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Hearing Screening with Otoacoustic Emissions and Auditory Brainstem Response in High-Risk Neonates: *A Prospective Observational Study in a Tertiary Care Neonatal Unit*

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Abstract
Background: *Congenital and early-onset hearing impairment is one of the more easily overlooked disabilities in the neonatal period largely because affected infants look and behave at least outwardly much like their normally hearing peers. Neonates who pass through a difficult perinatal course prematurity, low birth weight, perinatal asphyxia, Hyperbilirubinemia or a stay in the neonatal intensive care unit carry a substantially higher likelihood of cochlear or retro-cochlear dysfunction than the general newborn population which is precisely targeted screening in this subgroup deserves close attention.*
Objective: *To evaluate the outcome of a two-stage hearing screening protocol combining Otoacoustic Emissions (OAE) and Auditory Brainstem Response / Brainstem Evoked Response Audiometry (BERA) in a cohort of high-risk neonates and to document the pattern of pass, fail and dropout across successive screening visits.*
Methods: *Two hundred high risk neonates fulfilling at least one Joint Committee on Infant Hearing (JCIH) risk indicator were enrolled and screened with OAE at 500, 1000, 2000, and 4000 Hz in both ears at one month of age with a repeat OAE at three months. Infants who did not clear OAE along with a representative subset subsequently underwent BERA at 70 dBnHL and 40 dBnHL bilaterally at three months. Demographic, perinatal and audiological variables were tabulated and analyzed descriptively.*
Results: *Of the 200 neonates studied 105 (52.5%) were male and 95 (47.5%) female; 158 (79.0%) were delivered vaginally and 42 (21.0%) by caesarean section. Mean gestational age was 39.51 ± 1.678 weeks, mean birth weight 2913.0 ± 327.785 g and mean APGAR score at five minutes 3.80 ± 0.401. At one month OAE pass rates in the right ear ranged from 82.0% to 85.0% across the four test frequencies and were marginally lower in the left ear (79.0%–79.5%). At three months pass rates on repeat OAE improved modestly once dropouts were accounted for (right ear 78.5%–81.0%; left ear 80.0%–80.5%). On BERA at 70 dBnHL wave V was present in 57.0% of right ears and 55.5% of left ears with mean wave V latencies of 3.47 ± 3.043 ms and 4.02 ± 3.521 ms respectively; a sizeable proportion (about 39–40%) could not complete BERA testing and were recorded as dropouts.*
Conclusion: *A combined OAE–BERA screening pathway remains a practical and reasonably sensitive way of identifying hearing impairment in high risk neonates though the appreciable dropout rate observed at the three*

month visit underlines the need for stronger follow-up mechanisms if the goal of early identification by six months of age as recommended under universal newborn hearing screening guidelines is to be realistically met.
Keywords: *otoacoustic emissions, auditory brainstem response, BERA, high-risk neonates, universal newborn hearing screening; sensory-neural hearing loss.*

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I. Introduction

Hearing is in a sense a quiet prerequisite for almost everything that follows in a child's development speech, language, cognition and social integration all lean on it more heavily than is generally appreciated until something goes wrong. Congenital sensory-neural hearing loss affects roughly 1 to 3 per 1000 live births in the general newborn population but this figure climbs sharply to somewhere between 2 and 4 per 100, once the denominator is restricted to infants admitted to a neonatal intensive care unit or otherwise classified as high risk[1].

The consequences of missing this window are not trivial. Unidentified hearing loss during the first year of life is associated with measurable delays in receptive and expressive language, and several long term follow-up studies have shown that children identified and fitted with amplification before six months of age go on to acquire language at a pace much closer to their normally hearing peers than those identified later[2]. It was this body of evidence accumulating steadily through the 1990s that pushed national and international bodies toward Universal Newborn Hearing Screening (UNHS) programmes with the Joint Committee on Infant Hearing (JCIH) formalizing the now widely cited 1-3-6 benchmark screening by one month diagnostic confirmation by three months and intervention by six months of age[3].

