DETERMINATION OF ALTERATIONS OF PHASE ANGLE OF ULTRASOUND TRANSMITTED THROUGH A MALIGNANT BREAST TUMOR: A Preliminary Investigation†

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INTRODUCTION

The overall experimental approach of the research discussed in this paper is the use of multidiscipline examination methods, namely, x-rays, ultrasound visualization, signal processing of ultrasound transmission data (FFT) and whole breast histology to elucidate the relation between structural features of breast tissue and their interaction with high frequency sound fields. The specific studies presented here are concerned with an attempt to determine the feasibility of using the phase angle data resulting from the FFT studies to assist in the recognition of differences between normal and malignant breast tissue.

A special preparation, namely, an excised, formalin-fixed breast with a known intact malignant tumor, was used in the investigations discussed in this paper. Examinations of such breast preparations for the purpose of detecting tissue alterations associated with the presence of the malignant mass and correlation of the results with whole breast histology has important advantages for the collection of data that is pertinent for early breast cancer detection.1-5 The experimental studies outlining the validity of examining such preparations by ultrasound visualization and the techniques associated with this procedure have been described in detail in a previous publication.7

The FFT studies were considered in the nature of a feasibility study and it is in that regard they are reported in this paper. Emphasis is given in this preliminary report of the evaluation of
The angle as a function of frequency as revealed by FFT techniques.

EXPERIMENTAL METHODS

The tumor was identified as malignant by needle biopsy and examination of the patient prior to mastectomy. After excision of the breast, (without surgical biopsy or removal of the breast) the breast was formalin-fixed and subsequently examined by a B-mode ultrasound visualization system. In addition to providing information on normal and pathological regions of the breast, the visualization echochograms allowed identification of structures in relation to surface landmarks, (such as the location of the tumor). These surface landmarks were later verified at the FFT data sampling sites. The pulse-echo visualization system was the same as that described below for the FFT transducer. Figure 1 is an example of the type of tissue accomplished by a single scan in the region of the tumor.

![Breast tissue echogram. The top arrow shows the site of the malignant tumor.](image)

**Fig. 1** Breast tissue echogram. The top arrow shows the site of the malignant tumor.

**Fig. 2** Data acquisition systems block diagram.

Figure 2 is a block diagram of the instrumentation used for the subject studies. An axisymmetric focused transducer was used as a transmitter, and a 10 MHz center frequency, 4 mm diameter PZT ceramic sandwich-type piezoelectric probe used as a receiver. A Panametrics Model 5050R unit pulse-excited the transmitter and a series unit attenuated the ultrasonic signals prior to their entrance into the amplifier receiver. The sending transducer was 1.9 cm in diameter, had a focal length of 7.5 cm, and a midband frequency response of 4.4 MHz. The breast preparation was mounted on a three-motion coordinate system in a temperature controlled mammalian Ringer's bath (average temperature 25°C) and positioned between the sending and receiving transducers, with the anterior aspect of the tissue facing the sending transducer. With this arrangement, any area of the tissue could be easily examined and the tissue could be moved in 1 mm steps in the three-axis coordinate system.

In order to record the system's reference waveform, transmitter and receiver transducers were placed facing each other and
in position to receive the optimum amplitude signals. A
rigid test of the system was performed by setting the attenua-
tion at different values and comparing the corresponding outputs
of the FFT spectrum. The system was found to be accurate to ± 1 db
at the usable frequency band, for any particular transmitting trans-
ducer. The received ultrasonic waveforms were digitized at a sample
rate of 10 or 20 nanoseconds using a Biomation Model 8100
digitizer and were parallel transferred to the PDP-11/45 computer.
As four waveforms were digitized at each point of interest,
the computer disc, and later analyzed using a 1024 point
Fourier transform. The tissue was sampled at points previously identified by
the computer, and visualization, by moving the specimen across the ultra-
sonic beam on the three-axis system. The anatomical points of
interest discussed in this paper are the malignant tumor tissue path-
ing the back surface of breast for path that includes the tumor
and the upper, outer aspect of the breast, which was assumed
representative of a normal, fatty region of breast tissue.

Each of these waveforms represented sound transmission through
the fat areas of the same region of interest. In general, each
waveform recorded represented sound transits at entrance points
under 2 mm of surface tissue. In order to obtain attenuation
and phase-speed versus frequency plots, they were deconvolved with
the signal system's reference waveform. The waveforms were trans-
fomed into the frequency domain and the absolute amplitude for
the frequency domain of the absolute amplitude for
the frequency domain of the reference waveform was compared with the amplitude of the reference wave-
form the relative attenuation measurement. To obtain the phase
information for each waveform, the phase was compared with
the reference waveform and later linearized for each frequency.
Maximum frequency resolution, appropriate sampling intervals
were selected on the Biomation digitizer. The output was presented
in graphical form in three different formats, namely, normalized
amplitude, attenuation and phase-speed spectra. The pres-
nence and attenuation data was previously published.

RESULTS

The phase angle plots derived from transmission through a nor-
mal region of the breast tissue, namely, the upper, inner
tissue, are shown in Fig. 3. The linear nature of these plots in-
no substantial acoustic velocity changes as the wave passes
through such tissue.

Figure 4 shows the phase angle plot for the waveforms that were
taken through the tumor region tissue paths. The non-linearit
y nature of these plots are in sharp contrast to those
in Fig. 3. The variations of the phase angle are indicative
of elastic waves that are going through a velocity dispersion or
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**Fig. 3** Phase-frequency plot for the fatty tissue of the breast.
Phase-frequency plot for the tumor region tissue path.

Fig. 5 Phase-frequency plot for a tumor region tissue path which apparently consists of a mixture of tissue types (see text).
Figure 5 shows results obtained from four sound transits in another area of the tumor tissue path. Before considering phase angle data for this region of the tumor path, it is of interest to discuss the conjectured character of the tissues of the mass itself, as indicated by the attenuation values previously reported for the tumor mass in this specific region. In that the attenuation values indicated: (1) the tissue represented by plot A consisted of fat; (2) that represented by plot B was probably made up of a mixture of normal and malignant tissue; (3) that C and D were more characteristic of the most malignant part of the tumor.

Phase angle data of Fig. 5 apparently is in agreement with conclusions based on the attenuation data, i.e., the phase angle of plot A is comparable to that found for normal fatty tissue; plot B has reasonable linear characteristics in the frequency range below 7 MHz but shows non-linearity beyond that frequency; finally, the phase angle data of plots C and D are nonlinear.

CONCLUSION

It is proposed that consideration be given to the apparently significant alteration of phase angle versus frequency in the tissue which includes both normal tissue and malignant tumor in comparison to the phase angle versus frequency of the tissue paths which consist of only normal tissue, and further that these alterations are considered in terms of the structure of the tumor as determined by whole breast histology. Preliminary data seems to indicate significant differences in patterns for phase angle versus frequency for the tumor region in comparison to normal fatty regions of breast tissue. If such pattern differences are valid, it is thought that this information would be valuable in making differentiated diagnoses of breast tumors. In view of the serious need for more definitive and accurate breast tumor structures, these preliminary results are of great interest to recommend that further phase angle data be carried out.

At the time of writing of this paper, the histological studies have not been completed.

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REFERENCES


