

## Original Articles

# The Universal Neonatal Hearing Screening (UNHS) Program in Hong Kong: The Outcome of a Combined Otoacoustic Emissions and Automated Auditory Brainstem Response Screening Protocol

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### Abstract

**Objectives:** Eight Hospital Authority (HA) birthing hospitals in Hong Kong have been using a two-stage automated auditory brainstem response (AABR) protocol as the tool for universal neonatal hearing screening since February 2007. Recognizing the high annual cost of the consumables involved in AABR testing, a retrospective study was conducted to assess the feasibility of a two-stage combined distortion otoacoustic emission test (DPOAE) and AABR screening protocol for implementation in local hospitals, and to compare the performance of the two screening protocols in terms of final referral rate, equipment and consumables cost per infant, and average screening time per infant. **Design:** Retrospective descriptive study. **Settings:** Two local birthing hospitals in Hong Kong: Hospital A (Union Hospital, a private hospital), Hospital B (Queen Elizabeth Hospital, an HA hospital). **Participants:** From 1 September 2007 to 31 March 2008, a group of 3,006 infants at Hospital A underwent hearing screening using a combined DPOAE and AABR screening protocol. Results were compared with the results of an AABR-only screening protocol administered to a group of 3,330 infants at Hospital B. **Results:** The combined DPOAE and AABR protocol had a final referral rate similar to that of the AABR-only protocol, but was about 2.5 times cheaper and almost 3 times faster. **Conclusion:** The two-stage combined DPOAE and AABR screening protocol is a feasible screening protocol for hospital-based universal neonatal hearing screening in Hong Kong.

### Key words

Automated auditory brainstem response (AABR), Infants; Distortion product otoacoustic emission test (DPOAE); Hearing loss; Neonatal hearing screening

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## Introduction

Hearing impairment is one of the most common congenital birth defects. Every year, approximately 1 to 3 infants per 1000 live births are born with significant bilateral hearing impairment of at least a moderate degree.<sup>1,2</sup> Early detection of and intervention for childhood hearing loss within the first six months of life can result in achieving normal or near normal language and communication skills.<sup>3,4</sup>

In the past two decades, there has been much debate on the early identification and subsequent management of infants with significant hearing impairment. Current healthcare standards suggest screening for all infants for hearing loss before 1 month of age, the confirmation of hearing loss before 3 months of age and intervention before 6 months of age.<sup>5</sup> The devices that are currently used to screen infant hearing include the evoked otoacoustic emission (EOAE) test and the automated auditory brainstem response (AABR) test. In brief, EOAEs are low-intensity sounds generated by the motile activity of the cochlear outer hair cells that can be detected in response to acoustic stimuli (either clicks or tonal stimuli) in most normally hearing subjects using a microphone coupled to the external meatus.<sup>6-8</sup> Transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs) are the two forms of EOAEs most widely applied in newborn hearing screening. AABR is a simplified version of the auditory brainstem response (ABR) measurement, and assesses the average neural response to a large number of repeated soft "click" sounds at the 35 dBnHL level delivered to the baby's ear via disposable earphones. To conduct the test, three electrodes are attached to the infant's forehead, nape, and shoulder to pick up the electrical responses, and the signals are then sent to a machine for automatic analysis.

Both the EOAE and the AABR test are well established for infant hearing screening, and the application of both procedures during the first few days of life has been proven to achieve a high pass rate at discharge.<sup>9</sup> The pros of EOAE test is that it is quick, simple and causes minimal nuisance to infants because it does not require electrode attachment. In addition, the testing is less affected by myogenic interference that can occur when testing a quiet baby. Under ideal conditions, the actual testing time can be as little as 20 seconds per ear. The cost of the disposable EOAE test kit is relatively cheap, and is estimated to be approximately HK\$5 per baby. However, the EOAE screening performs in the first few days of life may results in a high false positive rate due to vernix in the ear canal or transient fluid in the

middle ear.<sup>10,11</sup> Furthermore, EOAE cannot detect retrocochlear pathology.

The AABR test is also a reliable hearing screening device, and is also quick, easy to administer, and has a low referral rate, even for screening performed in the first few days of an infant's life. Furthermore, it allows the assessment of the entire auditory pathway. However, the cost of the disposable test kit is generally higher than that of the EOAE test at an estimated HK\$82 per infant. In addition, the skin preparation, placement and removal of the electrodes and the use of earphones may cause discomfort to the infant.

