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Evaluation of a Probe-Tube Insertion Technique for Measuring the Real-Ear-to-Coupler Difference (RECD) in Young Infants

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Abstract

A common strategy for measuring the real-ear response of the real-ear-to-coupler difference (RECD) in the pediatric population is to insert a probe-tube separately from the eartip. This strategy is at times difficult to implement while attempting to obtain the measurement from a young infant. An RECD probe-tube insertion technique that involves connecting the probe-tube to an eartip with plastic film for simultaneous insertion was examined on 30 infants. Repeated measurements were completed on each infant to obtain within-session test-retest reliability data. Probe-tube insertion depth was also examined across participants to provide a guideline for the infant population. Findings indicate that reliable RECD values can be obtained in infants when the probe-tube is extended approximately two to four millimeters (mm) beyond the eartip or 11 mm from the entrance to the ear canal. Clinical implications of this work are discussed.

Key Words: Hearing aid, infant, probe-tube technique, real-ear-to-coupler difference, RECD

Abbreviations: EHDI = Early Hearing Detection and Intervention; OAE = otoacoustic emissions; RECD = real-ear-to-coupler difference

Sumario

Una estrategia común para medir en la población pediátrica las respuestas de oído real a partir de la diferencia oído real-acoplador es la inserción de un tubo de prueba separado de la oliva de inserción. Esta estrategia es a veces difícil de implementar cuando se intenta lograr la medición en un niño pequeño. Se examinó una técnica de inserción del tubo de prueba para RECD en 30 infantes. Se completaron mediciones repetidas en cada infante para obtener datos de confiabilidad en un test-retest dentro de la misma sesión. La profundidad de inserción del tubo de prueba también se examinó en todos los participantes, para aportar una guía para la población infantil. Los hallazgos indican que se pueden obtener valores de RECD confiables en infantes, cuando el tubo de prueba se extiende aproximadamente dos a cuatro milímetros (mm) más allá de la oliva, o a11 mm de la entrada del conducto auditivo. Se discuten las implicaciones clínicas de este trabajo.

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Palabras Clave: Auxiliar auditivo, infante, técnica de tubo de prueba, diferencia de oído real a acoplador, RECD

Abreviaturas: EHDI = Detección e Intervención Auditiva Temprana; OAE = emisiones otoacústicas; RECD = diferencia de oído real a acoplador

With the emergence of Early Hearing Detection and Intervention (EHDI) programs, it is recommended that infants have a complete hearing assessment by three months corrected age and be enrolled in some form of intervention by six months corrected age (Joint Committee on Infant Hearing, 2000). For most infants, the fitting of hearing instruments is a component of early intervention. Contemporary protocols for fitting hearing instruments to young infants require that individually measured ear canal acoustics be applied throughout the hearing instrument fitting process (American Academy of Audiology, 2003). To obtain these values, it is recommended that pediatric audiologists perform a real-ear-to-coupler difference (RECD) measurement. The RECD is the difference between the sound pressure level (SPL) measured in an individual's occluded ear canal and the SPL measured in a 2-cc coupler across frequencies (Moodie et al, 1994). The 2-cc coupler approximates the volume of an average adult ear canal and is used for calibration of insert earphones and to conduct measurements of hearing instrument performance. Given the same input, the SPL that is measured in an infant's occluded ear canal varies significantly from the average adult, and a difference of as much as 20 dB may be noted (Feigin et al, 1989). This difference must be accounted for when fitting hearing instruments to infants, thus emphasizing the need to compare the difference between individual real-ear SPL measurements to the SPL measured in a 2-cc coupler. If this difference is not taken into consideration, one risks providing too much amplification to an infant with hearing loss.

The two components of an RECD measurement include (1) obtaining the SPL, across frequency, of a signal presented in a 2-cc coupler, and (2) measuring the SPL, across frequency, for the same signal in an individual's occluded ear canal (Moodie et al, 1994). The difference between the coupler and real-ear SPL measures are the RECD values across frequency in dB. These values are used throughout the hearing instrument fitting process in some prescriptive algorithms (i.e., DSL *m*[i/o], NAL-NL1) to calculate hearing thresholds in SPL and to predict real-ear hearing instrument performance from 2-cc coupler measures. Application of RECD values is especially important in the pediatric population because rapid growth of the ear canal occurs in the first few months of life. In addition, these young patients are unable to provide verbal comments regarding the quality of their listening experiences with hearing instruments.

