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A visual comparison between the Ultrasound X6-1 Matrix transducer and MRI in lesion detection in the dome of the liver

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Thesis

A VISUAL COMPARISON BETWEEN THE
ULTRASOUND X6-1 MATRIX TRANSDUCER AND
MRI IN LESION DETECTION IN THE DOME OF THE LIVER

by

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ULTRASOUND X6-1 MATRIX TRANSDUCER AND
MRI IN LESION DETECTION IN THE DOME OF THE LIVER
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ABSTRACT

Imaging the dome of the liver can be a very challenging area to image by Ultrasound. Due to its position inside the ribcage there can be difficulty with rib shadowing artifacts causing the sonographer to miss small lesions. The X6-1 Matrix transducer is one of the newest of its kind and claims to be the better multi-use transducer. Its larger aperture reduces rib artifacts and is composed of PureWave Crystal Technology. A phantom will serve as a great approach in this abdominal study to visually compare the lesions between MRI (gold standard) and the new X6-1 Matrix Ultrasound transducer. The X6-1 transducers did reveal minimal rib shadowing and the small lesions were identified.
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LIST OF ABBREVIATIONS

DWI: Diffusion Weighted Image

\( \gamma \) (Gamma): Gyromagnetic Ratio

GE: General Electric

MRI: Magnetic Resonance Imaging

MHz: Mega Hertz

\( \omega \) (Omega): Larmor Frequency

PDW: Proton Density Weighted Image

RF: Radio Frequency

Rayl: Unit of Acoustic Impedance (Ultrasound)

T: Tesla (MRI)

TR: Repetition Time

Z: Acoustic Impedance
Introduction

The dome of the liver can be a very challenging area to image by Ultrasound since it sits inside the rib cage. When imaging this region with the C5-1 transducer on the Ultrasound, the sonographer has a difficult time imaging due to the rib shadowing effect. Therefore, if there are lesions in this region, it often goes unnoticed until it grows to a larger and more problematic size for the patient. Currently, lesions less than 5mm cannot be seen by Ultrasound and two thirds of lesions larger than 5mm can only be located by Ultrasound as a secondary imaging modality.¹ This is the case especially in obese patients as their fatty layer also causes a shadowing effect. When this occurs, most patients are sent to either Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). MRI is much safer than CT, in that, it does not use ionizing radiation, but radio frequencies; thus, making MRI the gold standard in imaging soft tissue. Since many patients are claustrophobic and there is a much larger cost and time involved in getting an MRI, Ultrasound Imaging has shown to be a growing field. Usually when the patient has a choice between Ultrasound and MRI, nearly all patients would choose Ultrasound because of comfort, ease, time, and cost. Recently, there has been a new Ultrasound transducer, X6-1 matrix, claiming it is the better multi-use transducer in Ultrasound over the C5-1 transducer.

In this study, a phantom was made for abdominal imaging. This phantom simulates the liver region composed with lesions for detection purposes. These lesions were embedded in 3% Agarose gel that suggests the liver. A layer of gel was placed each subsequent layer to represent the muscle and fatty layer, respectively. The bones were
simulated by Barium vials. These layers of the phantom were tested for both imaging modalities, Ultrasound and MRI, where images reflected excellent clarity and design. The phantom’s integrity and purpose truly showed it was design-specific for the area of interest.

**Background**

**Ultrasound:**

The Philips X6-1 Matrix is the world’s first 2D array specifically designed for abdominal and OB applications, with the largest 2D aperture and highest resolution in the family of Matrix transducers. The X6-1 Matrix has a large aperture that delivers near isovoxel imaging resolution. 2D imaging on this transducer offers a 100° field of view, whereas volumetric imaging is 90 x 90°. This large aperture and field of view provides for excellent intercostal imaging and reduces rib artifacts. The X6-1 Matrix Transducer is composed of PureWave Crystal Technology, where its general purpose is abdominal, obstetrical, fetal echo, and gynecological applications.

An important ultrasound property of any tissue or material is acoustic impedance \( Z \) which is the product of sound velocity \( (v) \) and density \( (\rho) \) in the material. This can be stated in the following equation:

\[
Z = \rho \times v
\]

The units of acoustic impedance is referred to as a Rayl and is also independent of frequency of the material range. Air and lungs have very low acoustic impedances, bones
have high acoustic impedance, and piezoelectric crystals have much higher acoustic impedances than bone. The difference in these values at the interface determines the energy that is reflected back at the interface.³

Piezoelectric transducer elements are responsible for delivery of Ultrasound Energy into the scanned region of interest and then to convert the returning sound echoes into electric signals. The image quality depends on the elements’ coupling efficiency to convert electrical energy to mechanical energy. PureWave crystal material is more uniform and exhibits fewer defects, lower losses, and no gain boundaries. Compared to conventional transducer material, the PureWave crystals are purer, more uniform, and lower losses and are able to transfer energy with greater precision and efficiency. PureWave crystals achieve significant additional gains in bandwidth and sensitivity. When able to gather, process, and display more diagnostic information results in images of remarkable clarity and fine detail with greater uniformity throughout the entire image field.⁴, ²

