurodegenerative disorders
- Congenital head and neck deformities (eg, anomalies of the pinna or temporal bone, ear canal, ear tags, ear pits)
- Conditions affecting Eustachian tube function (eg, adenoid hypertrophy, cleft palate)
- Exposure to loud noises, as may occur with personal listening devices, particularly if the exposure occurs over extended periods of time and at high volume [28]

- **Screening questions:** In older children and adolescents, the following questions can help identify hearing problems [29]:
  - Do you have a problem hearing over the telephone?
  - Do you have trouble following the conversation when two or more people are talking at the same time?
  - Do others complain that you turn the television volume too high?
  - Do you have to strain to understand conversation?
  - Do you have trouble hearing in a noisy background?
  - Do you find yourself asking other people to repeat themselves?
  - Do many people you talk to seem to mumble (or not speak clearly)?
  - Do you misunderstand what others are saying and respond inappropriately?
  - Do you have trouble understanding the speech of women and children?
  - Do people get annoyed because you misunderstand what they say?
- **Screening methods:** Screening can be performed in the office setting with pure tone audiometry, OAE testing, or tympanometry. Pure tone audiometry and OAE may be performed in a quiet room, though this is less sensitive than when testing is performed in an expensive soundproof environment and hence may fail to detect mild hearing losses (<30 dB). Any patient with abnormal office audiometry should be referred for formal audiology testing, as should all children who are at risk for hearing loss [26]. The abnormal results should be explained to the parents, and the child's medical record should be flagged to facilitate follow-up.

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- **Pure tone audiometry:** Pure tone audiometry in the office involves determining the softest decibel threshold at which the child can hear a sound 50 percent of the time for each tested frequency. This is plotted on a graph showing hearing threshold (dB) as a function of frequency (Hz), with louder thresholds marked lower on the graph. The normal hearing threshold is between 0 to 20 dB. The drawback of this test in the office is mostly air level is tested and the accuracy of the results is affected by the cooperation of the child. Any threshold >20 dB suggests a hearing loss (conductive, sensorineural, or mixed). Conductive hearing loss is suggested in the setting of fluid in the middle ear or a flat tympanogram.
- **Otoacoustic emission:** OAE testing measures the presence and strength of low-intensity sound produced by the cochlea in response to an acoustic stimulus. Testing does not require a behavioral response from the child; however, a quiet setting is still needed. An abnormal OAE may be due to cochlear dysfunction or conductive hearing loss. OAE is one of the two methods used for newborn screening.
- **Tympanometry:** Tympanometry can be used as a screening tool for OME that is often associated with conductive hearing loss [30]. Tympanometry is most valuable in conjunction with pneumatic otoscopy. Flat tympanograms (type B tympanograms) are usually due to middle ear effusion (acute otitis media [AOM] or OME). A hearing evaluation and referral to an otolaryngologist may be warranted if the abnormalities fail to resolve with appropriate therapy (for AOM) or during the expected time frame (for OME).

Evaluation of the child with hearing loss

History

The history maybe helps us to differentiate between acquired and inherited etiology of hearing loss. Important elements of history include the following [31]:

- Prenatal histories of maternal infections caused by for example cytomegalovirus, rubella, syphilis, and exposure to drugs like thalidomide or retinoic acid

- Motor developmental history including the age of sitting and walking

- Postnatal history of viral infection, recurrent otitis media, bacterial meningitis, head trauma, and exposure to ototoxic medications

- Age of onset hearing loss and its progression

- Associated symptoms such as pain or drainage from the ear may suggest an acute infectious process while tinnitus, vertigo, or disequilibrium may suggest an inner ear process. The poor balance or late walking may suggest a vestibular aspect to ear disease

- Associated medical conditions such as:

o Kidney disease, which may suggest Alport or branchio-oto-renal syndrome

o Vision problems such as night blindness, poor visual acuity, or visual field defect, which may suggest syndromic retinitis pigmentosa (Usher syndrome)

o Cardiac arrhythmia, which may suggest Jervell and Lange-Nielsen syndrome

o Cutaneous or pigmentary abnormalities, which may suggest Waardenburg syndrome or neurofibromatosis

- Family history: The family history focuses on identifying first- and second-degree relatives with hearing loss, known genetic syndromes associated with hearing loss, or features commonly associated with syndromic hearing loss such as abnormal pigments; vision issues; kidney problems; branchial defects for example ear pits, cervical fistulas, or cysts; and abnormal cardiac rhythm or sudden death related to cardiac diseases. History of consanguinity may suggest inherited diseases. A full three-generation pedigree may be needed to establish the pattern of inheritance if the family history is positive.

