Proceedings – 23rd Annual Conference – IEEE/EMBS Oct.25-28, 2001, Istanbul, TURKEY

COCHLEAR MATURATION AND OTOACOUSTIC EMISSIONS IN PRETERM INFANTS: A TIME-FREQUENCY APPROACH

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Abstract-**Click-evoked otoacoustic emissions (CEOAEs) from preterm infants were analyzed to characterize developmental changes of cochlear active mechanisms. Due to their strong time-varying properties, CEOAEs were studied with the wavelet transform. Results obtained in our study give a clear indication that time-frequencies characteristics of CEOAEs are not fully developed in preterm babies and reach the complete maturation at about 38 wks post-conception. Also, in agreement with previous physiological and behavioral findings, our results show that the maturation of cochlear active mechanisms is not the same along the cochlear partition but exhibit a spatial gradient proceeding from base to apex.**
Keywords **- Cochlear maturation, otoacoustic emissions, preterm babies, cochlear modeling, wavelet transform**

I. INTRODUCTION

Otoacoustic emissions (OAEs) are acoustic signals produced by the active contraction of the outer hair cells of the organ of Corti. OAEs can be evoked by click stimuli and are recorded in the external auditory canal with a probe containing a miniature microphone and a transducer (for a review, see [1]).

Click-evoked otoacoustic emissions (CEOAEs) are delayed transient signals and show a frequency dispersion similar to the well established frequency distribution along the cochlea. The waveform of a CEOAE response typically depends on the spectral energy of the stimulus. When a broad-band stimulus (such as a click) is used, the corresponding emission response shows spectra with several dominant frequencies with different onset times and damping, resulting in a OAE with a complex waveform. Analysis of the time-frequency properties of CEOAEs is of considerable interest due to their close relation with cochlear mechanism [2].

Because of the strict relation to active cochlear mechanism, the analysis of morphological changes in the OAEs of preterm infants during the first weeks after birth is a non-invasive and simple way to characterize the developmental changes of cochlear active processes.

In this study, CEOAEs of preterms were analyzed by means of a time-frequency technique - the wavelet transform - in order to characterize and quantify the changes in their time-frequency patterns and to compare our findings with previous physiological findings.

II. METHODOLOGY

A. Subjects and Measurements

Thirty four preterms, admitted to the NICU, were considered in this study. Their mean gestational age at birth was 30.3 wks (s.d.=1.4 wks). A total number of 58 ears were tested by CEOAEs (24 out of 34 preterms had bilateral measurements and 10 out of 34 had monolateral measurements). Each ear had a minimum of three and a maximum of 11 subsequent CEOAE measurements in a period ranging from 1 to 8 wks after birth. A total of 307 CEOAEs were thus obtained.

Also, CEOAEs were measured from a control group of full-term babies (n=333) at the third day after birth.

B. Time-frequency analysis

The time-frequency analysis of each CEOAE response was obtained by means of the wavelet transform (WT) [3]:

$$W(t\ ,\ f) = \sqrt{f / f_0} \cdot \int x(t) \cdot \gamma(f / f_0\ (t - t\ ))dt$$

The function $\gamma(t)$ is the 'mother' wavelet, which is a band-pass function centered around $t = 0$ and $f = f_0$ in the time and frequency domains, respectively. In the present study, we choose [4]:

$$\gamma(t) = (1 + t^8)^{-1} \cdot \cos(20t)$$

On a more practical ground, the $WT(t\ ,\ f)$ of signal $x(t)$ at the generic time t and frequency f is equal to the inner product of $x(t)$ with a translated and dilated version of the mother wavelet $\gamma(t)$.

In the specific case of CEOAEs, according to [4], the WT has the best time-frequency resolution among all the other time-frequency methods.

The original signal $x(t)$ can be synthesized by adding all the contributions $WT(t\ ,\ f)$:

$$x(t) = c \cdot \sqrt{f / f_0} \cdot \iint_{t'\,f} WT_\gamma(\tau, f) \cdot \gamma(f / f_0 (t - \tau)) \cdot (f / f_0)^2 \cdot d\tau \cdot df$$

where c is a constant which depends on $g(t)$. As demonstrated by Tognola et al. [4], the above expression can also be used to derive the contribution of the generic component $x_{\Delta f_i}(t)$ of $x(t)$ in a frequency band $\Delta f_i = f_i - f_{i-1}$ by restraining the integration in the frequency range $f_{i-1} \le f \le f_i$ (where $f_i > f_{i-1}$).

