# Temperature dependencies of ultrasound signals backscattered from an agar-oil soft-tissue mimicking material

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Abstract

Tissue mimicking materials for ultrasound research, phantoms, should be acousticaly similar to the tissues. Such requirements are filled by the AGO (agar-oil) phantoms. Here, they were used in the experiment of heating internal region of samples by a high intensity ultrasound (HIFU) transducer. During heating the RF (radio frequency) ultrasound signals were collected. It is demonstrated that the temperature changes in AGO phantoms can be described by special properties of the backscattered RF signals, namely the shape parameter of the Nakagami distribution and SNR (signal to noise ratio) of signal envelope random distribution. The revealing of qualitative relationships between the temperature increase/decrease measured by thermocouples and the statistical parameters changes are main results of the paper.

*Keywords: soft tissue phantom, absorption of acoustic energy, temperature marker, signal-to-noise ratio, Nakagami distribution*

## 1. Introduction

Phantoms intended for quality assurance and performance assessment of imaging systems must have acoustic properties similar to those exhibited by a soft tissue. The well-characterized phantoms are required to validate procedures that attempt to generate quantitative ultrasound feature images based on these properties. The statistical properties of a received signal envelope are now often used as one of the methods for the differentiation of soft tissues *in vivo* and *in vitro*, cf. [6]. The thermal characterization of one type of AGO by the statistical characteristics of backscattered signals has already been done in [4]. In the paper four different types of samples are used. They are characterized by different oil content, what follows different acoustic energy absorption. Section 2 contains a description of phantoms, experiment procedures and methods. In Section 3 the results and final remarks are given.

## 2. Materials and Methods

### *2.1. Agar-oil phantom*

Different types of samples used in experiments were prepared as a mixture of water agar solution and from edible safflower oils, see Table 1.

Table 1: Phantoms content

| Phantom name | Oil in % | Water in % | Agar in % |
|---|---|---|---|
| AGO 10 | 10 | 89.10 | 0.90 |
| AGO 25 | 25 | 74.25 | 0.75 |
| AGO 33 | 33 | 66.33 | 0.67 |
| AGO 50 | 50 | 49.50 | 0.50 |

Small amount of surface tension reducing agent, dishwashing liquid was added to obtain more fine emulsion. Production of such phantom, called AGO (agar-oil) has been documented in our previous paper [4]. In the image of a phantom microstructure the mixing process is visible in characteristic texture formed from the oil phase in water- agar solution, cf. Fig. 1.

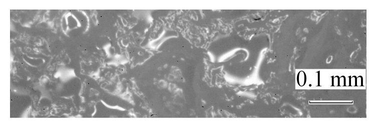


Figure 1: AGO material image made with optical microscope (Nikon Microphot) with the lens Nikon BD Plon 5x/0.1

### *2.2. Experiment description*

The heating of the samples was performed using a system consisting of a generator (Agilent 332, Aprings Colorado, USA), an amplifier ( ENI 1325LA, Rochester NY, USA), a spherical ultrasonic transducer (central frequency 2.2 MHz, diameter 44.5 mm, 44.5 mm focal length, area S = 15.2 cm2 ) and an oscilloscope (Tektronix TDS3012B). Irradiation of the samples with a series of acoustic bursts (20 cycles of 2 MHz sine wave repeated every 50 micros) of average acoustic power equal 6 W was performed. During 10 minutes of heating and 10 minutes of cooling the temperature changes were measured using thermocouples and registered by a USB module - TEMP. The temperature within the sample was measured along the beam axis at distances of 30, 35, 40, 45, 50 mm from the transducer. The geometrical focus was located 44.5 mm from the surface of the transducer, while the maximum temperature was observed at a distance of 40 mm. An ultrasound imaging system (Sonix TOUCH, ULTRASONIX, British Columbia, Canada) equipped with a 128-elements linear probe (L14-5/38) was used for acquisition of the ultrasonic radio frequency (RF) echoes from the heated sample. The probe was located transversely to the axis of the heating beam at a distance of 40 mm from the heating transducer. The sample was scanned every 5 sec during 20 min of the experiment. Each scan was performed in a 200 ms break in the heating to ensure that

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imaging process is free from interference coming from the heating beam. The probe elements were driven by 2 periods of 6.7 MHz sine and the scanning was done with use of the synthetic aperture technique. In a single transmit-receive cycle a pair of adjacent elements emitted a spherical wave and all supported elements received the echoes. In successive transmit-receive cycles the transmit aperture was moved by a single element. In our experiments only 42 probe elements were used due to the limitation of the transmit sequence length in the Sonix TOUCH system. The collected RF echoes were reconstructed off-line with use of the Matlab software.