Figure 1 shows the comparison of traditional broadband technology to the PureWave crystal technology for harmonic applications.⁴
PureWave crystal and technology provides significant benefits in both tissue and contrast harmonic applications. Lower frequency from the PureWave crystal technology has brought transducer design technology to a new level. PureWave crystal technology provides dramatic improvements in the efficiency, sensitivity, and bandwidth of Ultrasound transducer.4

The conventional transducer has a 1-D array with 128 elements; whereas, the X6-1 Matrix transducer has 9,212 elements of PureWave Crystals each with its own microbeamformer and 8 million transistors.5,2

The X6-1 PureWave matrix transducer features xPlane, which allows imaging in two planes simultaneously, without manually rotating the transducer. Since you no longer have to rotate the transducer to see the second plane, you do not risk losing a tiny object during manual rotation. Clinical trials have shown that xPlane speeds workflow, improves imaging precision, and has the potential to minimize repetitive stress injuries.6

MRI:

Magnetic resonance (MR) is based on the interaction between an external magnetic field and a nucleus that has spin. Nuclear spin is one of several intrinsic characteristics of an atom where its value depends on the atom’s composition. The nucleus is thought of to be constantly rotating about an axis at a constant rate. This self-rotation axis is perpendicular to the direction of rotation. When a nucleus is constantly rotating with a positive charge, this produces a magnetic field parallel to the axis of rotation. This is analogous to a bar magnet where the magnetic field is thought to be oriented from the south to the north pole. MR measurements are made not based on an
individual proton, but on a collection of similar protons. When the tissue is placed inside a magnetic field, $B_0$, the individual protons begin to rotate, or precess, about the magnetic field. Here the protons are tilted slightly away from the axis of the magnetic field, however, the axis of rotation is parallel to $B_0$. This precession occurs because of the interaction of the magnetic field with the precessing positive charge of the nucleus.\(^7\)

The rate or frequency of precession is proportional to the strength of the magnetic field and is expressed by the Larmor equation:

\[
\omega_0 = \gamma B_0
\]

The Larmor equation describes the dependence between the magnetic field, $B_0$, and the angular precessional frequency, $\omega_0$, where $\gamma$ is the gyromagnetic ratio unique to each element.\(^7, 8\)

The Larmor frequency is directly proportional to the magnetic field strength. There Larmor frequency for 1.5Tesla MRI is \(~64\) MHz and \(~128\) MHz for 3TMRI. In clinical MR, protons have the highest Larmor Frequency at any field strength.\(^3\)

When protons are placed in a magnetic field, it produces a new magnetization that is parallel to the direction of the external magnetic field. Relaxation occurs when the protons release energy that was once absorbed from the radiofrequency (RF) pulse. Relaxation is necessary in MR for image contrast. During relaxation, protons release energy and return to their original state. Relaxation times are measured for gray matter and cerebrospinal fluid as a whole rather than for the individual water or fat molecules.
within the organs. There are two relaxation times that are measured: T1 and T2. Longitudinal or spin-lattice relaxation is known as T1 relaxation. This is the time it takes for 63% of the magnetization to recover in the tissue following an excitation pulse. T1 is long for Cerebral Spinal Fluid (CSF) and short in medium viscosity materials such as liver, kidneys, White matter, and grey matter, also in fat. Contrast agents (gadolinium-DTPA) shortens T1. A T1 weighted image is attained using short repetition time (TR) that uses T1 differences. Transverse or spin-spin relaxations is known as T2 relaxation. This is the time it takes for 37% of the signal to return to its initial value. This process is irreversible. Liquids have a long T2 and viscous materials (fat, liver, kidneys, and white matter) have short T2 times. MR signal is mostly acquired in echoes which are formed from transverse magnetization. These echoes occur at a certain time (TE), which can be either long or short. If the TE value is short, it will produce no difference in tissues with different T2 values. Short TE values are known to have minimal T2 weighting; whereas, long TE values that are greater than 60ms produce T2-weighted images.

A Diffusion Weighted Image (DWI) is obtained with structured details of tissues where diffusion depends on the random motion in water molecules in tissues. Proton density weighting contrast (PDW) is the difference in signal intensity between tissues. This contrast is achieved by reducing T1 recovery and T2 decay. Both longitudinal recovery and transverse decay uses long TR and a short TE. Typically, a PDW image has a low contrast leaving the contrast-to-noise ratio not better than T1 or T2-weighting image.
Materials

Materials were gathered and/or made in order to start making the phantom. These included 1.8L rectangular container, marbles (MRI and Ultrasound Compatible) for lesions (6mm, 5mm, and 4mm), Barium (Creamy Vanilla Smoothie, Readi-Cat 2, Barium Sulfate Suspension (2.1% w/v, 2.0% w/w), EZ-EM Cat # 7550) for bones, along with water and oil (Olive oil) references placed in 2 inch x 0.5 inch diameter 10ml capacity plastic screw cap vials, 1000mL Erlenmeyer Flask, hot plate/ stirrer combination, Ultrapure water (UltraPure water, Molecular grade), and Agarose (UltraPure Agarose, Invitrogen Cat# 16500-500).

