# Early Detection of Neonatal Hearing Loss: Screening Algorithm

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Received: February 20, 2026. | Accepted: May 15, 2026.

## ABSTRACT

A screening test is used to detect a group of relevant diseases in the neonatal period, including hearing loss, which is defined as the decrease or absence of the ability to perceive and interpret sound waves. Untreated hearing loss constitutes a serious obstacle to the development of oral language, writing, and cognition, as well as to the child's education and social integration.

The neonatal hearing screening (NHS) is performed using two tools: Otoacoustic Emissions (OAE) and Auditory Brainstem Response (ABR), which complement each other for the timely detection and treatment of hearing loss.

An algorithm is proposed to optimize the understanding, application, and follow-up of the neonatal hearing screening (NHS). Based on risk factors and the results of otoacoustic emissions (OAE) as the first universal test, the need to perform auditory brainstem response (ABR) is determined, and the corresponding follow-up plan is established.

**Keywords:** newborn hearing screening, newborn hearing loss, auditory brainstem response.

## INTRODUCTION

Human beings relate to one another through their senses, forming alliances, experiencing emotions, and establishing ethical and social norms. Therefore, untreated hearing loss constitutes a serious obstacle to development, education, and social integration in childhood. This condition isolates the individual from information about their environment, hindering the acquisition of spoken language, writing, and cognitive development. In Mexico, it is estimated that 10 million people suffer from some type of hearing loss, of whom between 200,000 and 400,000 are completely deaf. Furthermore, it is estimated that between 2,000 and 6,000 children are born each year with congenital deafness; therefore, hearing loss is considered a public health problem [1].

A determining factor in this condition is the age at which intervention begins. Children whose hearing loss is detected early and who receive prompt and appropriate rehabilitation achieve better results and greater progress than those whose hearing loss is detected late. Therefore, it is crucial to recognize that hearing impairments can be detected in the first hours after birth. Intervention during the maturation and modeling stages of cortical structures is essential, as this critical period defines the prognosis and future development of newborns with deafness or profound hearing loss born each year in our country [2].

In the practice of medicine, the ultimate goal is disease prevention. For this reason, newborn hearing screening and follow-up are vital, given that hearing loss is often asymptomatic and usually goes unnoticed. Screening should be universal, applied to all newborns regardless of whether they present risk factors. Furthermore, it is essential that this strategy be known not only by medical personnel, but also by parents or guardians, thus ensuring timely intervention that promotes development and cognition appropriate for the child's age.

## NEWBORN HEARING SCREENING

A “screen” refers to “...the act of examining, carefully selecting, or refining and choosing with care and thoroughness...”, according to the Royal Spanish Academy (RAE) [2]. In other words, a screen is used to detect a group of relevant diseases in the neonatal stage, including hearing loss.

Hearing loss is the decrease or absence of the ability to perceive and interpret sound waves and, therefore, auditory sensations. Different degrees of hearing loss can be classified:

- **Mild hearing loss:** threshold between 30 and 40 dB.
- **Moderate hearing loss:** hearing threshold between 41 and 60 dB.
- **Severe hearing loss:** threshold between 61 and 90 dB.
- **Profound hearing loss:** threshold above 90 dB.

Newborn hearing screening (NHS) can be performed in one or two steps using Otoacoustic Emissions (OAEs) and/or Auditory Brainstem Response (ABR) testing. OAEs are performed on all newborns without exception, and if the result is abnormal or if the newborn has risk factors, an ABR test should be performed at three months of corrected age to avoid false negatives that could occur with OAEs. OAEs have a sensitivity >80% in healthy newborns; however, in newborns with risk factors, the sensitivity decreases to less than 60% [1].

## PHYSIOLOGY OF HEARING

The cochlea is divided into three compartments: the vestibular scala, the tympanic scala, and the middle compartment or scala media; the latter contains the organ of Corti and is separated from the first two by Reissner's membrane and the basilar membrane, respectively. This entire system is distributed along the cochlear modiolus, from the base to the apex. (Figure 1) [3].