In the past ten years, several hearing screening programs were initiated in Hong Kong to determine the best screening protocol before the formal launch of the universal neonatal hearing screening (UNHS) program. These programs have focused on the issues of high risk versus universal screening; a hospital-based strategy versus a community-based strategy at Maternal and Child Health Centres (MCHCs); and screening technologies and protocols, including EOAE alone, AABR alone, or a combination of EOAE at the first stage and AABR at the second. Finally, in February 2007 a two-stage universal neonatal hearing screening using AABR was implemented at birth in all Hospital Authority (HA) birthing hospitals in Hong Kong and prior to hospital discharge. The programmes were conducted and managed by Paediatric departments in 6 HA hospitals and by Ear, Nose and Throat departments in 2 HA hospitals.

Since its implementation, the high cost of consumables associated with the two-stage UNHS using AABR has continued to be an issue of concern for administrators. Between 1 July 2007 and 30 June 2008 a total of 41,079 infants were born at eight Hospital Authority birthing hospitals, of which 38,150 were screened using the AABR test. Assuming that each infant consumes one set of disposable earphones and electrodes, the total cost of consumables would thus have been HK\$3,128,300 per annum.

## Purposes

Recognising the high annual cost of consumables associated with AABR testing, the goal of this study is to assess the feasibility of a two-stage combined distortion otoacoustic emission test (DPOAE) and automated auditory brainstem response (AABR) screening protocol in local hospitals, and to compare its performance with a two-stage AABR screening protocol in terms of final referral rate after two stage screening, the equipment and consumables cost per infant, and the screening time per infant.

## Ethical Considerations

The study was a retrospective assessment of anonymous patient information with no additional intervention imposed on the subjects. Ethical approval was obtained before the start of the study.

## Methods

### *Study Population*

All newborns delivered between 1 September 2007 and 31 March 2008 at Hospital A (Union Hospital, a private hospital) and Hospital B (Queen Elizabeth Hospital, an HA hospital) formed the cohort for universal newborn hearing screening program. Both hospitals were selected as the neonatal hearing screening programs were conducted and managed by ENT departments and both hearing screening programs were carried out by trained audiological staff. Anyhow, the main focus of the present study is to compare the two screening methods, namely OAE-AABR and AABR-AABR, this study was not attempt to compare the hearing screening programme between private and HA hospitals. In the same argument, Hospital A does not represent the private hospital in general. However, Hospital B does represent the HA hearing screening programme because the screening protocol, testing equipment and consumables, pass/fail criteria, the refer rate and failure rate are similar among the other seven HA birthing hospitals.

### *Equipment, Screening Protocols and Methods*

#### *Hospital A*

The screening protocol applied at Hospital A was a two-stage DPOAE+/-AABR newborn hearing screening program for all infants. Both the DPOAE and AABR screening test were conducted by audiological staff. The tests were performed in a nursery ward next to the baby or sometimes in separate room near to the nursery ward. Hearing screenings were usually performed after feeding when the baby was in quiet state. Testing was usually avoided during the doctor's round or nurses handing-over the duties if possible.

All of the babies in the nursery were initially screened with DPOAE at the second day of life and then screened using AABR if the DPOAE "referred" in either one or both ears. If the infant failed both the DPOAE and the AABR tests, then they were re-screened in the following day before hospital discharge, initially with DPOAE and then

immediately with AABR if the DPOAE "referred". The rationale for the first screening attempted at infant's second days of life was to avoid the high false positive rate due to the vernix or transient middle ear fluid in the ear canal immediately after birth. For a two-stage hearing screening program, initial screening performed at infant's second day of life was feasible as the usual duration of hospital stays for normal spontaneous delivery was three days and five days for caesarean section.

The DPOAE testing was carried out with a AuDx Pro Plus portable hearing screening device (Bio-logic System Corp. Mundelein, IL) with the default screening protocol. The levels of the primary tones L1 and L2 were 65 and 55 dB SPL, respectively, and the f2/f1 ratio was 1.22. The DPOAEs were measured at a frequency of 2f1-f2 for the f2 frequencies of 2, 3, 4, and 5 kHz. A "Pass" outcome for DPOAE screening was defined as a signal to noise value of at least 6 dB with a minimum response of -5 to -8 dB SPL and an acceptably low noise floor of -5 dB SPL or less in a minimum of three out of the four test frequency regions.

