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Evoked Otoacoustic Emissions and Auditory Brainstem Responses: Concordance in Hearing Screening Among High-risk Children

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Objective—Evoked otoacoustic emissions (OAEs) and diagnostic auditory brainstem responses (ABRs) were determined in 379 high-risk children referred for hearing screening.
Material and Methods—This was a retrospective, cross-sectional study. The records of 379 children referred for hearing screening between January 2002 and March 2003 at the Ear Unit of the Philippine General Hospital were evaluated.
Results—Of the 379 children, 53.6% were male and 46.4% were female and the mean age was 41 ± 47 months. The age distribution was as follows: ≤ 12 months, 32.2%; 12–24 months, 52.2%; and > 24 months, 11%. Out of 229 right and 232 left ears, 111 (48.5%) and 112 (48.3%) had "pass" responses and 113 (49.3%) and 116 (50.5%) had "refer" responses, respectively. Five right and four left ears had "noise" responses. Out of 266 right and 209 left ears, the ABR results showed 72 (27.1%) and 30 (14.4%) with normal auditory pathways and 194 (72.9%) and 179 (85.6%) with abnormal auditory pathways, respectively. Of the 131 children whose parents gave their consent for concomitant OAE and ABR testing, agreements were observed between the two tests in terms of classifying the results as normal or abnormal of 78.9% ($\kappa = 0.51$; $p = 0.00$) in right and 78.6% ($\kappa = 0.51$; $p = 0.00$) in left ears. When the children were classified as either "with hearing loss—bilateral abnormal ABRs" or "at least one normal ABR", there was an observed agreement of 81% ($\kappa = 0.6$; $p = 0.00$). OAEs had a sensitivity of 76.9% (95% CI 66.7–84.8%) and a specificity of 90% (95% CI 75.4–96.7%).
Conclusion—There is good concordance between OAE and ABR results among high-risk children referred for hearing screening. *Key words: auditory brainstem response, evoked otoacoustic emissions, hearing screening, sensitivity, specificity.*

INTRODUCTION

With heightened awareness of the importance of preventing hearing loss at an earlier age, universal neonatal hearing screening has been advocated by many institutions worldwide. This would enable health professionals to identify cases of hearing loss earlier and therefore institute treatment and rehabilitation for patients identified as having hearing loss before irreversible consequences could ensue. Since 2000, our institution has used otoacoustic emissions (OAEs) and auditory brainstem responses (ABRs) to evaluate the hearing status of high-risk children (1). At present, universal hearing screening is still not practicable given the difficulties of establishing a program, which requires logistic and financial resources. Thus, hearing screening of high-risk children is the responsibility of the Ear Unit, which receives referrals for hearing evaluation from pediatricians and other otorhinolaryngologists both within and outside the hospital.

Evoked OAEs and ABRs each have advantages and disadvantages in hearing screening, and the following parameters should be considered: (i) the ease of testing and obtaining results; (ii) cost; and (iii) technician dependence. In terms of reliability for screening, the diagnostic ABR remains the preferred test, with OAE testing as the initial investigation, as evident in most universal hearing screening protocols (2, 3). Thus, a "refer" response from OAE testing will be followed by an ABR test for confirmation, considering that false-positive and -negative responses may occur with OAE testing.

In our setting, where patients often want to optimize their spending, a single, reliable, accessible, non-invasive and valid hearing test is usually desired to minimize the inconvenience and discomfort to patients, and in particular children. Determining the concordance between OAE and ABR testing, and identifying cases where non-agreement occurred, might be helpful in planning a more efficient flow of patients and may assist in identifying patients who are likely to have or to develop hearing loss with minimum cost.

We aimed to determine the concordance between OAE testing and ABRs for assessing the hearing status of children referred for hearing evaluation at a tertiary institution.

MATERIAL AND METHODS

The records of all patients referred to the Ear Unit for hearing screening between January 2002 and March 2003 were reviewed, where hearing status was assessed using both OAEs and ABRs. For every patient referred for hearing evaluation, both OAE and ABR testing were usually performed, after obtaining consent from the parents and/or guardian. Otherwise, only the procedure (either OAE or ABR) requested by the referring otorhinolaryngologist was performed.