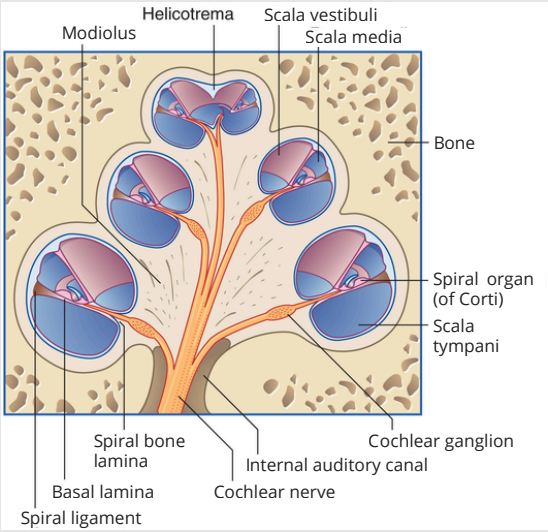



**Figure 1.** Cross-sectional anatomy of the cochlea. *Mtui E, Fitzgerald T. Clinical Neuroanatomy and Neuroscience. 8th ed. Elsevier; 2022.*

The hair cells (Figure 2) are interconnected by the cytoarchitecture of the organ of Corti; thus, when several cells move in synchrony, their mechanical responses can be summed. Therefore, this activation of large numbers of coordinated cells can change the mechanical response of the cochlea. The outer hair cells mechanically influence the responses of the inner hair cells [3].

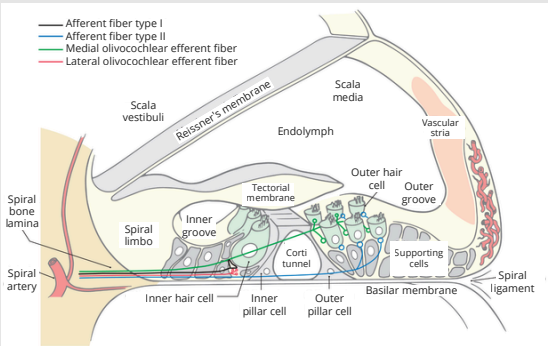



**Figure 2.** Cross-section of a typical turn of the cochlear labyrinth. *Haines DE. Principles of Neuroscience: Basic and Clinical Applications. 5th ed. Elsevier; 2019.*

The inner hair cells transmit the auditory message to the brain, while the outer hair cells provide high sensitivity and frequency selectivity to the cochlea (Figure 2). Cochlear hearing loss is sometimes associated with hair cell damage. Occasionally, the inner hair cells may be non-functional or absent, meaning that the auditory nerve innervation in these areas may not be functioning or may have degenerated [3].

## OTOACOUSTIC EMISSIONS

Otoacoustic emissions are mechanical vibrations generated in the cochlea, which are transmitted through the lymphatic fluid and through the middle ear to the external auditory canal, where faint sounds can be recorded with a microphone (Figure 3) [3].

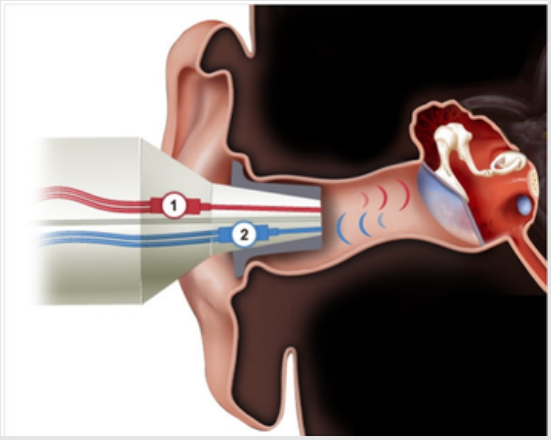



**Figure 3.** Diagram of otoacoustic emissions. 1 = probe emitting the stimulus sound; 2 = microphone picking up the sound emitted by the hair cells. *Taken from: Puel J-L. Otoemissions [online]. https://www.cochlea.eu/es/exploracion-funcional/metodos-objetivos/otoemisiones*

The organ of Corti receives sounds, processes them, and sends them via the auditory pathway to the brain; at the same time, it produces and emits spontaneous sounds through the activity of its structures. This is known as spontaneous otoacoustic emissions [3].

