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Ultrasound Signals For Temperature Measurement In a Tissue Model

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Abstract

In hyperthermia applications, the modality of ultrasound signal treatment is used to eliminate tumor areas in tissue clinically. According to the other techniques, ultrasound is less costly and has simple signal processing methods. Therefore, the usage of ultrasound modality increases in temperature evaluation. By applying ultrasound signals to the tissue, it is expected that temperature will increase according to the specific properties of the tissue. To observe and evaluate this temperature increasing, general knowledge will be provided by basic sound waves and ultrasound properties in this study. In the next steps, a tissue model/ phantom will be created by a simulation programme with defining the tissue properties. The temperature change will be examined by applying ultrasound signals to this model.

Keywords: Hyperthermia, temperature, tissue model, ultrasound.

1. INTRODUCTION

Ultrasound is an attractive modality for temperature monitoring because it is non-ionizing, convenient, inexpensive, and has relatively simple signal requirements [1].

Ultrasound is an imaging modality that utilizes high-frequency sound waves to produce cross-sectional images of the body. In addition to the usage of ultrasound in imaging, we have known that it is used to destroy tumor areas in thermal therapy.

Hyperthermia is a cancer treatment in which tumors are elevated to cytotoxic temperatures (41-45 ^{0}C) in order to aid in their control. A clinically useful method is needed to measure 3D temperature distributions to within 0.5 ^{0}C in 1 cm^3 volume [1].

When ultrasound waves are applied to the tissue, that tissue expands according to its specific properties. The aim of this study is to review the scientific literature researching ultrasound wave properties, transducers, tissue models, hyperthermia applications, and temperature estimation.

2. LITERATURE REVIEW

The ultrasound wave is a kind of sound wave that is a longitudinal and mechanical wave. The ultrasound frequency range is greater than the human hearing frequency range and also medical ultrasound produces sound waves between the range of 2 MHz to 10 MHz (Fig. 1).

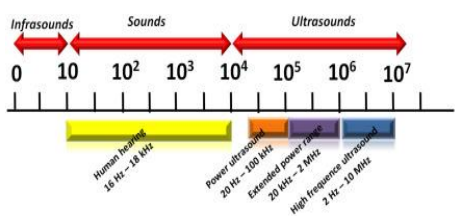

Figure 1. Sound wave types of frequency range [2].

The characteristic of a sound wave can be described by some parameters. Period (T), the wave period is the time it takes to complete one cycle. Frequency (f) is the speed of vibration. Wavelength (λ) means the distance between two waves. Amplitude (A) is the maximum height of a wave. Velocity (c) means the speed of sound. Also, these terms are used for ultrasound wave terminology. Frequency and wavelength terms are known as important parameters for wave: terminology and they have an inverse relationship formula.

$$c = f.\lambda \qquad (1)$$

In this formula, the c term means the speed of sound and this term has different values for each tissue. It can be called a specific value. Although different speed of sound values, in practice, it should be an average constant value in soft tissue, 1540 m/s. The other values are shown in (Fig. 2 and Fig. 3).

Material	Speed of Sound
Air	330 metres/second
Metal	5000 m/sec
Pure Water	1430 m/sec

Figure 2. Speed of sound in different materials [3].

Soft Tissue Type	Speed of Sound
Fat	1450m/sec
Liver	1550m/sec
Blood	1570m/sec
Muscle	1585m/sec
Bone	4080m/sec

Figure 3. Speed of sound in different tissue types [3].

Ultrasound waves are produced by a transducer also known as the beam. The transducer has many types depends on their display modes. Transducer's working principle based on piezoelectricity. According to this principle, transducers are made of special ceramic crystal, piezoelectric. In this process, when an electric field is applied to the crystal, it vibrates and produces sound waves. In reverse, when mechanical pressure is applied to the crystal, it produces electric energy. The working principle of the transducer is based on two basic principles. These are known as emit ultrasound waves and detect reflected ultrasound from tissue boundary by using the speed of sound and the time of each echo's return (Fig. 4).

Figure 4. Transducer and tissue boundary scheme.

When used in an ultrasound scanner, the transducer sends out a beam of sound waves into the body. The sound waves are reflected back to the transducer by boundaries between tissues in the path of the beam. When echoes hit the transducer, they generate electrical signals that are sent to the ultrasound scanner. Using the speed of sound and the time of each echo's return, the scanner calculates the distance from the transducer to the tissue boundary. These distances are then used to generate two-dimensional images of tissues and organs.

Temperature-dependent ultrasonic parameters are based on the phenomenon of a thermo-acoustic coupling. The acoustic parameters used in order to monitoring temperature include some terms. Echo-shifts due to changes in tissue thermal expansion and speed of sound. These terms are depending on the tissue's specific properties. Variations in acoustics attenuation. Changes in the backscattered energy of ultrasound. Then, changes in parameters of statistics of the backscattered signal envelope. The acoustic absorption coefficient, density, specific heat and thermal conductivity terms are the medium's physical properties. When an ultrasound beam passes through a volume of tissue, some of the energy of the primary acoustic field is absorbed locally by the tissue and turned into heat according to the medium's physical properties [4].