The AABR testing was performed with a Natus Algo 3i portable newborn hearing screener manufactured by Natus Medical Inc., San Carlos, CA. The Algo 3i system transmits 34 clicks per second via coupler earphones at a level of 35 dB nHL. Both ears are stimulated at the same time with a slightly different sampling rate being used for each ear. The "Pass" or "Refer" result is displayed automatically on the screen.

All infants who passed the screening bilaterally were discharged from the hearing screening program and their parents advised to continue observing the child's speech and language development. The parents were also recommended to attend the health and development surveillance program at a Maternal and Child Health Centre (MCHC) as a follow up.

Infants who failed the two-stage screening were referred to an audiologist for further diagnostic evaluation, including tympanometry and diagnostic auditory brainstem response (ABR) measurement. An auditory steady state response (ASSR) measurement was also arranged for babies diagnosed with a severe to profound degree of hearing impairment. Babies with confirmed hearing impairment of any degree were referred to otolaryngologists for medical consultation and aural habilitation. Figure 1 shows the hearing screening protocol at Hospital A.

#### *Hospital B*

The screening protocol carried out at Hospital B was the two-stage AABR newborn hearing screening program

currently implemented in all HA birthing hospitals. All of the hearing screening tests were conducted by audiological staff. For the initial testing, newborns were screened using AABR on their first day of life. If the babies referred on the AABR test in one or both ears, then the test was repeated on the following day. Infants who passed the screening bilaterally were discharged from the program and their parents advised to continue observing the child's speech and language development and to attend the health and development surveillance program at the Maternal and Child Health Centre (MCHC) as a follow up. The AABR testing was performed with a Natus Algo 3 PC-based

newborn hearing screener manufactured by Natus Medical Inc., San Carlos, CA. The algorithm for the Algo 3 is the same as that for the Algo 3i: it transmits 34 clicks per second via coupler earphones at a level of 35 dBnHL. Both ears are stimulated at the same time using slightly different sampling rates for each ear. The "Pass" or "Refer" result is displayed automatically on the screen.

Infants who failed the two-stage hearing screening were referred to an audiologist for diagnostic evaluation, including tympanometry and diagnostic ABR measurement. An auditory steady-state evoked response (ASSR) test was also arranged for infants found to have