Transient otoacoustic emissions are frequency responses that arise in the cochlea and can be measured in the external auditory canal after a brief acoustic stimulus, such as a click or a burst tone. These emissions are present in all individuals with normal hearing and are an expression of normal cochlear function [3].

Most hearing losses are associated with lesions in the external ear, middle ear, or cochlea, specifically affecting the outer hair cells; these can be detected using otoacoustic emissions. On the other hand, emissions tests are unable to detect lesions beyond the outer hair cells; therefore, they do not detect retrocochlear hearing loss. Auditory brainstem response (ABR) are more specific and sensitive for detecting hearing loss due to auditory neuropathy. For this reason, hearing screenings have been adopted that include evaluation with both otoacoustic emissions (OAEs) and ABR [4,5].

## AUDITORY BRAINSTEM RESPONSE

In pediatric audiology, auditory brainstem response (ABR) testing provides an objective assessment of hearing, the severity of hearing loss, and the location of the lesion. This is because it is a qualitative and

quantitative method for recording the activity generated by the central auditory nervous system in the brainstem in response to acoustic stimulation. The test involves stimulating the auditory pathway with a click (which stimulates most of the cochlea). This mechanical stimulus is transformed in the organ of Corti into an electrical stimulus that travels along the auditory pathway to the auditory cortex.

ABR testing is a fundamental tool in screening programs for cochlear and retrocochlear hearing loss, especially in young children and in cases where audiometry results are difficult to obtain.

The test is performed by placing one electrode on each mastoid process and another active electrode on the forehead. These are coupled with transducer paste, which facilitates the transmission of electrical activity, and are fixed to the skin with self-adhesive patches (Figure 4). The sound stimulus is delivered through conventional headphones, in-canal headphones, or a bone vibrator, by previously setting the number of clicks per second, as well as the morphology, duration, and intensity of the stimulus.




**Figure 4.** Auditory brainstem response application. (1) Active electrode (-) mastoid. (2) Air conduction transducer, hearing aid. (3) Midline electrode (ground). (4) Reference electrode (+). *Senced. Auditory evoked potentials: limitations and advantages [online]. https://audiopacks.es/es/blog-audiosocial/2013/01/27/potenciales-evocados-limitaciones-y-ventajas*

Subsequently, a 5-wave pattern will be reflected, which will guide us to the patient's auditory state (Figure 5).

- **Wave I:** Electrical activity of the spiral ganglion.
- **Wave II:** Posterior portion of the anteroventral cochlear nucleus and anterior portion of the posteroventral cochlear nucleus.
- **Wave III:** Anterior portion of the ipsilateral anteroventral cochlear nucleus and contralateral medial nucleus of the trapezoid body.
- **Wave IV:** Isolator and contralateral cells of the superior medial olive.
- **Wave V:** Cells of the lateral lemniscus and/or inferior colliculus.

