Hearing Loss by Week of Gestation and Birth Weight in Very Preterm Neonates

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Objective To gain insight into health and related costs associated with very preterm births, one needs accurate information about the prevalence of the disabling conditions, including neonatal hearing loss (NHL).

Study design We assessed the prevalence of NHL by week of gestation and categories of birth weight in very preterm neonates. Results of the 2-stage Automated Auditory Brainstem Response nationwide Newborn Hearing Screening Program in Dutch Neonatal Intensive Care Units and diagnostic examinations were centrally registered between October 1998 and December 2012 and included in this study. NHL was defined as impaired when the neonate conventional Auditory Brainstem Response level exceeded 35 dB near Hearing Level at diagnostic examination. Birth weight was stratified into <750 g, 750-999 g, 1000-1249 g, 1250-1499 g, and ≥1500 g, and by small for gestational age (SGA; <10th percentile) vs appropriate for gestational age. Logistic regression analyses and recursive partitioning were performed.

Results In total, 18 564 very preterm neonates were eligible. The prevalence of NHL consistently increased with decreasing week of gestation (1.2%-7.5% from 31 to 24 weeks) and decreasing birth weight (1.4%-4.8% from ≥1500 g to <750 g, all $P < .002$). Most vulnerable to NHL were girls <28 weeks, boys <30 weeks, and SGA neonates. The SGA effect started at 27 weeks.

Conclusions Gestational age and birth weight quantify the risk of NHL. This information can be used at the individual level for parent counseling and at the population level for medical decision making. *(J Pediatr 2015;166:840-3)*.

Survivors of very preterm births face a lifetime of disability.[1] The annual societal economic burden associated with preterm birth is high, especially among the smallest and most immature neonates.[2] To gain better insight into health and related costs associated with very preterm births, accurate information about the prevalence of the disabling conditions is required. Besides cerebral palsy, intellectual disabilities, and vision impairment, neonatal hearing loss (NHL) is 1 of the 4 major disabling conditions in very preterm neonates.[1,2] NHL is a serious health condition that may adversely affect speech, language development, academic achievement, and social-emotional development.[3] NHL also has an impact on societal costs, including medical, early intervention, and special education services.[2]

Although studies have shown an association between NHL and prematurity and low birth weight,[4] the prevalences of NHL by week of gestation and categories of birth weight in neonates born <32 weeks of gestation have not been reported. Our aim is to assess the prevalence by using the results of the nationwide Newborn Hearing Screening Program (NHSP) in Dutch neonatal intensive care units (NICUs).

Methods

In The Netherlands, all neonates born with a gestational age (GA) <30 weeks and most (~85%) neonates with a GA between 30 and 32 weeks are treated in 1 of the 10 level-III NICUs. From 1998 to 2002, a 2-stage automated auditory brainstem response (AABR) NHSP was implemented gradually in Dutch NICUs.[5] The 2-stage AABR screening consists of a first AABR test before discharge from the NICU and a second AABR test as an outpatient in the NICU clinic if the neonate has failed the first AABR test. Two commercially available AABR hearing screening devices were used. The ALGO Portable/ALGO3i by Natus Medical Inc (Pleasanton, California) uses a 35 dB near Hearing Level click stimulus, rate 37/sec with a broadband acoustic spectrum from 750 to 5000 Hz. The second device is the MB11 BERAphone by Maiko Diagnostics (Berlin, Germany) with the same stim-

AABR	Automated auditory brainstem response
AGA	Appropriate for gestational age
GA	Gestational age
HL	Hearing loss
NDI	Neurodevelopmental impairment
NHL	Neonatal hearing loss
NHSP	Newborn Hearing Screening Program
NICU	Neonatal intensive care unit
SGA	Small for gestational age

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ulus level (rate 93/sec), an acoustic spectrum from 135 Hz to 8000 Hz, with inbuilt CE-Chirp stimulus technology. All neonates who failed the 2-stage AABR test were referred for further audiologic diagnostic procedures.

Results of the screening and first diagnostic examination at the audiologic center in NICU graduates born between October 1998 and December 2012 with 1 or more risk factors according to the Joint Committee on Infant Hearing[3] were registered centrally in an electronic registration system and included in this study. Note that (almost) all very preterm neonates have at least 1 risk factor, because "neonatal intensive care of more than 5 days" is a risk factor according to the Joint Committee of Infant Hearing. Parents were informed about the AABR hearing screening by a brochure. Institutional review/ethical board approval was not required for this study.

NHL was defined as impaired when the conventional auditory brainstem response level exceeded 35 dB near Hearing Level in 1 (unilateral) or 2 (bilateral) ears at diagnostic examination at the audiologic center. Birth weight, GA, and sex also were registered in the registration system. Birth weights were measured by trained health professionals by the use of calibrated digital baby scales. GA was determined from early ultrasound examination during pregnancy. We included all neonates with a GA <32 weeks who survived the admission period. We excluded neonates with missing values on birth weight and those with birth weights exceeding 5 SD above the median at the GA and sex-specific growth charts ("outliers").[6]

Birth weight was stratified into 2 categories of extremely low birth weight (<750 g, 750-999 g), 2 categories of very low birth weight (1000-1249 g, 1250-1499 g), and in the category ≥1500 g. Birth weight also was categorized in 2 groups: small for gestational age (SGA; <−1.3 SD [ie, below the 10th percentile] on GA and sex-specific growth charts[6]) vs appropriate for gestational age (AGA). GA was truncated to complete weeks (eg, from 26 weeks and 0-6 days to 26 weeks). Descriptive statistics and exact binomial CIs were calculated for subgroups with a sufficient (>100) sample size. Logistic regression analyses were performed with unilateral or bilateral NHL as dependent variable and GA in weeks and/or birth weight in kilograms as independent variables. Note that the OR of the logistic regression analyses present the odds of NHL given a certain GA (or category of birth weight) divided by the odds of NHL when GA is 1 week less (or one category of birth weight lower). The variance inflation factor was calculated to analyze the magnitude of multicollinearity in the analysis because GA and birth weight are correlated.