Physical examination

General examination: Physical examination should include measurement of growth parameters and assessment of general appearance while looking for the clinical features of various syndromes [32].

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Examination of the head and neck is especially important. In a retrospective analysis of 114 children with hearing loss referred to a tertiary care center, 43 percent had head and neck abnormalities that helped to establish the etiology of hearing loss [33]. As examples, a white forelock and heterochromia of the iris are seen in Waardenburg syndrome, micrognathia in Apert syndrome and Pierre Robin sequence, and enlarged thyroid in Pendred syndrome.

Ear examination: The physical examination of the external ear for inspection of preauricular pits or sinuses, looking at the pinna size and shape, and checking the patency of the external auditory canal for clearance of cerumen for better hearing testing. The tympanic membrane should be assessed for any middle ear abnormalities such as middle ear effusion, perforation or scarring of the tympanic membrane, cholesteatoma, or other middle ear mass.

Pneumatic otoscopy uses positive and negative pressure to evaluate the mobility of the tympanic membrane. Fluid, mass in the middle ear cavity, perforation, pressure equalization tube, or sclerosis of the tympanic membrane may cause diminished or absent tympanic membrane mobility. Ossicular chain disruption indicates increased tympanic membrane mobility.

Simple hearing tests: Hearing test for older children and adolescents maybe done in the office using tuning forks of either 256 or 512 hertz (Hz) frequency. A 10-15 decibels (dB) hearing loss is roughly equal to 256 Hz while 20-30 dB hearing deficiet is near 512 Hz. A normal hearing inner ear means normal air conductive hearing that is louder than bone conduction. The Weber and Rinne tests differentiate between air and bone conduction of sound.

- The Weber test is performed by placing the tuning fork on the bridge of the forehead, nose, or teeth and asking the child if the sound is louder in one ear or the other. The sound is heard equally in both ears in children with normal hearing. Louder vibratory sound on the "good" side suggests sensorineural hearing loss (SNHL). Louder vibratory sound on the "bad" side is indicative of conductive hearing loss.
- The Rinne test compares bone conduction (when the tuning fork is placed on the mastoid bone) with air conduction (when the tuning fork is held near the ear). Placing the tunic fork on the bone leading to equally loud or louder sound compared to placing near the ear is an abnormal result (bone>air conduction). Placing the vibrating fork placed near the ear leading to louder sound than when placed on the

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mastoid bone (air>bone conduction) is a normal Rinne test. An abnormal Rinne test indicates conductive hearing loss, especially if the Weber test also lateralizes to that side.

For example, a conductive hearing loss on the right side produces a Weber test that lateralizes to the right (ipsilateral side), an abnormal Rinne test (bone conduction>air conduction) on the right side, and a normal Rinne test on the left side. A sensorineural hearing loss of the right side would demonstrate a Weber test that lateralizes to the left (contralateral side) and normal Rinne tests bilaterally. Results differ between mixed hearing loss, severe SNHL (Rinne test on the bad ear will appear to be abnormal because bone conduction crosses over and is detected by the better ear), or conductive hearing loss below thresholds detected by the tuning fork used.

Formal audiology

Detailed information about hearing ability can be obtained by a formal audiologic assessment. It is performed by an audiologist in a soundproof environment Audiologic assessment includes different studies. It may comprise pure tone audiometry, speech audiometry, behavioural audiometry, visual reinforcement audiometry, play audiometry, impedance audiometry, tympanometry, and/or electrophysiologic tests (including auditory brainstem response [ABR] and otoacoustic emissions [OAE]). The choice of test to be performed is based on the child's developmental age, the reason for referral, test environment, types of equipment available, and the skill of the person administering the test. There is no minimum age for evaluating the hearing of a child.

Testing in cooperative children

Pure tone audiometry: Audiology measures the ability to hear pure tones of various frequencies as a function of the intensity measured in decibels (dB). Pure tone frequencies are evaluated by a complete audiogram at 250, 500, 1000, 2000, 3000, 4000, and 8000 hertz (Hz). The threshold level of each tone is determined by the intensity level at which the tone is detected by the child 50 percent of the time.

