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Numerical Analysis of the Microwave Auditory Effect

N. M. Yitzhak, R. Ruppin, R. Hareuveny

Soreq NRC, Yavne, Israel

INTRODUCTION

Pulsed microwave and radiofrequency radiation can produce a hearing sensation in human beings and mammals. The correct identification of the thermoelastic expansion as the mechanism responsible for the effect has been proposed by Foster and Finch(1). The absorption of the electromagnetic (EM) energy produces a fast thermal expansion, resulting from a small but rapid temperature rise, of the order of 10^{-6} °K. This launches a thermoelastic wave that travels to the inner ear, which causes an auditory sensation. A detailed review of the results of human, animal and modeling studies, which support this explanation of the hearing effect, has been published by Elder and Chou(2).

Several analytical calculations of this phenomenon were presented(3-6). However those calculations assumed a simplified homogeneous spherical head model and an absorption pattern of spherical symmetry. Numerical analyses, employing anatomically based head models, were also presented. These analyses were performed only for an EM plane wave of a single frequency (915 MHz)(7) or for high-pass birdcage MRI coil for several lower frequencies (64, 300 and 400 MHz)(8).

In the present work a numerical calculation of the thermoelastic wave propagation in a full male body is performed. The EM energy absorption and the elastic wave propagation are calculated by the finite-difference time-domain (FDTD) technique. An analysis of the results for different pulse width is presented.

METHOD OF ANALYSIS

The calculations were executed in two steps. The first one was the interaction of an incident electromagnetic plane wave with male body model. This was calculated numerically using the Yee FDTD algorithm for solving Maxwell's curl equations. For this step the commercial software XFdtd, supplied by Remcom Inc., State College, PA, USA, was employed. The model, also supplied by Remcom Inc., was of the height of 1.875 m, resolution of 5x5x5 mm^3 and 39 different tissue types. The mesh of this model was converted directly from the data generated by the Visible Human Project sponsored by the US National Library of Medicine.

In the second step a Yee type explicit leapfrog time stepping scheme was employed, in which the stress tensor components and the velocity components were alternately updated(7). The linear thermal expansion coefficient was taken to be 2.7×10^{-5} °K^{-1} for hard tissues and 13.0×10^{-5} °K^{-1} (the value for blood) for soft ones(9). Since the experimental data on the elastic properties of tissues vary over several magnitudes approximately median values have been taken and those values and a literature review will be published elsewhere.

RESULTS

A typical example of the pressure wave which develops in the cochlea is shown in figure 1 and its fast Fourier transform (FFT) is presented in figure 2. This was calculated for a plane wave pulse of frequency 2450 MHz incident from the back side, with horizontal polarization, pulse width of 70 μs and a power density of 1 mW/cm^2. The main acoustic frequency is approximately 8 kHz as in a previous analysis(7).

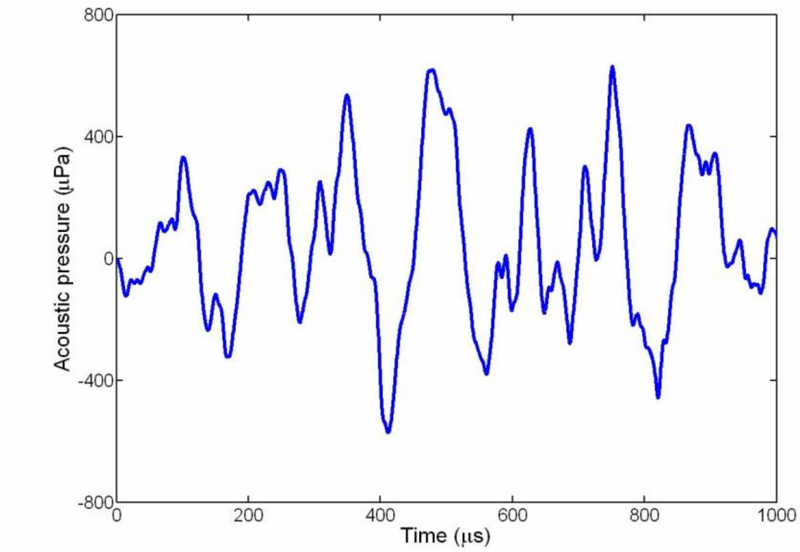

Figure 1. Calculated pressure waveform at the cochlea

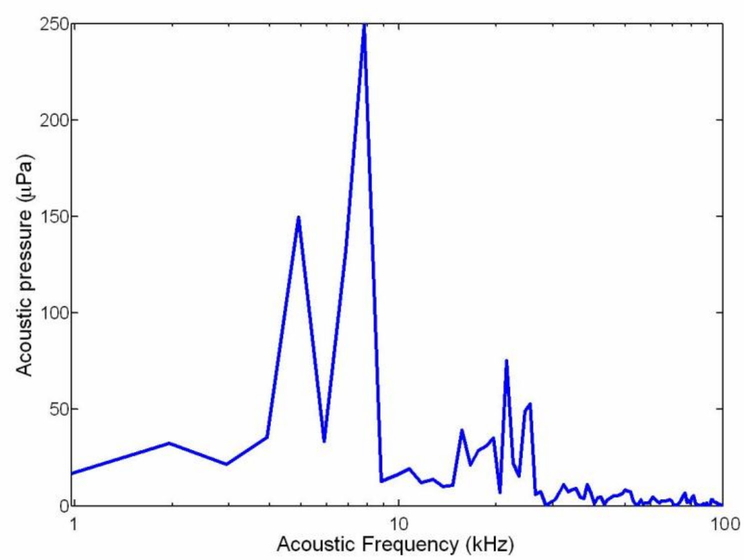

Figure 2. Calculated power spectra of the pressure waves at the cochlea

In the case of the homogeneous spherical head model, for which analytical solutions have been derived[6] it was found that the pulse width dependence of the induced pressure amplitude anywhere in the head, for acoustic angular frequency ω_m is of the form:

$$P(\tau) = A|\sin(\omega_m \tau/2)| \qquad (1)$$

Here τ is the pulse width and the amplitude factor A is independent of the pulse width.

We have found that this dependence on the pulse width holds to a good approximation even for the complicated models treated here. This is demonstrated in figure 3 (calculated for irradiation from the front by a vertically polarized 915 MHz pulse), in which the pulse width dependence of the amplitudes for number of selected acoustic frequencies, as obtained by a FFT of the pressure in the cochlea, is shown by the discrete points and the corresponding curves were obtained by fitting the calculated points to the functional form of the eq. 1, using a nonlinear least squares algorithm.

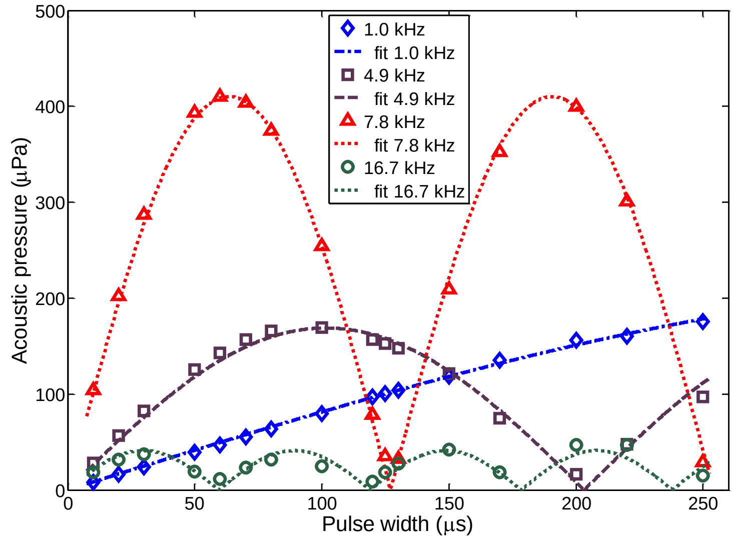

Figure 3. Pulse width dependence of the amplitude of a number of acoustic frequencies and a curve of the analytic dependency.

This dependency might be used to define a new method to analyze this phenomenon. The results of A as defined in eq. 1 as function of the acoustic frequency (calculated for two irradiations of 915 MHz pulse, one is vertically polarized from the front and the second is horizontal polarized from the back) is presented in figure 4. As was mentioned above, the main acoustic frequency is about 8 kHz, but there are more frequencies with non negligible intensity.

CONCLUSIONS

A full male body biological model was used to calculate the excitation of pressure waves at the cochlea following the irradiation by a microwave pulse. We have shown, by a FFT of the pressure waves in the cochlea, that the pulse width dependence of the amplitudes at various acoustic frequencies obeys a simple sinusoidal relation (eq. 1). This is due to the fact that the complicated biological model has an effective resonant cavity for each acoustic frequency.

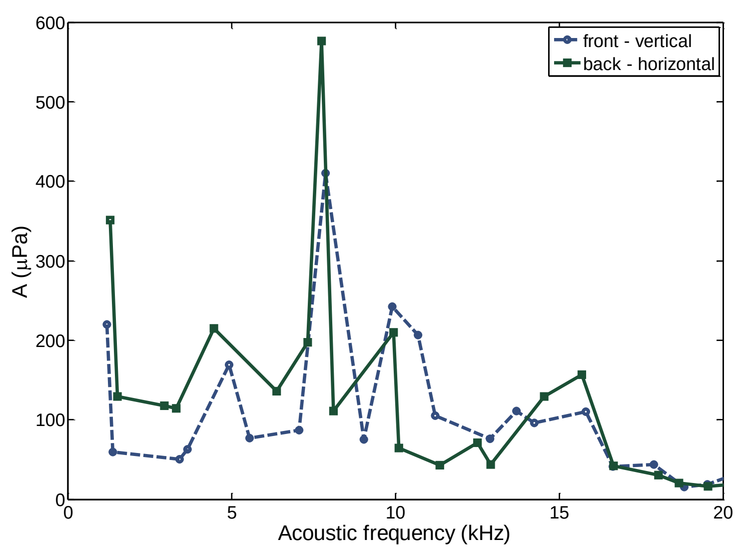

Figure 4. The quantity A as defined in eq. 1 for different acoustic frequencies and two irradiation types.

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