In this study, CEOAE components were extracted for 12 adjacent bands, 0.5-kHz-wide, with central frequencies ranging from 0.5 to 6 kHz.

Finally, the developmental changes in the CEOAEs of the studied population were characterized by means of the following quantitative parameters: root-mean-square (RMS) amplitude of the original CEOAE and of its wavelet-derived

0-7803-7211-5/01$10.00©2001 IEEE

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25OCT2001	N/A	-

Title and Subtitle Cochlear Maturation and Otoacoustic Emissions in Preterm Infants: A Time-Frequency Approach	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) CNR Center of Biomedical Engineering, c/o Polytechnic of Milan, Milan, Italy	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research Development & Standardization Group (UK) PSC 803 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from the 23rd Annual International conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 3	

frequency components; latency of CEOAE frequency components.

III. Results

The mean RMS amplitude of the CEOAEs as a function of the post-conceptional age (PCA) is shown in Fig. 1. The RMS amplitude has a significant increase up to about 37 wks PCA and reaches a plateau for PCAs greater than 37 wks.

As an example of the proposed technique for the extraction of the CEOAE frequency components, Fig.2 shows a CEOAE from a preterm baby and its wavelet-derived frequency components.

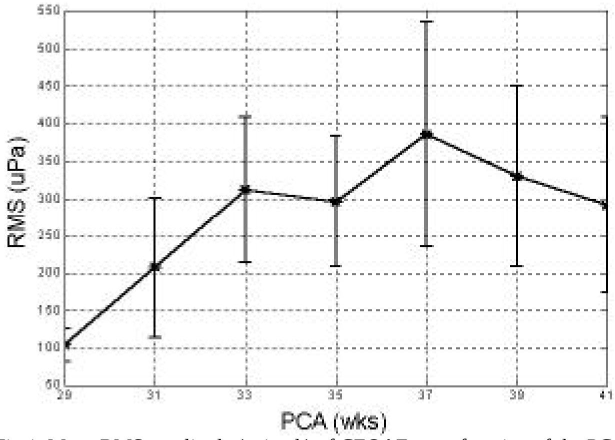

Fig.1. Mean RMS amplitude (± 1 s.d.) of CEOAEs as a function of the PCA.

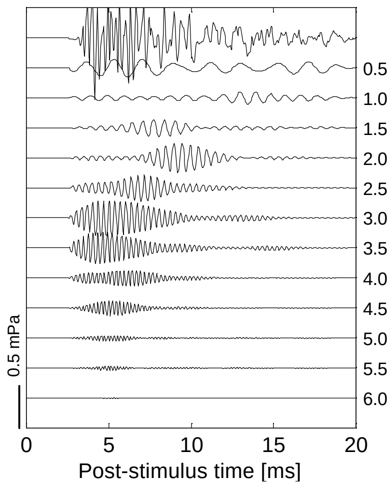

Fig. 2. Example of an emission evoked by an acoustic click at 80 dB SPL (trace at the top) and its wavelet-derived components in the 0.5-6.0 kHz range. To reduce the influence of the stimulus artifacts, OAE response has been windowed 2.5 ÷20 ms post-stimulus time.

Fig. 3 illustrates the comparison between the RMS amplitude of the CEOAE frequency components of preterm babies (measured at 28-30 and 34-36 wks PCA) and full-term babies. CEOAEs from full-term babies were measured at the third day after birth. The comparison shows that at 28-30 wks PCA, the amplitudes of CEOAE bands are significantly smaller than for term babies for all frequencies. Also, at 28-30 wks PCA, there is a predominance of low frequencies against mid-to-high frequencies, in contrast to what is observed in term infants. On the contrary, at 34-36 wks PCA, the amplitudes of CEOAE bands are very similar to those of term babies. It is to note that mid-to-high frequencies grow faster than low frequencies: on average, the increase rate is about 3-5 μPa/wk for mid-to-high frequencies against 1 μPa/wk for low frequencies.