A key component to measuring the RECD is accurate placement of the probe-tube in the individual's ear canal (Dirks et al, 1994; Bagatto, 2001). Several procedures for probe-tube placement in the pediatric population have been described. For example, the constant insertion depth method involves guiding the probe-tube to a predetermined depth from the intratragal notch (Hawkins et al, 1991; Hawkins and Mueller, 1992). Ear canal and concha lengths for infants have been documented by Keefe and Bulen (1994) and can be used to obtain an appropriate real-ear measurement using the constant insertion depth method. Another method for obtaining accurate probe tube insertion depth for an RECD measurement is the 6 kHz acoustic procedure that uses standing waves to position the probe-tube appropriately in the ear canal (Storey and Dillon, 2001). This acoustic technique involves inserting the probe-tube into the ear canal while presenting a 6 kHz tone from the loudspeaker of a real-ear measurement system. While moving the probe-tube into the ear canal, the clinician notes the minimum SPL response measured by the probe microphone. This minimum is created by standing waves in the ear canal. To avoid standing wave notches, the probe-tube is then inserted approximately 9 mm further (in adults) into the ear canal (Dillon, 2001). The reliability of the constant insertion depth method and the 6 kHz acoustic method for probe-tube placement were compared in infants by Tharpe and her colleagues (2001). They found that both methods resulted in reliable RECD measures at most test frequencies and that there was no evidence to suggest an advantage of using one method over the other (Tharpe et al, 2001). More importantly, it was reported that the constant insertion depth strategy is less time-consuming and avoids contact with the tympanic membrane and was therefore recommended (Tharpe et al, 2001).

Since the inception of EHDI programs, pediatric audiologists find themselves seeing very young infants regularly in the clinic. High between-subject variability in RECD values has been documented for children 12 months of age and younger (Bagatto et al, 2002). For foam or immittance eartip coupling, RECD values can vary by as much as 15 dB in infants under the age of six months, especially in the high-frequency region (Bagatto et al, 2002). This underscores the importance of measuring the RECD in this population whenever possible. Despite the detailed methods described for accurate probe-tube insertion depth, and the research supporting the validity and reliability of using individual RECD measurements in the hearing instrument fitting process, surveys have indicated that few pediatric audiologists regularly perform probe-tube microphone measures (Hedley-Williams et al, 1996; Tharpe, 2000). Low rates of measured RECDs in the infant population may occur because probe-tube insertion methods described for adults and toddlers may not be feasible for young infants because of their very small ear canals and the position of the infant during the measurement.

Valid and reliable strategies for measuring RECDs have been described for use with infants and children who require personal amplification (Sinclair et al, 1996; Scollie et al, 1998). A common approach for obtaining an RECD measurement on a pediatric patient is to insert the probe-tube, at a predetermined insertion depth, separately from the eartip. This strategy, however, may not be easily implemented while attempting to acquire an RECD measurement on a young infant. During many audiological procedures, infants are typically resting in a stroller or held close to the caregiver's body. This position makes it difficult for the audiologist to access the ear canal for comfortable and accurate probe-tube placement. Furthermore, infants characteristically have a short distance between their head and shoulders as well as poor head and neck control compared to adults and older children. This results in the infant's outer ear coming in contact with the shoulder, which sometimes makes stable and appropriate probe-tube placement difficult. A method of probe-tube insertion that allows the clinician to feel comfortable while obtaining accurate probe-tube placement may be needed in order for clinicians to obtain this measurement regularly and with more confidence.

Given the variability in RECD values within and between infants, the RECD measurement is a crucial component of the hearing instrument fitting process for this population. Appropriate placement of the probe-tube in the ear canal is an important part of the RECD measurement and can be a challenging procedure with small infant ears. Therefore, a new probe-tube insertion technique was assessed on a sample of young infants in this investigation. Specifically, the study aimed to (1) examine a probe-tube insertion strategy as part of an RECD measurement that involved simultaneous insertion of the probe-tube and eartip into the ear canal, (2) investigate the test-retest reliability of this new probe-tube insertion technique in young infants, and (3) determine an average probe-tube insertion depth for young infants using this new technique.