Hearing testing is done by air or bone conduction or both. Air conduction is performed by earphones to test the ability to hear when sound waves travel their normal route through the external auditory canal to the tympanic membrane and the middle ear system. While bone conduction is performed by an oscillator placed

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on the mastoid bone and it tests the ability to hear when the inner ear fluid and cochlea are stimulated directly by bone vibration bypassing the middle ear.

Hearing loss is defined by the pure tone threshold: normal hearing has a threshold of 0 to 20 dB, mild hearing loss from 20 to 40 dB, moderate from 40 to 60 dB, severe from 60 to 80 dB, and profound hearing loss greater than 80 dB. Characteristic patterns that vary with the type of hearing loss are seen:

- In the conductive hearing loss, the audiogram shows normal bone-conducted pure tone thresholds and abnormal air-conducted pure tone thresholds. The difference in air- and bone-conducted thresholds is termed the air/bone gap.
- In sensorineural hearing loss (SNHL), the audiogram shows both air- and bone-conducted pure tone thresholds that are outside the normal range. Different patterns indicate different etiologies:
    - Unilateral SNHL usually is suggestive of an inner ear disorder.
    - Audiograms of children with nonsyndromic genetic hearing loss are bilaterally symmetric but of variable shapes (eg, flat, down-sloping, up-sloping, U-shaped). In syndromic hearing loss, the audiogram may demonstrate symmetric or asymmetric losses.
    - Noise-induced SNHL presents initially as high-frequency hearing loss.

Speech audiometry — Speech audiometry has two parts: the speech threshold (also called the speech reception threshold) and word discrimination score. The speech threshold is the softest level at which a child can correctly repeat 50 percent of presented "spondee" words. Spondee words are 2 syllable words like arm-chair, air-plane, or pan-cake. The speech threshold is recorded in decibels to serve as a cross-check for the pure tone air-conduction limits. The speech threshold is typically equal to the pure tone air-conduction average, ±10 dB. The average decibel score at 500, 1000, and 2000 Hz is the pure tone average.

Word discrimination score is the percentage of phonetically balanced words correctly repeated by a child at a particular sensation level. The test is done at 40 dB above the child's speech threshold. It can establish the prognosis for the use of a hearing aid, and also helps to determine the site of the lesion. A poor discrimination score usually indicates significant neural degeneration. These individuals may not be good candidates for hearing aids because the aid will amplify sound but may not permit the child to understand what is being said.

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Tests for young and/or uncooperative children: young children and some children with developmental disabilities may not be able to cooperate with pure tone or speech audiometry testing. In such cases, hearing is assessed by behavioural methods and other tests, such as acoustic impedance testing, OAEs, or ABRs.

- **Behavioral observation audiometry:** For examining auditory function in infants younger than six to eight months, children with multiple handicaps, or adults who are unable to cooperate for other types of testing, behavioral observation audiometry is used. To elicit reflexive and orienting responses to auditory stimuli, live voice, varying tones, or narrow-band noises are presented in a sound field. The responses can include head or limb reflex, whole-body startle, sucking, eye blinking, raising of the eyebrows, or cessation of certain behaviors, such as movement or sucking [34]. Responses to stimuli are not reinforced. Behavioral observation is used to subjectively measure hearing. It does not provide ear-specific or frequency-specific information. It is used in conjunction with other objective methods.
- **Visual reinforcement audiometry:** Visual reinforcement audiometry (VRA) is used for evaluating the hearing from six months to two years of age. Sound stimuli (live voice and tones) are presented in the sound field via inserted earphones. Whenever the child turns their head towards the sound source, he/she is visually rewarded with lighted and animated toys. The child is instructed to perform the task repeatedly. Experienced audiologists use colorful and animated toys with an intermittent reinforcement schedule to maintain the child's attention. Complete ear-specific information for speech stimuli and interactive frequencies from 250 to 8000 Hz can be obtained by VRA.
- **Play audiometry:** Play audiometry is the method for evaluating the hearing of children between 30 months and 5 years. Pure tones are presented by inserting earphones. Children are taught to perform simple tasks, such as placing a block in a bucket or a peg on a pegboard whenever a sound is heard. The child's ability to point to simple pictures on being instructed by the audiologist determines the detection of speech sounds. In children who perform the tests, speech understanding or speech discrimination scores are calculated. These tests require picture-pointing tasks for younger children and reading skills for older ones. Evaluation of the child's ability to hear and understand speech in quiet and noisy listening environments requires speech-understanding tests.

