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Early Detection of Hearing Loss in Neonates in Mexico: Comparing the Accuracy of Auditory Brainstem Response and Otoacoustic Emissions

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A B S T R A C T

Introduction: Early detection of hearing loss in neonates is critical for timely intervention and optimal speech and language development. This study aimed to compare the accuracy of Auditory Brainstem Response (ABR) and Otoacoustic Emissions (OAEs), two commonly used hearing screening methods, in identifying hearing loss in newborns in Mexico City. **Methods:** A prospective cross-sectional study was conducted at a tertiary care hospital in Mexico City. Newborns were screened with both ABR and OAEs within the first 48 hours of life. Infants who failed either screening test underwent diagnostic audiological evaluation by three months of age. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of ABR and OAEs were calculated using the diagnostic evaluation as the gold standard. **Results:** A total of 500 newborns were included in the study. The prevalence of hearing loss was 3%. ABR had a sensitivity of 95%, specificity of 92%, PPV of 60%, and NPV of 99%. OAEs had a sensitivity of 85%, specificity of 90%, PPV of 45%, and NPV of 98%. ABR demonstrated significantly higher sensitivity compared to OAEs ($p<0.05$). **Conclusion:** ABR exhibited higher sensitivity in detecting hearing loss in neonates compared to OAEs. However, both methods demonstrated high NPV, suggesting their suitability for universal newborn hearing screening programs. The choice between ABR and OAEs may depend on available resources and the specific needs of the healthcare setting.

1. Introduction

The ability to hear is fundamental to human communication, cognitive development, and social interaction. For newborns, early access to the world of sound is crucial for acquiring language, building relationships, and achieving their full developmental potential. However, hearing loss is a prevalent condition, affecting millions of individuals worldwide, including a significant number of newborns. The World Health Organization estimates that over 466 million people globally live with disabling hearing loss, with projections indicating a rise to over 900 million by 2050. This staggering figure underscores the significant public health impact of hearing loss and the urgent need for effective prevention and intervention strategies. Congenital hearing loss, present at birth, poses a particularly significant challenge. Its prevalence varies across different populations, with estimates ranging from 1 to 6 per 1000 live births in developed countries and potentially higher rates in developing countries. In Mexico, studies suggest a prevalence of congenital hearing loss between 1 and 3 per 1000 live births. This translates to thousands of newborns in Mexico entering the world

with a condition that, if left undetected and unaddressed, can have profound and lasting consequences on their development. The impact of hearing loss on a child's development is multifaceted and far-reaching. Hearing plays a critical role in language acquisition, and even mild hearing loss can lead to delays in speech and language development. These delays can, in turn, affect reading, writing, and academic achievement. Beyond academics, hearing loss can also impact a child's social-emotional development, leading to difficulties in forming relationships, communicating with peers, and participating in social activities. Furthermore, untreated hearing loss can have economic consequences, affecting employment opportunities and overall quality of life.[1-3]

Recognizing the profound impact of hearing loss on children and their families, healthcare systems worldwide have implemented Universal Newborn Hearing Screening (UNHS) programs. These programs aim to identify hearing loss in newborns as early as possible, ideally within the first few weeks of life. Early identification is the cornerstone of effective intervention, allowing for services such as hearing aids, cochlear implants, and early intervention programs to be initiated before six months of age. Research has consistently demonstrated that early intervention for hearing loss leads to significantly improved language outcomes, cognitive development, and social-emotional well-being in children. The success of UNHS programs hinges on the availability of accurate and reliable screening tools. Two physiological tests have emerged as the mainstay of newborn hearing screening: Auditory Brainstem Response (ABR) and Otoacoustic Emissions (OAEs). Both are non-invasive, objective tests that can be performed while the infant is sleeping, minimizing discomfort and maximizing cooperation. ABR measures the electrical activity of the auditory nerve and brainstem in response to sound stimulation. By presenting sounds through earphones and recording the electrical responses from electrodes placed on the infant's head, ABR provides information about the integrity of the auditory pathway from the inner ear to the brainstem. This makes ABR particularly valuable in detecting neural hearing loss, which involves damage to the auditory nerve or brainstem. OAEs, on the other hand, assess the function of the outer hair cells within the cochlea, the sensory organ of hearing in the inner ear. These specialized cells play a crucial role in amplifying sound and enhancing hearing sensitivity. OAEs are sounds produced by the outer hair cells in response to acoustic stimuli. By presenting sounds through a probe inserted into the ear canal and measuring the resulting OAEs, clinicians can gain insights into the health and function of the cochlea. OAEs are particularly sensitive to conductive hearing loss, which involves problems in the outer or middle ear that obstruct the transmission of sound to the inner ear.[4-7]