In practice however, universal screening of every newborn is not always logistically or financially feasible particularly in resource constrained settings such as many parts of India where the sheer volume of deliveries and the limited availability of trained audiologists make blanket coverage difficult. A targeted, risk-based approach screening only those neonates who carry one or more recognised risk indicators has therefore continued to be practiced alongside or in place of universal screening in a number of centres. The JCIH risk register includes factors such as a family history of permanent childhood hearing loss, NICU stay exceeding five days, Hyperbilirubinemia requiring exchange transfusion, ototoxic medication exposure, in-utero infections (the so-called TORCH group), craniofacial anomalies, low birth weight, low APGAR scores and mechanical ventilation among others[4, 5].

It is worth noting though, that risk-based screening alone tends to miss roughly half of all congenitally deaf infants since a substantial fraction of children with hearing loss have no identifiable risk factor at birth which is precisely the argument that keeps universal screening on the table even where it is difficult to implement.

Two physiological tools dominate current screening practice otoacoustic emissions (OAE) and the auditory brainstem response (ABR) sometimes referred to in South Asian clinical literature as Brainstem Evoked Response Audiometry or BERA. OAE testing capitalizes on the fact that healthy outer hair cells within the cochlea generate faint sounds of their own evoked otoacoustic emissions in response to an acoustic stimulus recording these emissions with a sensitive probe placed in the ear canal offers a quick, non-invasive and reasonably objective index of cochlear (specifically outer hair cell) function[6].

ABR/BERA on the other hand, measures the synchronous electrical activity generated by the auditory nerve and brainstem pathways in response to a click or tone-burst stimulus and is therefore able to detect neural hearing loss including auditory neuropathy spectrum disorder that OAE testing alone would miss since OAE can remain entirely normal even when retro cochlear conduction is disrupted[7].

Neither test used in isolation is ideal. OAE testing is fast and inexpensive but is confounded by transient middle-ear debris, vernix or fluid which is common in the first days of life and can produce a false 'refer' result that has nothing to do with true hearing status. ABR/BERA is more time-consuming requires the infant to be settled or asleep and is correspondingly more resource-intensive but it interrogates the auditory pathway more comprehensively[8]. For this reason most contemporary protocols including the one followed at our centre combine the two an initial OAE screen followed in infants who do not clear OAE (and often in a subset who do for the purpose of ruling out neural pathology) by a confirmatory BERA[9].

Against this background this study was undertaken to examine how a two-tier OAE–BERA screening protocol actually performs when applied prospectively to a cohort of high-risk neonates at our institution specifically to describe the pass, fail and dropout rates at one month and three months of age and to document wave V latency findings on BERA so that the operational strengths and shortcomings of the pathway (dropout being a recurring theme in the results as will become apparent) can be assessed in a setting broadly representative of a tertiary care teaching hospital in northern India[10].

II. Materials and Methods

2.1 Study design and setting

This was a prospective, hospital-based observational study carried out in the Neonatal Intensive Care Unit and Audiology Unit of a tertiary care teaching institution. Neonates admitted to the NICU along with those referred from the postnatal wards were screened for the presence of at least one JCIH high-risk indicator and eligible infants were enrolled consecutively over the study period after obtaining written informed consent from a parent or legal guardian. Institutional Ethics Committee clearance was obtained prior to commencement and the study conformed to the principles laid down in the Declaration of Helsinki.

2.2 Participants

A total of 200 high-risk neonates were enrolled. High-risk status was assigned on the basis of one or more of the following, broadly following JCIH criteria, NICU admission for more than 48 hours, low birth weight (below 2500 g), low APGAR score, perinatal asphyxia, Hyperbilirubinemia requiring phototherapy or exchange transfusion, mechanical ventilation, ototoxic drug exposure (notably amino glycosides), a family history of childhood sensory-neural hearing loss and craniofacial anomalies. Neonates with external or middle ear malformations that would preclude probe placement, and those whose parents declined consent, were excluded.

2.3 Screening protocol

All enrolled neonates underwent distortion product otoacoustic emission (DPOAE) testing bilaterally at approximately one month of postnatal age, performed in a quiet room with the infant in natural or light sleep. Emissions were recorded at four frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz for each ear and results were classified as 'pass' or 'fail' according to the equipment's built-in pass criteria (signal-to-noise ratio and reproducibility thresholds). OAE testing was repeated at approximately three months of age for the same four frequencies in both ears partly to confirm initial fail results and partly to capture infants who had missed the first visit.