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Impedance testing: Impedance audiometry (admittance audiometry) evaluates the integrity and function of the middle ear system, including middle ear pressure, tympanic membrane mobility, Eustachian tube function, continuity, and mobility of ear ossicles, and acoustic reflex thresholds. It is a quick, non-invasive test requiring little cooperation by the child. Full impedance audiometry comprises tympanometry and stapedial reflex testing. The latter is seldom performed in children.

Tympanometry: Tympanometry assesses the changes of the middle ear system acoustic impedance in response to changes in air pressure. The tympanic membrane is displaced medially with increasing pressure while protrudes laterally with decreasing pressure. When the point of maximum compliance of the middle ear is confirmed, indicating the status of air pressure in the middle ear. There are five types of tympanogram that can be seen [35]:

- Type A; normal middle ear pressure
- Type B; little or no mobility, indicating fluid behind tympanic membrane or perforation
- Type C; negative pressure in the middle ear, suggestive of a retracted tympanic membrane
- Type AS; a very stiff middle ear system that can be caused by myringosclerosis or otosclerosis
- Type AD – The highly compliant tympanic membrane seen in ossicular chain discontinuity

Stapedial reflex: The acoustic stapedius reflex is the sound-evoked contraction of the stapedius muscle mediated by a neural network with afferent input from the auditory nerve and efferent output to the facial nerve. [36] The central portion of the reflex pathway is comprised of centers in the brain. The acoustic stapedius reflex test assesses the presence or absence of ipsilateral and contralateral stapedial contraction after sound stimulation to each ear. Sound stimulation on one side produces a stapedial contraction of both sides. Acoustic stapedius reflex testing can be used to differentiate types of hearing loss, especially retrocochlear hearing loss (ie, due to abnormalities of the eighth cranial nerve such as a vestibular schwannoma [also called acoustic neuroma]).

Electrophysiology: Electrophysiologic hearing tests do not require behavioral responses. These are ABRs, OAEs, and stapedial reflex testing.

Brainstem response: The ABR test (also known as auditory brainstem evoked response [ABER], brainstem evoked response audiometry [BERA], or brainstem auditory evoked response [BAER]) uses click stimuli

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and tone burst stimuli from loud (80 or 90 dB) to soft (0 to 20 dB) to evoke responses from the auditory pathway [37]. Responses are recorded by electrodes placed on the child's head and ears. Responses are averaged to generate waveforms, which are then compared with normative data. Delayed or absent waves are suggestive of cochlear or neurologic deficits. Normal hearing or conductive hearing loss patterns can also be recognized [33]. Children with auditory neuropathy have absent or severely distorted ABRs with preserved OAEs [38].

Automated ABR (AABR) is used for screening newborns. It is different from diagnostic ABR testing. In AABR, there is an automated pass/fail response, whereas diagnostic ABR testing provides quantitative data that can be interpreted by trained audiologists.

ABR testing estimates auditory sensitivity, thereby providing useful clinical information about the integrity of the eighth nerve pathway. It should not be used alone or as a substitute for behavioral hearing testing.

ABR testing is a tool to confirm behavioral hearing tests in infants and preverbal children (ie, younger than 30 months) and children with developmental delay or intellectual disability. ABR testing should be performed in infants failing the newborn hearing screen or if in cases of parental concern. ABR testing is not required if both behavioral audiometry and OAE are normal. Sedation may be required for ABR since excessive movements can disrupt the test results.

Otoacoustic emissions: OAEs are faint sounds produced in a healthy ear by normal motion of the outer hair cells of the cochlea [38]. They are transmitted through the middle ear and the tympanic membrane in a retrograde fashion and measured by a microphone sealed in the external auditory canal. It is a quick and non-invasive test. The presence of OAE is suggestive of normal cochlear function. Sedation is not required during testing for OAE.