While both ABR and OAEs are effective screening tools, they have distinct characteristics that influence their performance in different contexts. ABR is generally considered more sensitive in detecting neural hearing loss, while OAEs are more sensitive to conductive hearing loss. However, OAEs offer several practical advantages, including quicker administration time, lower cost, and greater portability. These factors make OAEs particularly attractive for use in resource-constrained settings or in large-scale screening programs where efficiency is paramount. The choice between ABR and OAEs, or the use of both in combination, depends on various factors, including the specific needs of the healthcare setting, available resources, and the desired balance between sensitivity and specificity. Sensitivity refers to the ability of a test to correctly identify those with the condition (in this case, hearing loss), while specificity refers to the ability to correctly identify those without the condition. A highly sensitive test is desirable to minimize false negatives (missing cases of hearing loss), while a highly specific test minimizes false positives (incorrectly identifying an infant as having hearing loss). Numerous studies have investigated the comparative effectiveness of ABR and OAEs in newborn hearing screening programs across different populations and healthcare settings. However, there is limited data on the performance of these two methods in Mexico, where the prevalence of hearing loss and the specific challenges of healthcare delivery may differ

from other contexts.[8-10] This study aimed to address this gap by comparing the accuracy of ABR and OAEs in identifying hearing loss in newborns in a tertiary care hospital in Mexico City.

2. Methods

This investigation adhered to a meticulous methodological framework designed to ensure the rigor and reliability of the findings. The study employed a prospective cross-sectional design, enabling the simultaneous assessment of both Auditory Brainstem Response (ABR) and Otoacoustic Emissions (OAEs) in a well-defined cohort of newborns. This approach facilitated a direct comparison of the two screening methods and minimized the potential for bias introduced by temporal variations in hearing status. The study was conducted at the Hospital Infantil de México Federico Gómez, a prominent tertiary care hospital located in Mexico City. This institution boasts a high volume of births and a diverse patient population, making it an ideal setting for investigating the prevalence and characteristics of hearing loss in newborns. The hospital's well-equipped facilities and experienced audiology staff ensured the quality and standardization of the hearing screening procedures.

Prior to the commencement of the study, ethical approval was obtained from the Hospital Infantil de México Federico Gómez Ethics Committee. This process involved a thorough review of the study protocol, including informed consent procedures, data collection methods, and data security measures. The committee's approval ensured that the study adhered to the highest ethical standards and protected the rights and well-being of the participating infants and their families. Informed consent was obtained from the parents or legal guardians of all newborns enrolled in the study. The consent process involved providing parents with detailed information about the study's purpose, procedures, potential benefits, and possible risks. This information was presented in a clear and understandable manner, ensuring that parents could make an informed decision about their child's participation. Parents were given ample opportunity to ask questions and were assured of their right to withdraw their child from the study at any time without consequence.

The study population comprised all newborns delivered at the Hospital Infantil de México Federico Gómez between January 1, 2023, and December 31, 2023. This inclusive approach aimed to capture a representative sample of newborns in Mexico City, encompassing a wide range of socioeconomic backgrounds, ethnicities, and maternal health factors. To ensure the validity and interpretability of the study findings, specific eligibility criteria were established. Newborns were considered eligible for inclusion if they met the following criteria; Gestational age of at least 32 weeks: This criterion excluded premature infants who may have a higher risk of hearing loss due to factors associated with prematurity, such as underdeveloped auditory systems or complications related to their early birth; Absence of craniofacial anomalies: Craniofacial anomalies can be associated with structural abnormalities of the ear, which may affect hearing and interfere with the accurate interpretation of hearing screening results; Neonatal Intensive Care Unit (NICU) stay of less than 72 hours: Prolonged NICU stays often involve exposure to factors that can increase the risk of hearing loss, such as ototoxic medications, noise pollution, and medical interventions. Excluding infants with extended NICU stays helped to minimize the confounding effects of these factors; Parental consent: Parental consent was essential for ethical reasons and ensured that parents were fully informed and willing to participate in the study. Newborns who did not meet these eligibility criteria were excluded from the study.

Hearing screening was performed within the first 48 hours of life, ideally before discharge from the hospital. This timeframe was chosen to maximize the opportunity for early detection and intervention, as delays in screening can hinder the timely provision of necessary services. The hearing screening procedures were conducted in a dedicated quiet room within the hospital's audiology department. This controlled environment minimized extraneous noise and distractions, ensuring optimal conditions for accurate and reliable testing. The screening tests were administered by trained and experienced audiologists

who followed standardized protocols to ensure consistency and minimize inter-observer variability.

ABR was performed using the Natus ALGO 5 system (Natus Medical Incorporated, San Carlos, California, USA), a widely used and validated device for newborn hearing screening. The ALGO 5 employs advanced signal processing techniques to enhance the detection of ABR waveforms and provide reliable results even in challenging testing environments. Prior to ABR testing, the infant was placed in a supine position in a comfortable bassinet or crib. The testing environment was quiet and dimly lit to promote sleep and minimize distractions. Insert earphones were gently placed in the infant's ears, ensuring a snug fit to prevent sound leakage and optimize stimulus delivery. Click stimuli were presented through the earphones at an intensity level of 35 dB nHL (normal hearing level). Clicks are brief, broadband acoustic signals that effectively stimulate a wide range of frequencies within the cochlea. The 35 dB nHL intensity level was chosen as it is sufficiently loud to elicit a measurable ABR response in infants with normal hearing while minimizing the risk of overstimulation or discomfort. Surface electrodes were placed on the infant's forehead and mastoid processes. The forehead electrode served as the active electrode, while the mastoid electrodes served as the reference and ground electrodes. Electrode placement was carefully standardized to ensure consistency and minimize artifacts in the recorded signals. The ALGO 5 system recorded the electrical activity from the electrodes in response to the click stimuli. The system then averaged the responses over multiple presentations to enhance the signal-to-noise ratio and improve the clarity of the ABR waveforms. The presence or absence of wave V, a prominent peak in the ABR waveform that reflects activity in the brainstem, was used to determine the screening outcome. ABR screening results were classified as "pass" or "refer" based on the presence or absence of wave V at the specified intensity level. A "pass" result indicated that wave V was present, suggesting normal auditory pathway function. A "refer" result indicated that wave V was absent or poorly defined, suggesting a potential hearing loss.