At the three-month visit neonates underwent BERA testing bilaterally using click stimuli presented at two intensities 70 dBnHL and 40 dBnHL with recording of wave V latency where a discernible response was obtained. Testing was performed during natural sleep or under mild sedation where clinically indicated, in an acoustically shielded room, following standard electrode placement (vertex-active, mastoid-reference, forehead-ground). A subset of neonates could not complete either OAE or BERA testing at the three-month visit most commonly because of failure to report for follow-up restlessness precluding a technically adequate recording or inter-current illness and these were recorded separately as 'dropout' rather than being coded as pass or fail so as not to overstate either category.

2.4 Variables recorded

Demographic and perinatal data collected included sex, mode of delivery, gestational age at birth, maternal age, five-minute APGAR score, birth weight and presence or absence of documented antenatal (pre-natal) risk factors. Audiological data comprised OAE pass/fail status at each of the four test frequencies for both ears at one and three months, BERA response status (present/absent or pass/fail depending on intensity) at 70 dBnHL and 40 dBnHL for both ears and wave V latency in milliseconds where recordable.

2.5 Statistical analysis

Data were entered into a structured spreadsheet and analyzed using IBM SPSS-2024 Statistics. Categorical variables (sex, mode of delivery, OAE and BERA outcome categories) are presented as frequencies, percentages and continuous variables (gestational age, maternal age, APGAR score, birth weight, wave V latency) are expressed as mean ± standard deviation with minimum and maximum values. No formal hypothesis testing was pre-specified for this descriptive analysis the emphasis throughout has been on characterizing the distribution of screening outcomes across visits and test frequencies rather than on comparative inference between subgroups.

III. Results

Two hundred high-risk neonates were enrolled and followed through the screening protocol described above. The demographic and perinatal characteristics of the cohort are summarized first followed by the audiological screening outcomes at one month and three months of age.

3.1 Demographic and perinatal profile

Of the 200 neonates studied, 105 (52.5%) were male and 95 (47.5%) females giving a male-to-female ratio of roughly 1.1:1 a distribution that did not depart meaningfully from what one would expect in an unselected high-risk population (Table 1, Figure 1).

Table 1: Distribution of the study cohort by gender.

Gender	Frequency (n)	Percentage (%)
Male	105	52.5
Female	95	47.5
Total	200	100.0

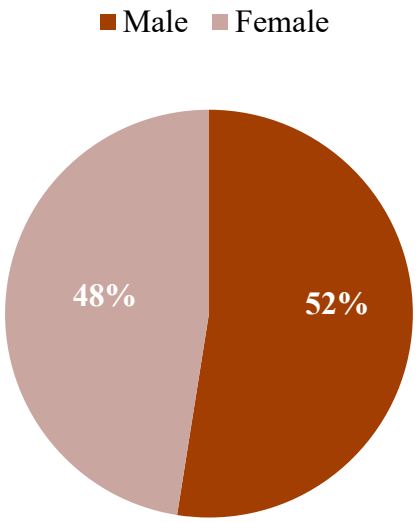

Figure 1: Gender distribution of the high-risk neonatal cohort.

Mode of delivery was vaginal (normal delivery) in 158 infants (79.0%) and caesarean in the remaining 42 (21.0%) which is broadly consistent with delivery patterns reported from comparable tertiary obstetric units though caesarean rates of this order do vary a fair amount between institutions and are not by themselves especially informative about hearing risk (Table 2, Figure 2).

Table 2: Mode of delivery among the study cohort.

Mode of delivery	Frequency (n)	Percentage (%)
Normal (vaginal) delivery	158	79.0
Caesarean delivery	42	21.0
Total	200	100.0