METHOD

Participants

A sample of 37 infants ranging from two to six months corrected age served as participants in this study. This age group was chosen as it is most commonly seen in audiology clinics through EHDI programs (Joint Committee on Infant Hearing, 2000). Of the 37 infants, complete data was collected on a total of 30 infants (mean = 3.98 months;

standard deviation [SD] = 1.45). The participants were patients of the Ontario Infant Hearing Program—Southwest Region, which is housed in the H.A. Leeper Speech and Hearing Clinic at the University of Western Ontario, London, Ontario, Canada.

Procedure

Equipment Preparation

The Audioscan® Verifit real-ear measurement system was used to conduct the RECD measurements. In the first step of the measurement, the HA-2 2-cc coupler was attached to the Audioscan RE770 transducer and coupler microphone (see Figure 1). The SPL, across frequencies, was measured in the coupler using a shaped noise signal. Next, a probe-tube was placed along an ER-10 otoacoustic emission (OAE) eartip. Initially, the end of the tube was extended approximately 2 mm beyond the sound outlet of the OAE eartip. The probe-tube was secured to the eartip using plastic film to make an eartip/probe-tube unit (see Figure 2A). Finally, the eartip was connected to the Audioscan RE770 transducer, and the probe-tube was connected to the probe module (see Figure 2B).

RECD Measurement

Otoscopic examination and immittance measurements, using a high-frequency probe-tone (678 Hz or 1000 Hz), were performed on one ear of each participant prior to the RECD measurement. The test ear was determined by the absence of physical barriers (e.g., cerumen) in the most readily accessible ear. Abnormal immittance for a high-frequency probe tone was indicated by an admittance value of 0.6 mmho or less (Margolis et al, 2003). Infants

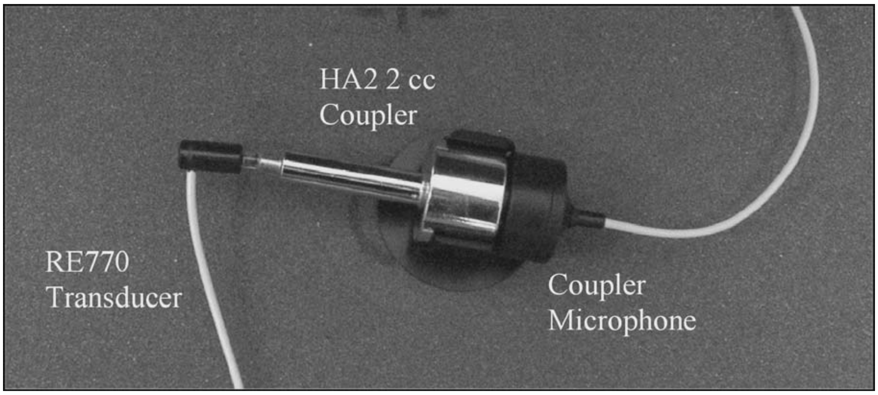

Figure 1. Coupler measurement portion of the real-ear-to-coupler difference. The RE770 transducer is connected to the HA-2 2-cc coupler that is connected to the coupler microphone of the Verifit. A signal is delivered to the coupler to measure the coupler response across frequency.

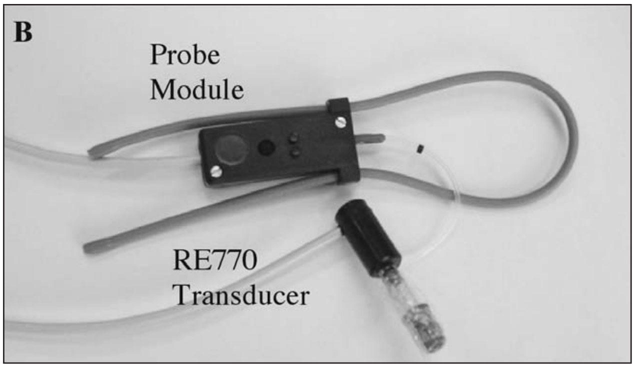

Figure 2. *(A)* Probe-tube coupled to a 3.5 mm ER-10 otoacoustic emission eartip using plastic film. *(B)* Eartip/probe-tube unit connected to the Verifit real-ear module and RE770 transducer for measurement of the real-ear portion of the real-ear-to-coupler difference (RECD).