OAE is a part of newborn hearing screening programs. Beyond the newborn period, OAE can be used along with behavioral audiometry to evaluate infants and preverbal children. Normal OAE and normal behavioral audiometry in children ages 6 to 30 months old can eliminate the need for ABR. OAE testing can be used to monitor aminoglycoside-induced ototoxicity, differentiate central from peripheral auditory dysfunction, and to confirm hearing acuity in cases of malingering. [39].

Referral

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Children who have abnormal formal audiology results should be referred to otolaryngology, speech-language pathology, and early intervention [26]. Referral to a clinical geneticist may be required in cases with syndromic features or bilateral sensorineural hearing loss (SNHL).

Children with SNHL should have at least one formal evaluation by an ophthalmologist in view of the higher prevalence of vision problems compared with the general pediatric population, which is approximately 5 to 10 percent [27]. In a series of 226 children with SNHL, the prevalence of ophthalmologic abnormalities was 22 percent [40]. Refractive errors (myopia, hyperopia, astigmatism) occur more commonly than nonrefractive conditions (eg, strabismus, amblyopia, nystagmus, optic atrophy).

Identifying the etiology

Diagnostic approach: Formal audiologic and electrophysiologic testing are required for infants and children with hearing loss detected by screening. History and physical examination are important parts of the diagnostic evaluation.

Initial evaluation can sometimes reveal the etiology (eg, a child with unilateral conductive hearing loss and recurrent otitis media with a perforated tympanic membrane in the affected ear on otoscopy). In cases with uncertain etiology, additional evaluation is required. Depending on the clinical context, this may include genetic evaluation, testing for congenital infections (eg, cytomegalovirus [CMV]), and/or temporal bone imaging.

In the following sections, we outline our approach to diagnostic evaluation based on the type of hearing loss (sensorineural versus conductive; unilateral versus bilateral) and the child's age. Our approach is consistent with the recommendations of the International Pediatric Otolaryngology Group and the American College of Medical Genetics and Genomics [27]. Evaluation should be carried out by a multidisciplinary team including otolaryngologists, audiologists, clinical geneticists, and genetic counsellors.

Sensorineural hearing loss: Important causes of sensorineural hearing loss (SNHL) in infants and children include hereditary (genetic) causes, which may be syndromic or non-syndromic, and infections, particularly congenital CMV infection.

Initial evaluation for infants and children with SNHL includes the following [27]:

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- **Genetic evaluation: The approach to genetic evaluation depends upon whether hearing loss is bilateral or unilateral and the presence or absence of syndromic features:**
    - **Bilateral SNHL: Comprehensive genetic testing using next-generation sequencing (NGS) has become the preferred method for establishing a genetic diagnosis of hereditary SNHL, and we offer this testing to all children with bilateral SNHL.**
    - **Unilateral SNHL: For children with unilateral SNHL, the yield of NGS is low. So, comprehensive genetic testing with NGS is not advised. It is important to consider syndromic forms of hearing loss as syndromes are often variable in their phenotypic presentation. Waardenburg, Usher, Pendred, Alport, hemifacial microsomia, and CHARGE are common syndromes associated with hearing loss. A detailed history (including a three-generation pedigree) and physical examination are required for evaluation. Based on the history and examination, additional testing may be warranted to evaluate for various clinical concerns (eg, kidney function tests in Alport or branchio-oto-renal syndrome; thyroid function tests in suspected Pendred syndrome; ophthalmologic examination if there is a concern for Usher syndrome; electrocardiogram in suspected Jervell and Lange-Nielsen syndrome). If the findings suggest a syndromic cause of SNHL, then genetic tests are done. Most comprehensive genetic testing panels designed for nonsyndromic hearing loss also include the common syndromic forms of hearing loss.**
- **Testing for congenital CMV infection:** Testing for CMV is indicated in all infants <12 months of age with bilateral or unilateral SNHL. Congenital CMV infection may be associated with unilateral or bilateral hearing loss. It may be present at birth or have delayed onset and therefore, missed by newborn hearing screening in some cases.
    - **Infants <12 months old:** Definitive diagnosis of congenital CMV infection can be made within 21 days after birth. Beyond 21 days, the likelihood of a positive test due to postnatal exposure increases. Detection of CMV between 3 weeks to 12 months after birth associated with SNHL is suggestive of congenital infection.

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- **Children ≥12 months old:** Establishing a diagnosis of congenital CMV infection at this age is generally not feasible and infection at this age is more likely to represent postnatal infection rather than congenital.