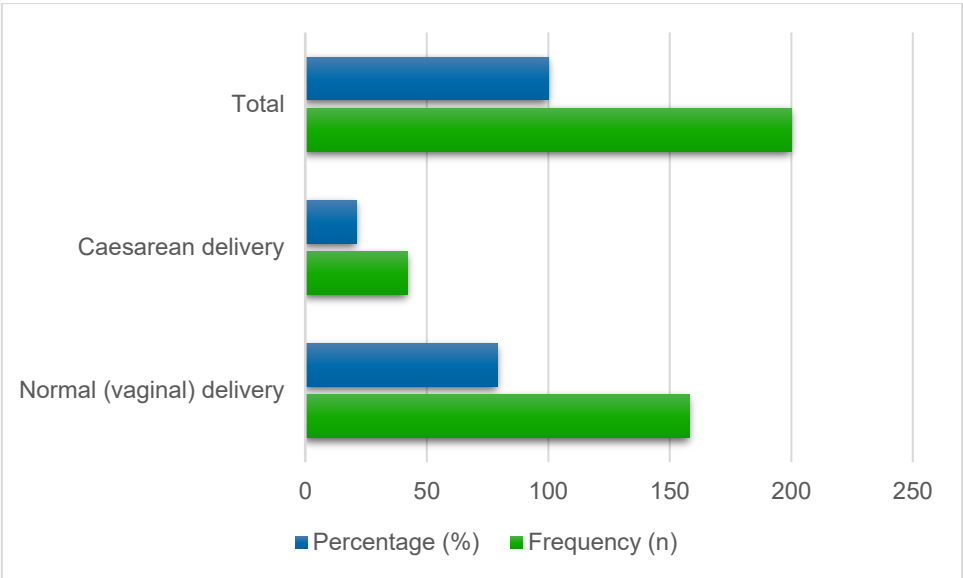

Figure 2. Distribution of neonates by mode of delivery.

Table 3 sets out the anthropometric and perinatal continuous variables. Gestational age ranged from 32 to 42 weeks (mean 39.51 ± 1.678 weeks), indicating that the majority of infants were term or near-term despite their high-risk classification, which is a reminder that prematurity is only one of several routes into the high-risk category. Maternal age ranged from 21 to 40 years (mean 26.95 ± 3.057 years). The five-minute APGAR score ranged narrowly from 3 to 4 (mean 3.80 ± 0.401), reflecting the fact that a depressed APGAR score was itself one of the enrolment criteria for a considerable proportion of the cohort. Birth weight ranged from 2000 to 4000 g (mean 2913.0 ± 327.785 g).

Parameter	Minimum	Maximum	Mean	SD
Gestational age (weeks)	32	42	39.51	1.678
Maternal age (years)	21	40	26.95	3.057
APGAR score (5 min)	3	4	3.80	0.401
Birth weight (g)	2000	4000	2913.0	327.785

Table 3: Anthropometric and perinatal parameters of the study cohort.

A documented antenatal (pre-natal) risk factor such as maternal infection, pregnancy-induced hypertension, or antenatally recognized fetal growth restriction was present in 44 neonates (22.0%), while the remaining 156 (78.0%) had no such factor recorded (Table 4), suggesting that in this cohort, perinatal and postnatal risk indicators (low birth weight, NICU stay, low APGAR score, and so on) contributed more heavily to high-risk classification than antenatal factors did.

Antenatal risk factor	Frequency (n)	Percentage (%)
Absent	156	78.0
Present	44	22.0
Total	200	100.0

Table 4: Presence of documented antenatal (pre-natal) risk factors.

3.2 Otoacoustic emission screening at one month

At the one-month visit, OAE pass rates in the right ear were highest at 500 Hz (85.0%) and declined gradually with increasing frequency, falling to 82.0% at 4000 Hz. The left ear showed a broadly similar but slightly less favorable pattern, with pass rates clustering around 79.0–79.5% across all four frequencies (Table 5, Figure 3). This right–left asymmetry, though modest in absolute terms, was consistent across all four frequencies, which argues against it being a chance finding attributable to a single outlying frequency band.

Frequency	Right ear – Pass (%)	Right ear – Fail (%)	Left ear – Pass (%)	Left ear – Fail (%)
500 Hz	85.0	15.0	79.5	20.5
1000 Hz	84.5	15.5	79.5	20.5
2000 Hz	83.0	17.0	79.5	20.5
4000 Hz	82.0	18.0	79.0	21.0

Tables 5: OAE pass and fail rates at one month, right and left ears, by test frequency.