### *2.3. Methods*

We use the simplified Pennes model bio-heat equation without perfusion for modeling the heat transfer in agar oil (AGO) soft tissue phantoms with special source produced by HIFU (high intensity focused ultrasound) transducer, cf. [2]. The result of FEM calculation allowed to determine the region of samples which were heated, cf. Fig. 3. Next, the signals from this regions were used to perform the statistical analysis. At first, the attenuation compounding is performed same as [1]. Than envelopes were obtained by the Hilbert transform. The optimalization of the choice of a parameter to measure temperature variation has been proceeded similarly as in [4]. The optimality criteria used consist the quality of matching histograms to probablity distributions and the highest sensitivity to temperature changes. The chosen parameters are the shape parameter of the Nakagami distribution and SNR (signal to noise ratio). They were calculated for four types of AGO materials in 1200 time points during the heating process, see Fig. 4.

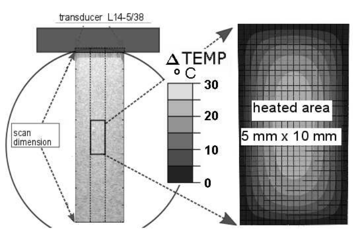


Figure 2: FEM simulation of temperature distribution and the heated region of sample

## 3. Results and conclusions

The shape parameter of the Nakagami distribution and the SNR variations during the heating proces are shown in Fig. 3. There are much greater fluctuations in parameters values during heating than cooling. This may be caused by a long relaxation times (viscoelastic effect) or by the random interference with signals from the heating transducer. The second observation is that the changes of AGO 10 and AGO 50 parameters exhibit worse effect of the temperature rise, cf. in Fig. 3.

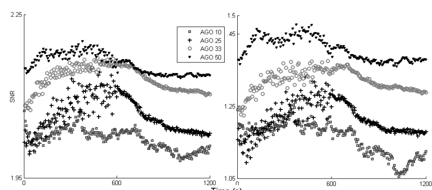


Figure 3: SNR and Nakagami parameter for AGO 25 and AGO 33 as functions of time

The temperature measured by thermocouples as a function of time was fitted to an exponential function with the high values of goodness of fit measures. Similarly, the fitings are done for the Nakagami parameter as a function ot time, see Fig. 4.

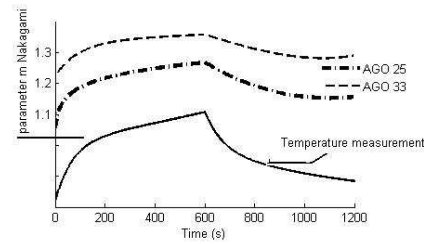


Figure 4: Comparison of Nakagami parameter changes and measured temperature changes during heating/cooling process

The rise and fall of the Nakagami parameter values is consistent with the changes in the temperature measured by thermocouples, besides the rates of changes reflect the differences between heating and cooling. Independently, the FEM modelling of temperature fields can be used to approximate the thermal conductivities of different AGO materials. This technique was recently presented in [5], when the thermal comductivity of the soft tissue sample *in vitro* was obtained.

## References

[1] Gambin, B., Doubrovina, O., *Complex Analysis and Potential Theory*, Azeroglu, T.A., Golberg, A., Rogosin, S. Eds., Cambridge Scientific Publishers, pp. 63-76, 2014.

[2] Gambin, B., Kruglenko, E., Kujawska, T., Michajłow, M., Modeling of tissue in vivo heating induced by exposure to therapeutic ultrasound, *Acta Physica Polonica A*, 119, pp. 950-956, 2011.

[3] Karwat, P., Litniewski, J., Kujawska, T., Secomski, W., Krawczyk, K., Noninvasive Imaging of thermal fields induced in soft tissues in vitro by pulsed focused ultrasound using analysis of echoes displacement, *Archives of Acoustics*, 39, pp. 139-144, 2014.

[4] Kruglenko, E., Gambin, B., RF signal amplitude statistics during temperature changes in tissue phantoms, *Hydroacoustics*, 17, pp. 115-122, 2014.

[5] Kujawska, T., Secomski, W., Kruglenko, E., Krawczyk, K., Nowicki, A., Determination of tissue thermal conductivity by measuring and modeling temperature rise induced in tissue by pulsed focused ultrasound, *PLOS ONE*, 9, pp. 1-8, 2014.

[6] Mamou, J., Oelze, M.L. (Eds), *Quantitative Ultrasound in Soft Tissues*, Dortrecht- Heidelberg-New York-London, Springer, 2013.