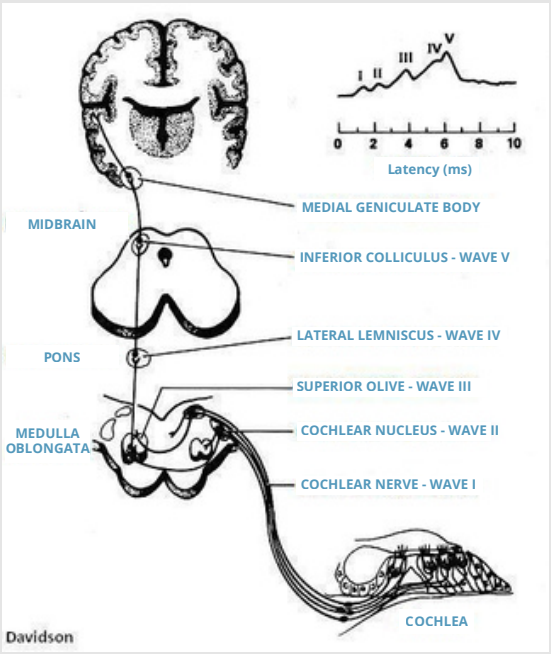



**Figure 5.** Waves through the auditory pathway. Schematic representation of the anatomical generators of the auditory brainstem evoked response (ABR) waves (I–V) along the auditory pathway, from the cochlea to the midbrain. *Taken from: Lafuente DA. Auditory brainstem evoked potentials (ABRs) [online]. https://www.sorderayvertigo.com/sordera/pruebas//*

Quantitative diagnosis is performed by identifying wave V, which is the last to disappear and the easiest to visualize.

It is of great importance to perform ABR tests, especially in patients with risk factors for developing hearing loss, since, in addition to guiding us toward early detection, it is a non-invasive test that allows for a fairly accurate diagnosis of hearing impairment.

## PROPOSED ALGORITHM FOR NEWBORN HEARING SCREENING

The WHO recommendations suggest a hearing screening protocol with the "1-3-6" principle, which serves as a mnemonic for:

- **1** - All children should undergo hearing screening within the first month of life.
- **3** - All children with initial and subsequent screening who require diagnostic testing should receive an appropriate hearing evaluation within the first three months of life to confirm their hearing status.
- **6** - Once hearing loss is diagnosed, the child and family should have immediate access to intervention strategies. This should begin as soon as possible after the diagnosis and no later than six months of age.

A study was conducted on newborns at the *Hospital Regional de Alta Especialidad "Dr. Ignacio Morones Prieto"* to determine the diagnostic validity of OAEs in high-risk patients (Table 1). The study showed that, of the 134 patients in the sample, OAEs yielded a "no problem" result in 7, while the remaining 127 passed.

Subsequently, when the same group underwent the ABR test, 115 newborns showed normal hearing, while 19 showed abnormal results [1].

**Table 1.** Risk factors for developing hearing loss.

| Risk factors |
|---|
| • In utero infection |
| • Intraventricular hemorrhage |
| • NICU stay >24 hours |
| • Severe perinatal asphyxia |
| • Weight less than 1500 g |
| • Ototoxic medications |
| • Craniofacial abnormalities |
| • Early and late sepsis |
| • Mechanical ventilation |

*NICU = Neonatal Intensive Care Unit. Table compiled by the author, with information obtained from: González-Amaro C. Validity of otoacoustic emissions to detect hearing loss in high-risk neonates. Pediatr Mex. 2013;15(3):80-83*

Currently, based on studies that have been carried out and recommendations from the WHO, the screening and diagnosis of hearing problems is carried out as follows (Figure 6):

1. Screening is performed using OAEs within the first month of life (preferably before hospital discharge) [5]. This screening can have two results:
   a. Pass: correct cochlear conduction of the auditory stimulus.
   b. Fail: alterations in the conduction and/or reception of the auditory stimulus.

2. Once the results are obtained, different paths can be followed:
   a. "Pass" result in both ears, without risk factors: Discharge and follow-up in primary care, due to the low risk [6].
   b. "Pass" result in both ears, with risk factors: ABR at 3 months of corrected age, due to the risk [5,6].
   c. "Fail" result in one or both ears, without risk factors: Repeat the OAEs.
      i. "Pass" result: follow-up in early intervention and monitoring.
      ii. "Fail" result: perform ABR within the first 3 months of corrected age [5,6].
   d. "Fail" result in one or both ears, with risk factors: ABR at 3 months of corrected age [6].

In all cases, follow-up should be performed at one, three, and six years of age, as late-onset hearing loss may occur; although this condition is less frequent, this protocol helps prevent it from being overlooked.