with normal and abnormal immittance findings were included in this study. The RECD measurement was performed according to the recommended Audioscan Verifit protocol (Version 2.0.18). Briefly, the RE770 transducer was attached to the HA-2 coupler for the 2-cc coupler response. This was completed during equipment preparation. For the real-ear response, the eartip/probe-tube unit was inserted into the infant's ear canal until the most lateral portion of the eartip was flush with the opening of the infant's ear canal (Bagatto, 2001). The same signal used for the coupler measurement was presented through the Audioscan RE770 transducer and measured in the real ear (see Figure 3).

Validation of Real-Ear Responses

The next step was to examine the real-ear responses of the RECD measurement for appropriate high- and low-frequency results (Bagatto, 2001). If the real-ear SPL values at 3000, 4000, and 6000 Hz were lower than the value at 2000 Hz by 3 dB or more, this was considered high-frequency roll-off (Dirks and Kincaid, 1987). When noted, the eartip/probe-tube unit was removed from the infant's ear, and the tube was extended approximately 1 mm further past the sound outlet as the presence of roll-off implies that the insertion depth of the probe-tube is too shallow (Dirks and Kincaid, 1987). After reinsertion of the adjusted eartip/probe-tube unit, the RECD was remeasured, and the high-frequency region was assessed for appropriate representation. This process was repeated until values at 3 kHz and above were within 3 dB of the value at 2 kHz. Additionally, the low-frequency region was examined for negative values. A negative value at 250 or 500 Hz that was below -10 dB was considered to be a result of a tympanic membrane perforation or the presence of a myringotomy tube. When this was noted, the values were accepted. Values above -10 dB in the low-frequency region were considered to be caused by a leakage of the signal from the eartip and ear canal connection (Bagatto, 2001). When noted, the eartip/probe-tube unit was reinserted, earmold lubricant was applied, or a larger diameter eartip was used. Once the appropriate adjustments to the eartip/probe-tube unit were made, it was reinserted into the infant's ear canal, and the RECD measurement was completed. This process was repeated until values associated with low-frequency leakage were eliminated.

The eartip/probe-tube unit was removed and reinserted into the same ear for a second RECD measurement to examine repeatability of the procedure.

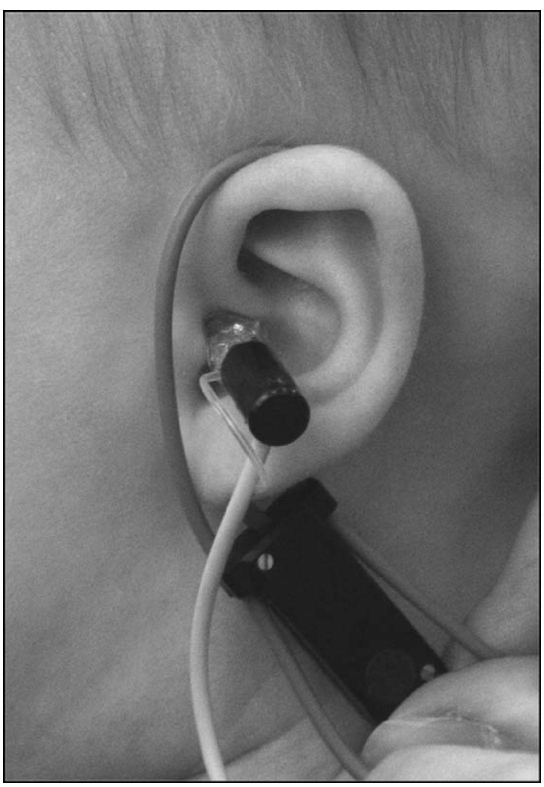

Figure 3. Real-ear measurement portion of the real-ear-to-coupler difference (RECD). The eartip/probe-tube unit is inserted into the ear canal, and a signal is delivered from the RE770 transducer. The difference between the SPL measured in the coupler and the SPL measured in the real ear are the RECD values across frequency.