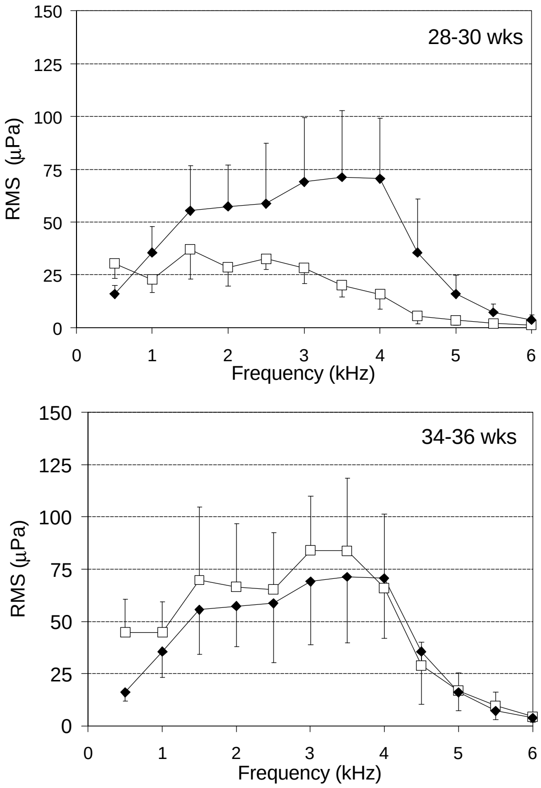

Fig. 3. Mean RMS amplitude (+ 1 s.d.) of CEOAE frequency bands for preterm babies (*open squares*) at 28-30 and 34-36 wks PCA and full-term babies (*black diamonds*).

Results in Fig. 4 show the comparison between CEOAE latencies as a function of frequency for preterm babies and full-term babies. Data from preterm infants were measured at different wks post-conception. For both populations, it is possible to note the typical trend of greater latencies for lower frequencies, as already observed in the CEOAEs of adults [2].

In preterm infants, the latency progressively decreases as the PCA increases and reaches values similar to those of full-term babies at about 34-38 wks PCA. As observed for the RMS amplitude, the latency of mid-to-high frequencies changes faster than for low frequencies (about 0.15 ms/wk against 0.11 ms/wk).

IV. Discussion & Conclusion

It is well established that cochlear functionality initiates at the age of about 20 wks [5], whereas cochlear morphological changes are terminated at 30-32 wks post-conceptional age [6]. As to the maturation of cochlear active mechanisms (due to the activity of the outer hair cells), no agreement has been reached yet. During the last decades, several studies were devoted to the investigation of developmental changes of OAEs to try to characterize the maturation of cochlear active mechanisms (see, for example, [7-10]).

In our study, there is evidence that OAE properties are related to the PCA: the amplitude and latency of both the CEOAE and its frequency components change until the age of about 38 wks post-conception, whereas after 38 wks PCA, OAE properties appear to be very similar to those of term babies. This is a strong indication that OAEs are not fully developed in preterm infants. In particular, the amplitude is characterized by a significant increase whereas the latency tends to decrease with age.

These developmental changes are not uniformly distributed across the different frequency bands but show a faster rate of change for mid-to-high frequencies than for low frequencies. Our results seem to be in agreement with current physiological findings indicating that cochlear epithelium differentiation proceeds from base to apex, that is, from high to low frequencies [11].

Also, the developmental changes observed in the latency of CEOAE frequency components are very similar to those revealed by Eggermont and coll. in a study of developmental changes in auditory brainstem responses (ABR) [12]. Similar to our findings, the latencies of derived ABR octave bands progressively decreased with age and showed a spatial gradient of maturation proceeding from base to apex.

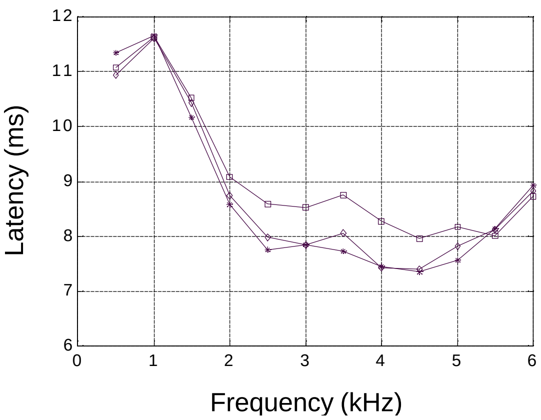

Fig. 4. Latency of CEOAE components of preterm babies and full-term babies (*stars*). Preterm babies were tested at various PCA: <34 wks (*open squares*) and at 34-38 wks (*open diamonds*).

ACKNOWLEDGMENT

CEOAEs of preterm babies were kindly provided by Dr. P. Brienesse and Dr. P. de Jager of the University Hospital Maastrict, ENT Department. This study was partially supported by the EC Project AHEAD (contract n. QLRT-2000-01613).

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