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Abstract: A new breast cancer detection method that is based on tissue bioelectric and acoustic characteristics has been developed by using a hybrid magnetoacoustics method. This method manipulates the interaction between acoustic and magnetic energy upon moving ions inside the breast tissue. Analytical calculation on the performance of the system has been done on normal and pathological mice breast tissue models. Calculation result shows that, hybrid magnetoacoustic method is capable to give unique characteristics between normal and pathological mice breast tissue models since ultrasonic and bioelectric characteristics of tissues vary greatly between normal and pathological states and this method hold promises for breast cancer detection.

Key-words: magnetic field, acoustic wave, breast tissue, normal and pathological.

1 Introduction

The emergence of magnetoacoustic method, a combination between acoustic and magnetic energy has been explored since 2 decades ago for impedance mapping of tissue [1-5]. Basically, magnetoacoustic method manipulates the interaction that rises when acoustic and magnetic energy acting simultaneously on random ionic particles inside a tissue. Biological tissue is a conductive element due to the presence of random charges that is mainly contributed by intra and extracellular diffusion that supports cell metabolism. Propagation of ultrasound wave will cause charges inside the breast tissue to move at high velocity due to the back and forth motion of the wave. Moving charges in the present of magnetic field will experienced Lorentz Force that separate the positive and negative charges, producing an externally detectable voltage that can be collected using a couple of skin electrode. However, previous researches [1-5] apply magnetoacoustic method for bioimpedance mapping purposes only. The ultrasound wave that is used to stimulate ionic particle motion is not taken into account though its output delivers valuable information with regards to tissue mechanical properties. In this study, a hybrid magnetoacoustic method has been developed in which this system is not only collecting the magnetoacoustic voltage that rises from acoustic and magnetic energy interaction for conductivity evaluation, but also captured back the ultrasound echo that is initially used to induced charge motion inside the breast tissue for mechanical
evaluation. This paper describes the quantitative analysis through a one dimensional analytical calculation of hybrid magnetoacoustic method for normal and pathological breast tissue evaluation.

1.1 Theory

Consider a one dimensional example of an ion inside a breast tissue having charge $q$. An ultrasound transducer delivers a longitudinal ultrasound wave in the $x$ direction perpendicular to magnetic field $B_0$ which is in the $y$ direction. The longitudinal particle motion of the ultrasound wave at position $x$ and time $t$ will cause the ion to oscillate back and forth in the tissue with velocity $v(x,t)$. In the presence of the constant magnetic field $B_0$, the ion is subjected to Lorentz Force of

$\mathbf{F} = qv(x,t) \times \mathbf{B}_0 \quad (1)$ \[1-2\]

This force is equivalent to an electric field of

$E_0 = \mathbf{v}(x,t) \times \mathbf{B}_0 \quad (2)$

that establishes a current density of:

$\mathbf{j}_0 = \sigma \mathbf{v}(x,t) \times \mathbf{B}_0 \quad (3)$

Total current is derived by integrating (3) over the transducer beam width $W$ and the ultrasound path.

$I(z) = WB_0 \int_{\text{wave path}} \sigma(x) v(x,t) dx \quad (4)$ \[1-2\]

Hence, the resulting voltage collected by the system circuitry with impedance $R$ is:

$V(z) = \alpha R_c WB_0 \int_{\text{wave path}} \sigma(z) v(z,t) dx \quad (5)$ \[1-2\]

From the equation, it is known that the amplitude of magnetoacoustic voltage is proportional to the tissue conductivity since another parameter such as $\mathbf{v}$, $B_0$, $\alpha$, $R$ and $W$ is controlled by the system. In the present study, the value of $R$ is 600$\Omega$ for Ag/AgCl electrodes and $\alpha$ is set to 10%.

Using the equation of wave motion, the resulting voltage in (5) can also be expressed in terms of ultrasound pressure and spatial gradient of tissue conductivity and density as:

$V(z) = c_l W B_0 \int_{\text{wave path}} [p(x,t) \frac{\partial}{\partial x} \frac{1}{\rho(x)} \frac{\partial}{\partial x}] dx \quad (6)$ \[1-2\]

Since the resulting voltage is proportional to the tissue conductivity, it is very valuable to be used in breast tumor characterization since in general; pathological tissue will have higher conductivity compared to normal tissue due to increased rate of metabolism.

Besides the magnetoacoustic voltage that rises from the acoustic and magnetic energy interaction, the transmitted ultrasound wave packet in the $x$ direction that is initially used to induced ionic particle motion will further propagates inside the breast tissue. The ultrasound propagation in one dimensional is governed by the wave equation:

$\frac{\partial^2 \Phi}{\partial x^2} - \frac{1}{c_l^2} \frac{\partial^2 \Phi}{\partial t^2} = 0$ \[1-2\]

In which $c_l$ is the longitudinal speed of sound in breast tissues and $\Phi$ is the velocity potential. As the ultrasound propagates further, part of the wave will be reflected back when it hits tissue boundary and another part will be further transmitted and attenuated inside the tissue. The echoes captured back from the system carry information on wave attenuation and time of flight that is valuable for mechanical breast tumor characterization.