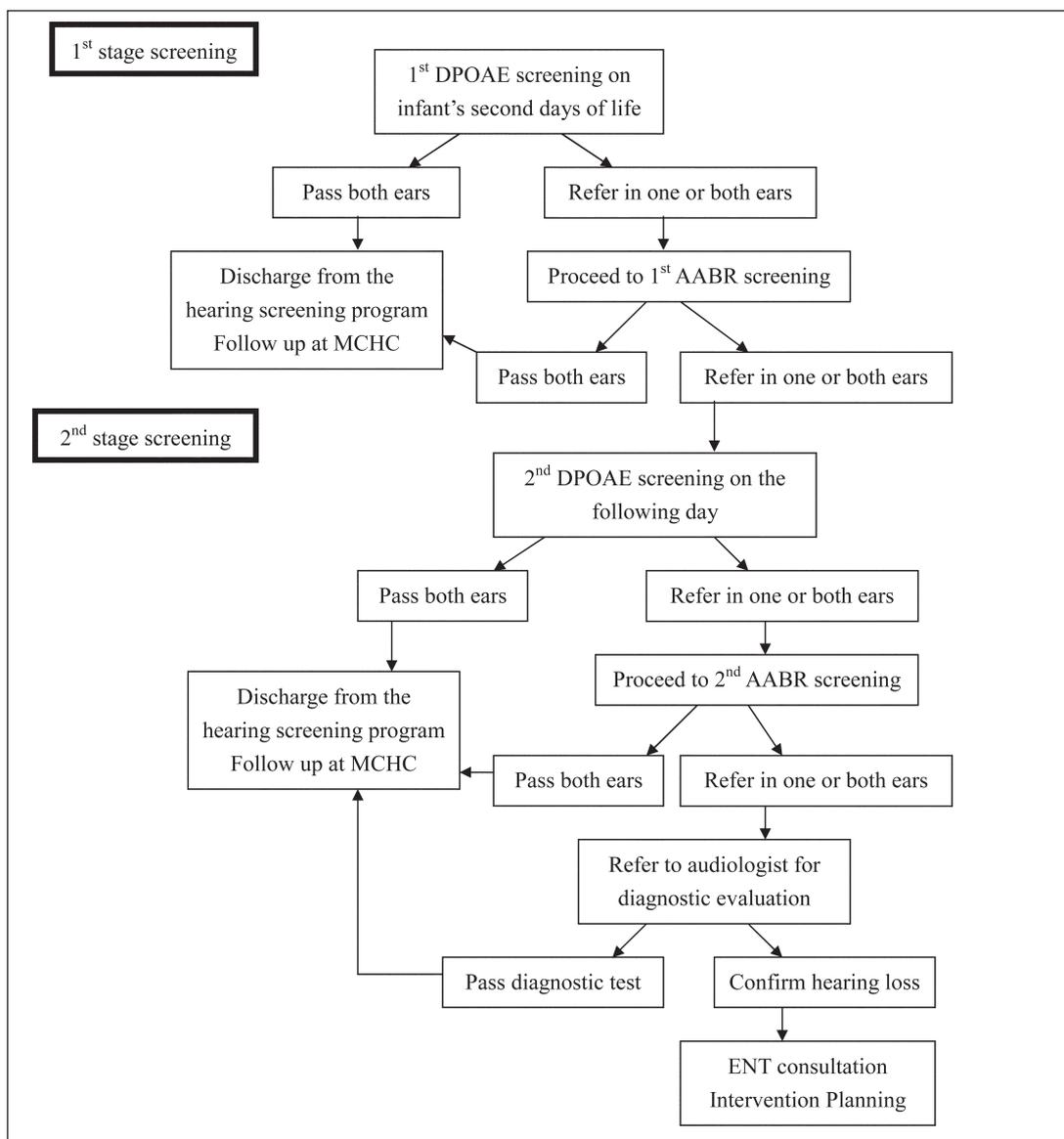


Figure 1 The hearing screening protocol at Hospital A.

a severe to profound degree of hearing impairment. Again, infants confirmed with hearing loss were referred to otolaryngologists for medical consultation and aural habilitation. Figure 2 shows the hearing screening protocol at Hospital B.

During the study period, there were a total of 6,805 live births, of which 6,336 were recruited into the study. The coverage rate for Hospital A and Hospital B were 94.5% and 91.9% respectively. Of the 3,006 infants initially screened at Hospital A, there were 2295 (76.3%) infants passed the first DPOAE test bilaterally and 711 (23.7%) failed the DPOAE test either one or both ears and proceeded to the AABR test. Finally, there were 225 (7.5%) infants passed the AABR test and 486 infants (16.2%) failed the AABR screening and proceeded to the second stage hearing screening.

Second hearing screening was performed on infant's third

### Results

#### 1. Final Refer Rate After Two-stage Screening

Table 1 summarises the final referral rate of the two screening protocols.

