Identification of sensory neural hearing loss in very preterm infants by brainstem auditory evoked potentials

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SUMMARY Brainstem auditory evoked potentials were recorded in 117 newborn infants of less than 33 weeks of gestation. The potentials were absent in 10 infants (bilaterally in eight and unilaterally in two) and present in 107. By 1 year of age nine of the 10 infants with absent brainstem auditory evoked potentials were shown to have sensory neural hearing loss and required hearing aids: the remaining infant had secretory otitis media. None of the 107 infants whose auditory evoked potentials were present were found to have sensory neural hearing loss but 13 had secretory otitis media. Measurement of brainstem auditory evoked potentials is an accurate method of identifying sensory neural hearing loss in very preterm infants.

Very preterm infants are at risk for sensory neural and conductive hearing loss.^{1,2} Early diagnosis is important so that causes can be explored and treatment started as soon as possible. Brainstem auditory evoked potentials have been used as an objective test of hearing in adults³ and children.⁴ These potentials can also be elicited in newborn infants,^{5,6} including those born well before term.^{7,8}

This study was carried out to determine whether measurement of brainstem auditory evoked potentials in very preterm newborn infants predicted hearing status at 1 year of age.

Infants studied and methods

Infants studied. A total of 217 infants who had been born before 33 weeks of gestation were admitted to the Neonatal Unit of University College Hospital in the years 1980 to 1982. Sixty (28%) died and 35 (16%) were sent back to their referring hospitals before testing of brainstem auditory evoked potentials could be carried out. The remaining 122 infants were tested. Their median gestational age was 30 weeks (range 24 to 32 weeks), and their median birthweight was 1285 g (range 600 to 2230 g). Sixty nine were boys and 53 were girls. Seventy five were born in University College Hospital and 47 were referred from other hospitals. Five of the 122 infants

died after testing had been done, leaving 117 long term survivors.

Measurements of brainstem auditory evoked potentials were first carried out when the infants were at a median postnatal age of 15 days (1 to 85 days) and a median gestation equivalent age (gestational age at birth plus postnatal age) of 32 weeks (range 26 to 42 weeks). All 122 infants were tested at a gestation equivalent age of at least 30 weeks and 79 were tested twice or more before discharge from the neonatal unit.

Measurement of brainstem auditory evoked potentials. Tests were performed when the infants were in a stable enough condition to tolerate gentle handling. They were usually being nursed in open or closed incubators and many were being mechanically ventilated or receiving oxygen in a head box.

A Medelec Amplaid Mk III system was used in 1980 and an Amplaid Mk IV system with a Texas Instruments Silent 733 terminal for data collection in 1981 and 1982. Details of the two systems are given in Table 1. Two standard silver/silver chloride electrodes were positioned over the mastoid processes and one at the vertex. The electrodes were held in place by Blutack and Netelast.⁹ The skin under the electrodes was very slightly abraded and electrode cream (Redux) was used to ensure good

Table 1 Details of brainstem auditory evoked potentials measurement

Year	1980	1981-82
Equipment	Medelec Amplaide Mk III	Amplaide Mk IV
Earphones	TDH 39	TDH 49
Stimulus type	Wide band high frequency rarefaction click	Wide band high frequency rarefaction click
Duration	100 μ s	100 μ s
Rate	20 pps	21 pps
Intensity*	100 dB PE SPL (80 dB HL)	100 dB PE SPL
Filter		
Type	6 dB/octave roll off	6 dB/octave roll off
Bandpass	250-3200 Hz	100-2000 Hz
Analysis time	20 ms	30 ms
Prestimulus delay	5 ms	10 ms
Number of responses	1024	2048
Data collection	UV sensitive paper	Digital cassette

*Calibrated using Bruel and Kjaer Type 2203 sound level meter and Bruel and Kjaer Type 152 artificial ear.
dB PE SPL=decibels peak equivalent sound pressure level.
dB HL=decibels hearing level.

electrical contact: impedances between pairs of electrodes were 3 k Ω or less. The electrode leads were plaited to reduce the effects of electrical interference.

The measurements were made while the infant was sleeping, preferably lying prone. Artefact rejection was set at ± 2.5 μ V or ± 5 μ V to prevent the recording of muscle activity. Tests were made ipsilaterally and each ear was tested independently at least twice. If no response was obtained at the initial stimulus level (Table 1) the intensity was increased by 10 decibels (dB) peak equivalent sound pressure level (PE SPL) and a second test was done. If no response was again obtained at least three tests were made on each ear at each stimulus level, and the infant was retested on at least one further occasion before discharge from hospital.

A response was judged to be 'present' when waves I, N, III, and V could be detected (see Figure), as compared with the averaged prestimulus trace, which was used as a reference. If no waves could be discriminated on repeated testing the response was judged to be 'absent'. Tests took about 30 to 60 minutes to complete.