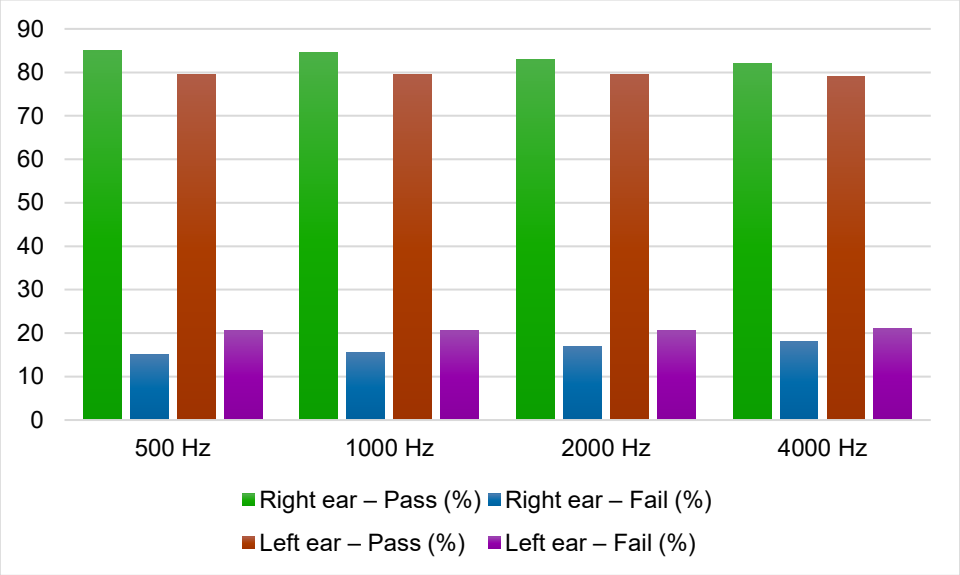

Figure 3: OAE pass rate at one month of age across four test frequencies, right versus left ear.

3.3 Otoacoustic emission screening at three months

On repeat OAE testing at three months, right-ear pass rates ranged from 78.5% at 500 Hz to a peak of 81.0% at 1000 Hz, with fail rates now considerably lower (6.0–8.0%) than at the one-month visit largely, one suspects, because transient conductive debris that commonly confounds early testing had resolved by three months. However, a substantial dropout rate of roughly 13% was recorded at every frequency, reflecting infants who did not return for the follow-up visit or in whom a technically adequate recording could not be obtained (Figure 4).

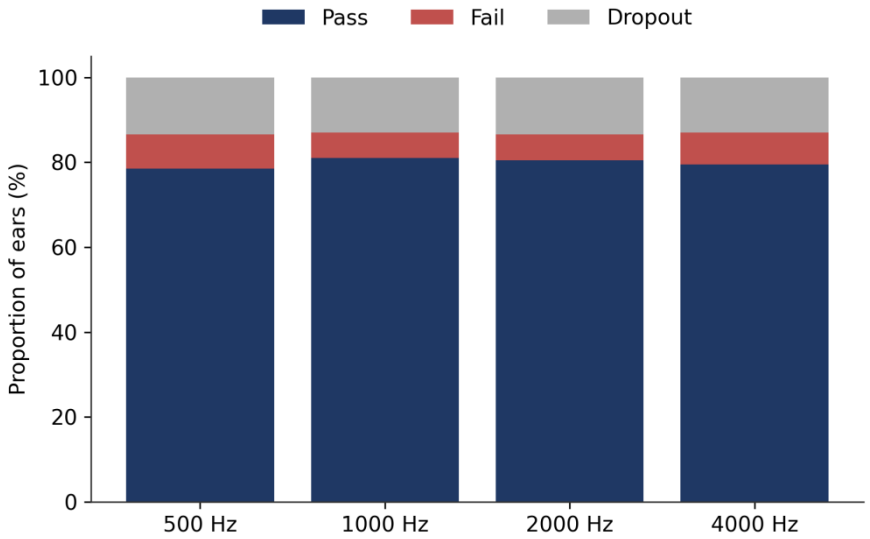

Figure 4: OAE outcome (pass / fail / dropout) at three months, right ear, by test frequency.

The left ear followed a closely similar pattern at three months, with pass rates of 80.0–80.5%, fail rates of 6.5–7.5%, and dropout rates of 12.5–13.0% (Figure 5). Taken together, the one-month and three-month OAE data suggest that the true fail rate once dropouts are set aside settled somewhere in the range of 6–8% by three months, appreciably lower than the 15–21% fail rates recorded at one month, which is broadly what one would expect as early conductive confounders clear.

