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Development of a New Tool for Better Imaging of High BMI Patients

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Abstract

Ultrasound of obese patients does not produce clearer image results as compared to that of patients with normal Body Mass Index (BMI). This is because the fat molecules are tightly packed and do not leave much space for anything to pass through. The aim of our study is to tackle this fat temporarily via External Ultrasound Assisted Liposuction (XUAL) technique and make room for ultrasound waves to pass as much as possible. An ultrasound signal was fed to 3 different types of medium having the properties of: soft tissue, solid human body fat, and liquefied fat. The signal strength in fat decreases considerably throughout the wave propagation as compared to soft tissue. Whereas in liquefied fat, the signal strength does not reduce to such level rather it resembles to soft tissue. Thus it was shown virtually that when, practically, a transducer probe with both the ultrasound and XUAL properties will be made, it will yield better results for high BMI patients.

Keywords: External Ultrasound Assisted Liposuction, Fat, k-Wave, Liquefied Fat, Obese, Soft Tissue, Signal, Transducer, Ultrasound, Wave, BMI

1. Introduction

Ultrasound is a technique used for the imaging of different parts of the body while XUAL is used for the removal of excess body fat (adipose tissue). In our work, we have combined these two techniques to develop a new probe which can produce better imaging results of patients having very high BMI.

1.1 Literature Review

The most practical and commonly used definition of obesity is a Body Mass Index (BMI) greater than 30 kg/m[2,1]. If there's a thick fat layer over the abdomen then it gets difficult for ultrasound beam to penetrate and reflect back with enough intensity to be recorded as meaningful information. The imaging specialist plays a crucial role in the management of the obese pregnant woman. The vital areas such as anatomical development evaluation of the fetus, fetal well-being observation and the utero-placental insufficiency, Estimation of Fetal Weight (EFW) and managing the imaging options for maternal complications that may occur during pregnancy or the postpartum period. Although ultrasound is always the preferred choice for imaging study but the imaging specialist must judge whether the problems associated with an obese body requires an advanced or different imaging techniques such as Magnetic Resonance Imaging (MRI)[2,3]. In such cases comprehensive knowledge of ultrasound image optimization parameters, better algorithms, and improved software/hardware options may be helpful to transform these suboptimal examination into a diagnostic evaluation. It is also important to communicate to obese pregnant patients the reality of the limitations of an obstetrical ultrasound evaluation. The sonographer must also be aware of the fact that the scan may be difficult or impossible to complete. Data collected for over 8,000 women showed that detection → rates → of → cardiac → anomalies → were significantly lower and the missed diagnosis rate was significantly → higher → in → obese women[4]. Investigators in the United States[5,6] have

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shown poor visualization rates ranging from 20% to 50% in obese women at the time of fetal anatomic scanning in the second trimester, it is mostly related to cardiac and spinal structural disorders. There are certain methods available like postural manipulations and endo-vaginal scans. The later one is painful and very few experts are available in this domain in our region. Most importantly in Pakistan women are also reluctant to have such scans.

We plan to design an ultrasound probe that can provide better imaging. This modality should be non-invasive, easy for technicians and as safe as any other clinical ultrasound.

1.2 Summary

The rapidly growing global problem of obesity is one of the many risk factors in obstetric care. Almost 40% of pregnant women fall into a high-risk category because of this specific problem. It has been evaluated that how obesity affects the quality of patient care in terms of the limitation in completion of fetal well-being imaging, organs like kidney and cardiac development surveys and techniques that may improve imaging quality and ensure patient safety.

The researchers suggest that an urgent need is there to refine the ability to detect those fetuses at greatest risk for stillbirth[7] and growth restriction and to understand the potentially multigenerational impact of maternal obesity. Utilization of emerging technologies such as laser Doppler, evolving MRI technology, and expanded roles for ultrasound will become increasingly important[8].

External UAL delivers ultrasonic energy to subcutaneous fat by means of applying a paddle-shaped instrument directly to the overlying skin. It soon became apparent that external UAL provided no benefit, and it is now rarely used. This might be a positive point for our project. Since its not useful that means it's not that destructive. Our goal is to tackle the fat not to remove it. So XUAL may be used just to temper the fat characteristics spatially and temporarily. So that it becomes supportive for the ultrasound beam and let it pass through to bring back stronger signal for imaging.

It may also be combined with laser liposuction principal to make it even safe and effective. The proposed method may be a series of transmitted beams in such a way that first should tackle fat (XUAL) followed by a conventional B Mode imaging ultrasound beam.

