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# SHEAR WAVE IMAGING OF LIQUID INCLUSION IN SOFT TISSUES

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An imaging technology, shear wave elasticity imaging (SWEI), was applied to the visualization of liquid type pathologies in soft tissue. SWEI relies on the acoustic radiation force to remotely generate shear waves in tissues. A high intensity acoustic field was induced by means of a single, spherically focused ultrasonic transducer to excite shear strain in soft tissue. Medium strain in focal point and those located in some distance from it were registered using the Doppler approach. Reconstruction of tissue pathological zone spatial localization was made through the analysis of shear waves propagation time. The experiments were carried out using cow breast tissue containing the liquid inclusion about $1.5 \times 2$ cm in size. There was showed the principal possibility of liquid inclusion localization in tissue through the analysis of shear waves propagation data.

**KEY WORDS:** ultrasound, radiation force, soft tissue, shear strain, relaxation, shear modulus.

Certain pathological or physiological processes can be the reason of soft tissues elastic properties change [1]. Pathologies that occur in soft tissues are of different origin and can appear as tissue soft lesions or cavities with liquid contents (cyst, complex cysts, fibroadenoma, lipoma, haematoma etc.). Ultrasound imaging technique are often used as a supplementary to mammography method to define the type of tissue pathological changes. This is extremely important when differentiation of infiltrations and cysts because the former are often a malignant neoplasm [2]. However the differentiation of tissue infiltrations and cyst is rather complicated task and is often executed using the indirect features during the analysis of tissue suspect zone obtained images.

For example to study the possibility of cysts in soft tissues distinguishing from hypoechoic cancer zones in some woks [3-5] there was studied the difference of correlation coefficient ($R$) values of corresponding tissue zone images. It is supposed that such a supplementary characteristic could have decreased the number of complex cyst biopsies. The phase-sensitive 2-dimensional and 3-dimensional speckle tracking algorithm was used to obtain the coefficient of correlation between tissue images when it is compressed. The correlation coefficient $R$ value was defined for the damaged zone and intact tissue. As a result all estimations of $R$ value in cysts were at 7-29% lower than those of ambient intact tissue. These estimations had such low values due to random signal in cysts that changed rapidly between precompression and postcompression images. The correlation coefficient value corresponding to hypoechoic cancer zones had $R$ estimations not exceeding 10% or a little higher than this for intact tissue. It was also suggested to use the method of liquid motion registration in acoustic flows that occur when ultrasound passes through the liquid as a diagnostic method of solid and liquid structures differentiation in tissues.

In general it has to be mentioned that such methods provide one with rather ambiguous results and often the results obtained need a supplementary checking via biopsy.

## MATERIALS AND METHODS

The main task of ultrasound visualization is the detection of structural heterogeneities of studied organ and study of these features can provide one with the necessary information about the presence of certain pathological changes in tissue. The principle possibility of rigid structural heterogeneities visualisation in soft tissues gelatine phantoms using shear waves was demonstrated earlier [6]. In the SWEI method for tissues elasticity imaging the amplitudes measurement of shear waves induced in tissues is used [7].

In this study cows breast tissue was investigated. The main difference of native tissue and tissue gelatine phantom used earlier [6] is its heterogeneity that is seen in structures that differ in viscoelastic properties: vessels walls, fat layers, pathological changes of different type: cysts, infiltrations etc. Obviously heterogeneities presence can essentially complicate the interpretation of data obtained on displacements amplitude and shear strain relaxation dynamic.

On the other hand it is known that in fact shear waves do not propagate in liquid. Taking this fact to account in the present work there were carried out the studies of possibility to use SWEI method to define its diagnostic abilities to distinguish liquid inclusions in soft tissues *in vitro* from infiltration type pathologies typical for malignant neoplasm. To imaging of liquid inclusions in soft tissues we used the propagation time of shear waves.

Studies were carried out using the equipment and according to the scheme described in details in [6]. tandard pulses used in common visualization «B»-mode were used as probing ones. Probing pulses had the ollowing parameters – working frequency 3.5 MHz, pulses repetition rate 3.66 KHz, pulses duration – 1 $\mu s$, ocal distance – 75 mm. Power pump transducer used for radiation pressure force application had the following arameters – working frequency 1 MHz, pump pulses duration – 2.18 $\mu s$, pulse intensity in transducer focus $I_{SPPA} = 145\ W/cm^2$, pulses repetition rate 14.59Hz, focal distance – 68 mm. During the experiment pump and robing transducers focal points were superpose by means of positioner. On Fig. 1 the focal area of transducer reating the radiation pressure in tissue (at -6 $dB$ level) is marked out with white oval.

