mats is a joint project between the Institute of Fundamental Technological Research, Polish Academy of Sciences, and the Mirosław Mossakowski Medical Research Center. The application of poly(lactic acid) copolymers has yielded the first positive results. The mats were applied as a barrier to scar growth, placed into an open spinal canal (patent pending 2011) in the course of spinal laminectomy conducted on a rat model (Fig. 3). The membrane was placed on the surface of the exposed spinal cord and covered with the surrounding dura mater. Ultrastructural and immunohistochemical tests carried out after a certain period of time on dura mater and spinal cord specimens showed a lack of inflammation. Astroglials and connective tissue scars that could be potentially dangerous to regeneration were also shown to be absent. Bone fragments of the spine overgrew normally as part of the healing process. The outcome of this experiment raises expectations for the development of a clinically approved barrier material used to prevent post-operative complications commonly related to the scarring process following spinal surgeries.

References

Kowalewski T.A., Błoński S., Barral S. (2005). Experiments and modeling of electrospinning process. *Bulletin of the Polish Academy of Sciences – Technical Sciences*. 53, 385-394.

Kowalewski T.A., Barral S., Kowalczyk T. (2009). Modeling electrospinning of nanofibers. *Modelling Nanomaterials and Nanosystems*. R. Pyrz, J.C. Rauhe (Eds.), Springer Science+Business Media B.V., IUTAM Bookseries vol. 13, 279-292.

Kowalczyk T., Nowicka A., Elbaum D., Kowalewski T.A. (2008). Electrospinning of Bovine Serum Albumin. Optimization and the use for production of biosensors. *Biomacromolecules* 9, 2087-2090.

Institute of Fundamental
Technological Research
ul. Pawińskiego 5B, 02 -106 Warszawa
phone: 48 (22) 826 12 81
fax: 48 (22) 826 98 15
e-mail: director@ippt.gov.pl
www.ippt.gov.pl

The Synthetic Aperture technique for tissue attenuation imaging

J. Litniewski | Z. Klimonda | A. Nowicki | Institute of Fundamental Technological Research | Polish Academy of Science

Introduction

The attenuating properties of biological tissue are of great importance in ultrasonic medical imaging. It has been emphasized in many publications that ultrasound attenuation is closely related to the type and pathological state of the tissue. Investigations performed *in vitro* and *in vivo* have shown correlations between pathological changes in the tissue and variation of the attenuation coefficient. The liver is the most frequent example. The *in vivo* characterization of this organ is often restricted to its attenuation properties and it has been proved that the ultrasonic attenuation coefficient increases as the amount of pathological fat in the liver increases. Also, the study of excised cancer tissue has revealed differences in acoustic attenuation among cancer types and degrees of pathology. Saijo et al. (1996) employed a scanning acoustic microscope to measure five types of gastric cancer and reported different attenuation coefficient and sound speed compared to normal tissue. Bigelow et al. (2008) investigated the possibility of predicting premature delivery based on noninvasive ultrasonic attenuation determination in rats and in humans. Worthington and Shear reported that thermal coagulation of porcine kidney changes attenuation and Zderic et al. demonstrated strong attenuation changes in porcine liver related with HIFU treatment.

The long term goal of this study is to develop the attenuation parametric imaging technique and to apply it for *in vivo* characterization of tissue.

Attenuation determination

When a wideband ultrasonic pulse with mean frequency f_0, propagates within the homogenous medium the dispersion of the attenuation coefficient results in the shift of the pulse mean frequency. The new mean frequency f_m can be expressed by:

$$f_m = f_0 - \sigma^2 \alpha_0 x \quad (1)$$

The value σ^2 is the Gaussian variance of the pulse spectrum, x denotes penetrated distance, and α_0 is the attenuation coefficient. Gaussian pulse spectrum preserves its shape during propagation in a linearly attenuating medium, i.e. σ^2 is constant.

