Section: Paediatrics

Original Research Article

HEARING EVALUATION IN HIGH-RISK INFANTS USING DISTORTION PRODUCT OTOACOUSTIC EMISSIONS AND BRAINSTEM EVOKED RESPONSE AUDIOMETRY: A PROSPECTIVE HOSPITAL-BASED STUDY

Shiela Raman K[1], Nishitha N K[1], Aswin M[1], Urmila K V[2]

[1]*Department of Otorhinolaryngology, Academy of Medical Sciences (ACME), Kannur, Kerala, India*
[2]*Department of Paediatrics, Academy of Medical Sciences (ACME), Kannur, Kerala, India*

Received *: 12/09/2026*
Received in revised form *: 16/10/2026*
Accepted *: 28/10/2026*

Corresponding Author:
Dr. Shiela Raman K,
Professor, Department of Otorhinolaryngology, Academy of Medical Sciences (ACME), Kannur, Kerala, India
Email: sheilaraman150@gmail.com

DOI: 10.70034/ijmedph.2026.4.272

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (4); 1789-1797

ABSTRACT

Background: Permanent congenital hearing loss that is identified and managed by six months of age allows language and social development to keep pace with physical growth. Screening based on otoacoustic emissions (OAE) alone cannot detect auditory neuropathy, so high-risk infants need confirmation with brainstem evoked response audiometry (BERA). This study evaluated hearing in high-risk infants using a two-stage distortion product OAE (DPOAE) protocol with BERA confirmation.

Materials and Methods: This hospital-based prospective study was conducted over one year in the Department of Otorhinolaryngology, Academy of Medical Sciences, Pariyaram, Kerala. A total of 184 consecutive infants with at least one Joint Committee on Infant Hearing (2007) risk factor underwent DPOAE screening. Infants who failed were retested after two weeks, and those who failed again underwent BERA at one month. Hearing threshold was defined as the lowest click intensity at which wave V was identifiable. Associations were tested with the chi-square test, and the diagnostic accuracy of DPOAE was assessed against BERA.

Results: Of the 184 infants, 94 (51.1%) were male. At the first screen, 100 infants (54.3%) failed DPOAE in at least one ear; 35 of the 98 retested still failed and underwent BERA. Hearing loss was confirmed in 29 infants (22 bilateral), an incidence of 15.76% (95% CI 10.50–21.03%). Of the 70 ears tested with BERA, 24.3% had profound, 22.9% moderate, 10.0% moderately severe, 10.0% severe and 5.7% mild hearing loss. Family history of congenital deafness ($p < 0.001$), maternal fever with rash ($p < 0.001$), oligohydramnios ($p = 0.031$), neonatal convulsions ($p = 0.001$) and ototoxic drug exposure beyond seven days ($p = 0.016$) were significantly associated with hearing loss. Hyperbilirubinaemia was less frequent among infants with hearing loss (44.8% vs. 67.7%, $p = 0.018$). Mean wave V latency at threshold fell from 8.56 ms in normal ears to 6.83 ms in severely impaired ears. Against BERA, DPOAE had a sensitivity of 92.2%, specificity of 57.9%, positive predictive value of 85.5%, negative predictive value of 73.3% and diagnostic accuracy of 82.9%.

Conclusion: Nearly one in six high-risk infants in this cohort had hearing loss, frequently of profound degree. DPOAE is a sensitive screening tool that complements, but cannot replace, BERA. A two-stage DPOAE–BERA protocol is a practical approach to the early detection of hearing loss in high-risk infants.

Keywords: Brainstem evoked response audiometry; Distortion product otoacoustic emissions; High-risk infants; Newborn hearing screening; Sensorineural hearing loss.

INTRODUCTION

Hearing is a prerequisite for the acquisition of speech and language, and children born with significant hearing loss may remain without speech unless they are identified and rehabilitated early. The auditory pathway and its higher centres must be stimulated from a very early age to mature normally. When congenital hearing loss is identified and intervention begins by six months of age, infants maintain language and social–emotional development commensurate with their physical development.[1,2] The definition of early identification has therefore moved from diagnosis before 18 months to diagnosis by three months with intervention by six months.[3,4]

Hearing impairment is a substantial public-health problem. The World Health Organization estimates that around 250 million people worldwide are deaf, that hearing loss is the second most common cause of disability, and that about 38,000 deaf children are born each year in South-East Asia; in India, the prevalence of moderate to severe hearing impairment is about 6.3%.[5,6] The incidence of hearing loss among all newborns ranges from about 0.1% to 0.5%, but it may reach 1–5% among high-risk infants.[7] underscoring the need for compulsory hearing screening at birth.[8]

The Joint Committee on Infant Hearing (JCIH) identifies the main risk indicators as a family history of permanent childhood hearing loss, in-utero infections, craniofacial anomalies, birth weight below 1500 g, hyperbilirubinaemia requiring exchange transfusion, ototoxic medications, bacterial meningitis, postnatal asphyxia and mechanical ventilation for five days or longer.[3] Newborn hearing screening currently uses one or more of automated OAE, transient evoked OAE (TEOAE), DPOAE and automated auditory brainstem response (AABR).[9]

OAEs are low-intensity sounds generated by the active mechanics of the cochlear outer hair cells and recorded with a probe microphone in the ear canal. They are pre-neural in origin and directly reflect outer hair cell integrity.[10] BERA, in contrast, is an objective electrophysiological test that records activity from the auditory nerve to the brainstem in response to acoustic stimuli, assessing the neural integrity of the auditory pathway.[11] OAEs are preserved in auditory neuropathy/dys-synchrony, which arises from damage to inner hair cells, their synapses, spiral ganglion neurons or the eighth nerve, single-stage programmes that rely only on OAEs will miss these children.[1,9,12]

In India, DPOAE followed by AABR or diagnostic BERA is widely used as a two-stage protocol, and DPOAE is considered particularly suitable for high-risk neonates because of its good correlation with the wave V threshold of the ABR.[13-15] However, few studies have evaluated this protocol in high-risk infants, and to our knowledge none has been reported from northern Kerala.[16] This study therefore aimed to determine the incidence and degree of hearing loss in high-risk infants, the factors associated with it, the hearing threshold by wave V of BERA, and the diagnostic efficacy of DPOAE as a screening tool when compared with BERA.

MATERIALS AND METHODS

Study design and setting: This hospital-based prospective study was conducted in the Department of Otorhinolaryngology, Academy of Medical Sciences, Pariyaram, Kannur, Kerala, India, over a period of one year. High-risk infants referred from the Department of Paediatrics (outpatient department, paediatric ward and neonatal intensive care unit) for hearing evaluation were assessed in the ENT outpatient department using a structured proforma. Written informed consent was obtained from a parent or guardian of every infant.

Sample size and sampling: The sample size was calculated using the formula n = 4PQ/d2, where P is the expected prevalence of hearing loss in high-risk infants (8%, based on Parmar et al,[17]), Q = 100 − P, and d is the absolute precision (50% of P). This gave a sample size of 184. Consecutive sampling was used, and all eligible high-risk infants seen during the study period were enrolled.

Eligibility criteria: Infants with at least one of the following JCIH 2007 high-risk indicators were included.[3]

- family history of hereditary childhood sensorineural hearing loss;
- congenital infections (toxoplasmosis, syphilis, rubella, cytomegalovirus, herpes simplex);
- craniofacial anomalies, including morphological abnormalities of the pinna and ear canal;
- birth weight below 1500 g;
- hyperbilirubinaemia at serum levels requiring exchange transfusion;
- exposure to ototoxic drugs (aminoglycosides);
- bacterial meningitis;
- postnatal asphyxia (Apgar score ≤ 5 at 1 minute or ≤ 6 at 5 minutes);
- mechanical ventilation for five days or longer; and
- stigmata or other findings of a syndrome known to include sensorineural or conductive hearing loss (e.g., Waardenburg or Usher syndrome).

Healthy term infants, infants with severe multiple anomalies, untreated otitis externa, atresia or stenosis of both external auditory canals, and infants whose parents did not consent were excluded.

Data collection and screening protocol: For each infant, gestational age, sex, birth weight, admitting diagnosis, duration of hospitalisation and risk factors were recorded. All infants underwent otoscopic examination to exclude vernix or debris in the external auditory canal. A two-stage screening protocol was followed [Figure 1]. All infants were first screened with DPOAE; those who passed in both ears required no further testing. Infants who failed in one or both ears were retested with DPOAE after two

weeks, and those who failed again underwent diagnostic BERA one month later. Infants with normal BERA were considered at low risk of hearing loss and were not tested further.

DPOAE testing: DPOAE testing was performed in a quiet room after cleaning the external auditory canal to minimise false-positive results. DPOAEs were recorded at 1000, 2000, 3000, 4000 and 5000 Hz with primary tone levels L1 = 65 dB SPL and L2 = 55 dB SPL. A signal-to-noise ratio of at least 6 dB at three of these frequencies was taken as a pass. No sedation was required, and each test took one to five minutes under optimal conditions.

BERA testing: BERA was performed in a sound-proof, air-conditioned room free from electromagnetic interference, using an Intelligent Hearing Systems instrument. Infants were sedated with oral triclofos (25 mg/kg) half an hour before the procedure. The vertex, forehead and both mastoid regions were cleaned with NuPrep gel and surface electrodes were placed. Testing was monaural, with headphones held against the ear while avoiding collapse of the ear canal. Rarefaction clicks were presented at 11.1 clicks/s, and 2000 sweeps were averaged at each level, starting at 99 dB and decreasing in 10-dB steps until wave V was no longer identifiable. The lowest intensity at which wave V was identifiable was taken as the hearing threshold. Hearing was graded as normal (0–25 dB), mild (26–40 dB), moderate (41–55 dB), moderately severe (56–70 dB), severe (71–90 dB) or profound (> 90 dB) impairment. The absolute latency of wave V at the threshold intensity was recorded for each ear.

Statistical analysis: Data were analysed using SPSS version 20. Continuous variables were summarised as mean ± standard deviation (SD) or median with interquartile range (IQR), and categorical variables as frequency and percentage. The association between each risk factor and BERA-confirmed hearing loss was tested with Pearson's chi-square test, comparing the 29 infants with hearing loss with the remaining 155 infants (149 who passed DPOAE screening and six with normal BERA). Because several exposures were rare, Fisher's exact test p values are also reported. The 95% confidence interval (CI) for incidence was calculated using the normal approximation. The diagnostic accuracy of DPOAE (sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV] and overall accuracy) was calculated per ear for the 70 ears that underwent BERA, with BERA as the reference standard. A p value < 0.05 was considered statistically significant.

RESULTS

Baseline characteristics: Of the 184 high-risk infants, 94 (51.1%) were male and 90 (48.9%) were female. The mean age at screening was 59.9 ± 80.8 days (median 29 days, IQR 15–56; range 5–365 days). Most infants were preterm, the largest group being born at 31–32 weeks (35.9%), and 68.5% weighed 1500 g or less at birth. Caesarean section was the most common mode of delivery (69.6%) [Table 1].

Table 1: Baseline characteristics of the high-risk infants (n = 184)

Characteristic	n	%
Sex		
Male	94	51.1
Female	90	48.9
Age at screening (days)		
Mean ± SD	59.9 ± 80.8	–
Median (IQR)	29 (15–56)	–
Range	5–365	–
Gestational age (weeks)		
< 27	2	1.1
27–28	24	13.0
29–30	25	13.6
31–32	66	35.9
33–34	45	24.5
35–37	22	12.0
Birth weight (g)		
750–999	18	9.8
1000–1249	40	21.7
1250–1500	67	36.4
> 1500	58	31.5
Mode of delivery		
Caesarean section	128	69.6
Normal vaginal	54	29.3
Instrumental	2	1.1

IQR, interquartile range; SD, standard deviation.

Risk factor profile: Pregnancy-induced hypertension (PIH) was the most frequent antenatal risk factor (33.2%), followed by gestational diabetes (10.3%), oligohydramnios (9.8%) and intrauterine growth restriction (IUGR) (7.6%). Five infants (2.7%) had a family history of congenital deafness. Resuscitation or assisted ventilation was required in a large proportion of infants, most often endotracheal

(ET) ventilation (33.2%) and continuous positive airway pressure (CPAP) (29.3%). Hyperbilirubinaemia (64.1%) and respiratory distress (52.2%) were the most common neonatal complications, and 54.9% of infants received ototoxic drugs for more than seven days [Table 2].

Table 2: Antenatal, perinatal and neonatal risk factors in the study cohort (n = 184)

Risk factor	n	%
Antenatal		
Pregnancy-induced hypertension	61	33.2
Gestational diabetes mellitus	19	10.3
Oligohydramnios	18	9.8
Intrauterine growth restriction	14	7.6
Multiple gestation	13	7.1
Infertility treatment	13	7.1
Maternal hypothyroidism	6	3.3
Family history of congenital deafness	5	2.7
Maternal fever with rash	4	2.2
Maternal fever without rash	4	2.2
Polyhydramnios	4	2.2
Eclampsia	3	1.6
Consanguineous marriage	1	0.5
Resuscitation / assisted ventilation		
Endotracheal ventilation	61	33.2
CPAP	54	29.3
Oxygen hood	18	9.8
Bag and mask ventilation	16	8.7
Neonatal complications		
Hyperbilirubinaemia	118	64.1
Respiratory distress	96	52.2
Sepsis	41	22.3
Hypocalcaemia	28	15.2
Hypoglycaemia	13	7.1
Neonatal convulsions	2	1.1
Bacterial meningitis	1	0.5
Multiple congenital anomalies	1	0.5
Ototoxic drug exposure		
≤ 7 days	57	31.0
> 7 days	101	54.9
None	26	14.1

CPAP, continuous positive airway pressure. Categories are not mutually exclusive.

Screening outcomes: At the first DPOAE screen, 75 right ears (40.8%) and 69 left ears (37.5%) failed. Overall, 84 infants (45.7%) passed in both ears, while 56 (30.4%) failed unilaterally and 44 (23.9%) bilaterally. Bilateral failure was more frequent among males (27.7%) than females (20.0%). Of the 100 infants who failed, 98 returned for repeat DPOAE after two weeks (two were lost to follow-up). At the repeat screen, 63 (64.3%) passed in both ears and 35 (35.7%) failed, 13 unilaterally and 22 bilaterally. All 35 infants underwent BERA, which confirmed hearing loss in 29 and normal hearing in six [Table 3, Figure 1]. The incidence of hearing loss among the high-risk infants was therefore 15.76% (29/184; 95% CI 10.50–21.03%). Hearing loss was bilateral in 22 infants and unilateral in seven. It was present in 16 of 94 males (17.0%) and 13 of 90 females (14.4%), a difference that was not significant ($\chi 2 = 0.230$, $p = 0.632$).

Table 3: Results at each stage of the two-stage DPOAE–BERA protocol

Stage / outcome	Right ear n (%)	Left ear n (%)	Infants n (%)
Stage 1: initial DPOAE (n = 184)			
Pass	109 (59.2)	115 (62.5)	84 (45.7) bilateral pass
Refer	75 (40.8)	69 (37.5)	100 (54.3)
Unilateral refer	–	–	56 (30.4)
Bilateral refer	–	–	44 (23.9)
Stage 2: repeat DPOAE at 2 weeks (n = 98)*			
Pass	70 (71.4)	69 (70.4)	63 (64.3) bilateral pass
Refer	28 (28.6)	29 (29.6)	35 (35.7)
Unilateral refer	–	–	13 (13.3)
Bilateral refer	–	–	22 (22.4)
Stage 3: diagnostic BERA at 1 month (n = 35)			
Hearing loss confirmed	–	–	29 (82.9)
Normal hearing	–	–	6 (17.1)

*Two of the 100 infants who failed the initial screen were lost to follow-up. BERA, brainstem evoked response audiometry; DPOAE, distortion product otoacoustic emissions.

Degree of hearing impairment: Of the 70 ears of the 35 infants who underwent BERA, 19 (27.1%) had normal hearing. Profound hearing loss was the most common grade (17 ears, 24.3%), followed by moderate (16 ears, 22.9%), moderately severe (7 ears, 10.0%), severe (7 ears, 10.0%) and mild (4 ears, 5.7%) loss. Profound loss was more frequent in left ears (10 vs. 7) [Table 4, Figure 2].

Table 4: Degree of hearing impairment on BERA by ear (n = 70 ears in 35 infants)

Degree (threshold, dB nHL)	Right ear n (%)	Left ear n (%)	Total n (%)
Normal (0–25)	10 (28.6)	9 (25.7)	19 (27.1)
Mild (26–40)	2 (5.7)	2 (5.7)	4 (5.7)
Moderate (41–55)	9 (25.7)	7 (20.0)	16 (22.9)
Moderately severe (56–70)	2 (5.7)	5 (14.3)	7 (10.0)
Severe (71–90)	5 (14.3)	2 (5.7)	7 (10.0)
Profound (> 90)	7 (20.0)	10 (28.6)	17 (24.3)
Total	35 (100)	35 (100)	70 (100)

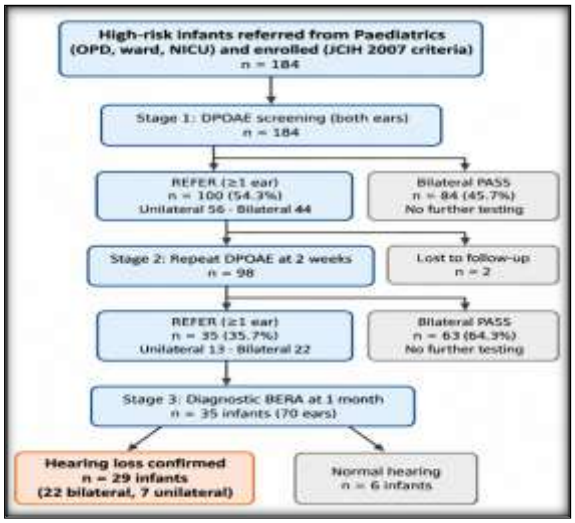


Figure 1: Flow of high-risk infants through the two-stage DPOAE–BERA hearing screening protocol. DPOAE, distortion product otoacoustic emissions; BERA, brainstem evoked response audiometry; JCIH, Joint Committee on Infant Hearing.

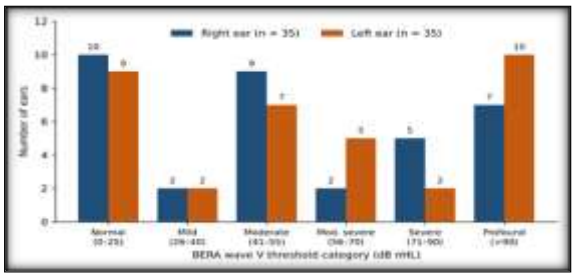


Figure 2: Degree of hearing impairment on BERA in the right and left ears of the 35 infants who failed both DPOAE screens.

Factors associated with hearing loss: Among antenatal factors, a family history of congenital deafness (13.8% vs. 0.6%; $p < 0.001$), maternal fever with rash during pregnancy (13.8% vs. 0%; $p < 0.001$) and oligohydramnios (20.7% vs. 7.7%; $p = 0.031$) were significantly associated with hearing loss. All four infants with maternal fever with rash had hearing loss; one had congenital rubella syndrome, two mothers had rubella infection (one in the first and one in the third trimester), and one had varicella infection in the first trimester. PIH, gestational diabetes, IUGR, polyhydramnios and fever without rash were not significantly associated with hearing loss [Table 5, Figure 3].

ET ventilation was more frequent among infants with hearing loss (48.3% vs. 30.3%), but the difference did not reach significance ($p = 0.059$). CPAP showed no significant association ($p = 0.119$). Among neonatal factors, neonatal convulsions (6.9% vs. 0%; $p = 0.001$) and ototoxic drug exposure for more than seven days (84.6% vs. 59.8% of exposed infants; $p = 0.016$) were significantly associated with hearing loss. Hyperbilirubinaemia was significantly less frequent among infants with hearing loss than among those without (44.8% vs. 67.7%; $p = 0.018$). Respiratory distress and sepsis were not significantly associated. The single infant with multiple congenital anomalies had hearing loss; with one case, this association could not be meaningfully evaluated (Fisher's exact $p = 0.158$). Gestational age and birth weight were not significantly associated with hearing loss. Fisher's exact test confirmed all associations found significant by the chi-square test, except for multiple congenital anomalies [Table 5].

Table 5: Association of risk factors with BERA-confirmed hearing loss

Risk factor	Hearing loss (n = 29) n (%)	No hearing loss (n = 155) n (%)	χ2	p value	Fisher's exact p
Antenatal					
Family history of congenital deafness	4 (13.8)	1 (0.6)	15.975	< 0.001	0.002
Maternal fever with rash	4 (13.8)	0 (0.0)	21.854	< 0.001	< 0.001
Oligohydramnios	6 (20.7)	12 (7.7)	4.640	0.031	0.043
Pregnancy-induced hypertension	6 (20.7)	55 (35.5)	2.413	0.120	0.137
Intrauterine growth restriction	3 (10.3)	11 (7.1)	0.367	0.545	0.466
Gestational diabetes mellitus	2 (6.9)	17 (11.0)	0.437	0.508	0.743
Maternal fever without rash	1 (3.4)	3 (1.9)	0.263	0.608	0.500
Polyhydramnios	0 (0.0)	4 (2.6)	0.765	0.382	1.000
Resuscitation / assisted ventilation					
Endotracheal ventilation	14 (48.3)	47 (30.3)	3.553	0.059	0.084
CPAP	5 (17.2)	49 (31.6)	2.433	0.119	0.181

Neonatal					
Neonatal convulsions	2 (6.9)	0 (0.0)	10.807	0.001	0.024
Hyperbilirubinaemia	13 (44.8)	105 (67.7)	5.576	0.018	0.022
Respiratory distress	13 (44.8)	83 (53.5)	0.745	0.388	0.423
Sepsis	9 (31.0)	32 (20.6)	1.523	0.217	0.229
Multiple congenital anomalies	1 (3.4)	0 (0.0)	5.374	0.020	0.158
Ototoxic drugs > 7 days*	22/26 (84.6)	79/132 (59.8)	5.778	0.016	0.024

$\chi 2$ and p values are Pearson chi-square (df = 1) as computed in the original analysis; Fisher's exact p values (two-sided) are added because of small expected cell counts. *Compared with exposure ≤ 7 days, among the 158 infants who received ototoxic drugs. The no-hearing-loss group comprises 149 infants who passed DPOAE screening and six with normal BERA. Bold indicates p < 0.05. CPAP, continuous positive airway pressure.

Absolute latency of wave V: The mean absolute latency of wave V at threshold intensity was 8.56 ± 0.60 ms in normal ears, 7.85 ± 0.14 ms with mild, 7.63 ± 0.59 ms with moderate, 7.22 ± 0.51 ms with moderately severe and 6.83 ± 0.37 ms with severe hearing loss. In ears with profound loss, wave V was absent at maximum stimulus intensity. Because normal ears reach threshold at lower stimulus levels, and wave V latency lengthens as intensity decreases, latency at threshold shortened progressively with increasing degree of impairment [Table 6, Figure 4].

Representative DPOAE and BERA recordings are shown in [Figure 5].

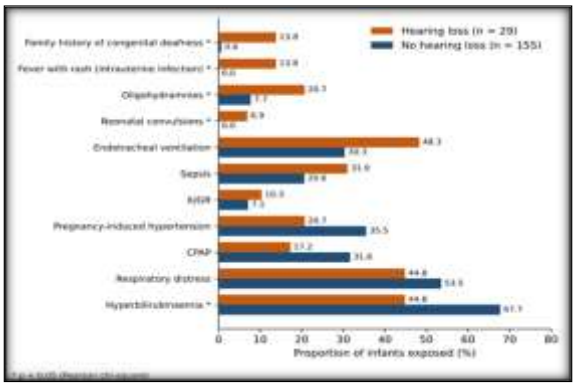


Figure 3: Proportion of infants exposed to each risk factor among those with (n = 29) and without (n = 155) BERA-confirmed hearing loss. Asterisks mark associations significant at p < 0.05 by Pearson chi-square.

Table 6: Absolute latency of wave V at threshold intensity by degree of hearing impairment

Degree of hearing	Ears (n)	Mean latency (ms)	SD (ms)
Normal	18	8.56	0.60
Mild	4	7.85	0.14
Moderate	16	7.63	0.59
Moderately severe	7	7.22	0.51
Severe	7	6.83	0.37
Profound	17	Wave V absent	–

Latency data were available for 18 of the 19 ears with normal hearing. SD, standard deviation.

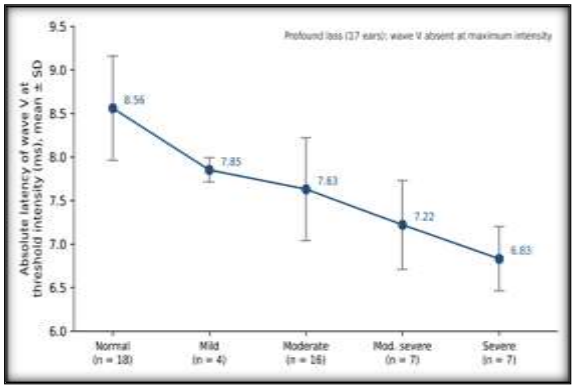


Figure 4: Mean (± SD) absolute latency of wave V at threshold intensity by degree of hearing impairment. Latency shortens as the threshold rises, reflecting the inverse relationship between stimulus intensity and wave V latency.

Diagnostic accuracy of DPOAE: Of the 70 ears evaluated with both DPOAE and BERA, 47 were positive and 11 negative on both tests; there were eight false-positive and four false-negative DPOAE results. With BERA as the reference standard, DPOAE had a sensitivity of 92.2%, specificity of 57.9%, PPV of 85.5%, NPV of 73.3% and overall diagnostic accuracy of 82.9% [Table 7].

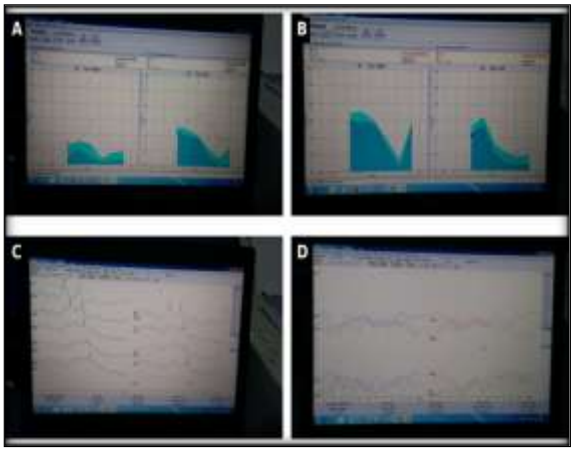


Figure 5: Representative recordings from the study. (A) DPOAE showing bilateral PASS. (B) DPOAE showing bilateral REFER. (C) BERA showing bilateral normal hearing, with wave V identifiable down to low stimulus intensities. (D) BERA showing bilateral profound hearing loss, with no identifiable waveforms at maximum intensity.

Table 7: Diagnostic accuracy of DPOAE compared with BERA as the reference standard (n = 70 ears)

DPOAE result	BERA (reference standard)		Total
	Hearing loss	Normal	
Refer (positive)	47 (TP)	8 (FP)	55
Pass (negative)	4 (FN)	11 (TN)	15
Total	51	19	70
Diagnostic indices			
Sensitivity	92.2%		
Specificity	57.9%		
Positive predictive value	85.5%		
Negative predictive value	73.3%		
Diagnostic accuracy	82.9%		

TP, true positive; FP, false positive; FN, false negative; TN, true negative. Analysis is per ear and is limited to infants who failed both DPOAE screens and therefore underwent BERA.

DISCUSSION

Congenital hearing loss accounts for most hearing loss in childhood, and its effects extend beyond the child's speech, language and cognitive development to the psychological well-being of the family. No single test is sufficient for the early detection of childhood hearing impairment, and most newborn hearing screening programmes use a one- or two-step protocol in which OAE screening is followed by ABR for infants who fail.[18] The JCIH recommends ABR technology as the only appropriate screening technique for infants in the NICU because of the risk of neural hearing loss.[3] In this study we used a two-stage DPOAE protocol with BERA confirmation in 184 high-risk infants from northern Kerala.

The sex distribution of our cohort (51.1% male) was similar to that reported by Jose et al,.[16] Parmar et al,.[17] Beigh et al,.[19] Maung et al,.[13] and Aiyer and Parikh.[20] whereas females outnumbered males in the study by Jain et al,.[21] Hearing loss was slightly more frequent in males, in keeping with several earlier reports.[13,16,17,19,20] although the difference was not statistically significant. The mean age at screening in our study (60 days) was considerably higher than the 2.6 days reported by Bedajit et al,.[22] reflecting the referral of infants after discharge from neonatal care. The first-stage DPOAE refer rate of 54.3% fell to 35.7% at the repeat screen, showing how a second OAE test reduces referrals for diagnostic testing. Beigh et al. reported bilateral OAE refer in 70% of children.[19] and a high refer rate at the second OAE screen was also observed by Jose et al,.[16] Transient middle-ear effusion, residual vernix and immaturity of the auditory system in preterm infants probably explain many early failures. Two-stage protocols are known to reduce referral and false-positive rates in newborn screening.[23,24]

The incidence of hearing loss in our high-risk infants was 15.76% (95% CI 10.50–21.03%). The reported incidence among high-risk infants varies widely, from about 1% to 28%.[25] depending on the definition of risk, the age at testing and the referral pattern. Our figure was close to the 18% reported by Bhagya et al,.[26] higher than the 8% of Parmar et al,.[17] the 5% of Bhatt et al,.[27] and the 3.1% of Bedajit et al,.[22] and lower than the 35.2% of Thirunavukarasu et al,.[28] the 57% of Jain et al,.[21] and the 64.9% of Lakshmi et al,.[29] Al-Kandari and Alshuaib reported hearing loss in 46.7% of high-risk newborns compared with 2% of well babies [30]. Studies with very high incidence generally included older children referred for suspected hearing loss, whereas ours was an infant screening cohort.

Profound hearing loss was the most common grade in our study (24.3% of ears), followed by moderate loss (22.9%). This is consistent with most studies of high-risk children, in which profound loss predominates.[19,21,26,28] Bhagya et al. found profound loss in 50 of 147 at-risk infants.[26] and Kartas et al. and Loh and Yiap reported severe to profound loss in most children tested.[31,32] In our study, 22 infants had bilateral and seven unilateral hearing loss, a pattern similar to that described by Bedajit et al.[22]

High-risk infants are often exposed to several risk factors at once, and the hypoxia associated with intensive care can cause oedema, degeneration and necrosis of the cochlea and brainstem, some of which may be reversible.[29,33] The incidence of deafness rises as the number of coexisting risk factors increases.[17] Among antenatal factors, a family history of congenital deafness was strongly associated with hearing loss: all four infants with an affected first-degree relative had hearing loss, consistent with the findings of Bedajit et al. and Jain et al,.[21,22] Intrauterine infection, presenting as maternal fever with rash, was also significant, in agreement with Parmar et al., Maung et al. and Aiyer and Parikh.[13,17,20] Only one infant in our cohort was born of a consanguineous marriage, whereas consanguinity was the leading risk factor in the studies by Jain et al. and Beigh et al,.[19,21] Oligohydramnios was associated with hearing loss, while multiple gestation, which Parmar et al. identified as a risk factor.[17] was not.

ET ventilation was more common among infants with hearing loss, as reported by Bedajit et al. and Kumar et al,.[22,34] although the association did not reach statistical significance in our cohort. Infants receiving CPAP are exposed to high-intensity noise in the postnasal space, close to the inner ear, which could contribute to cochlear damage, particularly at high flow rates. Low Apgar score was not significant in our study, although it was the most common perinatal risk factor in the series of Parmar et al,.[17] Gestational age and birth weight were also not significantly

associated with hearing loss, although the risk of hearing impairment has been reported to increase sharply as gestational age and birth weight fall.[34] and Thirunavukarasu et al. associated birth weight above 3.5 kg with hearing loss, possibly through birth trauma.[28]

Hyperbilirubinaemia is widely regarded as a risk factor for sensorineural hearing loss.[16-17,35-37] Bilirubin toxicity can damage the brainstem auditory nuclei, auditory nerve and spiral ganglion, producing either transient or persistent loss.[38-40] In our cohort, however, hyperbilirubinaemia was significantly less common among infants with hearing loss (44.8% vs. 67.7%). The most likely explanation is that neonatal jaundice was very common in this largely preterm population (64.1% overall) and was mostly of moderate severity and treated promptly with phototherapy, so it did not distinguish infants at risk. The JCIH indicator is hyperbilirubinaemia severe enough to require exchange transfusion.[3] and we did not grade bilirubin levels. Individual cases showed this heterogeneity: one infant with bilirubin encephalopathy due to Rh incompatibility had profound hearing loss, whereas one infant who required exchange transfusion and another with kernicterus had normal hearing. Strict control of jaundice, with objective monitoring of serum bilirubin and efficient phototherapy, remains essential.[38,40]

Ototoxic drug exposure for more than seven days was significantly associated with hearing loss. Aminoglycosides such as amikacin and gentamicin, and loop diuretics, damage the outer hair cells, and aminoglycoside cochleotoxicity typically produces high-frequency sensorineural loss before it becomes clinically apparen.[36] Shoaib et al. recommended that amikacin should not be used for more than four days in newborns,[36] and moderate hyperbilirubinaemia may compound the risk.[37] Neonatal convulsions were also significantly associated with hearing loss, in agreement with Bhagya et al,.[26] Sepsis was present in 31% of infants with hearing loss but was not statistically significant, although it has been identified as a risk factor by Nazir et al. and Aiyer and Parikh.[20,35]