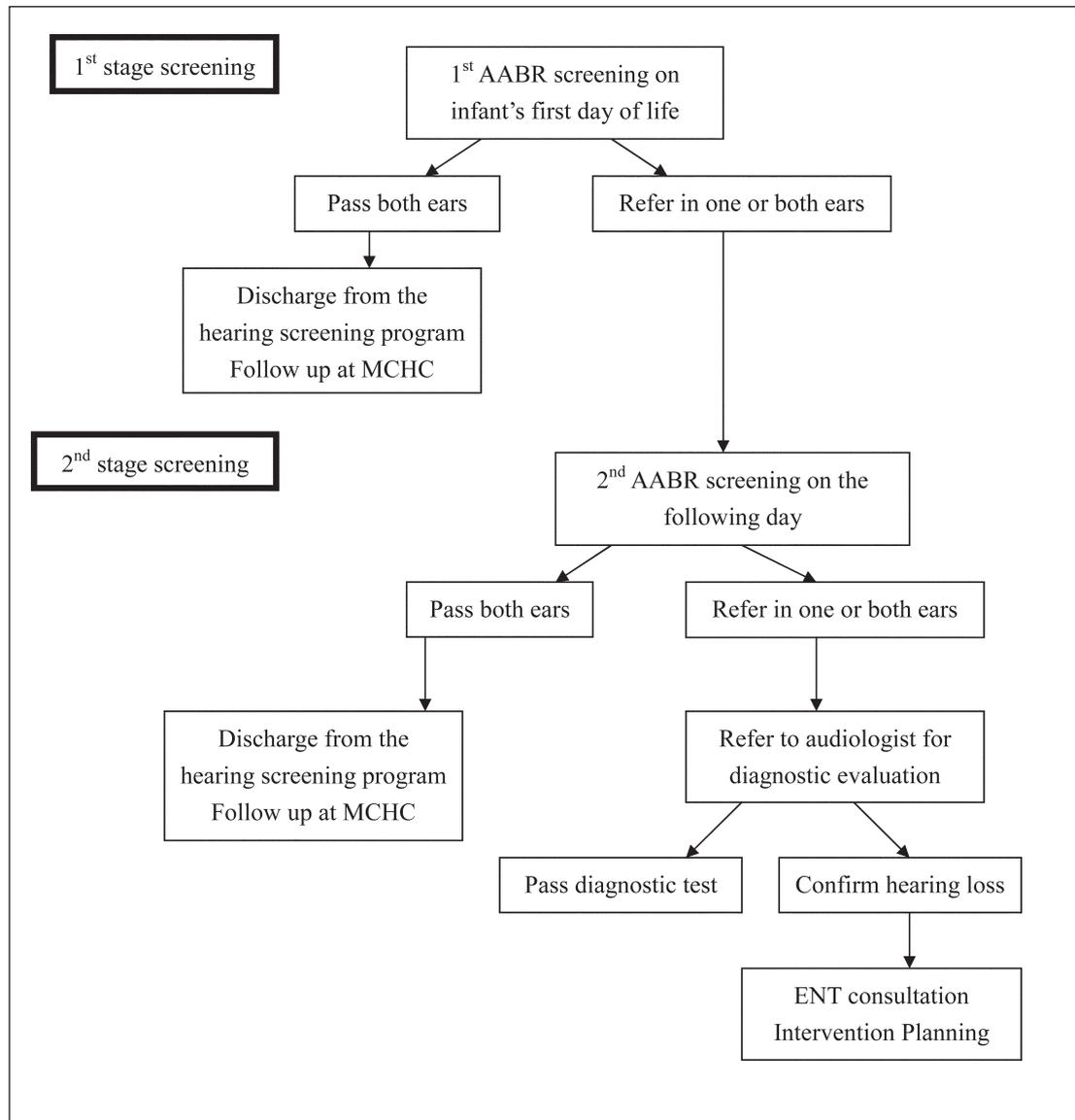


Figure 2 The hearing screening protocol at Hospital B.

day of life before hospital discharge for those who were born by normal delivery. Among the 486 infants (16.2%) who went on to the second stage of screening, 222 (7.4%) infants passed the second-stage DPOAE and 80 (2.7%) passed the second stage AABR screening. Finally, there were 60 infants who failed the two-stage screening and were referred for a diagnostic audiological evaluation. The final screening referral rate after two-stage screening was thus 2.0%. However, in between the first and second stages of screening, there were 124 infants who did not proceed to the second stage of screening. There were two reasons for that: firstly, some infants were transferred to HA hospitals for intensive care due to the poor physical conditions. Secondly, the hearing screening service was suspended on Sundays and public holidays and some infants may be discharged.

Of the 3,330 infants who underwent AABR screening at Hospital B, there were 3,254 (97.7%) passed the initial screening. There were 76 infants (2.3%) underwent a repeat AABR screening the following day, and only 9 infants (0.3%) passed the second-stage AABR screening. Sixty-four infants were referred for further diagnostic audiological evaluation, giving a final referral rate of 1.9%.

In summary, the final referral rate after two-stage of screening was 2.0% at Hospital A and 1.9% at Hospital B. Thus, the referral rates for the two-stage DPOAE+/-AABR and AABR-only screening protocols were similar.

## 2. Equipment and Consumables Costs

The second aim of this study was to compare the

equipment and consumables costs of the two hearing screening protocols. The costs associated with neonatal hearing screening include equipment costs, consumables costs, staff costs, the cost of confirmatory tests, and education costs. As the final referral rate after two stages of screening was similar in the two screening programs (see Table 1), the cost of the confirmatory tests and the education costs were almost the same for both protocols. Secondly, both hearing screening protocols were conducted by trained audiological staff the staff costs were also similar. Thus, it is believed that the main difference between the costs of the two hearing screening protocols is the equipment costs and the consumables costs. Table 2 summarises the costs of the two screening protocols.