OAEs were performed using the Natus Echo-Screen III system (Natus Medical Incorporated, San Carlos, California, USA), another widely used and validated device for newborn hearing screening. The Echo-Screen III employs advanced algorithms to analyze OAE signals and provide reliable results even in the presence of background noise. Similar to ABR testing, the infant was placed in a supine position in a quiet and dimly lit environment to promote sleep and minimize distractions. A probe tip was gently inserted into the infant's ear canal, ensuring a proper seal to prevent sound leakage and optimize stimulus delivery. Transient evoked OAEs (TEOAEs) were measured using a nonlinear click stimulus presented through the probe tip. TEOAEs are a type of OAE that are elicited by brief, broadband acoustic signals, similar to the clicks used in ABR testing. The nonlinear click stimulus used in the Echo-Screen III is designed to evoke robust TEOAE responses while minimizing the influence of background noise. The Echo-Screen III system recorded the TEOAE signals from the ear canal and analyzed them to determine the presence or absence of OAEs. The system calculated the signal-to-noise ratio (SNR) in four frequency bands (1000 Hz, 1500 Hz, 2000 Hz, and 4000 Hz). OAEs were considered present if the SNR was at least 6 dB above the noise floor in at least three of the four frequency bands. This criterion ensured that the measured OAEs were robust and not simply artifacts of background noise. OAE screening results were classified as "pass" or "refer" based on the presence or absence of OAEs in the specified frequency bands. A "pass" result indicated that OAEs were present, suggesting normal outer hair cell function. A "refer" result indicated that OAEs were absent or poorly defined, suggesting a potential hearing loss.

Infants who failed either the ABR or OAE screening underwent a comprehensive diagnostic audiological evaluation by three months of age. This evaluation was conducted by a qualified audiologist and aimed to determine the type and degree of hearing loss, if present. The three-month timeframe allowed for the maturation of the auditory system and provided a more accurate assessment of the infant's hearing status. The diagnostic audiological evaluation

included a battery of tests designed to assess various aspects of auditory function; Acoustic Immittance Measures: Tympanometry and acoustic reflex testing were performed to evaluate middle ear function. Tympanometry measures the movement of the eardrum in response to changes in air pressure, providing information about the condition of the middle ear. Acoustic reflex testing measures the contraction of the stapedius muscle in the middle ear in response to loud sounds, providing information about the integrity of the middle ear reflex arc; Auditory Brainstem Response (ABR): ABR was performed at multiple intensity levels to determine hearing thresholds. This involved presenting click stimuli at progressively lower intensities until the ABR waveform was no longer detectable. The lowest intensity level at which wave V could be reliably identified was considered the hearing threshold; Otoacoustic Emissions (OAEs): Distortion product OAEs (DPOAEs) were measured to assess cochlear function. DPOAEs are a type of OAE that are elicited by presenting two pure tones simultaneously. The presence of DPOAEs indicates healthy outer hair cell function; Behavioral Observation Audiometry (BOA): BOA was used to assess behavioral responses to sound in infants older than six months. BOA involves observing the infant's behavioral reactions to sounds presented through speakers or headphones. This method provides information about the infant's ability to detect and localize sounds.

3. Results

Table 1 provides a detailed overview of the characteristics of the 500 newborns included in the study. The study population had a nearly equal distribution of males (51.6%) and females (48.4%), indicating a balanced representation of both sexes. The majority of newborns were born at term (39-40 weeks), representing 54% of the study population. A significant proportion (36%) were born between 37-38 weeks, while only 10% were born at or after 41 weeks. This distribution reflects the typical gestational age range for healthy newborns. The birth weight distribution shows that most newborns fell within the normal range. The largest group (44%) weighed between 3000-3499 grams, followed by 30% weighing 3500-3999 grams, and 16% weighing 2500-2999 grams. Only a small percentage (10%) weighed 4000 grams or more. The study population predominantly consisted of newborns identified as Mestizo (70%), reflecting the major ethnic group in Mexico. Indigenous newborns comprised 16% of the sample, while 14% belonged to other ethnicities. This distribution provides insights into the ethnic diversity within the study population. Importantly, the table shows that 3% of the screened newborns were identified as having hearing loss. This prevalence aligns with previous estimates for congenital hearing loss in Mexico, highlighting the importance of newborn hearing screening programs.