Insertion Depth

Following the two RECD measurements, each eartip/probe-tube unit was examined. The final length of the tube extension beyond the eartip sound outlet was measured for each infant's eartip/probe-tube unit. In addition, the length of the eartip was measured. This was used to determine an overall probe-tube insertion depth for each infant.

RESULTS

A new RECD probe-tube insertion technique was examined on a sample of infants two to six months corrected age. Measurements were completed twice on the same ear of each infant to obtain within-session test-retest reliability data. In addition, probe-tube insertion depth was examined across participants to provide a guideline for the infant population.

Insertion Depth

Of the 30 infants involved in this study, 17 were awake during the measurement, and 13 were asleep. Additionally, 21 of the infants had normal immittance results, and 9 demonstrated reduced static admittance suggestive of abnormal middle ear function. None of the participants had a tympanic membrane perforation or myringotomy tubes. Compared to RECD values from infants with normal middle ear function, average values from infants with abnormal middle ear function were no greater than 3 dB across frequency. Measurements obtained with eleven infants demonstrated roll-off in the high frequencies or low-frequency leakage requiring adjustments to the eartip/probe-tube unit. Furthermore, three participants required the use of an eartip with a slightly larger diameter (i.e., 4 or 5 mm) to prevent slit-leak venting. The OAE eartip shown in Figure 2A was used with the remaining 27 infants. When appropriate adjustments were made to the eartip/probe-tube unit, the resulting RECD measurement was considered acceptable in all cases. The acceptable measurement was used for data analysis in this study. The average extension of the probe-tube from the sound outlet of the OAE eartip was 3.8 mm (SD = 0.89). The average overall insertion depth from the entrance to the ear canal was 11.25 mm (SD = 0.80).

RECD Values

RECD values for the 30 infants involved in this study are presented in Figure 4. As demonstrated in this figure, larger RECD values are associated with increasing frequency, and few low-frequency values fell below 0 dB. Average RECD values from all measurements obtained (i.e., repeated measurements for each infant) are reported in Table 1. Values range from a low of 0.9 dB at 250 Hz to a high of 21.8 dB at 6000 Hz. Figure 5 provides a comparison of the average RECD values obtained in this study to previously published 95% confidence intervals for four-month-old infants (Bagatto et al, 2002). Overall, the mean RECD values obtained from this study fall within the 95% confidence interval data for infants at all frequencies. When compared to average RECD values for four-month-olds, collapsed across frequency, the mean values obtained in the present study differed by no more than 1.8 dB across frequencies on average. The largest difference was 4.2 dB at 6000 Hz, and the smallest difference was 0.3 dB at 500 Hz.

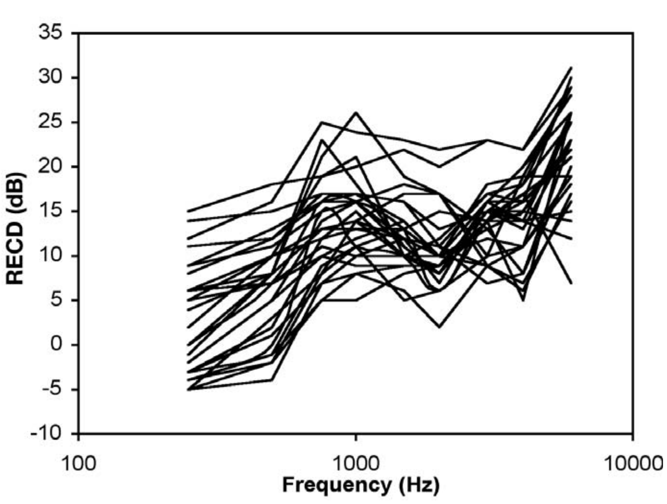

Figure 4. RECD values across frequency from infants enrolled in this study.