The cost of consumables for the AABR test is higher because it includes the cost of the two coupler earphones and three adhesive electrodes, whereas the DPOAE test requires a simple ear probe only. At the first stage screening, the combined EOAE and AABR screening approach at Hospital A reduced the final cost of consumables by one third compared with the AABR-only protocol used at Hospital B. During the second stage of screening, the number of infants referred for second screening at Hospital A was higher than at Hospital B, which may be due to the ear status of individual infants, electrical and myogenic interference or the relatively loud ambient noise in the screening location.

The higher equipment cost for the combined DPOAE+/-AABR approach at Hospital A was due to the purchasing of both a DPOAE and an AABR machine. However, there are now several machines available on the market that combine

**Table 1** Final referral rate of two hearing screening protocols

	Hospital A	Hospital B
Protocol	2-stage DPOAE+/- AABR	2-stage AABR
Live births (Total: 6,805)	3,180	3,625
Infants screened (Total: 6,336)	3,006	3,330
Coverage	94.5%	91.9%
<b>First stage of screening</b>		
DPOAE "Pass"	2,295 (76.3%)	N/A
DPOAE "Refer"	711 (23.7%)	N/A
AABR "Pass"	225 (7.5%)	3,254 (97.7%)
AABR "Refer"	486 (16.2%)	76 (2.3%)
Infants discharged between 1st and 2nd stage of screening	124 (4.1%)	0
<b>Second stage of screening</b>		
2nd stage DPOAE "Pass" rate	222 (7.4%)	N/A
2nd stage AABR "Pass" rate	80 (2.7%)	9 (0.3%)
Final referral rate after two stages of screening	<b>60 (2.0%)</b>	<b>64 (1.9%)</b>

OAE and AABR technology in one device, which eliminates the need to buy a second screening device and allows the rapid switch to the other test mode.

The cost of hearing screening per infant was about 2.5 times cheaper for the combined DPOAE+/-AABR approach (\$35.3 per baby) than for the AABR-only protocol (\$87.3 per baby).

### 3. Testing Time

The third purpose of this study was to compare the testing time of the two screening approaches. Neither hospital measured the testing time during screening. Thus, to calculate the testing time in this retrospective study, the approach of Meier et al (2004) was used. According to Meier et al (2004), the average time for DPOAE and AABR testing should include the device start-up time, the preparation time, the actual measurement time, and the device shut down time. The final median testing time for the DPOAE was 26 seconds

and for the AABR measurement was 468 seconds.<sup>12</sup> Table 3 summarises the final testing time for the two screening protocols.

According to the information provided by Meier et al (2004), the median testing time for DPOAE measurement (26 seconds) is 18 times faster than that of the AABR measurement (468 seconds).<sup>12</sup> This is probably because the DPOAE screening requires only the placement of the probe tip into the infant's external ear canal, whereas the AABR requires skin preparation, the placement and removal of the electrodes, and the installation of the earphones in the infant's ears. Using the DPOAE as the initial screening and then the AABR test for infants who fail the DPOAE test one could save the time in the hearing screening process.

The final average screening time per baby for the combined DPOAE+/-AABR at Hospital A was 161.62 seconds (2.69 minutes), whereas the two-stage AABR protocol at Hospital B took an average of 478.68 second

**Table 2** Summary of the hardware costs of the two screening protocols

	<b>Hospital A</b>	<b>Hospital B</b>
Screening protocols	Two stages DPOAE+/-AABR	Two stages AABR
Cost of consumables (DPOAE)	\$5	–
Cost of consumables (AABR)	\$82	\$82
Infants screened (between 1 September 2007 and 31 March 2008)	3,006	3,330
<b>First stage of screening</b>		
Cost of 1st stage OAE testing	\$15,030 (3,006 x \$5)	–
Cost of 1st stage AABR testing	\$58,302 (711 x \$82)	\$273,060 (3,330 x \$82)
Total cost of consumables at the 1st stage	\$73,332	\$273,060
<b>Second stage of screening</b>		
Cost of 2nd stage OAE testing	\$1,810 (362 x \$5)	–
Cost of 2nd stage AABR testing	\$11,480 (140 x \$82)	\$6,232 (76 x \$82)
Total cost of consumables at the 2nd stage	\$ 13,290	\$ 6,232
Total cost of consumable after two stages of screening	\$86,622	\$279,292
Total cost of consumables per baby	\$28.8 (\$86,622/3,006)	\$83.9 (\$279,292/3,330)
Equipment cost	\$233,000 (OAE: \$83,000, AABR: \$150,000)	\$150,000 (AABR only)
Machine cost per baby (assuming the depreciation of the equipment after 7 years) (see note 3)	\$6.46	\$3.4
<b>Equipment and consumables cost per infant</b>	<b>\$35.3</b>	<b>\$87.3</b>

**Notes:**

1. All costs are calculated in Hong Kong dollars.
2. The consumables costs for both the DPOAE and AABR tests are based on the latest price quoted in July 2008.
3. The equipment cost per baby is determined by the total machine cost divided by the annual delivery rate (infants screened divided by 7 months and multiplied by 12 months) and the years of depreciation, assuming that the equipment will depreciate in value after 7 years.