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All procedures were performed at the Ear Unit, which provides a quiet and conducive area for testing. OAE testing was done as previously reported (1), and ABR testing was done using the Pilot ABR Evostar 2/1 machine, after allowing the patient to sleep. Either diphenhydramine hydrochloride or chloral hydrate was used to sedate irritable or younger patients. Data were extracted from the request form, and included sex, age, diagnosis, OAE results and ABR readings. The results were analyzed using EPI-INFO 6.05 and SPSS (Version 9.05) software.

RESULTS

A total of 229 right and 232 left ears were subjected to OAE testing, while 266 right and 209 left ears underwent ABR testing. The majority of the referrals were for speech delay, suspected hearing loss or global developmental delay/autism/mental retardation, etc. (Table I). Of the 379 children, 53.6% were male and 46.4% were female and the mean age was 41 ± 47 months. The age distribution was as follows: ≤ 12 months, 32.2%; 12–24 months, 52.2%; and > 24 months, 11%. Out of 229 right and 232 left ears, 111 (48.5%) and 112 (48.3%) had "pass" responses and 113 (49.3%) and 116 (50.5%) had "refer" responses, respectively. Five right and four left ears had "noise" responses. Out of 266 right and 209 left ears, the ABR results showed 72 (27.1%) and 30 (14.4%) with normal auditory pathways and 194 (72.9%) and 179 (85.6%) with abnormal auditory pathways, respectively. Figure 1 shows the distribution of ABR results (normal, mild, moderate, severe and profound hearing loss) and the number of 'pass' and 'refer' responses per category.

Of the 262 ($n = 131$ children) ears subjected to both OAE and ABR testing, 152 (58.02%) were referred with an abnormal ABR, and 54 (20.6%) passed the OAE test and had a normal ABR, with a sensitivity (defined as the ability of the test to identify patients with hearing loss) of 77.9% (95% CI 71.3–83.4%) and a specificity (defined as the ability of the test to identify patients without hearing loss) of 80.6% (95% CI 68.8–88.9%) (Table II). In our setting, a patient with a "refer" response has a 92.1% (95% CI 86.6–95.6%) chance of having abnormal ABRs, while a patient with a "pass" response has a 55.7% (95% CI 45.2–65.6%) chance of having normal ABRs. In total, 43/262 ears (16.4%) had a "pass" OAE response and abnormal ABRs, representing false-positive results, while 13/262 ears (4.96%) gave false-negative results.

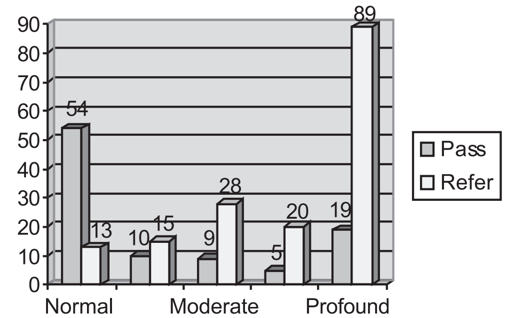

Fig. 1. Distribution of ABR results.

Table I. *Distribution of diagnoses of patients referred for hearing screening*

Diagnosis	*n* (%)
Speech delay	79 (30.27)
Suspected hearing loss	66 (25.29)
Global developmental delay/ mental retardation/autism/ attention deficit hyperactive disorder	42 (16.09)
Congenital rubella syndrome	15 (5.75)
Prematurity	10 (3.83)
Down's syndrome	10 (3.83)
Cerebral palsy	10 (3.83)
Ear malformation/microtia	9 (3.45)
Post-meningitic hydrocephalus	5 (1.92)
Meningitis	3 (1.15)
Others	12 (4.58)
Total	261 (100.0)

Of the 131 children whose parents gave their consent for concomitant OAE and ABR testing, agreements were observed between the two tests in terms of classifying the results as normal or abnormal of 78.9% ($\kappa = 0.51$; $p = 0.00$) in right and 78.6% ($\kappa = 0.51$; $p = 0.00$) in left ears, with an overall agreement of 79% ($\kappa = 0.51$; $p = 0.00$) for both ears. When the children were classified as either "with hearing loss—bilateral abnormal ABRs" or "at least one normal ABR", there was an observed agreement of 81% ($\kappa = 0.6$; $p = 0.00$). OAEs had a sensitivity of 76.9% (95% CI 66.7–84.8%) and a specificity of 90% (95% CI 75.4–96.7%). In total, 70/131 children (53.4%) had a bilateral "refer" response together with an abnormal ABR (Table III). Of these 70 patients, 10 used hearing aids and 39 had undergone speech therapy. Twenty of these (mean age 3.8 years) had baseline language assessment, 17 of whom (85%) were found to have delayed language development.