Follow up. One hundred and twelve of the 117 infants attended a special developmental clinic so that their progress could be assessed as previously described:¹⁰ particular attention was paid to auditory behavioural responses and the onset of language development. For the purposes of follow up, the infants' ages were corrected for preterm birth by

Figure (a) Normal brainstem auditory evoked potentials from an infant born at 29 weeks of gestation, weighing 1498 g, and tested at 6 weeks of age. Waves I, III, and V are labelled as described by Jewett and Williston;¹⁵ N=negative wave preceding wave III.⁶

(b) Absent brainstem auditory evoked potentials in an infant born at 32 weeks of gestation, weighing 1630 g, and tested aged 3 weeks.

S=stimulus.

subtracting from their chronological age the number of weeks that they had been born before term. Measurement of brainstem auditory evoked potentials testing was repeated at 3 months of corrected age on 59 infants born in 1981 and 1982. At 6 months, postauricular myogenic response testing was carried out on 107 infants.¹¹⁻¹³ Infants who failed to respond to the postauricular myogenic test at 76 dB PE SPL (60 dB hearing level) were retested within three months. A Griffiths baby test¹⁴ was done on 108 infants between the corrected ages of 47 and 91 (median 54) weeks by a psychologist who was unaware of the results of the neonatal brainstem auditory evoked potentials tests. Infants failing follow up auditory evoked potentials or postauricular myogenic response tests, or in whom there was any suspicion of hearing loss from developmental observations were referred to a neuro-otologist for otological investigation, acoustic impedance testing, behavioural distraction tests, and if necessary electrocochleography or measure-

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ment of brainstem auditory evoked potentials under general anaesthesia. Five of the 117 surviving infants emigrated aged 3 to 5 months, but information has been obtained about them, when aged 52 to 110 (median 77) weeks, from their parents and local doctors. All 117 survivors have been followed up for at least one year.

Results

In the neonatal period, 10 (8.2%) of the 122 infants had absent brainstem auditory evoked potentials; bilaterally in eight and unilaterally in two. Brief

clinical details of these infants are given in Table 2. The potentials were present in the other 107 infants; equivocal results were never encountered. The results were confirmed in 58 of the 59 infants who were retested aged 3 months, including eight infants with absent responses. In one infant, potentials were initially present, but absent on retesting. Bilateral conductive loss due to secretory otitis media or 'glue ear' was diagnosed: after removal of the fluid bilateral responses were obtained.

The results of brainstem auditory evoked potentials testing in the newborn period are related in Table 3 to the results of postauricular myogenic

Table 2 Clinical details of 10 infants with absent neonatal brainstem auditory evoked potentials (BAEP)

Infant	Sex	Gestational age (wks)	Birthweight (g)	Main neonatal diagnoses	Ultrasound brainscan	BAEP absent	SNHL aged 1 year
1	M	31	1735	HMD, MV, Pn'x, renal failure	PVH, post haemorrhagic hydrocephalus	R+L	R+L
2	F	31	1314	HMD, MV	PVH, mild ventricular distension	R+L	R+L
3	M	28	995	Down's syndrome	Normal	R	R(+bilateral SOM)
4	M	32	1630	HMD, MV, Pn'x	PVH, post haemorrhagic hydrocephalus	R+L	R+L
5	M	27	1196	HMD, MV, BPD	Generalised cerebral atrophy	R+L	R+L
6	F	30	1268	Klippel-Feil syndrome, HMD, MV	PVH	L	L(+bilateral SOM)
7	M	29	940	HMD, MV, BPD	Normal	R+L	R+L
8	F	26	955	MV	PVH, mild ventricular distension	R+L	R+L
9	M	28	859	MV, congenital abnormalities, thrombocytopenia	PVH, small thalamic haemorrhage	R+L	R+L
10	M	30	1277	HMD, MV	Normal	R+L	(bilateral SOM)

SNHL=sensory neural hearing loss; SOM=secretory otitis media; R=right ear; L=left ear; HMD=hyaline membrane disease; MV=mechanical ventilation; Pn'x=pneumothorax; BPD=bronchopulmonary dysplasia. Ultrasound scans were performed and interpreted as described by Stewart *et al.*¹⁰ PVH=periventricular haemorrhage: the only infant with intraparenchymal extension was infant 1.

Maximum total plasma bilirubin concentrations in the 10 infants ranged from 180 to 348 (mean 228) $\mu\text{mol/l}$ (10.5 to 20.3 (mean 13.3) $\text{mg}/100\text{ ml}$); and for gentamicin (trough values), 1.5 to 4.0 (mean 2.5) $\mu\text{g}/\text{ml}$. All infants except infant 10 had recurrent apnoeic spells.