(7.97 minutes). The combined OAE+/-AABR screening protocol was thus about three times faster than an AABR alone protocol.

## Discussion

The purpose of the present study is to assess the feasibility of a two-stage combined distortion otoacoustic emission test (DPOAE) and automated auditory brainstem response (AABR) screening protocol in hospitals, and to compare the performance with a two-stage AABR screening protocol currently implementing in HA birthing hospitals. In 2000, the Joint Committee on Infant Hearing (JCIH) released a position statement that suggested two important benchmarks for evaluating the success of the implementation of the UNHS program: a coverage rate of at least 95% within six months of the program initiation, and a final referral rate for diagnostic evaluation of 4% or less.<sup>13</sup>

## Coverage Rate

In this study, the coverage rates for Hospital A and Hospital B were 94.5% and 91.9%, respectively, which are slightly below the recommended coverage rate in the JCIH

position statement. The reduced coverage rate could be due to several factors. First, as there is no neonatal intensive care unit (NICU) at Hospital A, infants with poor physical conditions may have been transferred back to HA hospital for intensive care before the screening could be carried out. Second, the hearing screening service was suspended on Sundays and public holidays at Hospital A, and on Saturdays, Sundays, and public holidays at Hospital B due to a lack of manpower. Finally, the hearing screening service at Hospital A was usually bundled within the maternity package, and a small minority of parents refused to join the package and preferred to have their child's hearing screened at a Maternal and Child Care Centre (MCHC) after hospital discharge.

## Final Referral Rate After Two-stage Screening

The final referral rates for diagnostic evaluation for the two screening programs were similar, and were both below the 4% recommended by the JCIH. The inclusion of AABR in both screening programmes were effective in minimising the number of infants requiring further diagnostic evaluation.<sup>14</sup> It is also important to minimise the default rate for follow-up screening and to reduce undue parental anxiety.<sup>15</sup> In Hong Kong, the low default rate for follow up screening is important as there is an increasing number of

**Table 3** The testing time for the two screening protocols

	Hospital A	Hospital B
Screening protocol	Two-stage DPOAE+/-AABR	Two-stage AABR
Testing time for DPOAE	26 sec (Meier et al, 2004)	–
Testing time for AABR	468 sec (Meier et al, 2004)	468 sec (Meier et al, 2004)
Infants screened	3,006	3,330
<b>First stage of screening</b>		
Testing time for the 1st stage OAE testing	78,156 sec (3,006 x 26 sec)	–
Testing time for the 1st stage AABR testing	332,748 sec (711 x 468 sec)	1,558,440 sec (3,330 x 468 sec)
Total testing time for the 1st stage screening	410,904 sec	1,558,440 sec
<b>Second stage of screening</b>		
Testing time for the 2nd stage OAE testing	9,412 (362 x 26 sec)	–
Testing time for the 2nd stage AABR testing	65,520 (140 x 468 sec)	35,568 sec (76 x 468 sec)
Total testing time for the 2nd stage screening	74,932 sec	35,568 sec
Total testing time for the two stages of screening	485,836 sec	1,594,008 sec
<b>Average screening time per baby</b>	<b>161.62 sec (2.69 minutes)</b>	<b>478.68 sec (7.97 minutes)</b>

pregnant women from the Mainland China to Hong Kong to deliver and return promptly back to China after giving birth.

Based on the experience from the present study, the undue parental anxiety can be minimised in two ways. First, it is considered as a good practice to disclose the final result of hearing screening results to parents instead of intermediate result. For example, the hearing screening results will be disclosed if the infants passed the 1st stage hearing screening and if the infants failed both 1st and 2nd stage hearing screening. It is not suggested to disclose the result if the infant only fails the 1st stage screening as he/she may pass the hearing screening in the 2nd stage.