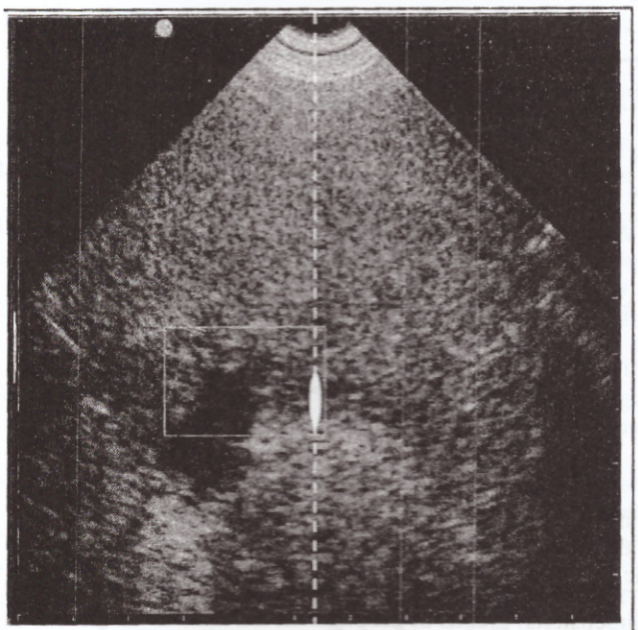

Fig.1. «B»-image of phantom with liquid inclusion.

Fresh extracted cow breast tissue was put into a special container about 2 litre in volume and placed in the acoustic stand. Structural heterogeneity imitating a cyst was formed by implantation of capsule with liquid through the incision in tissue. Heterogeneity represented the filled water polyethylene shell with wall thickness of about 20. The cross size of inclusion was 1.5 $cm$, longitudinal - 2 $cm$. Heterogeneity location was selected so as it was placed in some distance from transducer focus, in about 10-15 mm. Monitoring of heterogeneity size and location was made using the ultrasound «B»-image (Fig. 1).

Tissue displacement amplitude and shear waves propagation time measurements were carried out sequentially in points located in scanning plane neighbouring with the heterogeneity. The measurements were made in sequence in points located in each ray scanning plane with step 0.2 mm. Measurement zone is marked on Fig. 1 with white rectangle. On «B»-image liquid inclusion looks like a darkened oval zone against the surrounding breast tissue because of the low ultrasound reflectance. The pump beam axis of the ultrasonic transducer is designated by a vertical white dashed line.

Medium displacement maximum was located in transducer focus. Propagating shear wave was impaired as moving from its emergent point; this fact is registered due to medium displacement amplitude decrease. Time of medium distortions propagation to the points outlying from focus was defined using the time point when tissue displacements were maximal in point of observation.

Shear displacement values were calculated using the estimation of Doppler echo signal phase change value. Data was accumulated in the real time. To increase tissue displacements and propagation time measurements precision we used cumulative data of 10 measurements in one point with the further averaging.

Accumulation of data obtained in each point was possible because probing pulses repetition rate was aliquot to pump pulses repetition rate. As a result displacements amplitude measurements at the ending of each pump pulse started at the same phase of displacements induced in tissue relaxation process. Obtained data was then processed and analysed.

## RESULTS AND DISCUSSION

As a result of impulse excitation of ultrasound beam radiation force that was radiated by the power transducer in the beam focal area an axial tissue displacements occurred. Originated shear waves then propagated in both ways from focus and when reaching the inclusion boundaries interacted with it. These waves occur as a result of initial displacement strain relaxation in the focal area. Tissue displacements in points distant from power impact area was registered with some delay (propagation time) in time that was defined by the shear wave velocity and probing point radial coordinate.

For displacements and propagation time values comparison the experiments were carried out using breast tissue sample with inclusion as well as reference sample without liquid inclusion. Measurement zone was located identically to the transducer focus, at the same ultrasound beam range and with the same number of points for each ray. In both cases total number of points where data was registered was about 2500.

Because the probing transducer adjacent beams are on some angle to each other after registration the obtained data file was processed with Origin 7.0 program to obtain 2-dimensional bitmap image of shear waves

propagation time in this zone. Thus data processed was given as a two-dimensional array of propagation time current values. Similar value arrays were obtained for the check sample. This allows us to compare the «B»-images of studied zone and the image obtained by means of shear waves.

On Fig. 2a the obtained in homogeneous sample two-dimensional propagation time distribution is shown in zone corresponding to white rectangle on Fig. 1. Propagation time amplitude is marked with grey scale colors. Grey scale is given above on the figures. On Fig. 2b there is given the two dimensional distribution of propagation time that corresponds to the zone around the focus with the same coordinates in the phantom with heterogeneity. It is seen from the given figures that in contrast to homogenous tissue sample in which the value of shear wave propagation time increases gradually as a wave moves from the focus, in the sample with liquid enclosure the smooth pattern of propagation time values change abruptly distorts in enclosure zone.