DISCUSSION

In a setting in which there are various limitations in establishing an effective and affordable hearing program, the adoption of a universal hearing screening program has proven to be difficult, especially given the inherent problem of inadequate follow-up for most of our patients. Because of the high prevalence of bilateral hearing loss among babies with risk factors of $\approx 29\%$ (1), it is imperative to determine the value of

Table II. *Summary of sensitivity, specificity and predictive values of OAEs with ABR. Values given in parentheses are 95% CIs*

OAE	Sensitivity	Specificity	PPV	NPV	κ
Right ear	77.6% (67.8–85.1)	81.8% (63.9–92.4)	92.7% (84.2–97)	55.1% (40.3–69.1)	0.51
Left ear	78.4% (68.6–85.8)	79.4% (61.6–90.7)	91.6% (82.9–96.3)	56.3% (41.3–70.2)	0.51
Both ears	77.9% (71.3–83.4)	80.6% (68.8–88.9)	92.1% (86.6–95.6)	55.7% (45.2–65.6)	0.51

PPV = positive predictive value; NPV = negative predictive value.

OAE testing, in comparison with ABR, for screening during the last 10 years. This may be valuable in planning an effective screening program for neonates and infants that may be applicable to most institutions nationwide.

The majority of patients referred were aged 1–2 years, and most presented with speech delay or hearing loss. This group of patients may represent cases where risk factors for hearing loss are unknown, indicating that there is still much work to be done to identify risk factors that may give clues as to the cause of hearing loss, as well as predicting that a child may develop hearing loss. Congenital rubella and prematurity reflect the standard of prenatal care, and still pose risks to children. Ideally, in a given situation, hearing loss should be identified early enough in order to treat and prevent sequelae of speech delay. Thus, in many countries, identification of hearing loss is being advocated at the age of 6 months, to ensure early treatment and rehabilitation (2, 3). In our type of population, without the benefit of universal hearing screening, the use of OAE testing alone, considering the difficulties inherent in recording an ABR, may be justified, with certain limitations.

There seemed to be no difference between the right and left ears in terms of the parameters determined, and there was also no difference when both ears were analyzed together. Sensitivity and specificity were ≈ 77.9% and ≈ 80.6%, respectively.

In this study, the concordance between OAEs and ABRs seems to be adequate for our purposes, and in determining validity of OAE as a screening tool against ABR, the performance of OAE (sensitivity, 77.9%; specificity, 80.6%) may be acceptable as a screening tool among children referred for suspicion of hearing loss, although it is worse compared to most previous studies (4). With the kind of population we serve, the likelihood that a patient with a "refer" response will have hearing loss (positive predictive value) is 92.1%. In contrast, the likelihood that a patient with a "pass" response will not have hearing loss (negative predictive value) is 55.7%. These data suggest that for most patients with risk factors for developing hearing loss referred to our unit, a "refer" response may be reliable enough to warrant early intervention, with repeat testing using behavioral audiometry (visual reinforcement audiometry) being performed at an appropriate age. However, caution must be exercised in advising parents and/or guardians when the response registers as "pass", as the false-positive rate is ≈ 16%. This may lead to children who really have hearing loss and need further testing being missed. This may be due to the limitations of the screening test or, if associated with an abnormal ABR, may indicate possible auditory neuropathy. In previous studies (4), false-negative rates ranged between 5% and 13%. In recent reports (5–7), patients with normal OAE results but abnormal ABRs were considered to have a condition called auditory neuropathy or dyssynchrony. In our study, 24 (9.2%) patients were noted to have these findings and further follow-up is therefore necessary.

Table III. *OAEs and ABRs for the 131 children whose parents gave consent for OAE and ABR testing. Values shown represent numbers of patients, with percentages in parentheses*

	ABR		
OAE	With hearing loss	Without hearing loss	Total
Refer	70 (53.4)	4 (3.1)	74 (56.5)
Pass	21 (16)	36 (27.5)	57 (43.5)
Total	91 (69.5)	40 (30.5)	131 (100)

Observed agreement = 0.81; agreement due to chance = 0.53; $\kappa = 0.6$, $p = 0.00$; sensitivity = 76.9% (95% CI 66.7–84.8%); specificity = 90% (95% CI 75.4–96.7%); positive predictive value = 94.6% (95% CI 86–98.3%); negative predictive value = 63.2% (95% CI 49.3–75.2%).

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