Second, if the EOAE is included in the hearing screening program, it is observed that by beginning the first OAEs in infant's second day of life, one can minimise the risk of high false positive rate due to vernix in the ear canal which is often encountered when testing in the first 24 hours of life.<sup>16</sup>

### Staff Cost

In the present study, the hearing screening in the two study hospitals were conducted by audiological staff. This it was rather unusual in current practice in other HA birthing hospitals and probably will increase the staff cost and the overall screening cost. In fact, both OAE and AABR are easy to use devices. If the hearing screening programme becomes mature, both screening programmes should be performed by a trained nursing assistant. Staff cost should be included in the calculation of the cost of hearing screening programme.

### Tracking System

In this study, there was a high default rate (124/486) for the second hearing screening appointment at Hospital A either transferred to HA hospitals for intensive care or the unavailability of hearing screening service on Sunday and holidays. However, the exact number of defaulters in each group was missing in this screening protocol. It is advised that a comprehensive screening programme should include a tracking system for tracing defaulters who have failed hearing screening test similar to the Clinical Management System in HA settings in order to trace all the missing cases in the future.

### Limitation of the Study

The present study was based on the experience of a small cohort of babies in one HA hospital and one private hospital and not all birthing hospitals in Hong Kong.

### Future Directions

There are pros and cons of using either OAE or AABR devices. There is no hearing screening test with 100% sensitivity and specificity. OAE hearing screening may miss the hearing loss due to neural hearing loss or auditory neuropathy (AN). AABR hearing screening may also miss the hearing loss with etiology above brainstem auditory pathway.

AN is a disorder manifested by the presence of normal cochlear outer hair cells function (an OAE "pass") but abnormal neural functioning at the auditory nerve level (AABR "referred").<sup>15</sup> The actual prevalence of AN is unknown, but estimates of the number of patients with sensorineural hearing loss range from 1 per 200 to 15%.<sup>17-19</sup> The local incidence of AN for children with sensorineural hearing loss is about 2.44%.<sup>20</sup> Infants with a perinatal history of hyperbilirubinemia, anoxia, or infectious disease, or a family history of AN or syndromic and non-syndromic recessive inheritance are at risk of AN.<sup>21-24</sup> AN is also more common in infants requiring neonatal intensive care.<sup>25</sup> The clinical significance of AN is that it may affect normal auditory behavior and the development of speech and language. The JCIH (2007) position statement suggests that a hearing screening protocol should include detection for neural hearing loss such as AN.<sup>5</sup>

The future direction is a first of all, parents are advised to monitor the child's speech and language development and to continue follow up at Maternal and Child Health Centre (MCHC) to exclude neurological hearing loss or any acquired deafness even if they have passed the hearing screening programme at birth.

Secondly, for infants with known risk factors for AN and infants who are admitted to the NICU, hearing screening protocol should include both DPOAE and AABR tests even if they pass the initial DPOAE test bilaterally. In other words, it is recommended to continue the two-stage combined DPOAE+/-AABR screening protocol for well babies, and to initiate a two-stage DPOAE and AABR screening protocol for infants at risk of neurological hearing loss.<sup>26</sup>

## Conclusions

This study assessed the feasibility of a two-stage combined distortion otoacoustic emission test (DPOAE) and automated auditory brainstem response (AABR) screening protocol in local hospitals, and compared its performance with a two-stage AABR screening protocol in terms of final referral rate after two stage screening, the equipment and consumables cost per infant, and the screening time per infant. The results showed that the two-stage combined DPOAE+/-AABR screening protocol is a possible screening protocol to the hospital-based universal neonatal hearing screening program in Hong Kong. When compared with the existing two-stage AABR-only screening protocol, the combined DPOAE+/-AABR protocol was found to display the following:

1. A similar final referral rate after two stages of screening of 2.0%, compared with 1.9% for the AABR-only screening protocol.
2. A total equipment and consumables cost that was approximately 2.5 times cheaper per infant than that of the AABR-only protocol (DPOAE+/-AABR: \$35.3 per infant; AABR only: \$87.3 per infant).
3. A testing time that was approximately 3 times faster per infant than the AABR-only screening protocol (DPOAE+/-AABR: 2.69 minutes per infant; AABR only: 7.97 minutes per infant).

To include the detection of neurologic hearing loss such as neural hearing loss or auditory neuropathy in the UNHS program, it is recommended that infants with any high risk factor for AN or who are admitted to an NICU should be screened using both the DPOAE and AABR tests even if they pass the initial DPOAE test bilaterally.

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