The value f_m was estimated using the correlation estimator (IQ algorithm). The estimator is depicted by

$$f_m = \frac{1}{2\pi T_s} a\tan\left(\frac{\sum_{i=1}^{N} Q(i)I(i+1) - Q(i+1)I(i)}{\sum_{i=1}^{N} I(i)I(i+1) + Q(i+1)Q(i)} \right) \quad (2)$$

where T_s is the sampling period and N is the estimator window length. Q and I are quadrature and in-phase signal components and are obtained by the quadrature sampling technique. The N parameter is directly related to the axial resolution of the method. The f_m line is created point by point from the raw backscattered RF data.

The f_m lines are characterized by high variance due to the random character of signal backscattered in soft tissue. A reduction in the f_m line random variability was achieved using moving average filtration and the Singular Spectrum Analysis (SSA) technique. The SSA trend extraction algorithm operates along the f_m lines in axial direction. SSA is a relatively new technique of time series analysis. The aim of this technique is to decompose the input data series into a sum of components, which can be interpreted as the trend, oscillatory components, and noise (non-oscillatory components). Major applications of the SSA technique include smoothing the time series, finding the trend, and forecasting and detecting structural changes. The final attenuation estimates were enumerated from the smoothed f_m lines. The use of SSA and the averaging of the scan lines limits the variations of the attenuation estimate but it is still affected by errors.

Synthetic Aperture technique

Synthetic aperture (SA) methods are widely used in radar techniques, although it is also possible for them to be implemented in medical ultrasound systems with multielement probes. The motivation for using SA techniques in acquiring RF data to be subsequently processed for attenuation determination is twofold. We know that focusing introduces variation in the pulse spectrum, which results in incorrect assessment of attenuation. This effect of focusing must be compensated for. For standard delay and sum (DAS) beamforming, the focusing is performed only in several, fixed distances in the tissue. Thus the influence of focusing varies along the echo line. In the case of the SA technique, the focusing is performed at all points of the imaging tissue and its influence on the mean frequency of the signal is very similar through the whole imaging area. The correction of focusing effects is therefore much easier and more effective for SA imaging. Also, attenuation imaging requires averaging over adjacent echo lines and along a given line, reducing the spatial resolution of attenuation images. In the case of SA the averaging is much more effective because the areas in the vicinity of focus are statistically independent and averaging over just a few of them is required to reduce stochastic factors in the calculated attenuation. Out of focus (the case for most of the imaging area when standard beamforming is used) the areas insonificated by adjacent beams are overlapping and more averaging is required, worsening the resolution of the attenuation map.

Results

The experimental data were recorded using an ultrasonic scanner (UltrasonixSonic TOUCH) equipped with a linear probe (126 elements) operating at 7.0 MHz frequency. The system enables full control of transmission and reception, giving access to every single piezo-element of the multi-element ultrasonic probe. The RF data were collected using the SA scheme, with one element transmitting and all elements receiving. Next the data were processed and an attenuation map was created. The resolution and accuracy of the method was verified using a tissue mimicking phantom (DFS) with uniform echogenicity but varying attenuation coefficient. The phantom consists of two cylinders of 1.5 cm diameter with attenuation coefficient equal to 0.9 and 0.7 dB/(MHz·cm), respectively, embedded in a medium with attenuation of 0.5 dB/(MHz·cm) at a depth of 3 cm.