3. MATERIALS AND METHODS

k-Wave is an open-source MATLAB toolbox designed for the time-domain simulation of propagating acoustic waves in 1D, 2D, or 3D. The toolbox has a wide range of functionality, but at its heart is an advanced numerical model that can account for both linear and nonlinear wave propagation, an arbitrary distribution of heterogeneous material parameters, and power-law acoustic absorption. The software is designed for time domain acoustic and ultrasound simulations in complex and tissue-realistic media [5].

The simulation functions in k-Wave require four input structures. These define the properties of the computational grid, the material properties of the medium, the properties and locations of any acoustic sources, and the properties and locations of the sensor points used to record the evolution of the pressure and velocity fields over time. The other parameters are shown in Table 1.

Table 1. Phantom parameters values.

Property	Density (kg/m^3)	Speed of sound (m/s)	Attenuation (Np/m/MHz)	Specific heat (J/(kg·K))	Thermal conductivity (W/(m·K))
Water (at 293.7 K)	1000	1483	0.025	N/A	N/A
Tissue phantom	1044	1568	8.55	3710	0.59
Human tissue	1000–1100	1450–1640	4.03–17.27	3600–3890	0.45–0.56

In the simulation program, heat diffusion is observed in the homogeneous medium. In this study, only the diffusion properties are set. These can be defined in two ways, either by defining a single diffusion coefficient or by defining the density, specific heat capacity, and thermal conductivity of the tissue. All parameters can be specified as single scalar values in SI units. The initial temperature is specified by assigning a single scalar value or a matrix to source T0. Different frequencies of ultrasound waves were applied to the tissue model which was based on the two-dimensional model. With applying the ultrasound waves temperature changes were examined in the tissue model. Methodically, a k-wave toolbox was used to simulate this model.

4. RESULTS AND DISCUSSIONS

The result from this study is that there are different parameters that can be affect temperature in a tissue phantom. After all these methods, temperature and acoustic pressure changes in the tissue model were observed in Fig 6- Fig7- Fig8.

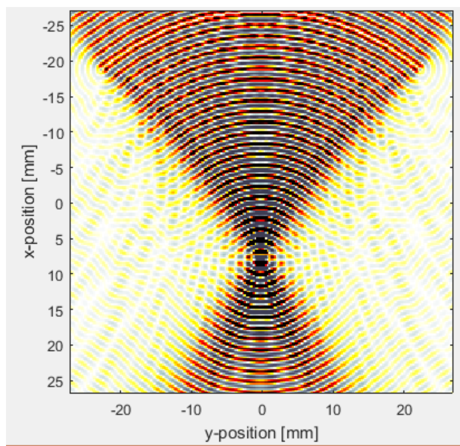

Figure 6. Acoustic pressure after heating.

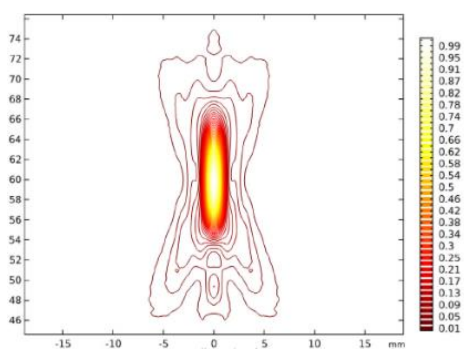

Figure 7. Temperature rise at 1ºC.

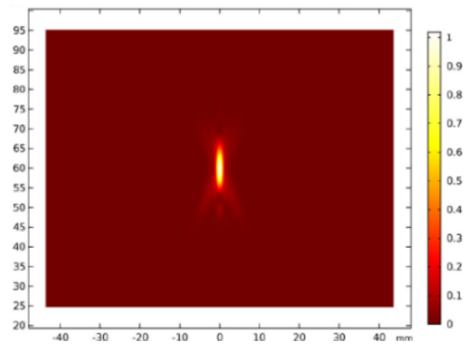

Figure 8. Temperature rise at 1ºC.

In the study, the absorbed acoustic energy is calculated and used as the heat source for the Bioheat Transfer interface model. Frequency domain interface is used to model simulation. Besides, the transducer is driven at the frequency of 1 MHz. and turned for 1 second. The model example shows how to model tissue heating induced by focused ultrasound. After running to the simulation, heating results are obtained in the tissue model. In this model, blood perfusion is not considered. If it can be considered, there will be different simulation results.

According to this review study, ultrasound wave properties are studied. Moreover, basic simulation ability is gained by using the k-wave toolbox.

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