Validation of a Quantitative MR Method for Imaging Medical Ultrasound

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Abstract

Previously, Walker *et al.* [1] have described a magnetic resonance (MR) imaging method which enabled the non-invasive and quantitative mapping of medical ultrasound (US) fields in tissue. The purpose of the current work is to validate the quantitative accuracy of MR measurements against hydrophone measurements of ultrasonic pressure. This will lend credibility to the MR phase-contrast technique as a new primary method of measuring US fields whose accuracy is guaranteed without reference to external standards. Good agreement between the hydrophone and MR pressure measurements was found suggesting that this technique can be used to investigate US propagation phenomena such as elastic scattering, nonlinear effects, and for verification of theoretical models.

Introduction

The MR ultrasound imaging technique involved the application of a strong (40G/c*m*) magnetic field gradient resonant with the applied ultrasound frequency to detect the nanometer scale motions associated with the ultrasound [1]. Based on these measurements, a direct assessment of the absolute pressure and intensity of the US wave can be obtained from the measured displacements through knowledge of the US frequency, density of and speed of sound in the medium. This is similar to the phase contrast MR techniques used in elastography [2] except, here, imaged particle amplitudes are much smaller and oscillation frequencies are much higher. The goal of this study is to assess the accuracy of the ultrasound pressure measurement from the MR technique by comparison with measurements from calibrated hydrophone. These devices can make direct measurements of the pressure fields with minimal disturbance to the field; however, unlike the MR technique, quantitative values are only achieved after a calibration of the hydrophone against a reference standard.

Methods and Materials

MR: A specially designed apparatus with a strong (4G/cm), fast (515kHz) switching gradient [3] and single element transducer (515kHz centre frequency) was used with a 1.5T MR imager (Signa, General Electric Medical Systems). The ultrasound images were acquired using a standard spin-echo scan (TR/TE=1500ms/120ms, N_f/N_p= 512/80, FOV=12×6cm , slice thickness=5mm) at 10 voltages (30-175V_{p-p}) applied to the transducer. To encode the US motion, 48 000 cycles of motion encoding gradient were applied in a phase locked excitation with the US insonation.

US: The response of the same transducer at each of the MR image acquisition voltages was measured in a hydrophone tank with a calibrated bilaminar membrane hydrophone (Sonic Technologies Inc., USA) placed manually at the transducer's focus in degassed water. The transducer was excited with a 20 cycle pulse at 515kHz and the received signal was sampled at 500MSa/s for 1 million samples, read on an oscilloscope (LC574AL, LeCroy, USA), and captured over GPIB on a computer.

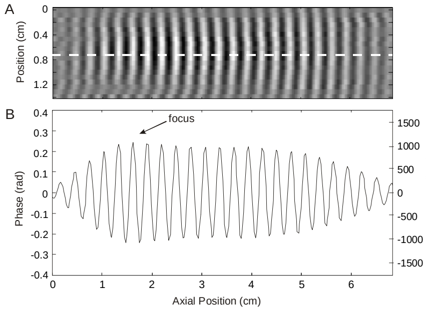

Figure 1. A) MR image of travelling US wave B) Profile indicated by the dashed line in A.

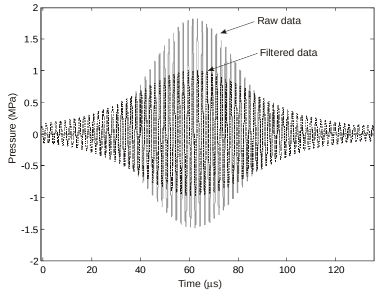

Figure 2. Raw and filtered US data as a function of time

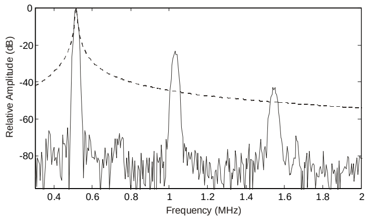

Figure 3. Fourier transform of US data (solid) and ME gradient frequency profile (dash).

Results

An MR ultrasound image of a travelling US wave and hydrophone measurement of an ultrasound pulse both taken at 173V_{p-p} are shown in figures 1 and 2 respectively. The Fourier transform of the ultrasound data is shown in figure 3 along with the frequency response of the motion-encoding gradient. The ultrasound data were found to have a larger frequency content than that of the MR data; thus, the frequency response of the motion-encoding gradient was applied for comparison of the hydrophone and MR data. The result of the filter is shown as the dotted line in figure 2. The peak of the filtered ultrasound hydrophone data is compared to the peak of the MR pressure data in figure 4 and demonstrates excellent quantitative agreement between the two methods

Discussion

These experiments illustrate that there is agreement, within experimental error, between the MR and hydrophone pressure values when experimental differences are accounted for. The overall uncertainty on the pressure values is estimated at 12% pertaining to error from the entire measurement process. The repeatability and accuracy of the MR measurements were found to be limited by the ability to measure the gradient amplitude. The slight underestimation of the MR data may be due to partial volume averaging the MRI data.

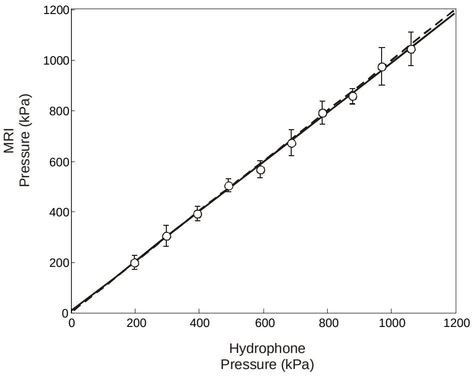

Figure 4. Comparison of mean of 3 MR and hydrophone pressure measurements. Solid line is the line of best fit through the data, dashed line is the ideal. Error bars reflect the standard deviation of the 3 data

Conclusion

This phase-contrast MR technique is still the only method that provides a non-invasive, three-dimensional assessment of the time dependent ultrasonic field in heterogeneous, optically turbid media. Unlike hydrophone measurements, MRI offers the advantage of requiring no external standards for calibration and is based on fundamental constants and a knowledge of the properties of the motion-encoding gradient. This opens the way to a new vehicle to study ultrasound biophysics.

References

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