Table 3 Relation between brainstem auditory evoked potentials (BAEP) response in the neonatal period, the results of postauricular myogenic response (PAM) tests, the Griffiths baby test, and hearing status at 1 year of age in 117 infants

BAEP response	PAM test	No	Griffiths test (a) Overall GQ (b) Hearing and speech subscale	No	Hearing status		
					Normal	SOM (Conductive loss)	SNHL
					No	No	No
Absent (n=10)	Pass	0	—	0	0	0	0
	Fail	8	(a) 90 (70–110)* (b) 70 (64–100)	6	0	1	7†
	Not tested	2	(a) 74, 97 (b) 32, 81	2	0	0	2
Present (n=107)	Pass	65	(a) 105 (57–137) (b) 102 (59–139)	65	65	0	0
	Fail	36	(a) 101 (63–115) (b) 96 (59–132)	34	25	11	0
	Not tested	6	(a) 100 (88–103) (b) 110 (98–117)	3	4	2	0

*=Median (range); †=two infants also had secretory otitis media.
SOM=secretory otitis media; SNHL=sensory neural hearing loss.

response tests, Griffiths tests (overall GQ, and the hearing and speech subscale), and hearing status assigned between 12 and 18 months of age. Two of the 10 infants with absent potentials did not undergo postauricular myogenic response testing because they had already been referred for investigation and found to have sensory neural hearing loss. The other eight underwent postauricular myogenic response testing and all failed: seven proved to have sensory neural hearing loss (together with secretory otitis media in two); the eighth had secretory otitis media requiring surgical intervention and, presumably, conductive loss. In accordance with the neonatal brainstem auditory evoked potential results, sensory neural hearing loss was bilateral in seven and unilateral in two. All nine infants required hearing aids. Of the 107 infants whose auditory evoked potentials were present, 101 had a postauricular myogenic response test and 36 failed. All 36 had audiological and otological investigations: 25 were judged to have normal hearing at 1 year of age and the other 11 had conductive loss due to secretory otitis media.

Discussion

Brainstem auditory evoked potentials are far field reflections of the electrical activity which occurs in the brain in response to an acoustic signal,⁸ and which can be extracted from the electroencephalograph by filtering and averaging.¹⁵ The response, described originally by Sohmer and Feinmesser in 1967,¹⁶ consists in the adult of a series of seven waves of neural activity with latencies of less than 9 msec, labelled I–VII by Jewett and Williston.¹⁵ Individual waves have been linked with specific generator sites in the auditory pathway,^{17 18} although more recent studies have indicated that the origin of the waves may not be so precisely located.^{19 20} In the normal newborn infant, waves I, N, III, and V are regularly elicited^{5–7} and the response provides an objective measure of the integrity of the auditory pathways. The response does not seem to be state dependent,²¹ and can be obtained in the quietly sleeping infant without sedation. Except in one continuing study of ‘high risk’ infants, giving early results similar to our own,²² and another in which infants with normal responses were apparently not followed up,²³ previous investigators have generally defined abnormalities of brainstem auditory evoked potentials in terms of waveform, latency, and threshold.^{24–28} By analogy with studies in older children and adults these measures have been assumed to indicate impairment of hearing. Measures of latency, however, are known to change with increasing

age,^{6 7 26 27 29 30} so interpretation is difficult or impossible in the absence of clearly defined gestation equivalent age-dependent norms. Also, both latency and threshold may be affected by fluid or other extraneous material in the middle ear or in the external auditory canal.^{31 32} In our experience this may cause particular problems in the interpretation of negative results in very preterm infants tested before 30 weeks of gestation equivalent age. Furthermore, preterm infants, particularly those who have been mechanically ventilated, are known to be susceptible to effusions in the middle ear that may recur intermittently during the first year of life.³³ It is therefore not surprising that poor correlations have been reported^{24 28} between ‘abnormal’ brainstem auditory evoked potentials in newborn infants and later hearing status.

In this study, abnormality of potentials was rigorously defined as no response to a stimulus level of 100 or 110 db PE SPL. This level was above the background noise level of 60 to 70 dB SPL. All the infants were tested after they had reached a gestation equivalent age of at least 30 weeks. Steps taken to enhance the precision of detection of potentials included ensuring good electrode contact with the scalp, setting the level of artefact rejection low enough to exclude potentials related to small movements of the eyes and face, and judging the presence or absence of a response by comparison with a reference trace.

Having adopted these simple methods, a strong association was found between the results of testing of brainstem auditory evoked potentials in the neonatal period and hearing status at 1 year of age. Nine of the 10 infants with absent potentials had sensory neural hearing loss requiring hearing aids, and the other infant had secretory otitis media. Conversely, none of the 107 infants whose potentials were present were found to have sensory neural hearing loss, though conductive loss due to secretory otitis media was detected in 13.

We conclude that measurement of brainstem auditory evoked potentials in very preterm infants is a comparatively simple and practical procedure which can be carried out in the neonatal intensive care unit and which seems to predict with great accuracy the presence or absence of sensory neural hearing loss severe enough to require hearing aids. Longer follow up is required, however, before final conclusions can be reached. All the children in this study are remaining under surveillance so that the relation between the results of brainstem auditory evoked potential testing in the newborn period and pure tone audiograms at the age of 4 years can be determined. By contrast with sensory neural hearing loss, secretory otitis media is an intermittent condi-

tion, so it is not surprising that potentials were present in some newborn infants who were later shown to have this. This emphasises the need for repeated tests of hearing in very preterm infants as they grow.

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