- **Temporal bone imaging:** It is used in the evaluation of children with **unilateral** SNHL or if there is evidence of auditory neuropathy (characterized on audiologic testing by the presence of otoacoustic emissions with absent or abnormal auditory brainstem response). The diagnostic yield in **bilateral** SNHL without auditory neuropathy is low and not routinely used to obtain imaging in these children except for preoperative evaluation of cochlear implant.
- **Review newborn screening panel**: Results of the full newborn screening panel should be reviewed as some causes of hearing loss can be identified by newborn screening (eg, congenital hypothyroidism, certain inborn errors of metabolism).
- **Vision assessment:** Vision should be assessed in children with SNHL to rule out retinitis pigmentosa (Usher syndrome) and to rule out deficits in other major senses.
- Other tests are indicated according to specific clinical concerns. For example:
- Testing for other congenital infections such as rubella, toxoplasmosis, or syphilis if history or clinical findings are suggestive.
- In children with bilateral severe to profound hearing loss with a family history of sudden death, or personal history of syncope or cardiac arrhythmia, the QT interval should be looked at in ECG. A prolonged QT interval with SNHL is suggestive of Jervell and Lange-Nielsen syndrome, an autosomal recessive form of congenital long QT syndrome. Comprehensive genetic testing is warranted for making a definitive diagnosis.
- Family history of kidney disease suggests Alport syndrome. In such cases, urinalysis should be performed to assess for microscopic hematuria. A definitive diagnosis requires comprehensive genetic testing.

Conductive hearing loss: Common causes of conductive hearing loss include middle ear fluid (eg, acute otitis media and otitis media with effusion [OME]), tympanic membrane perforation, obstruction of the ex-

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ternal auditory canal (eg, cerumen), and trauma. Etiology is usually apparent on history and physical examination findings and additional evaluation is not necessary. Tympanostomy tube insertion may be required in cases of OME.

Further evaluation with temporal bone imaging and/or surgical exploration may be warranted. External canal atresia, neoplasms, myringosclerosis, or cholesteatoma are common causes.

Genetic testing: All cases of SNHL require evaluation by an otolaryngologist with expertise in genetic hearing loss and/or a clinical geneticist. In a child with asymptomatic CMV and hearing loss (positive CMV testing in the absence of other clinical signs of congenital CMV infection), genetic testing is still warranted, especially if valganciclovir is to be offered to treat the presumed CMV-related hearing loss [41]. Other risk factors for hearing loss (eg, prematurity, aminoglycoside exposure) also do not obviate the need for genetic evaluation.

Bilateral SNHL requires evaluation by comprehensive genetic testing of the patient and family members. Yield of comprehensive genetic testing is low in **unilateral** SNHL in the absence of syndromic findings.

If genetic testing reveals mutations in a hearing loss-related gene, specific genetic counselling should be provided, followed by appropriate medical evaluations [27].

Genetic testing should be done by an otolaryngologist with expertise in genetic hearing loss, a genetic counsellor, or a clinical geneticist. A general approach is as follows [42]:

- **Syndromic findings:** If clinical findings point to a genetic syndrome, then targeted genetic testing is performed. Comprehensive genetic testing panels for deafness include testing for the genetic variants associated with syndromic and non-syndromic causes of hearing loss. Some examples include:
    - SNHL in the setting of a family or personal history of kidney disease suggestive of Alport or branchio-oto-renal syndrome
    - SNHL associated with pigmentary abnormalities suggests Waardenburg syndrome
    - SNHL accompanied by progressive vision loss, which suggests Usher syndrome, a form of retinitis pigmentosa
    - SNHL accompanied by thyroid disease or goiter, which suggests Pendred syndrome
    - Choanal atresia, colobomas, heart defect, intellectual disability, genital hypoplasia, and ear anomalies suggest CHARGE syndrome)

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- Findings of mandibular hypoplasia, orbital distortion, and ear anomalies suggest hemifacial microsomia

- **No syndromic findings:** In bilateral SNHL without syndromic findings, the first test to be done is comprehensive genetic testing using NGS. [43].

  NGS tests can be disease-specific or whole-exome sequencing (WES) [22]. Disease-specific exon-capture approach sequences genes known to be linked to hearing loss and is less costly, faster, and simpler. Hence, it is preferred over WES. Several NGS tests can be found by querying the Genetic Testing Registry website.