1.3 Objectives

- The primary objective is to find solution for better imaging of high BMI patients.
- To investigate the temporal and spatial impact of XUAL in mitigating the fat layers of the body.
- To design the protocol for imaging; combining the XUAL and B mode imaging.
- To physically implement the designed protocol after respective approvals and IRBs (if possible).
- Compare the results in terms of quality of image with and without the specially designed protocol.
- Cost effective health care modality based on indigenously developed technique.

2. Modelling and Simulation

Wave is an open source acoustics toolbox for MATLAB. It is designed for time domain acoustic and ultrasound simulations in complex and tissue- realistic media. The simulation functions are based on the k-space method and are both fast and easy to use[9].

2.1 Input signal

To drive transducer, a single input signal is used with the beamforming delays. It creates a single frequency sinusoid windowed by Gaussian with the specified number of cycles.
In the direction of transducer, the input signal is allocated to particle velocity. Subsequently, rather than in units of pressure, input signal needs to be scaled in units of velocity[10]. Table 1 shows the properties used to derive the transducer.

Table 1. Properties of input signal

Source strength	1 MPa
Tone burst frequency	0.5 MHz
Tone burst cycles	5

2.2 Transducer

Sizes are set in units of the grid points (values of the kgrid.dy, kgrid.dx, and kgrid.dz), physical size is dependent. For flat transducer, radius variables should be fixed to infinity. Inside computational grid, front face of the transducer is directing towards positive x-axis. Position of transducer inside grid is set using position field that describes position of adjacent grid point associated to transducer comparative to grid origin[10]. Table 2 shows the properties of the designed transducer.

Table 2. Properties of transducer

Number of elements	72
Active elements	21:52
Width of one element	1
Length of one element	12
Spacing between two elements	0
Radius of curvature of transducer	Infinity
Position of transducer	Centre of medium

2.3 Medium

The discretization of the medium is done by creating an object that contains the grid coordinates and matrices of wave number used in simulations of k- wave. The total grid points in x, y and z coordinates, as well as the spacing between them in each direction are used for computing the discretization.

The speed of sound speed is a matrix with dimension that of the computational grid. The acoustic absorption power law values are used to define the absorption properties of the medium.

The functions used for the propagation of waves in fluid medium require four input structures: the material properties of the medium, the properties of the computational grid, and the properties and locations of the sensor points, the properties and locations of any acoustic sources.

The density values for soft tissue and fat are 1000 and 950 g/m^3 respectively[11]. For liquefied fat the density value is 900±0.3 g/L[12]. The three basic equations[13] used for the propagation of sound waves through the medium are

1. Momentum conservation

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho_0}\nabla\rho$$

2. Mass conservation

$$\frac{\partial \rho}{\partial t} = -\rho\nabla_0 . u$$

3. Pressure Density relation

$$p = c_0^2\rho$$

u = acoustic particle velocity
ρ_0 = ambient density
ρ = acoustic density
p = acoustic pressure
c_0 = isentropic sound speed

3. Results and Discussion

When the sound wave propagate through the medium (soft tissue/fat/liquefied fat), the results were shown in the form of signal strength at three different positions in the medium.

- Figure 1 and 2 show the output results when the wave is passed through a medium having properties of soft tissue. In Figure 1, the three wave forms are from three different sensors placed in the medium. The sensors are placed at equal distance from each other. The first sensor is placed close to the top of the medium, second in the middle while third is close to the bottom of the medium. Figure 2 shows the peak amplitudes of the wave at these sensor positions. As the wave propagates through the medium, the amplitude strength of the ultrasound wave is shown at three different positions.
- Figure 3 and 4 show the output results when the medium is designed using solid human body fat properties. Comparing Figure 1 and 3, it can be seen that the signal strength (amplitude) in the fat medium reduces considerably as compared to that in the soft tissue medium. Also the time taken for the wave to reach at the sensor three positions is more than in the soft tissue medium. Comparison of Figure 2 and 4 shows the decrease in amplitude. The decrease in the amplitude results in poor imaging.
- Figure 5 and 6 show the output results when the medium is a having the properties of liquefied fat. When we compare Figure 1 and 5, we can see that the results at the different sensor positions are almost the same; while comparison of Figure 3 and 5 shows that the amplitude strength in liquefied fat is more as compared to that in solid fat. Comparing Figure 2, 4, and 6 shows that the peak amplitudes of waves at three different positions in fat is less than that in both soft tissue and liquefied fat

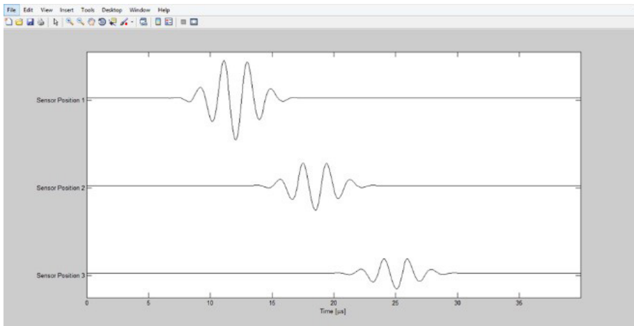

Figure 1. Signal amplitudes identified by three sensors placed at three different positions in soft tissue medium.