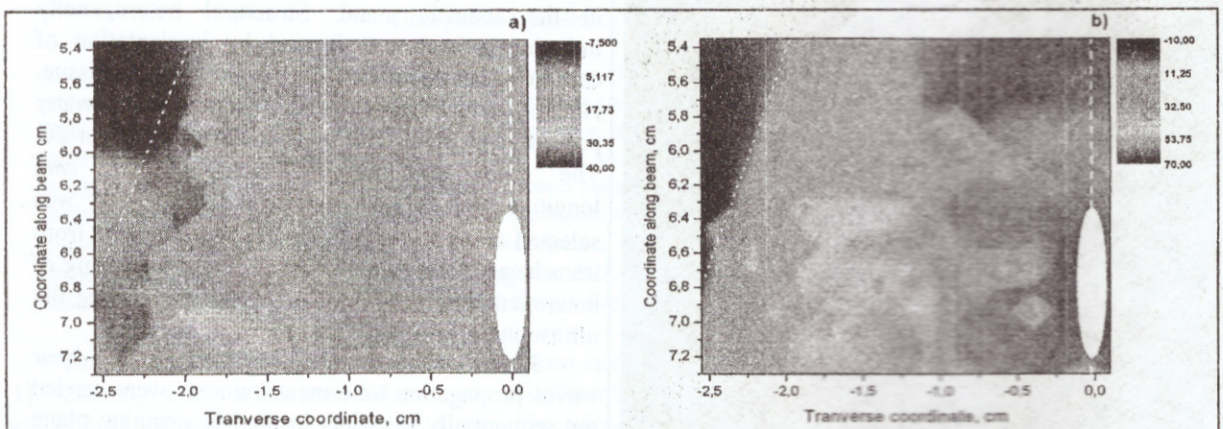


Fig 2. a) 2-dimensional propagation time distribution in homogenous phantom, b) 2-dimensional propagation time distribution in phantom with heterogeneous inclusion.
(The first beam axis of the probing ultrasonic transducer is designated by doted line as on Fig.1)

It also has to be mentioned that the obtained two dimensional graphs of propagation times in heterogeneous phantom (Fig.2b) does not allow us to define directly the location of heterogeneity and its boundaries because of the initial image distortions by propagation times spatial distribution caused by propagating shear wave. Using the same approach as previously [6], the combined processing was made for homogenous phantom propagation time values and the ones for the tissue with enclosure. To find the difference between the abovementioned values the initial image (Fig.2b) of the sample with heterogeneity was normalized to propagation times spatial distribution in homogenous tissue sample (Fig.2a).

The normalized image is given on Fig.3. It is seen from the figure that the obtained image allows to detect the spatial localization of enclosure more confidently. As on «B»-image fragment (Fig.1) the two dimensional image of the tissue with enclosure is placed asymmetrically to the pump beam axes. Besides this image spatial extension in axial and radial directions coincides with the one on Fig.1. As it is seen from the given figures of «B» - Image and obtained two-dimensional image a quite acceptable coincidence of liquid enclosure zone boundaries is observed.

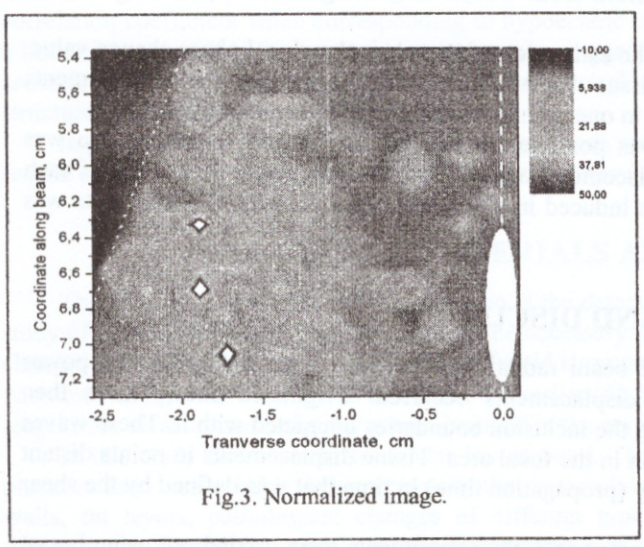


Fig.3. Normalized image.

It has to be emphasised that two-dimensional image of heterogeneity of liquid origin has a distinction of kind with the common «B»-image obtained using the interface reflectance in tissues. In our case the heterogeneity boundaries discernibility is defined not by echo signal amplitudes difference but by the difference of shear wave propagation time values in homogenous phantom and the corresponding ones in the enclosure zone.

Similar data obtained earlier during the study of elastic enclosure [6], located in some distance from focus give rather ambiguous view of obtained normalized image. In our opinion a possible reason for this can be that elastic enclosure proprieties differ a little from the surrounding tissue. In presence of liquid enclosure a zone filled with liquid leads to much more distortion of shear wave than an elastic enclosure that allows one to define the heterogeneity boundaries more exactly.

## CONCLUSIONS

In the given work there was studied the possibility of visualization using shear waves of structural heterogeneities in soft tissues with gangliac pathologies of liquid type. There was demonstrated the possibility of liquid enclosures in soft tissues visualization by means of registration of shear waves propagation time values using Doppler approach. The studies carried out can serve as supplementary tool of medical diagnostic to diagnose more accurately because they give some additive information on physical nature of heterogeneity. The approach used needs further improvement to remove the artifacts on images caused by ultrasound images speckle nature.

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