Depending on an unfavorable result of the ABR test, the decision will be made regarding further studies to determine the cause and follow-up of the hearing loss. This follow-up is carried out by audiologists or otolaryngologists. [5,6]

## CONCLUSIONS

It is of great importance for medical personnel to be knowledgeable about the Newborn Hearing Screening algorithm in order to detect hearing loss and deafness early.

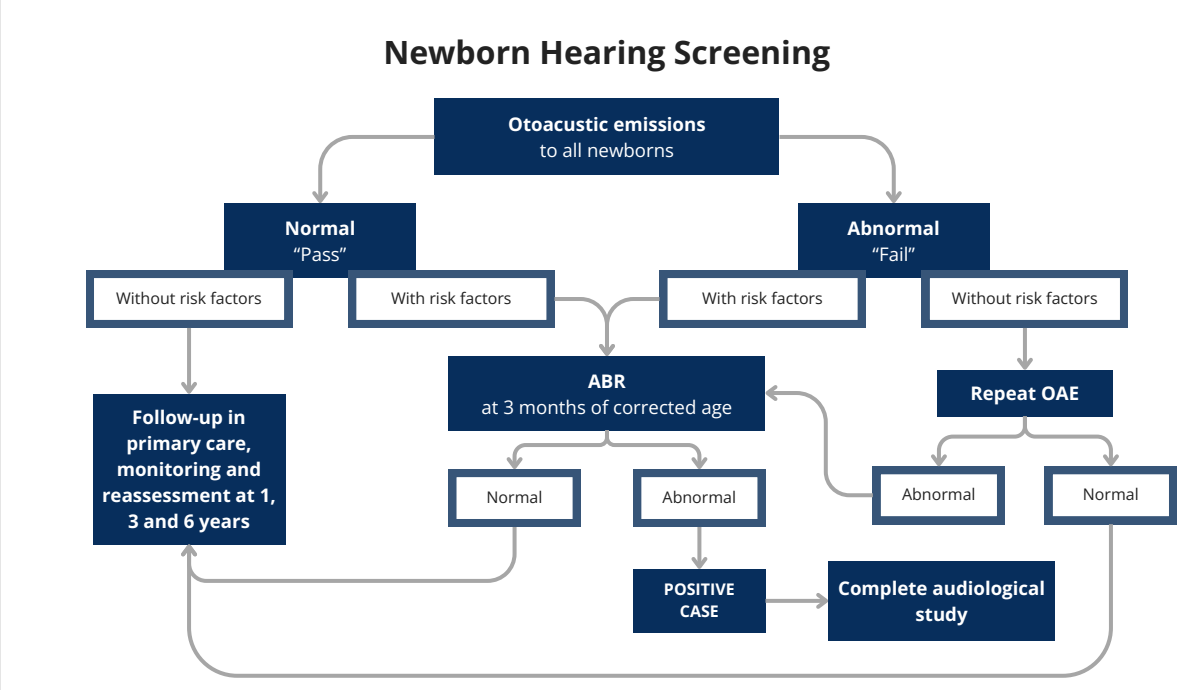



**Figure 6.** Algorithm for neonatal hearing screening and follow-up. *Diagram compiled by the author, with information obtained from: World Health Organization. Hearing screening: considerations for implementation. Geneva: World Health Organization; 2021. ABR = auditory brainstem response; OAE = otoacoustic emissions.*

As primary care physicians, it is relevant to promote the correct follow-up of the Newborn Hearing Screening algorithm among the parents and guardians of the newborn for the benefit of their well-being.

In conclusion, newborn hearing screening is a fundamental tool for detecting potential hearing problems in newborns early, enabling early interventions that promote their linguistic, cognitive, and social development, significantly improving their long-term quality of life.

**Funding**

This work received no external funding.

**Conflict of interest**

The authors declare no conflicts of interest.

**Ethical considerations**

This work did not involve the participation of human subjects or animals, nor the collection of primary data; therefore, it did not require approval from a research ethics committee. All data used were obtained from previously published and publicly accessible secondary sources.

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