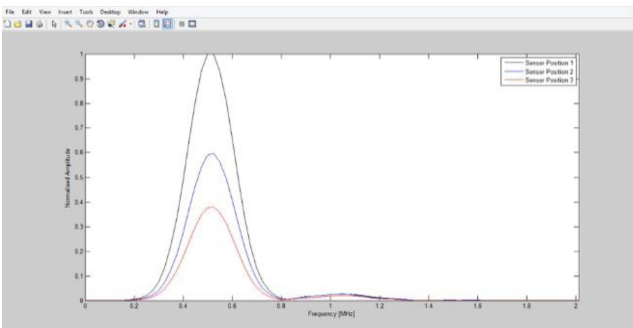

Figure 2. Peak amplitudes of the wave identified by three sensors placed at different positions in soft tissue medium.

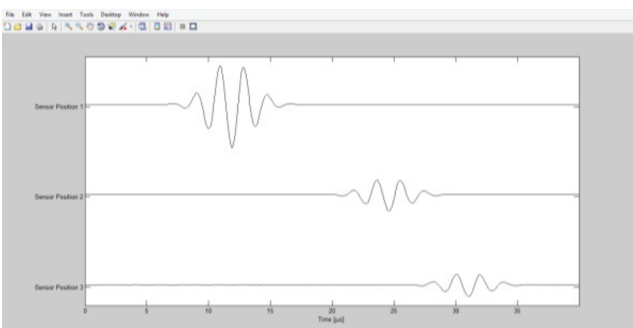

Figure 3. Signal amplitudes identified by three sensors placed at three different positions in fat medium.

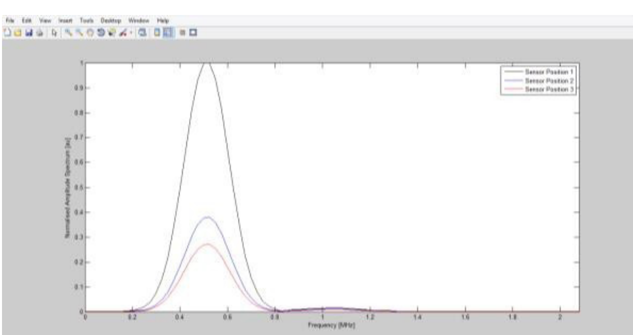

Figure 4. Peak amplitudes of the wave identified by three sensors placed at different positions in fat medium.

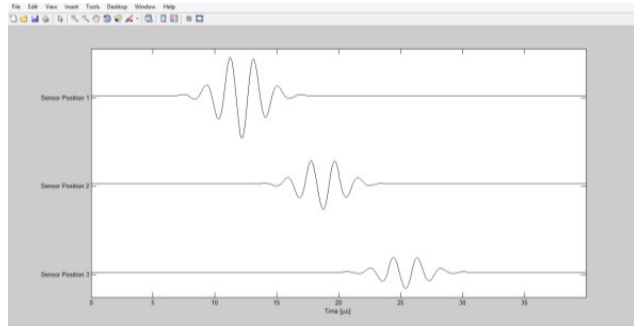

Figure 5. Signal amplitudes identified by three sensors placed at three different positions in liquefied fat medium.

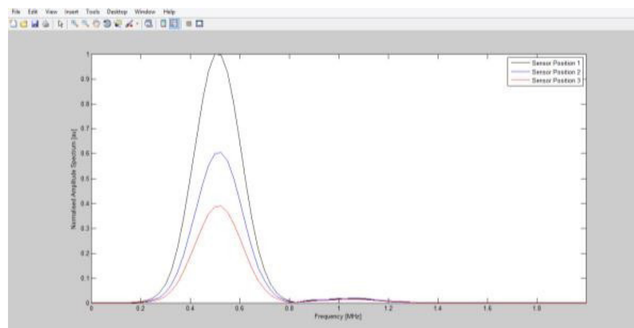

Figure 6. Peak amplitudes of the wave identified by three sensors placed at different positions in fat medium.

4. Conclusion

The temporary liquefaction of fat can help the ultrasound beams to penetrate deeper without the loss of much of signal strength.

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