Recursive partitioning (classification tree) was performed to explore subgroups with high risks of NHL according to (interactions of) GA, SGA, and sex. These subgroups were defined as most vulnerable to NHL. Recursively partitioning splits the data into homogeneous subgroups (ie, subgroups with relatively high or low risks of NHL). We first allowed a very complex model: (1) the complexity parameter was set at 0.001 and served as a penalty term to control the tree size; (2) we allowed a minimum size subgroup of 5; and (3) a minimum size of 10 to make a split. Then we used cross-validation to prune back the tree ("1 − SE" rule).[7] We calculated the relative error (ie, average deviance of the current tree divided by the average deviance of the null tree), and the cross-validation error (ie, a 10-fold cross-validation measured relative to the deviance of the null model). We set the prior probability at 0.5. The statistical analyses were performed in SPSS version 20.0 (SPSS Inc, Chicago, Illinois) for Windows (descriptive analyses and logistic regression analyses) and R version 3.0.2 (rpart). *P* values < .05 (2-sided) were considered statistically significant.

Results

Of the 18 636 surviving neonates born <32 weeks of gestation, 30 neonates were excluded because of missing values on birth weight, and 42 neonates were excluded as their birth weights exceeded 5 SD on the growth charts. Of the 18 564 eligible neonates, 318 (1.7%) had bilateral NHL, 85 (0.5%) had unilateral NHL, 2096 (11.3%) were SGA, and 9992 (53.8%) were male.

The prevalence of NHL in these neonates consistently increased with decreasing week of GA and birth weight (**Table I**). Logistic regression analyses revealed significant associations between GA and unilateral and bilateral NHL (OR 0.84, 95% CI 0.75-0.94 and OR 0.76, 95% CI 0.72-0.81, respectively), as well as between birth weight and unilateral and bilateral NHL (OR 0.22, 95% CI 0.11-0.44 and OR 0.31, 95% CI 0.22-0.43, respectively). GA and birth weight were independent risk indicators of NHL (aOR 0.83, 95% CI 0.77-0.88 and aOR 0.58, 95% CI 0.39-0.87, respectively; variance inflation factor 1.7).

Figure 1 compares the distribution of GA within very preterm neonates with NHL and within the total group of very preterm neonates. The number of neonates increased with increasing weeks of GA, and the number of neonates with NHL remained almost stable between 26 and 31 weeks of gestation. A small (11%) group of neonates born at 24-26 weeks' GA contributed more than a one-quarter of the total number of very preterm neonates with NHL.

Table II shows the prevalence of NHL in very preterm neonates stratified by weeks of gestation, SGA, and sex. The

Table I. Prevalence of NHL in very preterm neonates (n = 18 564)

	n	NHL,* % (95% CI)	Unilateral NHL, % (95% CI)	Bilateral NHL, % (95% CI)
GA, wk				
24.0-24.9	133	7.5 (3.7-13.4)	0.8 (0.02-4.1)	6.8 (3.1-12.5)
25.0-25.9	631	5.2 (3.6-7.3)	0.8 (0.3-1.8)	4.4 (3.0-6.4)
26.0-26.9	1336	4.6 (3.5-5.8)	1.0 (0.5-1.7)	3.6 (2.7-4.7)
27.0-27.9	1942	2.8 (2.1-3.7)	0.6 (0.3-1.0)	2.3 (1.7-3.0)
28.0-28.9	2521	2.2 (1.7-2.9)	0.4 (0.2-0.7)	1.8 (1.3-2.4)
29.0-29.9	3256	2.0 (1.5-2.5)	0.4 (0.2-0.7)	1.6 (1.2-2.1)
30.0-30.9	4188	1.6 (1.2-2.0)	0.4 (0.3-0.7)	1.2 (0.9-1.5)
31.0-31.9	4557	1.2 (0.9-1.6)	0.3 (0.2-0.5)	0.9 (0.7-1.2)
Birth weight, g				
<750	1193	4.8 (3.6-6.2)	1.0 (0.5-1.8)	3.8 (2.8-5.0)
750-999	3611	3.3 (2.7-3.9)	0.7 (0.5-1.1)	2.5 (2.0-3.1)
1000-1249	4722	2.1 (1.7-2.5)	0.4 (0.3-0.7)	1.6 (1.3-2.0)
1250-1499	4449	1.5 (1.1-1.9)	0.3 (0.2-0.6)	1.1 (0.8-1.5)
≥1500	4589	1.4 (1.1-1.8)	0.2 (0.1-0.4)	1.2 (0.9-1.6)

*Unilateral and bilateral.