Procedure/ Methods

Two sets of Barium vials were made (4 vials total) and two references: one vial with water, and the other with olive oil, 10mL each. The first gel was made to simulate the liver. This gel consisted of 3% Agarose. For this 400mL UltraPure Water and 12g Agarose was added to 1L Erlenmeyer Flask with a 1.5 inch magnetic stir bar and added to hot plate/ stirrer combination plate. This was placed on medium-high until solution boiled and Agarose dissolved completely and became transparent. With safe oven mitts, the flask was removed from the plate and gently swirled under cool tap water until warm to the touch. Solution was then added to 1.8L Capacity container to let solidify at room temperature. When gel has started to solidify, the reference vials were added to sit on the bottom of the container. Another 3% Agarose gel was prepared. Once the first gel has solidified completely, a small portion of the second gel was added to let semi-solidify. Then, the marbles/lesions were added (6mm, 5mm, and 4mm, respectively from head to
foot). These lesions were both MRI and Ultrasound compatible. When lesions were placed securely, remainder of gel was added and left at room temperature to solidify. A 1.5% Agarose gel was made in 400mL of Water. When second gel has solidified completely, half of the solution was added to let semi-solidify. The Barium vials/ bones were added, caps facing the outside of the container and perpendicular to the previous reference vials. When vials were place securely, the remainder of gel was added and left at room temperature to solidify. Another 3% Agarose gel in 400mL water was made. After the third gel had solidified completely, the solution was added and left at room temperature to solidify.

Figures 2a and 2b show the mid layer of the phantom with lesions, bones, and references already placed. The references, barium, and lesions were firmly embedded in the agarose gel.
**Ultrasound Imaging**

All Ultrasound Imaging was performed on Philips iU22 for X6-1 transducer, abdominal general parameters. Ultrasound gel was used to cover both the phantom and the transducer during imaging. The Phantom was placed on the bed analogous to a patient with proper orientation where images were acquired.

**MRI Imaging**

The Phantom was scanned on the 3T GE MRI using the standard head coil by GE. After the phantom was positioned, a reference scan was taken (as with patients) to ensure the landmark was placed correctly on the phantom. The scans that were acquired were T1 weighted, T2 weighted, Proton Density and Diffusion Weighted Images.

**Results:**

The images of the phantom were acquired by both imaging modalities, Ultrasound and MRI. The MRI images were attained on the 3T GE MRI where T1, T2, PD, and DWI were scanned. The Ultrasound images were attained on the iU22 Philips using the X6-1 Matrix Transducer where each lesion was scanned individually.
Figure 3 shows a sagittal view on T1 weighted contrast of the phantom showing all three lesions; 6, 5, and 4mm, respectively from head to foot. Matrix 320 x 224, slice thickness 4mm, and TR 563.
Figure 4 shows an axial view of a T2 weighted image of the phantom. This view shows the Barium (bones) as well as the other layers in the phantom. Matrix 320 x 256, slice thickness 5mm, and TR 4830.
Figure 5 is an Ultrasound image that was taken with the previous multi-use transducer, C5-1. This view was taken to show the rib shadowing effect that occurs when imaging the dome of the liver.
Fig 6 is an Ultrasound image taken with the X6-1 transducer showing the 6mm lesion is visible in the dome of the liver as it measures approximately 0.584 x 0.610 cm.
Fig 7 is an Ultrasound image taken with the X6-1 transducer showing the 5mm lesion is visible in the dome of the liver as it measures approximately 0.490 x 0.571cm.
Fig 8 is an Ultrasound image taken with the X6-1 transducer showing the 4mm lesion is visible in the dome of the liver as it measures approximately 0.379 x 0.463cm.

Discussion

Imaging the phantom with Ultrasound and visually comparing the lesions to the Gold Standard, MRI, revealed they are, indeed, visible. The main objective did reveal the lesions were visible; however, the accuracy was not visually comparable. Future studies should be done to quantify the lesions in both imaging modalities where a better representation will be revealed. As far as the measurements done on the Ultrasound, they did not seem as accurate as expected. The lesion size for the 6mm was measured at 0.584 x 0.610cm, for the 5mm lesion, the measurement was 0.490 x 0.571cm, and the 4mm
lesion was measured 0.379 x 0.463 cm. This shows the Ultrasound is able to detect lesions smaller than 5mm; however, calculating the size was not accurate. The X6-1 Transducer also revealed minimal rib shadowing over the Barium vials which proved to be a success over the previous C5-1 transducer. The limitations if this study in Ultrasound could have been related to user error, transducer malfunction, random handling by non-users of this transducer could result in damaging the crystal on the transducer array. There was also an upgrade of the Ultrasound scanners, which could have had an effect on the transducer’s reproducibility and clarity.

Conclusion

My results ideally prove that lesions less than 5mm can be seen with the new Ultrasound X6-1 Matrix transducer than previous studies; accuracy, on the other hand should be tested in future studies.
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