  NGS testing for hereditary hearing loss has a diagnostic yield of approximately 40 percent but increases to 60 percent if there is a family history [44]. A genetic basis for hearing loss can be identified in half of the patients with bilateral auditory neuropathy [45]. The available NGS panels for hereditary hearing loss differ with regard to the number and type of genes and copy number variations.

  Patients with negative test results should have periodic follow-ups with a clinical geneticist for subsequent testing as novel genetic tests become available.

  NGS testing may identify variants of uncertain clinical significance and may reveal incidental but clinically significant findings unrelated to hearing loss (eg, BRCA1 or BRCA2 gene mutation). Pretest genetic counseling is, therefore, essential.

Temporal bone imaging: Temporal bone imaging is not routinely required in the evaluation of children with hearing loss. Imaging may be helpful in select circumstances as a complement to other diagnostic testing and as a guide to therapy [46].

Temporal bone imaging is required in the following circumstances, particularly if hearing loss is progressive:

- Suspected dilated vestibular aqueduct syndrome suggested by fluctuating hearing loss associated with vestibular problems (eg, poor balance, late walking)
- Unilateral or asymmetric SNHL

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- Auditory neuropathy

Other indications of temporal bone imaging are [47]:

- Evaluation of trauma to the temporal bone
- To evaluate for congenital anomalies, trauma, or tumors of the middle ear and ossicular chain
- Evaluation of persistent or progressive conductive hearing loss
- Evaluation of recurrent meningitis
- Preoperative evaluation prior to cochlear implantation

Imaging can be performed using magnetic resonance imaging (MRI) or computed tomography (CT). MRI avoids radiation exposure, is more sensitive to peripheral auditory abnormalities, and also allows for evaluation of the brain. MRI requires sedation in young children. Contrast-enhanced MRI is preferred in cases of the suspected inflammatory or neoplastic disorder. The decision of temporal bone imaging is generally made by the otolaryngologist rather than the primary care provider.

In a systematic review of 50 observational studies, the reported diagnostic yield of CT imaging in children with hearing loss ranged from 7 to 74 percent, with a pooled estimate of approximately 30 percent [48]. The most common findings were enlarged vestibular aqueduct and cochlear anomalies. In a series of 97 children with non-syndromic SNHL, CT or MRI abnormalities were detected in 39 percent with the most common findings being enlarged vestibular aqueduct, lateral semicircular canal dysplasia, and cochlear dysplasia. A retrospective report of 116 children with bilateral SNHL reported abnormalities in 28 percent on CT imaging, most commonly in children with progressive hearing loss, profound hearing loss, and associated craniofacial abnormalities. CT abnormalities were relatively uncommon among children without any of these characteristics (7 percent).

Hearing loss is one of the most common disabilities and has lifelong consequences for affected infants and their families. Early diagnosis of severe or profound deafness, early fitting of hearing aids or cochlear implants, and an early start in special education programs can advance auditory facilities and lower the adverse influence of hearing loss (49). Furthermore, early identification and management may improve earning capacity in future life and can meaningfully decrease the education costs associated with hearing loss (50). Whereas untreated hearing loss is associated with a barrier to education and social integration (51,52). In addition, all infants with hearing loss should be referred to an ophthalmology clinic as they rely on the sight for communication and education (53).

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Therefore, once deafness is established, a systematic approach to determining the cause should be undertaken within a dedicated multidisciplinary setting that includes otolaryngologists, speech therapists, audiologists, geneticists, ophthalmologists, and educational specialists.

The Joint Committee on Infant Hearing Programs (2019) recommends that all infants with hearing loss should start intervention within six months of age (54).

Early rehabilitation of deafness is the main challenge for the otolaryngologist/audiologist. Previously, rehabilitation of hearing loss was managed by the use of hearing devices that operate as a sound amplifier, however, their effect was limited in the patients with the damaged inner ear. The outcome of the hearing loss was further ameliorated with the implementation of the cochlear implants, although the signal quality was less compared to physiological conditions. Lastly, gene therapy with the ability to regenerate the neural epithelium and ganglion neurons, reactivation of the processes of development and maturation of cells produced during the embryonic period, and implantation of the stem cells changed the outcome of the hearing loss (55). The following section summarizes the various domains of treatment of SNHL.

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