2 Methodology

![Fig. 1: Calculation set up of Hybrid Magnetoacoustic method.](image)
Figure 1 above shows the calculation set up of the developed system. This system consists of a set of permanent magnet, ultrasound pulser and receiver unit as well as an oscilloscope to collect the voltage data. In this study, a complete mathematical analysis has been done to test the efficiency of the hybrid system in differentiating normal and pathological mice breast tissue models. Normal and pathological mice breast models having breast carcinoma and simple cysts were evaluated in terms of its acoustic and electric characteristics.

2.1 Magnetic Field.
Static magnetic field having intensity of 0.1T is used in the calculation. The magnitude is assumed to be homogenous throughout the breast tissue model. The magnetic field direction is set in positive y direction, perpendicular to the ultrasound wave.

2.2 Ultrasound System
The ultrasound system delivers 10 MHz frequency pulses with amplitude of 400V via a PVDF transducer. Since the measured impedance of the PVDF transducer is 1.39e6 Ω, total electrical power delivered by the system is 0.115W. However, total acoustic power received by the tissue is only 0.0161W due to the low electroacoustic coupling factor of the PVDF. Total acoustic intensity delivered by the system is 634mW/cm² with 0.0254cm² beamwidth. The ultrasound beam is set to be in x direction. Since initial ultrasound intensity and pressure delivered to the tissue is known, total acoustic reflection and attenuation can be calculated and compared between each tissue model.

2.3 Tissue Modelling
The mice breast tissue has been modeled to have 5 basic layers based on Sudershan et al [6]: skin, subcutaneous fat, normal mammary gland, thoracic muscle and thoracic wall to represent normal breast. For pathological model, breast carcinoma layer and cysts layer is added as an additional layer during calculation. Each tissue layer is having 2mm thickness.

Table 1 shows the acoustic and electrical parameters that were used during analysis. The properties such as ultrasound attenuation coefficient (α) and acoustic impedance (Z) is used to analyze the propagation of ultrasound wave while tissue conductivity (σ) and tissue density (ρ) is used to analyze the amplitude of magnetoacoustic voltage that rise due to the interaction between ultrasound wave and magnetic field.

2.3 Ultrasound wave propagation analysis
As ultrasound wave enters the tissue and hit tissue boundary, part of its wave will be reflected and another part of the wave will be further transmitted. The amount of reflected and transmitted ultrasound wave intensity is calculated using the following formula:

% Reflection: \( \left( \frac{Z_t - Z_r}{Z_t + Z_r} \right)^2 \times 100 \)

% Transmission: 1 - % Reflection

Inside a particular tissue layer, the transmitted ultrasound intensity is further reduced due to to attenuation process in that layer. Attenuation was calculated using the following formula:

\[-dB=10 \log(I_0/I)\]
where \( I_0 \) is the initial wave intensity when ultrasound enters a particular layer and \( I \) is the intensity at the end of that layer.

These calculations were repeated every time the ultrasound wave passing through different layer of tissue to calculate the spontaneous ultrasound intensity at each layer.

As instantaneous ultrasound intensity is known from the ultrasound wave propagation analysis, that instantaneous intensity is converted to instantaneous pressure at each layer following the equation: \( P = p^2/Z \).

Then, the instantaneous pressure value for 10 seconds is calculated. The magnetoacoustic voltage that rises in the system can be further estimated using Equation (6) with \( B_0 \) equals to \( 0.1T \), beamwidth of \( 0.0254cm^2 \).

### 3. Result and Discussion

The developed Hybrid Magnetoacoustic method produced 2 outputs, the ultrasound echo from the ultrasound transducer and the magnetoacoustic voltage that rises due to the interaction between acoustic and magnetic energy.

The ultrasound echo carries information with regards to tissue mechanical property such as tissue density and tissue acoustic attenuation. Figure 6 shows the intensity of ultrasound echo from the calculation. At layer 5, it can be observed that breast carcinoma reflects high percentage of echo compared to simple cysts. This is because breast carcinoma has larger acoustic impedance (density and speed of sound) mismatch with its adjacent tissue compared to simple cysts. This observable fact makes simple cysts always appear hypoechogenic in B-Mode ultrasound due to a low reflection echo profiles. On the other hand, normal tissue model produce zero reflection at layer 5 since there is no tissue boundary as layer 4 and 5 is consists of the same tissue.

Figure 7 shows attenuation scale of the tissue models. From the calculation, it is obvious that normal tissue model highly attenuates acoustic wave followed by breast carcinoma and cysts.