The absolute latency of wave V is a stable parameter that is central to the interpretation of ABR.[29] Because wave V latency varies inversely with stimulus intensity, latency at threshold was longest in normal ears (8.56 ms) and shortest in severely impaired ears (6.83 ms). Our value for normal ears was close to the 8.43 ms reported by Nazir et al,.[35] Wave V was absent at 90 dB in 24.3% of ears, similar to the 23.3% reported by Agrawal et al,.[40] Prolongation of wave V latency in high-risk infants compared with controls has been described by Lakshmi et al. and Jiang et al,.[29,41] and the behavioural threshold can be estimated as 5–10 dB below the level at which wave V is just identifiable.[28]

With BERA as the reference standard, DPOAE had a high sensitivity (92.2%) and PPV (85.5%) but a lower specificity (57.9%). Nazir et al. reported a sensitivity of 87.7% and specificity of 74.5%.[35] and Maung et al. reported a sensitivity of 97.6% and specificity of 95.4% for DPOAE in high-risk newborns.[13] Bhatt et al. found a sensitivity of 70% at birth, with specificity rising from 61% to 99% at three months.[27] The lower specificity in our study is largely a consequence of verification bias: only infants who failed DPOAE twice underwent BERA, so true-negative results among infants who passed DPOAE were not captured. OAE results can also be affected by debris or vernix in the newborn ear canal.[42] Because DPOAE reflects only outer hair cell function, it cannot detect auditory neuropathy.[12] and in our view it should be used as a sensitive first-line screen followed by BERA.

Limitations: This study has limitations. The sample was relatively small and drawn from a single center, and no control group of well babies was included. Infants who passed DPOAE did not undergo BERA, so auditory neuropathy could have been missed and the diagnostic accuracy estimates are subject to verification bias. Because the study was time-bound, infants were not followed up at regular intervals to identify late-onset or progressive loss or to distinguish transient from permanent impairment. Several exposures were rare, which limits the precision of the associations, and no multivariable analysis was performed to adjust for coexisting risk factors. Birth history was obtained partly from parental accounts recorded in outpatient and inpatient charts, and bilirubin levels were not graded.

CONCLUSION

Hearing loss was found in nearly one in six high-risk infants (15.76%) in this study, and profound loss was the most common grade. Family history of congenital deafness, maternal fever with rash, oligohydramnios, neonatal convulsions and prolonged ototoxic drug exposure were significantly associated with hearing loss. DPOAE showed high sensitivity but modest specificity against BERA; it complements BERA but cannot replace it. A two-stage protocol of DPOAE screening followed by BERA confirmation is a useful and practical approach for the early detection of hearing loss in high-risk infants. All newborns, and high-risk infants in particular, should undergo hearing evaluation within the first six months, with thorough diagnostic evaluation and follow-up of those who fail initial screening.

REFERENCES

1. Handelsman JA, Van Riper LA, Lesperance MM. Early detection and diagnosis of hearing impairment. In: Flint PW, Haughey BH, Lund VJ, Niparko JK, Robbins KT, Thomas JR, et al., editors. Cummings Otolaryngology–Head and Neck Surgery. 6th ed. Philadelphia: Saunders Elsevier; 2015. p. 2970–4.
2. Downs MP, Yoshinaga-Itano C. The efficacy of early identification and intervention for children with hearing impairment. Pediatr Clin North Am. 1999;46(1):79–87.

