Experimental Measurement and Numerical Modelling of Nonlinear Propagation in Biological Fluids.

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Abstract: The nonlinear pressure fields generated in three biological fluids (amniotic fluid, urine and a 4.5% human serum albumin solution) by a circular 2.25MHz transducer with a focal gain of 12 have been investigated experimentally using a flexible measurement facility and compared with numerical predictions.

INTRODUCTION

Medical ultrasound systems are capable of producing acoustic pressures that can result in significant nonlinear distortion in water. The numerical models that have been developed to model this nonlinear propagation have mainly been validated by experimental measurements made in water (1-3). The aim of this work was to study nonlinear propagation in three biological fluids (amniotic fluid, urine and a 4.5% human serum albumin solution) and compare the results with numerical predictions. In order to facilitate comparison linear measurements of the acoustic properties of the fluids were also made on the same samples.

METHOD

The experimental apparatus (Figure 1) enables a range of linear and nonlinear measurements to be made on relatively small samples (1 litre) of test fluids. The fluid is contained within extendible bellows which are sealed with two transparent mylar end windows. The bellows are immersed in a temperature controlled water tank that provides a short path for acoustic signals in to and out of the fluid. The system can be used in two modes. Firstly, low amplitude measurements of the attenuation in the fluid can be made by placing the membrane hydrophore at a fixed position and varying the proportion of the path through the test fluid. Secondly, the development of nonlinear distortion can be studied by attaching the hydrophone to the moveable end of the bellows and varying the propagation distance through the fluid. In this case a 2.25 MHz, 38 mm diameter transducer with a focal gain of 12 was used as the acoustic source. The numerical modelling was performed with a finite difference model based on the KZK equation (the Bergen Code) that accounts for nonlinear propagation, diffraction and attenuation (4).

FIGURE 1. Experimental arrangement and example results for low amplitude attenuation in amniotic fluid.
RESULTS

Figure 2 shows examples of the results obtained for nonlinear propagation in two of the three fluids, amniotic fluid and 4.5% human serum albumin solution. In each case the axial variation of the fundamental frequency, and the first 4 harmonics generated by nonlinear propagation, are shown as a function of distance along the transducer axis. In order to obtain the agreement shown it was necessary to allow for the non-ideal vibration of the transducer. The experimental data and theoretical predictions are in reasonable agreement, although the results for the higher harmonics in amniotic fluid in the focal region are not as good. This is attributed to alignment problems, which are more significant for the higher harmonics, and tend to reduce the experimental results.

These results show that it is possible to model accurately the nonlinear propagation through biological fluids (with a higher loss than water) given an adequate knowledge of the fluids' attenuation properties. The results indicate the potential of the model for predicting the pressures that may be encountered in clinical situations where experimental measurements are not possible. The measurements also indicate that it is possible to generate significant levels of harmonic distortion in these situations. The use of such harmonics for improving image quality has been investigated (5) and is being exploited by some manufacturers.

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