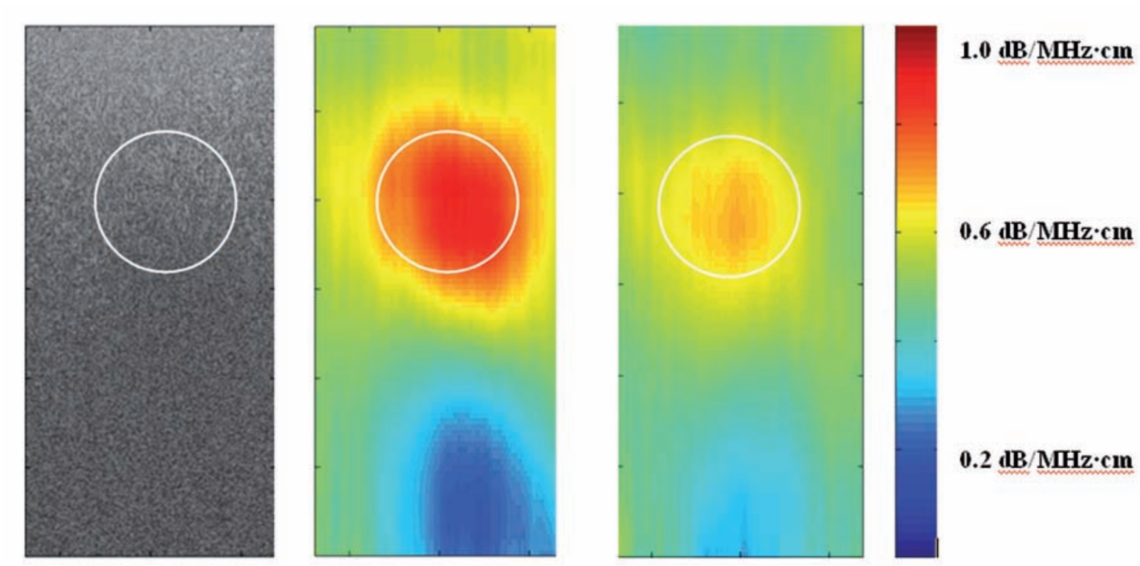

Fig. 1. B-scan image of the cylinder (attenuation 0.9 dB/MHz·cm) (a) its attenuation distribution image (b) and attenuation map of second cylinder (0.7 dB/MHz·cm) (c). Imaging area 60 mm x 30 mm. The white circles mark the real positions of cylinders. The shadows beneath the objects are artifacts and are caused by decreased signal-to-noise ratio (SNR) of echoes, due to increased attenuation

The images obtained using the SA technique and SonicTOUCH system are presented in Fig 1. The objects are invisible in B-mode and clearly visible in the attenuation images.

Conclusions

The mean frequency correlation estimator and SSA technique were implemented for processing of the RF ultrasonic echoes. The estimated attenuation values were equal to 0.7 and 0.9 dB/(MHz·cm) and agreed well with the real values. We have found the RF data obtained using synthetic aperture technique (SA) to be much more reliable in terms of attenuation extraction then echoes recorded using the standard delay and sum (DAS) beamforming. The imaging of attenuation in tissue seems to be a promising technique in medical diagnostics, although the precision of a single scan is often unsatisfactory. The synthetic transmit aperture technique allows similar quality images to be obtained as with the spatial compounding technique, which utilizes a dozen or so images for averaging. The SA technique uses a single scan only, which is more suitable for real time application.

References

Bigelow T.A., Mcfarlin B.L., O'Brien W.D., Oelze M.L. (2008). In vivo ultrasonic attenuation slope estimates for detecting cervical ripening in rats: Preliminary results. *Journal of Acoustical Society of America*, 123, 3, 17941800.

Litniewski J. (2006). Wykorzystanie fal ultradźwiękowych do oceny zmian struktury kości gąbczastej [Assessment of trabecular bone structure deterioration by ultrasound]. *Prace IPPT.*

Klimonda Z., Litniewski J., Nowicki A. (2009). Spatial Resolution of Attenuation Imaging. *Archives of Acoustics*, 34, 4, 461470.

Saijo Y., Sasaki H. (1996). High Frequency Acoustic Properties of Tumor Tissue. [In:] *Ultrasonic Tissue Characterization*, edited by Dunn F., Tanaka M., Ohtsuki S., Saijo Y. Springer-Verlag Tokio, Hong-Kong, 217230.

Institute of Fundamental
Technological Research
ul. Pawińskiego 5B, 02 -106 Warszawa
phone: 48 (22) 826 12 81
fax: 48 (22) 826 98 15
e-mail: director@ippt.gov.pl
www.ippt.gov.pl