3. American Academy of Pediatrics, Joint Committee on Infant Hearing. Year 2007 position statement: principles and guidelines for early hearing detection and intervention programs. Pediatrics. 2007;120(4):898–921.
4. Kemp DT, Ryan S. Otoacoustic emission tests in neonatal screening programmes. Acta Otolaryngol Suppl. 1991;482:73–84.
5. World Health Organization, Regional Office for South-East Asia. Deafness and hearing impairment in the South-East Asia Region. New Delhi: WHO SEARO; 2016.
6. Ministry of Health and Family Welfare. National Programme for Prevention and Control of Deafness (NPPCD): operational guidelines. New Delhi: Government of India. Available from: http://mohfw.nic.in
7. Anand NK, Gupta AK, Raj H. BERA – a diagnostic tool in neonatology. Indian Pediatr. 1990;27:1039–44.
8. Taneja MK. Deafness, a social stigma: physician perspective. Indian J Otolaryngol Head Neck Surg. 2014;66(4):353–8.
9. Uus K, Bamford J. Hearing screening in neonates and young infants. In: Gleeson M, Browning GG, Burton MJ, Clarke R, Hibbert J, Jones NS, et al., editors. Scott-Brown's Otorhinolaryngology, Head and Neck Surgery. 7th ed. Vol. 1. London: Hodder Arnold; 2008. p. 821–33.
10. Probst R, Lonsbury-Martin BL, Martin GK. A review of otoacoustic emissions. J Acoust Soc Am. 1991;89(5):2027–67.
11. Jewett DL, Williston JS. Auditory-evoked far fields averaged from the scalp of humans. Brain. 1971;94(4):681–96.
12. Norton SJ, Gorga MP, Widen JE, Folsom RC, Sininger Y, Cone-Wesson B, et al. Identification of neonatal hearing impairment: evaluation of transient evoked otoacoustic emission, distortion product otoacoustic emission, and auditory brain stem response test performance. Ear Hear. 2000;21(5):508–28.
13. Maung M, Lwin YY, Aung N, Tar T, Phyu K. Diagnostic accuracy of distortion product otoacoustic emissions (DPOAE) and transient evoked otoacoustic emissions (TEOAE) in high risk newborn: a comparative study. Clin Pediatr Open Access. 2016;1(4):69.
14. Kumar S, Mohapatra B. Status of newborn hearing screening program in India. Int J Pediatr Otorhinolaryngol. 2011;75(1):20–6.
15. Paul AK. Early identification of hearing loss and centralized newborn hearing screening facility—the Cochin experience. Indian Pediatr. 2011;48(5):355–9.
16. Jose DJ, Renjit RE, Manonmony S. Prevalence of hearing impairment among high risk neonates – a hospital based screening study. 2016;7(3):131–4.
17. Parmar B, et al. A clinical study of hearing screening with OAE in 300 high-risk newborns. Global J Res Anal. 2014;(9):83.
18. US Preventive Services Task Force. Universal screening for hearing loss in newborns: US Preventive Services Task Force recommendation statement. Pediatrics. 2008;122(1):143–8.
19. Beigh Z, Malik MA, ul Islam M, Yousuf A, Pampori RA. Clinical and audiological evaluation of hearing impaired children. Indian J Otol. 2012;18(4):200–7.
20. Aiyer RG, Parikh B. Evaluation of auditory brainstem responses for hearing screening of high-risk infants. Indian J Otolaryngol Head Neck Surg. 2009;61(1):47–53.
21. Jain NK. Study of risk factors associated in hearing loss in high risk children less than 10 years of age in rural area of West Uttar Pradesh. 2015;4(7):2013–5.
22. Bedajit RK, Babu AP, Kumar JS, Mallik P, Singh MM, Devi P. Brainstem evoked response audiometry for the assessment of auditory pathway in newborns and high risk infants – Imphal (Manipur). 2014;11(1):27–9.
23. Vignesh SS, Jaya V, Sasireka BI, Sarathy K, Vanthana M. Prevalence and referral rates in neonatal hearing screening program using two step hearing screening protocol in Chennai – a prospective study. Int J Pediatr Otorhinolaryngol. 2015;79(10):1745–7.
24. Kumar A, Shah N, Patel KB, Vishwakarma R. Hearing screening in a tertiary care hospital in India. J Clin Diagn Res. 2015;9(3):MC01–4.
25. Evaluation of risk factors on hearing ability in infants at risk by BERA. Int J Pharma Bio Sci. 2014;5(4):793–800.
26. Bhagya V, Brid SV, Doddamani M. Incidence of hearing loss in infants at risk. 2011;2(4):1102–5.
27. Bhatt J, Kuchhal V, Saklani K, Kumar V. Accuracy of OAE and BERA to detect the incidence of hearing loss in newborn. J Evol Med Dent Sci. 2015;4(49):8466–74.
28. Thirunavukarasu R, Balasubramaniam G, Kalyanasundaram R, Narendran G, Sridhar S. A study of brainstem evoked response audiometry in high-risk infants and children under 10 years of age. Indian J Otol. 2015;21(2):134.
29. Lakshmi T, Sultana ZS, Brid SV. Evoked response audiometry in high risk infants. Int J Recent Trends Sci Technol. 2014;Aug:8–12.
30. Al-Kandari JM, Alshuaib WB. Newborn hearing screening in Kuwait. Electromyogr Clin Neurophysiol. 2007;47(6):305–13.
31. Kartas E, Kanlikama M, Mumbuc S. Auditory functions in children at school for the deaf. J Natl Med Assoc. 2006;98(2):204–10.
32. Loh KE, Yiap KH. Objective assessment of hearing loss in children using the auditory brainstem response. Singapore Med J. 1984;25:278–86.
33. Schmutzhard J, Glueckert R, Sergi C, Schwentner I, Abraham I, Schrott-Fischer A. Does perinatal asphyxia induce apoptosis in the inner ear? Hear Res. 2009;250(1–2):1–9.
34. Kumar P, Adhisivam B, Vishnu Bhat B, Bharathi B, Francis F, Mondal N. Screening for hearing loss among high risk neonates – experience from a tertiary care center. 2016;20(1):43–6.
35. Nazir T, Gupta S, Mir GM, Jamwal A, Kalsotra P. Evaluation of otoacoustic emissions and auditory brainstem responses for hearing screening of high risk infants.
36. Shoaib A, Waqas M, Tahir M. Hearing assessment with BERA in infants who had received amikacin. Pak J Otorhinolaryngol. 2014;30:47–9.
37. Zamani A, Daneshjou K, Ameni A, Takand J. Estimating the incidence of neonatal hearing loss in high risk neonates. Acta Med Iran. 2004;42(3):176–80.
38. Akinpelu OV, Waissbluth S, Daniel SJ. Auditory risk of hyperbilirubinemia in term newborns: a systematic review. Int J Pediatr Otorhinolaryngol. 2013;77(6):898–905.
39. da Silva DPC, Martins RHG. Analysis of transient otoacoustic emissions and brainstem evoked auditory potentials in neonates with hyperbilirubinemia. Braz J Otorhinolaryngol. 2009;75(3):381–6.
40. Agrawal VK, Shukla R, Misra PK, Kapoor RK, Malik GK. Brainstem auditory evoked response in newborns with hyperbilirubinemia. Indian Pediatr. 1998;35(6):513–8.
41. Jiang ZD, Brosi DM, Li ZH, Chen C, Wilkinson AR. Brainstem auditory function at term in preterm babies with and without perinatal complications. Pediatr Res. 2005;58(6):1164–9.
42. Jewel J, Varghese PV, Singh T, Varghese A. Newborn hearing screening – experience at a tertiary hospital in northwest India. 2013:211–4.