Effects of Transmitted Phase on Echoes from Ultrasound Contrast Agents

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Abstract: Contrast-assisted imaging shows great promise for the imaging of microvascular perfusion, although current narrowband techniques cannot differentiate the echoes from tissue and ultrasound contrast agents and have limited spatial resolution. We have evaluated the potential for wideband contrast-assisted imaging through a systematic evaluation of the effects of imaging parameters on the received echoes. Here we present the effects of changing the phase of the transmitted wideband pulses. Specifically, we have found that when the phase of transmission is inverted, the polarity of the received bubble echo's time domain envelope is unchanged but a significant shift occurs in the mean frequency of the bubble echo.

INTRODUCTION

Current narrowband harmonic imaging techniques have difficulty differentiating contrast agent echoes from nonlinear components of tissue echoes. In addition, the transmission of a narrowband pulse degrades the spatial resolution achieved with these techniques. Our goal has been to discover optimal contrast agent detection schemes through the examination of echoes received from single bubbles for varying transmission parameters. Here we focus on the effect of transmitted phase, however the effects of transmitted pulse width and intensity were presented in (1). In (1), we demonstrate that the echo intensity received from contrast agents following wideband insonation is at least as large as or larger than that for narrowband insonation, therefore we consider wideband techniques which allow for improved spatial resolution. The echoes from a single-cycle transducer excitation with compression transmitted first (termed 0\(^\circ\)) are compared with the echoes from excitation with rarefractional transmitted first (termed 180\(^\circ\)) in order to determine the effect of transmitted phase. Through such a comparison, we have found two interesting effects which may prove to be useful in bubble detection. Specifically, we demonstrate that the polarity of the time domain envelope is unchanged by a change in phase. In addition, the mean frequency of the contrast agent echo is significantly shifted by the change in transmitted phase. Echoes from tissue, however, would not demonstrate the shift in frequency but would demonstrate a change in the polarity of the time domain envelope.

EXPERIMENTAL METHODS

A unique system is used that allows both optical and acoustical observation of single contrast agent microbubbles flowing through a phantom vessel. This system consists of two transducers mutually focused on 200 \(\mu\)m diameter cellulose tubing. One transducer is used to transmit pulses at a center frequency of 2.25 MHz and the other receives the signals scattered from bubbles in the vessel at 5 MHz. The phantom is also coupled to a microscope for optical viewing of the microbubbles. The transmitted pulses are generated using an arbitrary waveform generator and then amplified using an RF power amplifier. A broadband receiver is used to receive the echoes from the bubbles. A pair of single-cycle pulses with inverted phases is used to excite the transducer. The transmitted pulse pair is recorded by a needle hydrophone. Two contrast agents are used: MPl950, an experimental agent (Mallinckrodt, Inc., St. Louis, MO) with a phospholipid shell and Optison\textsuperscript{TM} (MBI, San Diego, CA) with an albumin shell.

RESULTS

In Figure 1, the transmitted pulse pair and a typical received echo are shown on the same time scale. The top trace shows the transmitted signal with the second pulse (180\(^\circ\)) an approximately inverted version of the first (0\(^\circ\)). So the 0\(^\circ\) transmission represents a large compressional half-cycle first while the 180\(^\circ\) transmission represents a large rarefractional half cycle first. The bottom trace shows the resultant echo received from a single contrast agent bubble. For both phases, the time domain envelope is very similar, with the first major peak being positive for each echo and the envelope consisting of a positive-negative-positive combination. In addition, the first major excursion in the bubble echo coincides with the transmitted rarefractional half-cycle for both phases.

For each phase of transmission, we have found that the echoes from individual bubbles are very consistent. In order to quantify this, signals similar to those shown by the lower trace on Figure 1 were used as templates and the
correlation of the bubble echoes with each template was calculated. For each of the two phase groups, the mean correlation was averaged. For MP1950, the mean correlation magnitude and standard deviation were $0.82 \pm 0.11$ and $0.93 \pm 0.03$ for the transmitted phases of $0^\circ$ and $180^\circ$, respectively.

The mean frequency was calculated for the received echo corresponding to the phase of each transmitted pulse. For MP1950 the results from over 350 received echo pairs are presented and for Optison the results from over 140 echo pairs are presented. The mean frequencies of echoes received from Optison for the $0^\circ$ transmission is 3.0 MHz and 3.8 MHz for the $180^\circ$ transmission. For MP1950, the mean frequency of echoes for the $0^\circ$ transmission is 3.4 MHz and 4.3 MHz for the $180^\circ$ transmission, thus demonstrating a slightly larger frequency shift for the more flexible lipid shelled agent. In Figure 2, the cumulative distribution of frequency shifts between pairs of pulses is presented for two signal-to-noise ratios (SNR). Figure 2 demonstrates that for the higher SNR, only 10% of the echo pairs received have a shift of less than 0.60 MHz and only 40% of the echo pairs received have a shift less than 1.03 MHz. If a frequency shift of 0.3 MHz is detectable by a given system, then 98% of the bubble echoes would be detected at a 14 dB SNR and 93% of bubble echoes would be detected at an 11 dB SNR.

CONCLUSION

The results presented here demonstrate that changing the phase of transmission produces two important effects that can be utilized in new bubble detection schemes. Specifically, we have shown that the time domain envelope of the echo from a single bubble is the same when the phase of the transmitted pulse is inverted. These time domain signals are very consistent, with the correlation between bubble echoes from the same phase transmission being high. We have also demonstrated that there exists a significant shift in the mean frequency of the received bubble echo. Thus, new bubble differentiation methods can utilize detection of the shift in frequency of the bubble echoes or use time domain correlation techniques.

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REFERENCES