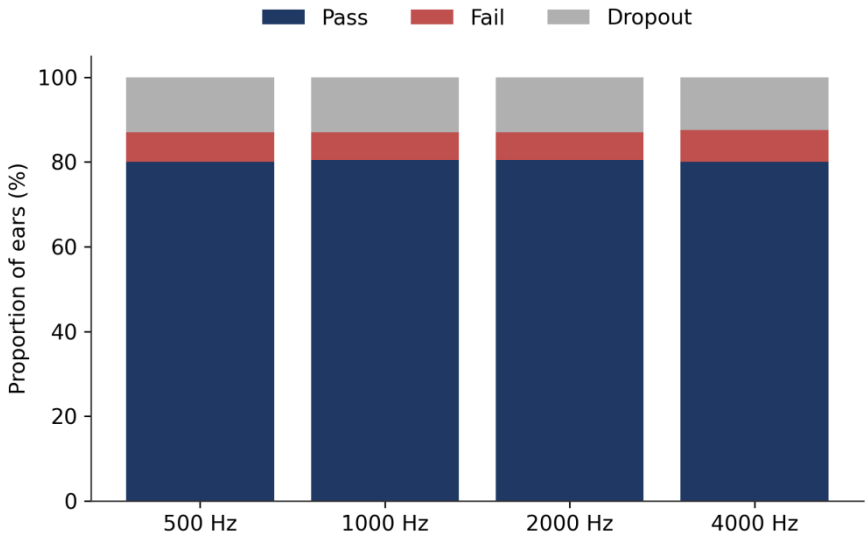

Figure 5: OAE outcome (pass / fail / dropout) at three months, left ear, by test frequency.

3.4 Auditory brainstem response (BERA) at three months

At an intensity of 70 dBnHL, a discernible wave V was present in 114 right ears (57.0%) and absent in only 7 (3.5%), with the remaining 79 (39.5%) recorded as dropouts. The left ear showed a comparable pattern wave V present in 111 Ears (55.5%), absent in 11 (5.5%), and dropout in 78 (39.0%) (Figure 6). The dropout figure here is worth dwelling on for a moment: at nearly 40%, it was considerably higher than the OAE dropout rate at the same visit, which is consistent with BERA being the more demanding of the two tests to complete in a wakeful or fretful infant.

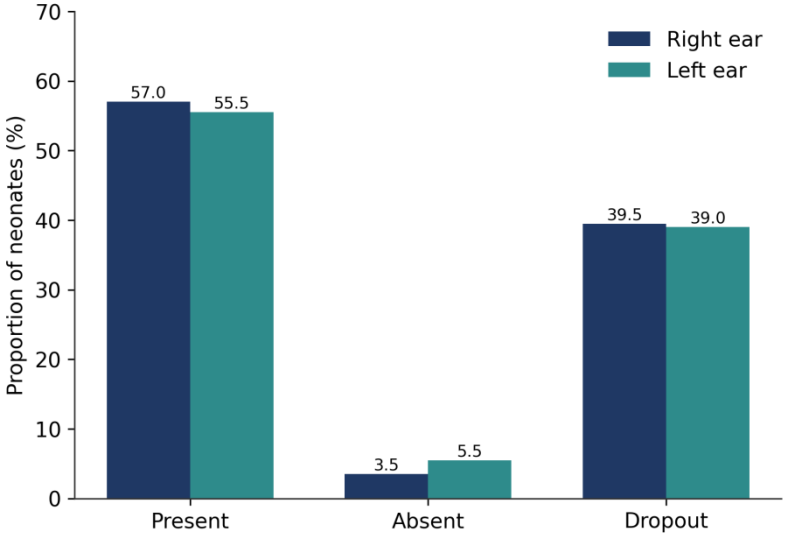

Figure 6: BERA wave V presence at 70 dBnHL, right versus left ear.

At the lower intensity of 40 dBnHL closer to the threshold used to infer a clinically significant hearing deficit a pass/present response was obtained in 116 right ears (58.0%) and 110 left ears (55.0%), with fail/absent responses in only 6 right ears (3.0%) and 10 left ears (5.0%); dropout again accounted for the remainder, 39.0% on the right and 40.0% on the left (Figure 7).