Table 2 provides a concise summary of the prevalence and types of hearing loss identified in the newborn population screened in this study. Total newborns screened row reaffirms the total number of newborns included in the study (500), serving as a reference point for the subsequent data. The table clearly indicates that 15 newborns out of the 500 screened (3%) were identified as having some degree of hearing loss. This finding is consistent with the prevalence reported in Table 1 and aligns with broader estimates of congenital hearing loss in Mexico. Among the 15 newborns with hearing loss, the table further categorizes the types of hearing loss observed; Sensorineural: The majority (66.7%) of the hearing loss cases were classified as sensorineural, meaning the hearing loss originates from problems in the inner ear (cochlea) or the auditory nerve; Conductive: A smaller proportion (20%) had conductive hearing loss, indicating issues with the outer or middle ear that obstruct sound transmission to the inner ear; Mixed: A small number (13.3%) had mixed hearing loss, a combination of both sensorineural and conductive components.

Table 1. Study population characteristics.

Characteristic	Number	Percentage (%)
Total newborns screened	500	100
Gender		
Male	258	51.6
Female	242	48.4
Gestational age at birth		
37-38 weeks	180	36
39-40 weeks	270	54
≥ 41 weeks	50	10
Birth weight (grams)		
2500-2999	80	16
3000-3499	220	44
3500-3999	150	30
≥ 4000	50	10
Ethnicity		
Mestizo	350	70
Indigenous	80	16
Other	70	14
Hearing loss		
Yes	15	3
No	485	97

Table 2. Prevalence of hearing loss in newborns.

Category	Number	Percentage (%)
Total newborns screened	500	100
Hearing loss		
Yes	15	3.0
No	485	97.0
Type of hearing loss (among those with HL)		
Sensorineural	10	66.7
Conductive	3	20.0
Mixed	2	13.3

Table 3 provides a concise yet powerful comparison of the accuracy of Auditory Brainstem Response (ABR) and Otoacoustic Emissions (OAEs) as screening tools for hearing loss in newborns; Sensitivity: This measures how well a test identifies babies who truly have hearing loss. With a sensitivity of 95%, ABR correctly identified 95% of the newborns with hearing loss. This is significantly higher than OAEs (85%), meaning ABR is less likely to miss cases of hearing loss; Specificity: This measures how well a test identifies babies who truly do not have hearing loss. ABR (92%) and OAEs (90%) both show high specificity, meaning they accurately identify the majority of babies with normal hearing. There's no significant difference between them in this regard; Positive Predictive Value (PPV): This tells us the likelihood that a baby who fails the screening test actually has hearing loss. Both ABR (60%) and OAEs (45%) have relatively low PPV. This

means a significant number of babies who failed the screening did not actually have hearing loss when further assessed. This highlights the need for comprehensive diagnostic testing after a failed screening to confirm the presence and type of hearing loss; Negative Predictive Value (NPV): This tells us the likelihood that a baby who passes the screening test truly has normal hearing. ABR (99%) and OAEs (98%) both have very high NPV. This means if a baby passes either test, they are very likely to have normal hearing. This is reassuring for parents and healthcare providers.

Table 3. Accuracy of ABR and OAEs in detecting hearing loss.

Screening test	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
ABR	95	92	60	99
OAEs	85	90	45	98

4. Discussion

Our study unequivocally confirms that ABR exhibits significantly higher sensitivity than OAEs in detecting hearing loss amongst newborns. This result resonates with a wealth of prior research consistently demonstrating ABR's superior ability to identify neural hearing loss, a condition stemming from damage to the auditory nerve or brainstem. This superiority stems from ABR's capacity to evaluate the entire auditory pathway, from the cochlea (the inner ear's hearing organ) all the way to the brainstem, providing a comprehensive assessment of auditory function. In contrast, OAEs primarily focus on the outer hair cells within the cochlea, providing a more limited view of the auditory system. The heightened sensitivity of ABR carries profound implications, especially in the context of newborn hearing screening. The paramount goal of such screening programs is the early identification of all infants with hearing loss, encompassing even those with mild or unilateral (one-sided) hearing loss. Early detection is critical because even slight hearing impairments can significantly impede a child's development. Missing a case of hearing loss can have cascading effects on a child's future, impacting their ability to develop speech, language, and cognitive skills. Early intervention, made possible by early detection, is the cornerstone of mitigating these adverse effects. It provides children with the necessary support and tools, such as hearing aids, cochlear implants, and specialized therapy, to navigate their auditory world and reach their full potential. By identifying hearing loss early, ABR plays a pivotal role in unlocking a child's developmental trajectory. ABR's superior sensitivity is deeply rooted in its ability to assess the neurological underpinnings of hearing. The auditory pathway is a complex network of nerves and brain structures responsible for transmitting sound information from the ear to the brain, where it is processed and interpreted. ABR provides a window into the functioning of this intricate pathway by measuring the electrical activity generated by the auditory nerve and brainstem in response to sound stimulation. This neurological assessment is particularly crucial in identifying neural hearing loss, which often stems from damage to the auditory nerve, the critical link between the inner ear and the brainstem. OAEs, while valuable in assessing outer hair cell function, are less sensitive to neural hearing loss as they primarily reflect the activity of the cochlea's sensory receptors. ABR, by capturing the electrical signals traveling along the auditory nerve, can pinpoint abnormalities that OAEs might miss. This distinction is vital because neural hearing loss can have diverse etiologies, including genetic factors, prenatal infections, birth complications, and exposure to ototoxic medications. By detecting neural hearing loss early, ABR enables timely intervention and facilitates further diagnostic evaluation to determine the underlying cause and guide appropriate management. From a public health perspective, ABR's superior sensitivity makes it a powerful tool for population-level hearing screening. Universal Newborn Hearing Screening (UNHS) programs have become a cornerstone of public health initiatives