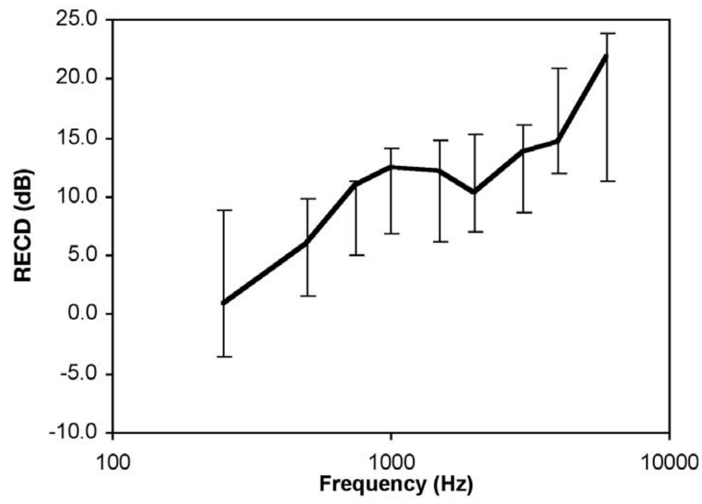

Figure 5. Comparison of current data to previously published norms. The solid line represents average RECD values from the current study. The error bars represent the 95% confidence intervals for average RECD values for four month olds from Bagatto et al (2002).

Table 1. Overall Means and Standard Deviations of All RECD Measurements Obtained in This Study across Frequency

Frequency (Hz)	Average	Standard Deviation
250	0.93	7.77
500	5.98	6.20
750	10.90	4.51
1000	12.38	4.24
1500	12.18	4.17
2000	10.33	4.02
3000	13.78	3.63
4000	14.58	4.50
6000	21.83	5.74

Test-Retest Reliability

The repeatability and reliability of the new probe-tube insertion technique was assessed at nine audiometric frequencies (i.e., 250 Hz, 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz). Mean test-retest values were calculated by determining the difference between absolute RECD values of the first and second measurement for each frequency (see Table 2). The overall mean difference between repeated RECD measures was 2.61 dB (SD = 2.61) across frequency. These results indicate high repeatability between measurements. Reliability coefficients (intraclass *r* values) for the repeated RECD measurements, as a function of frequency, are reported in Table 3. Reliability ranged from a low of 0.76 at 750 Hz to a high of 0.91 at 1500 Hz. All values were statistically significant at the $\alpha = 0.05$ level. All reliability coefficients were above 0.70, indicating good reliability (Portney and Watkins, 2000).

DISCUSSION

A new probe-tube insertion technique for measuring RECDs in young infants has been described and examined in this study. A probe-tube was secured to an OAE eartip with plastic film and the eartip/probe tube unit

Table 2. Mean Difference and Standard Deviation between Repeated RECD Measures across Frequency

Frequency (Hz)	M1-M2*	Standard Deviation
250	3.4	3.2
500	3.3	2.6
750	2.9	2.8
1000	2.4	2.7
1500	1.7	1.7
2000	2.0	1.8
3000	2.0	2.2
4000	2.6	2.8
6000	3.3	3.7

*M1 refers to the first RECD measurement obtained, and M2 refers to the second.

Table 3. Reliability Coefficients for the Repeated RECD Measures as a Function of Frequency

Frequency (Hz)	Reliability *(r)*	*p* value
250	0.82	<0.001*
500	0.87	<0.001*
750	0.76	<0.001*
1000	0.79	<0.001*
1500	0.91	<0.001*
2000	0.88	<0.001*
3000	0.81	<0.001*
4000	0.80	<0.001*
6000	0.78	<0.001*

*Significance at the $\alpha = 0.05$ level.

was inserted into the ear canals of infants two to six months corrected age. The findings of this study indicated that this technique is a reliable and feasible way to insert a probe-tube and eartip for obtaining RECD measurements in infants.