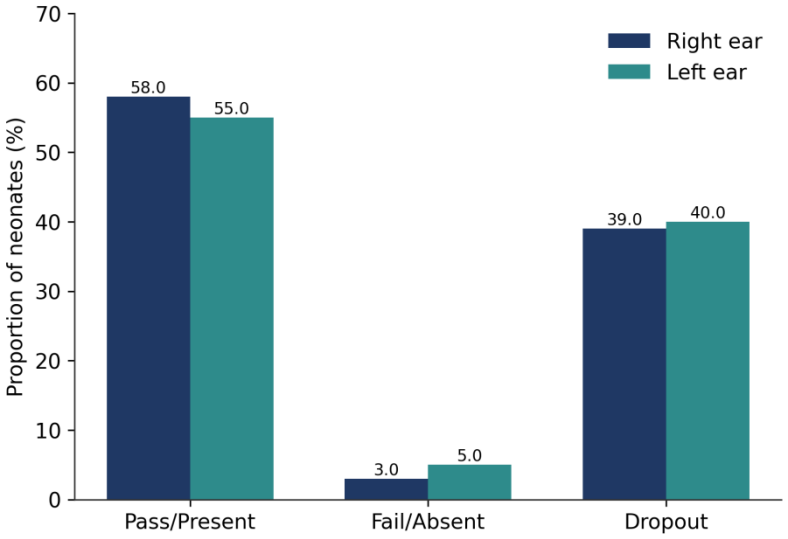

Figure 7. BERA response at 40 dBnHL, right versus left ear.

Mean wave V latency, calculated from the ears in which a response was actually recordable, was 3.47 ± 3.043 ms in the right ear and 4.02 ± 3.521 ms in the left ear (Figure 8). The comparatively wide standard deviations here reflect the heterogeneity of the high-risk cohort infants with mild transient conductive change and those with more substantial neural involvement were both represented in the sample, and latency values for the two groups are naturally quite different, which inflates the spread when pooled together.

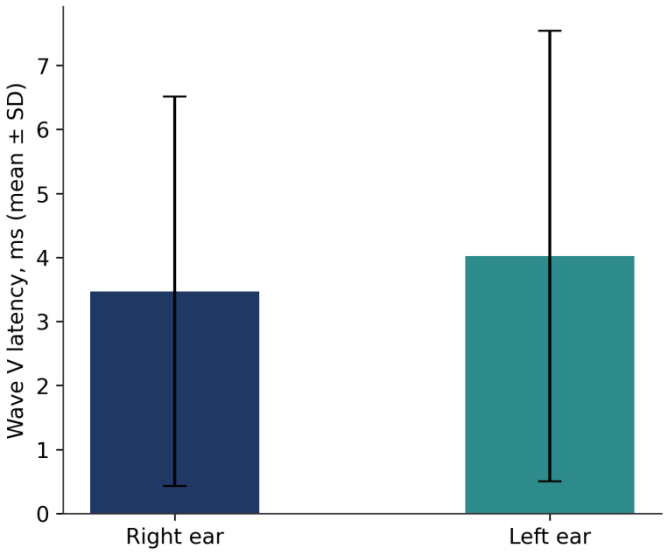

Figure 8. Mean wave V latency (± SD) at 70 dBnHL, right versus left ear.

IV. Discussion

The pass rates observed on OAE screening in this cohort roughly 82–85% in the right ear and 79–80% in the left ear at one month, improving modestly by three months once dropouts are excluded sit within the range reported by earlier multicenter and single-center studies of high-risk neonates, most of which have described initial OAE 'refer' (fail) rates anywhere from 10% to 25%, tapering considerably on rescreening[11,12]. The fall in fail rate between the one-month and three-month visits observed here mirrors what several authors have attributed to the resolution of transient middle-ear debris, vernix caseosa, and residual amniotic fluid, all of which are known to attenuate or distort otoacoustic emissions in the immediate newborn period without reflecting any true cochlear pathology[13].

The slight but consistent right–left asymmetry noted across all four OAE frequencies in this study the right ear performing marginally better than the left at every test frequency is an interesting, if modest, observation. A number of prior reports have similarly noted a right-ear advantage on neonatal OAE testing, which some authors have speculated may relate to subtle differences in cochlear maturation or to positional

factors during testing (the right ear frequently being tested first, while the infant is more settled), though this remains, admittedly, a somewhat under-investigated area and the explanation offered here should be read as a plausible hypothesis rather than an established mechanism[14,15].