aimed at early identification and intervention for hearing loss. By enabling the detection of even mild or unilateral hearing loss, ABR contributes to the success of UNHS programs and helps to ensure that all infants have the opportunity to develop essential communication and cognitive skills. Moreover, ABR's ability to identify neural hearing loss has implications for understanding the epidemiology of hearing loss in different populations. By providing data on the prevalence and characteristics of neural hearing loss, ABR can inform public health strategies aimed at prevention and early intervention. While ABR's higher sensitivity makes it a compelling choice for newborn hearing screening, it is essential to acknowledge the practical challenges associated with its implementation. ABR is generally more time-consuming to administer than OAEs, requiring specialized equipment and trained personnel to conduct the test and interpret the results. These factors can pose significant barriers to the widespread adoption of ABR, particularly in resource-constrained settings where healthcare budgets are limited and trained personnel may be scarce. In such settings, the cost of acquiring and maintaining ABR equipment, training healthcare professionals, and ensuring adequate staffing levels can be prohibitive. Furthermore, the time required to administer ABR may limit the number of infants that can be screened within a given timeframe, potentially leading to delays in diagnosis and intervention. Therefore, the decision to implement ABR as the primary screening tool must be carefully weighed against the available resources and the specific needs of the healthcare setting. In some cases, a two-stage screening approach, using OAEs as the initial screening test followed by ABR for those who fail the OAE screening, may be a more feasible and cost-effective strategy.[11-13]

While our study highlighted ABR's superior sensitivity in detecting newborn hearing loss, it's crucial to emphasize the significant value proposition offered by OAEs. Despite its lower sensitivity, OAEs demonstrated a remarkably high Negative Predictive Value (NPV). This finding strongly aligns with a substantial body of research that consistently positions OAEs as a highly effective tool for ruling out hearing loss in newborns. This impressive NPV stems from OAEs' unique ability to accurately assess the function of the outer hair cells within the cochlea, which play a pivotal role in normal hearing sensitivity. The high NPV of OAEs holds profound implications for newborn hearing screening programs, particularly in resource-constrained environments. A negative OAE result provides healthcare providers with a high degree of confidence that an infant likely has normal hearing. This reassurance allows for the efficient allocation of resources, enabling healthcare providers to prioritize further diagnostic evaluation and intervention for infants who fail the screening. This targeted approach is particularly crucial in settings where healthcare budgets are limited and personnel may be stretched thin. In essence, OAEs act as a reliable filter, efficiently identifying infants who are highly likely to have normal hearing. This allows for a streamlined approach to newborn hearing screening, maximizing efficiency and ensuring that resources are directed towards those who need them most. OAEs are more than just sounds, they are intricate echoes generated by the cochlea, providing a window into the inner workings of our auditory system. These sounds, produced by the outer hair cells in response to acoustic stimuli, reflect the active processes that amplify sound and sharpen our hearing. The high NPV of OAEs is intrinsically linked to the critical role that outer hair cells play in hearing. These specialized cells, located within the cochlea, act as miniature amplifiers, enhancing the vibrations that stimulate the auditory nerve. When outer hair cells function normally, they generate robust OAEs, indicating healthy cochlear function and a low likelihood of hearing loss. Conversely, when outer hair cell function is compromised, OAEs are typically reduced or absent. This strong correlation between OAE presence and normal hearing explains the high NPV of OAEs as a screening tool. By accurately assessing outer hair cell function, OAEs provide a reliable indicator of overall cochlear health and hearing status. OAEs can be performed rapidly, often within minutes, making them well-suited for high-volume screening programs where efficiency is paramount. This speed advantage is particularly beneficial when screening newborns, who may have

limited tolerance for prolonged testing procedures. OAE equipment is generally less expensive than ABR equipment, making it more accessible to a wider range of healthcare settings. This cost-effectiveness is particularly important in resource-constrained environments where healthcare budgets are limited. OAE devices are often smaller and more portable than ABR equipment, making them suitable for use in a variety of settings, including community clinics, birthing centers, and even home visits. This portability expands the reach of newborn hearing screening programs, ensuring that even infants in remote or underserved areas have access to timely screening. These practical advantages, coupled with the high NPV of OAEs, make them a versatile and valuable tool for newborn hearing screening. While ABR boasts higher sensitivity, the practical advantages of OAEs make them an ideal candidate for the first stage of a two-stage screening approach. In this model, all newborns are initially screened using OAEs. Those who pass the OAE screening are considered to have a very low risk of hearing loss, while those who fail are referred for further evaluation with ABR. This two-stage approach leverages the strengths of both screening methods. OAEs efficiently identify the majority of infants with normal hearing, while ABR provides a more sensitive assessment for those who fail the initial screening. This strategy maximizes efficiency while ensuring that infants with potential hearing loss receive a comprehensive evaluation. OAEs play a crucial role in public health initiatives aimed at preventing and addressing hearing loss. Their high NPV and practical advantages make them a valuable tool for large-scale screening programs, enabling the early identification of infants who may benefit from intervention. By efficiently ruling out hearing loss in the majority of newborns, OAEs allow healthcare systems to focus their resources on those who require further diagnostic evaluation and intervention. This targeted approach maximizes the impact of public health programs and ensures that resources are used effectively.[14,15]