The new probe-tube insertion technique described in this study has direct clinical significance. Results support the simultaneous insertion into the infant's ear canal of the probe-tube and eartip. Overall RECD values in this study closely approximate published RECD norms for four month olds (Bagatto et al, 2002). It is hoped that by developing a technique for simultaneous insertion of the probe-tube and eartip, pediatric audiologists will increase the use of the RECD measurement procedure when fitting amplification to infants. In addition, the results of this study provide concrete information to those who develop practice guidelines and evidence-based protocols for EHDI programs. It is important to remember, however, that the measurements gathered in this study were made by an experienced pediatric audiologist. Although the procedure has been shown to be reliable and feasible, there were instances where the measurement could not be obtained. During the course of this study, there were seven infants with whom the measurement was attempted but could not be completed because the child would not tolerate the eartip/probe-tube unit in the ear canal. This suggests that although the measurement technique is feasible, certain infants will not allow the eartip/probe-tube unit to be placed in their ear canal for a complete measurement. However, there is no reason to believe that these infants would have tolerated any other existing procedures of probe-tube insertion.

For clinicians attempting to apply this new approach, it is recommended that they develop their skills on older children and adults prior to attempting it with infants. While refining one's probe placement skills, the audiologist should become familiar with the typical RECD shape and values that are expected across frequency (Bagatto, 2001). The ability to troubleshoot the measurement is an integral part of obtaining an RECD and will result in accurate values, which will be used throughout the hearing instrument fitting process. It is important to note that approximately one-third of the infants in this study required repositioning of the eartip/probe-tube unit in order to get a good measurement. With experience conducting the measurement, clinicians will be able to identify potential errors. When the clinician has the confidence to make the measurement on infants, the procedure is more likely to be successful, especially on young patients who are active.

It should also be noted that the OAE eartip used in this study was not being evaluated. What is of significance in this study is the strategy of connecting the probe-tube to the eartip, at a specific distance from the medial end of the eartip, with plastic film prior to insertion into the ear canal. Clinicians have a variety of eartips to choose from, such as standard foam eartips or immittance eartips, when implementing this probe-tube insertion strategy with infants.

For those clinicians who prefer to insert the probe-tube separately from the eartip, an insertion depth guideline for infants was also described in this study. Marking the probe-tube approximately 11 mm from the medial end and locating the mark at the entrance to the infant's ear canal will result in a suitable insertion depth. The depth of the probe-tube is important for obtaining good high-frequency representation (Bagatto, 2001). The average insertion depth reported here is in good agreement with geometrically estimated infant canal lengths reported by Keefe and Bullen (1994). For infants three and six months corrected age, the estimated ear canal lengths were 16.5 and 17.5 mm, respectively. Therefore, applying the insertion-depth guideline obtained from this study will place the eartip of the probe-tube approximately 5 mm from the tympanic membrane. This is the suggested distance of the probe-tube from the eardrum when measuring the RECD in adults and children using traditional probe-tube insertion techniques (Dirks and Kincaid, 1987). Therefore, for those clinicians who prefer a constant insertion depth method of probe-tube insertion, using the guideline described in this study is a reasonable starting place.

Application of the probe-tube insertion technique described in this study may extend to real-ear measurements made with personal earmolds. Connecting a probe-tube to an infant's earmold with plastic film should be possible and result in suitable RECD values, provided the tube is extended an appropriate distance from the medial tip of the earmold. Although it has not been investigated, this strategy may be especially useful for toddlers who may be too active to complete an RECD measurement with traditional approaches. The child may be more likely to tolerate the procedure as a quiet state is not required while the probe-tube is being inserted into the canal, followed by the earmold. Attaching the tube to the earmold may reduce test time, and the child is likely to be oblivious to the probe-tube being placed in the ear canal. It is hoped that applying this technique to toddlers will result in audiologists measuring RECDs on a more regular basis.

SUMMARY

A new technique for positioning a probe-tube for measuring RECDs in young infants was described and examined in this study. The findings indicate that securing a probe-tube to an eartip with plastic film for simultaneous insertion into the ear canal is a reliable probe-tube insertion technique for obtaining RECD measurements in infants. Additionally, an insertion depth guideline of 11 mm from the entrance to the ear canal was determined for infants two to six months corrected age. As the technique has been shown to be practical and reliable in young infants, it is hoped that this strategy will facilitate the routine measurement of the RECD with a greater number of infants and children.

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