Perhaps the most clinically relevant finding of this study is the dropout rate recorded at the three-month visit approximately 13% for OAE and close to 39–40% for BERA. This is, frankly, a sobering figure, and it echoes a difficulty that has been flagged repeatedly in the Indian and broader South Asian newborn hearing screening literature: loss to follow-up between the initial screen and confirmatory diagnostic testing is, in many settings, the single largest obstacle to achieving the 1-3-6 benchmark set out by the JCIH[16]. Reasons commonly cited include the distance families must travel for follow-up visits, competing care giving and financial pressures in the early postpartum period, limited parental awareness of the significance of a 'refer' result, and, in some cases, simple logistical failure of the screening programme to communicate appointment schedules effectively[17,18]. Whatever the precise mix of contributing factors in our own setting, the practical implication is the same a screening protocol is only as good as the follow-up system that sits behind it, and the results reported here suggest that this is an area where the programme has room to improve.

The BERA findings, particularly the wave V presence rates at 70 dBnHL and 40 dBnHL, are broadly reassuring for the majority of infants who completed testing present or pass responses were obtained in over half the cohort at both intensities, with true fail/absent rates staying in the single digits. This pattern is consistent with the expectation that most high-risk neonates, despite carrying one or more risk indicators, will ultimately have normal or near-normal hearing, and that risk-based screening exists precisely to identify the smaller subset who do not[19]. The wide standard deviation around mean wave V latency is less easily explained away, and probably reflects genuine heterogeneity in neural maturation and possibly a handful of infants with more substantial conductive or neural involvement pulling the distribution's tail outward; a formal comparison of latency between infants with and without individual risk factors ototoxic exposure, Hyperbilirubinemia, prematurity was beyond the scope of the present descriptive analysis but would be a natural next step.

Comparisons with other Indian studies are instructive. Similar two-stage OAE–BERA protocols applied to high-risk neonatal cohorts in other tertiary centers have reported combined confirmed hearing-loss rates in the range of 3–6% of the screened population, once dropouts and false positives are accounted for[20,21]a figure that this study's data, interpreted cautiously given the substantial dropout, would not obviously contradict. Internationally, the multicenter OAE–ABR data reported by Norton and colleagues, and the position statements periodically updated by the JCIH, have consistently supported the combined-modality approach used here over either test used alone, precisely because OAE and ABR interrogate different points along the auditory pathway and therefore carry complementary rather than redundant diagnostic information[22].

4.1 Strengths and limitations

This study benefits from a reasonably sized cohort (n = 200), a prospective design, and a two-tier screening protocol that closely mirrors international recommendations. Its principal limitation is the dropout rate already discussed, which almost certainly introduces some degree of attrition bias infants lost to follow-up may differ systematically, in ways this study cannot characterize, from those who completed testing. The absence of long-term diagnostic confirmation (formal audiological threshold testing at six months or beyond) for infants who failed initial screening is a further limitation, as is the descriptive, non-comparative nature of the statistical analysis, which precludes any formal test of association between specific risk factors and screening outcome. Future work at this center would do well to incorporate a structured telephonic or community-health-worker-assisted follow-up mechanism, and to extend the analysis to formal diagnostic confirmation and risk-factor stratification.

V. Conclusion

In this cohort of 200 high-risk neonates, a combined OAE–BERA screening protocol identified the large majority of infants as having normal cochlear and neural auditory function, with true fail rates settling in the single digits once transient early confounders had resolved. The protocol appears to function reasonably well as a screening tool in principle, but the appreciable dropout observed at the three-month visit particularly for BERA is the finding most deserving of attention going forward. Strengthening the follow-up pathway, whether through reminder systems, community outreach, or integration with routine immunization visits (which most infants do attend), is likely to matter as much for early hearing loss identification in this population as any refinement to the screening technology itself.

Conflict of Interest: The authors declare no conflict of interest related to this study. There are no financial, personal, or professional relationships that could be construed to have influenced the design, data collection, analysis, interpretation, or reporting of the findings in this research.

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