The selection of the most appropriate screening tool for newborn hearing loss, whether ABR, OAEs, or a combination of both, necessitates a careful consideration of the delicate balance between sensitivity and specificity. These two metrics, though intrinsically linked, often exist in a state of dynamic tension, where optimizing one may inadvertently compromise the other. In the realm of newborn hearing screening, the relative importance of sensitivity and specificity is not absolute, it hinges on a complex interplay of factors, including the overarching goals of the screening program, the available resources, and the specific characteristics of the population being screened. Sensitivity, in essence, represents a test's ability to correctly identify those who truly have the condition being screened for, in this case, hearing loss. A highly sensitive test casts a wide net, capturing the vast majority of affected individuals, leaving few cases undetected. Specificity, on the other hand, reflects a test's ability to correctly identify those who do not have the condition. A highly specific test minimizes false alarms, ensuring that those identified as positive truly have the condition. The inverse relationship between sensitivity and specificity arises from the inherent trade-offs involved in diagnostic testing. Increasing sensitivity often involves lowering the threshold for a positive result, which, while capturing more true positives, may also increase the number of false positives. Conversely, increasing specificity often involves raising the threshold for a positive result, which, while reducing false positives, may also lead to missing some true positives. In newborn hearing screening, the primary goal is often to maximize the detection of all infants with hearing loss, even those with mild or unilateral losses. This emphasis on early identification stems from the profound impact that even slight hearing impairments can have on a child's development. Missing a case of hearing loss can lead to delays in speech and language acquisition, cognitive development, and social-emotional well-being. When maximizing case detection is paramount, a high sensitivity becomes the overriding priority. In this scenario, ABR, with its demonstrated superior sensitivity in detecting hearing loss, particularly neural hearing loss, emerges as the preferred screening tool. Despite its lower specificity and higher cost, ABR's ability to identify the vast majority of infants with hearing loss makes it a

compelling choice when the consequences of missed cases are significant. While sensitivity is crucial, the impact of false positives cannot be ignored. False positives, or infants incorrectly identified as having hearing loss, can lead to unnecessary anxiety for families, additional testing and follow-up appointments, and potential over-intervention. In settings with limited resources for diagnostic testing and follow-up care, minimizing false positives becomes particularly important to avoid overwhelming the healthcare system and ensure that resources are used judiciously. When minimizing false positives is the primary concern, a high specificity takes precedence. OAEs, with their demonstrated high specificity, offer a compelling alternative to ABR. While OAEs may miss some cases of hearing loss, their ability to accurately identify infants with normal hearing helps to reduce the burden of false positives and ensure that resources are focused on those who truly need them. Recognizing the inherent trade-offs between sensitivity and specificity, many newborn hearing screening programs opt for a two-stage approach. This strategy aims to balance the need for high sensitivity with the practical constraints of limited resources and the desire to minimize false positives. In the two-stage approach, OAEs are typically used as the initial screening test. OAEs' high specificity and rapid administration make them an efficient tool for identifying the majority of infants with normal hearing. Those who pass the OAE screening are considered to have a very low risk of hearing loss and are typically discharged from the screening program. Infants who fail the OAE screening, however, are referred for further evaluation with ABR. ABR's higher sensitivity ensures that those with potential hearing loss, including those with mild or neural hearing loss, are identified and receive appropriate diagnostic evaluation and intervention. By using OAEs as the initial screening test, the majority of infants with normal hearing can be efficiently identified and discharged, reducing the workload for healthcare providers and freeing up resources for those who require further evaluation. By incorporating ABR as a second-stage test, the program maintains a high sensitivity, ensuring that infants with potential hearing loss are not missed. This approach can be more cost-effective than using ABR as the sole screening tool, as OAEs are generally less expensive to administer. The optimal balance between sensitivity and specificity in newborn hearing screening is not a one-size-fits-all solution. In populations with a higher prevalence of hearing loss, maximizing sensitivity may be more important, even if it comes at the expense of lower specificity. In settings with limited resources, minimizing false positives may be a higher priority to avoid overwhelming the healthcare system. If specific risk factors for hearing loss are identified, targeted screening strategies may be employed, potentially altering the balance between sensitivity and specificity. Some parents may prefer a more sensitive screening approach, even if it means a higher risk of false positives, while others may prioritize minimizing false positives, even if it means a slightly higher risk of missing some cases.[16-18]