The second output collected by the system is the magnetoacoustic voltage. As shown by Figure 8, the calculation agrees well with previous

<table>
<thead>
<tr>
<th>Tissue</th>
<th>α reference value (dB/cm/MHz)</th>
<th>α calculated value (dB/2 mm/10MHz)</th>
<th>Acoustic Impedance ((Z) ) Mrayl (s )</th>
<th>Conductivity ((\sigma) ) S/m</th>
<th>Density ((\rho) ) kg/m(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gel</td>
<td>2.17e-3 @2 MHz [8]</td>
<td>2.17e-3</td>
<td>1.482 [8]</td>
<td>5.5e-6 [10]</td>
<td>1.00 [8]</td>
</tr>
<tr>
<td>Skin</td>
<td>0.06 @ 1MHz</td>
<td>0.12</td>
<td>1.61 [14]</td>
<td>0.11 [7]</td>
<td>100 [0]</td>
</tr>
<tr>
<td>Subcutaneous Fat</td>
<td>0.738 @ 10MH z [9]</td>
<td>0.147</td>
<td>1.327 [8]</td>
<td>2.3 [12][11]</td>
<td>928 [8]</td>
</tr>
<tr>
<td>Mammary gland</td>
<td>0.758 @ 1.5MH z [8]</td>
<td>1.540 [8]</td>
<td>2.3 [12][11]</td>
<td>102 [0]</td>
<td></td>
</tr>
<tr>
<td>Simple Cysts</td>
<td>2.17e-3 @2 MHz [b]</td>
<td>2.17e-3</td>
<td>1.482 [8]</td>
<td>5.5e-6 [10]</td>
<td>1.00 [8]</td>
</tr>
<tr>
<td>Thoracic Wall</td>
<td>3.54 @ 1MH z [8]</td>
<td>7.08</td>
<td>6.364 [8]</td>
<td>0.09 [11]</td>
<td>199 [0]</td>
</tr>
</tbody>
</table>

Table 1: Acoustic and Electric properties of breast tissues.

### 2.4 Conductivity and voltage analysis

The amplitude of voltage that rises due to ultrasound wave and magnetic field interaction is calculated using equation (6) from the z axis.
research in impedance imaging, in which the amplitude of collected voltage is in the order of milivolt [1-5]. Negative voltage amplitude indicates that the current tissue layer is less conductive compared to the next layer and positive voltage amplitude is produced when the current layer is more conductive than the next. Since magnetoacoustic voltage produced by the system is proportional to conductivity difference between adjacent tissue, it can be seen from the voltage graph that, mice breast tissue that models the carcinoma producing a negative voltage amplitude at layer 4 because carcinoma has higher conductivity then the mammary gland at layer 3. At layer 5, positive voltage amplitude is produced since muscle at layer 5 is also less conductive then the carcinoma layer at 4. Cysts, on the other hand produce moderate voltage amplitude due to large difference between conductivity of water (in the order of micro S/m) with its adjacent tissue (in the order of mili S/m) whilst normal breast producing lowest voltage amplitude.

![Fig 7: Attenuation scale of the ultrasound wave in different mice breast model](image)

![Fig 8: Magnetoacoustic voltage produced at tissue boundaries](image)

The acoustic and electric properties of the breast tissue models calculated in this study are summarized in table 2. From the table, it can be observed that Hybrid Magnetoacoustic Method is capable to give unique characteristics for the tissue models.

![Fig 6: Intensity of the ultrasound echo](image)

Table 2: Observed acoustic and electric properties of the mice breast tissue models from the calculation.

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Acoustic properties</th>
<th>Electric properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>High attenuation level</td>
<td>Very low voltage amplitude</td>
</tr>
<tr>
<td>Carcinoma</td>
<td>Moderate attenuation level</td>
<td>Very high voltage amplitude</td>
</tr>
<tr>
<td>Cysts</td>
<td>Low attenuation level</td>
<td>Moderate voltage amplitude</td>
</tr>
</tbody>
</table>

However, this calculation is done on a homogenous tissue layer model. In the case of heterogenous tissue layer such as in invasive
breast carcinoma that boundaries between tissue layers is no longer distinctive, the ability of this method is not yet predicted. Modification on calculation set up and procedure such as the used of focus ultrasound beam to increase a localize pressure, give a more localize ultrasound echo and more localized magnetoacoustic voltage maybe used for better signal localization in heterogenous media.

4. Conclusion

Quantitative analysis on the output of Hybrid Magnetoacoustic Method for detection of normal and pathological breast tissues have been completed. 3 mice breast tissue model representing normal, breast carcinoma and simple cysts were used. The calculation shows that, normal and pathological breast tissues produced distinctive characteristics that can be further manipulated for breast tumor detection.

References: