ARTICLE IN PRESS

Computers in Biology and Medicine xxx (2017) 1–7

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/compbiomed

Linear sound attenuation model for assessing external stimuli in prenatal period

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ARTICLE INFO

Keywords:
Acoustic stimulation
Prenatal stimulation
Prenatal development
Sound attenuation
Regression model

ABSTRACT

The popularization of acoustic stimulation during the prenatal period encourages the analysis of sounds reaching the inside of the uterus. To assess the distortion of any sound stimuli, a mathematical model of attenuation has to be used. In this paper a mathematical model is proposed on the basis of data from a physical model. The physical model consisted of muscle slices of two different thicknesses placed in a tank filled with water. The amplitudes of sinusoidal waves between 160 and 2000 Hz were measured under the water surface. Using the collected data, a linear mathematical model of sound attenuation on the way to the fetal ear was created. The results indicated a rise in the amount of sound attenuation for increasing frequencies. Analysis of slope coefficients for two muscle thicknesses revealed that there is no significant difference between attenuation by the thinner and the thicker tissue. Finally, the model was verified with data obtained during experiments on animals. The proposed model of the sound transmission allowed assessment of the attenuation by a soft tissue. It reveals changes in the sound reaching fetal ears, which can make acoustic stimulation different than what is heard in postnatal life. The model can be used to simulate the distortion of any sound which is proposed to prenatal stimulation and to assess its quality.

1. Introduction

The fetal environment is rich in sounds produced by the maternal body, movements and external noises. Sound levels from maternal cardiovascular, digestive and respiratory systems may have intensities between 60 dB for low-frequency components and 40 dB for high-frequency components [1,2]. Some sounds from maternal surroundings can be received but, they are attenuated and distorted [3]. Nonetheless, the uterus is a perfect place to live for a fetus. The intrauterine environment attenuates harmful sounds but provides physiological stimulation at the same time [4,5]. Selectivity of prenatal environment is important because the development of the auditory cortex and the whole hearing system is determined by auditory stimulation [6,7]. Therefore, over-stimulation may result in problems of language abilities [6], congenital malformations and small for gestational age newborns (SGA, smaller in size than normal for gestational age) [8].

In recent years, interest in fetal perception and cognition has increased. Mothers are aware of the hearing ability of their unborn babies and they believe that acoustic stimulation can improve its development [9]. The evidence for a positive effect of some sounds is mostly anecdotal. However, it is popularized by companies, who produce audio-recordings and devices specially developed for prenatal sound stimulation [9]. Since research on the effectiveness of prenatal music stimulation can be invasive, it is carried out on rodents. Such studies indicated an increase in total neuron number [10] and improvement in learning and memory functions [11] among the music stimulated individuals.

Despite the lack of the evidence of positive effect of sounds on human fetuses, acoustic stimulation in prenatal period is increasingly used [12,13]. Knowledge about transmission of sounds to the fetus is still insufficient. Therefore, additional prenatal acoustic stimulation may be unfounded. Considering possible deleterious effects of a loud sound stimulus on fetal development, a model of sound attenuation in an intrauterine environment should be proposed in order to assess the stimuli in the fetus' surrounding.

In the literature two kinds of models are described. The first one refers to measurements on living organism [1,14] while the second is based on artificial physical models, which use a synthetic material as a barrier [15,16].

Because of technical difficulties and ethical aspects, there is little work on sound transmission through abdominal walls conducted on pregnant women in the literature. Studies on 8 women during the first stage of labor [14] indicated that low-frequency sounds are enhanced

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https://doi.org/10.1016/j.compbiomed.2017.10.013
Received 14 April 2017; Received in revised form 11 October 2017; Accepted 12 October 2017
Available online xxxx

while passing through maternal tissues. For high frequencies, there is more reduction of the sound level for increasing frequencies, reaching at most a 10 dB reduction at 4000 Hz. Nevertheless, large differences in attenuation effects between patients were noticed. There was no explanation for the noticed changes in maternal body factors (like tissues' thicknesses).

Gerhardt and Abrams [1] presented a model of prenatal sound transmission based on tests on ewes, which are qualified as an animal model for such experiments [17]. The model was the graph of relative sound level recorded for particular frequencies in the uterus and fetal inner ear during 90 dB acoustic stimulation. Authors indicated that low frequencies are not attenuated in the uterus and the attenuation for frequencies between 250 and 4000 Hz increases by 6 dB for each octave. A cochlear microphone placed in the fetus' inner ear showed a 10–20 dB reduction of sound intensity for frequencies between 125 and 250 Hz. Furthermore, for 500 to 2000 Hz attenuation reached up to 45 dB.

Lecanuet et al. [15] proposed a model of pure tone transmission in the uterus. The model was a rubber sphere open at the top and filled with water. There were 3 sizes of this model: 11, 19 and 40 cm diameter and its thickness ranged from 0.1 to 1 mm. The set of pure sinusoidal waves between 100 Hz and 20,000 Hz at a constant sound intensity level of 100 dB was tested. The analysis considered, among other factors, the impact of the size of the model, the location of a sound receiver in the model, and the changes caused by a wall placed behind the model. It was noticed that the sound level of the frequencies between 100 and 1000 Hz was stable. For higher frequencies, sound level inside the model fell gradually. The researchers indicated a critical frequency range among which a series of peaks and drops was observed. This frequency value depends on various parameters of the model and the environment.

A noninvasive technique for assessment of acoustic changes in the uterus during sound stimulation was proposed by Antonets and Kazakov [16]. They designed a phone transducer which consisted of a soft leak-proof capsule filled with water. In this 150 ml device, a hydrophone was placed. Authors assumed that placing this device on pregnant woman's abdomen allowed measuring sounds occurring in the uterus during acoustic stimulation. However, it worked properly only for sounds frequencies below 1 kHz.

Models of sound attenuation, which have been proposed in the literature, are insufficient to discuss changes in sound intensity induced by maternal tissues. Models which are based on measurements performed on animals do not consider changes in tissue thickness. These kinds of changes can be included in physical model, but only synthetic, rubber barriers have been used so far. Therefore the available data are fragmentary. Additionally, these data are preferably descriptive, while only a mathematical description based on a well designed physical model allows the assessment of changes in any sound objectively. A mathematical model will enable digital filtering of a potential prenatal stimulus, determination of its distortion and decision on the meaningfulness of the stimulation.

The aim of this study is to create a mathematical model for sound filtration. The model will allow for an objective assessment of external acoustic stimuli used in prenatal period and for discussion about the validity of this kind of stimulation. The mathematical model is based on measurements on authors' physical model, which include animal muscle tissue as a barrier.

2. Materials and methods

Determination of the mathematical model was performed based on numerical data from authors' physical model. The sound barrier applied in the physical model was similar to maternal abdominal tissue, unlike literature data, which reported experiments on rubber models. Additionally, the registration of separated sounds generated in external environment was provided, which allowed for the assessment of changes in relevant data excluding noises produced by the maternal body.

2.1. Physical model

The physical model consisted of a glass tank with a square base and perpendicular walls with an open top. The simple design of the model was chosen to increase control of acoustic phenomena. The insides of the model were covered with sound absorbing and distracting synthetic material. The covering consisted of a three cm thick sponge and fleece fabric. To prevent sound transmission through walls, the tank was isolated with a three cm thick sponge from the outside. The dimensions of the vessel and the material covering were chosen based on a set of experiments, which indicated the smallest amplitude distortion in a whole range of tested frequencies for these conditions. This 13 × 13 × 21 cm tank was filled with water and the source of the sound was placed 13 cm above the station.

Porcine muscle tissue was located on the top of the tank. There were two versions of this sound barrier – 2.4 ± 0.4 cm thick and 1.5 ± 0.4 cm thick. The thinner barrier corresponded to the minimum thickness of the typical pregnant woman's abdominal wall including myometrium [18], subcutaneous fat tissue [19], muscle tissue [20] and skin [21]. The second variant of the barrier has been chosen as a representation of the thicker but still normative gestational abdominal wall. To take into account the heterogeneity of the acoustical barrier, 3 variants of its arrangement were established. The first, described as *basic*, referred to the tissue located horizontally on the water surface, the second (*inverted*) was the same tissue located upside-down, where the side which touched water previously was in the air during this arrangement. The last arrangement (*rotated*) was obtained by 90° rotation in a horizontal plane of the *basic* arrangement, the same side touched water surface but the thickness distribution was changed.

For data acquisition, a waterproof electret condenser microphone (Voice Technologies VT500WATER) was placed in the middle of the tank. The microphone position was selected on the basis of a set of measurements which indicated that the location in the middle (in relation to the tank walls), about 2 cm under water surface allows the sound reflection in the recorded signal to be minimized. The schema of the physical model is presented in Fig. 1.

Sound stimuli consisted of 8 digitally generated sinusoidal waves at frequencies: 160; 250; 400; 500; 800; 1000; 1600; 2000 Hz. The selection of the stimulus resulted from a fetus hearing range and was limited by the method of data analysis. In the last trimester the child is able to hear sounds at frequencies from 100 Hz to 4 kHz [22,23]. To provide an integer number of samples in a single period of each stimuli, the frequencies which are aliquots of sampling frequency (40,000 Hz) had to be chosen. For frequencies 100 Hz, 2500 Hz and 4000 Hz some artifacts have been noticed, therefore they were excluded from the analysis. Amplitudes of the sounds were set for each sinusoidal wave individually

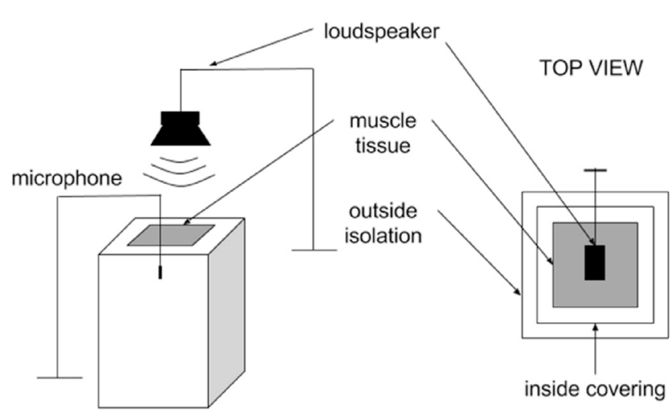

Fig. 1. The front and the top view of the schema of the physical model, which was used to obtain data for the mathematical model. The main part is the tank filled with water surrounded by soundproof material. During the experiment 2.4 cm and 1.5 cm thick muscle tissues were used.