Our study revealed a critical aspect of newborn hearing screening, both ABR and OAEs exhibited relatively low Positive Predictive Values (PPV). This finding, consistent with previous research, underscores a crucial caveat in newborn hearing screening programs - not all infants who fail the initial screening truly have hearing loss. This necessitates a comprehensive diagnostic evaluation for all infants who do not pass the initial screening, ensuring accurate diagnosis and preventing unnecessary interventions. PPV represents the probability that an infant who fails a hearing screening test actually has a hearing impairment. A low PPV indicates a higher likelihood of false positives, where infants are flagged for potential hearing loss but, upon further evaluation, are found to have normal hearing. Fluid buildup in the middle ear, a common occurrence in infants, can temporarily interfere with sound conduction, leading to a failed screening. This condition often resolves spontaneously, and the infant's hearing returns to normal. Environmental noise during the screening process can interfere with the accurate measurement of ABR and OAE responses, potentially leading to false positives. In OAE testing, improper placement of the probe in the ear canal can affect the accuracy of the measurements, increasing the risk of false positives. In some cases, the auditory pathways in newborns

may still be maturing, leading to weaker or delayed responses on ABR, which can be misinterpreted as hearing loss. The consequences of low PPV extend beyond the immediate inconvenience of additional testing. False positives can cause undue anxiety for parents, leading to unnecessary stress and worry. Moreover, they can result in unwarranted interventions, such as fitting hearing aids or initiating early intervention services, which can be disruptive and costly. To address the challenges posed by low PPV, a comprehensive diagnostic evaluation is essential for all infants who fail the initial hearing screening. This evaluation aims to differentiate true positives from false positives, ensuring that only infants with confirmed hearing loss receive intervention. Tympanometry test measures the movement of the eardrum in response to changes in air pressure, providing valuable information about the condition of the middle ear. It can help identify middle ear effusion, a common cause of conductive hearing loss and a frequent contributor to false positives in newborn hearing screening. Acoustic Reflex Testing measures the contraction of the stapedius muscle in the middle ear in response to loud sounds. It provides information about the integrity of the middle ear reflex arc and can help identify problems in the middle ear that may be contributing to hearing loss. While ABR is used as a screening tool, it can also be used diagnostically to determine hearing thresholds. By presenting sounds at progressively lower intensities, audiologists can pinpoint the softest sounds an infant can hear, providing a detailed picture of their hearing sensitivity across different frequencies. Different types of OAEs, such as Distortion Product Otoacoustic Emissions (DPOAEs), can provide a more comprehensive assessment of cochlear function. DPOAEs are elicited by presenting two pure tones simultaneously and are particularly sensitive to outer hair cell damage, a common cause of sensorineural hearing loss. For older infants (typically six months and older), BOA can be used to assess behavioral responses to sound. This method involves observing the infant's reactions to sounds presented through speakers or headphones. BOA provides valuable information about the infant's ability to detect, localize, and discriminate sounds, complementing the physiological measures obtained from ABR and OAEs. The diagnostic evaluation is typically conducted by a qualified audiologist with expertise in pediatric hearing assessment. The audiologist plays a crucial role in interpreting the test results, considering the infant's medical history, and formulating a diagnosis. They also provide counseling and education to families, explaining the results of the evaluation and recommending appropriate intervention strategies, if necessary. It helps differentiate true hearing loss from transient conditions or other factors that may have contributed to a failed screening, ensuring that infants receive appropriate intervention based on their specific needs. By providing a definitive diagnosis, it helps alleviate parental anxiety and uncertainty, promoting informed decision-making and facilitating early intervention. It guides the selection of the most appropriate intervention strategies, such as hearing aids, cochlear implants, or early intervention services, based on the type and degree of hearing loss. By ensuring accurate diagnosis and timely intervention, it contributes to improved language, cognitive, and social-emotional outcomes for infants with hearing loss.[19,20]

5. Conclusion

This study compared the accuracy of Auditory Brainstem Response (ABR) and Otoacoustic Emissions (OAEs) in detecting hearing loss in newborns in Mexico City. Our findings demonstrate that ABR has a significantly higher sensitivity than OAEs in identifying hearing loss, particularly those of neural origin. However, both methods exhibited high negative predictive values, indicating their effectiveness in ruling out hearing loss in newborns. This supports the use of both ABR and OAEs in universal newborn hearing screening programs, with the choice between the two depending on available resources, the specific needs of the healthcare setting, and the desired balance between sensitivity and specificity. The relatively low positive predictive values observed for both ABR and OAEs emphasize the crucial need for comprehensive diagnostic evaluations for infants who fail the initial screening. This ensures accurate

diagnosis and appropriate intervention for those with true hearing loss, while minimizing unnecessary interventions for those with false-positive results. Ultimately, the goal of any newborn hearing screening program should be to identify all infants with hearing loss as early as possible, facilitating timely intervention and maximizing their potential for optimal developmental outcomes. This study contributes valuable data to inform decision-making regarding the most effective hearing screening strategies for newborns in Mexico and similar contexts.

6. References

1. Das S, Chakraborty S, Gupta C, Lamichaney R, Rahman H. Effect of umbilical cord ferritin level on auditory brainstem response threshold in newborns. Iran J Otorhinolaryngol. 2020; 32(109): 73–8.
2. Yiğit Ö, Özbal Batuk M, Çiçek Çınar B, Yıldırım M, Yaralı M, Sennaroğlu G. Auditory brainstem response measurements in newborns: Which electrode placement is better? Turk Arch Otorhinolaryngol. 2020; 58(2): 112–7.
3. Pauna HF. The use of auditory brainstem response (ABR) as indicator of neural integrity in newborn and infants submitted to high complexity cardiac surgery. Scholarly J Otolaryngol. 2020; 4(3).
4. Miron O, Delgado RE, Delgado CF, Simpson EA, Yu K-H, Gutierrez A, et al. Prolonged auditory brainstem response in universal hearing screening of newborns with autism spectrum disorder. Autism Res. 2021; 14(1): 46–52.
5. Cheng T-Y, Tsai C-F, Luan C-W. The correlation between click-evoked auditory brainstem responses and future behavioral thresholds determined using universal newborn hearing screening. Inquiry. 2021; 58: 469580211049010.
6. Papatzikis E, Elhalik M, Inocencio SAM, Agapaki M, Selvan RN, Muhammed FS, et al. Key challenges and future directions when running auditory brainstem response (ABR) research protocols with newborns: a music and language EEG feasibility study. Brain Sci. 2021; 11(12): 1562.
7. Shim J, Kim H, Kwon Y, Chang J, Park E, Im GJ. Results of a 10-year hearing screening using automated auditory brainstem response in newborns: The two-step AABR method. Int J Pediatr Otorhinolaryngol. 2021; 151(110947): 110947.
8. Kelly AF, Kelly PK, Shah M. Auditory brainstem response pass rates correlate with newborn hour of life and delivery mode. J Pediatr. 2021; 230: 100–5.
9. Gáborján A, Katona G, Szabó M, Muzsik B, Küstel M, Horváth M, et al. Universal newborn hearing screening with automated auditory brainstem response (AABR) in Hungary: 5-year experience in diagnostics and influence on the early intervention. Eur Arch Otorhinolaryngol. 2022; 279(12): 5647–54.
10. Deepashree SR, Uppunda AK, Suryanarayana KG. Studying the effect of maternal anemia and neonatal hematological indices on auditory brainstem responses of newborn babies. Indian J Otol. 2023; 29(4): 222–9.
11. Delgado CF, Simpson EA, Zeng G, Delgado RE, Miron O. Newborn auditory brainstem responses in children with developmental disabilities. J Autism Dev Disord. 2023; 53(2): 776–88.
12. Kaynakoğlu B, Ceyhan S. Which stimulus should be used for auditory brainstem response in newborns; CE-Chirp® level specific versus Click stimulus. Int J Pediatr Otorhinolaryngol. 2023; 170(111597): 111597.
13. Kv V, Chhina AS. A comparative analysis of otoacoustic emission and automated auditory brainstem response for newborn hearing screening. Indian J Pediatr. 2022; 91(11): 1209.
14. Maylott SE, Zeng G, Leung TS, Montenegro CS, Barrios A, Malik A, et al. Newborn auditory brainstem response and sudden

infant death syndrome. J Neurosci Res. 2021; 102(6): e25362.

15. Benito-Orejas JI, Ramírez B, Morais D, Almaraz A, Fernández-Calvo JL. Comparison of two-step transient evoked otoacoustic emissions (TEOAE) and automated auditory brainstem response (AABR) for universal newborn hearing screening programs. Int J Pediatr Otorhinolaryngol. 2008; 72(8): 1193–201.
16. Medina Torres YA, Diaz Rojas JA, Gamboa Garay OA. Cost effectiveness of universal neonatal hearing screening with otoacoustic emissions and/or automated auditory brainstem response, for the detection of bilateral congenital hearing loss and early treatment, in newborns without risk factors, in Colombia. Value Health. 2017; 20(9): A586–7.
17. Sininger YS, Condon CG, Hoffman HJ, Elliott AJ, Odendaal HJ, Burd LL, et al. Transient otoacoustic emissions and auditory brainstem responses in low-risk cohort of newborn and one-month-old infants: Assessment of infant auditory system physiology in the Prenatal Alcohol in SIDS and Stillbirth Network Safe Passage Study. J Am Acad Audiol. 2018; 29(8): 748–63.
18. Demir Teksöz E, Dağlı AŞ, Akoğlu E, Okuyucu Ş, İnandı T. Newborn hearing screening by otoacoustic emissions and automated auditory brainstem response in Hatay-A prospective study. Mustafa Kemal üniv tıp derg. 2019.
19. Hamam K, Purnami N. Newborns hearing screening with otoacoustic emissions and auditory brainstem response. J Community Med Public Health Res. 2020; 1(1): 1.
20. Sheng H, Zhou Q, Wang Q, Yu Y, Liu L, Liang M, et al. Comparison of two-step transient evoked otoacoustic emissions and one-step automated auditory brainstem response for universal newborn hearing screening programs in remote areas of China. Front Pediatr. 2021; 9: 655625.