Detecting breast phantom lesions with acoustic radiation force in MR images: experiment and finite-element simulations

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Introduction

Acoustic radiation contrast (ARC) in MR phase images is a recently developed method to image and quantify non-invasively the viscoelastic properties *in vivo* [1,2]. It is well known that tissue elastic properties may be altered by tumors. Young's modulus of breast tumors may differ from surrounding tissues by a factor of 90-fold. The ARC-MR images may be helpful in the distinction of benign from malignant masses. To test the applicability and feasibility of ARC-MR, a commercially available breast phantom was investigated and finite-element simulations were performed. Combining measurements and finite-element simulations yields the elastic and acoustic parameters of the phantom.

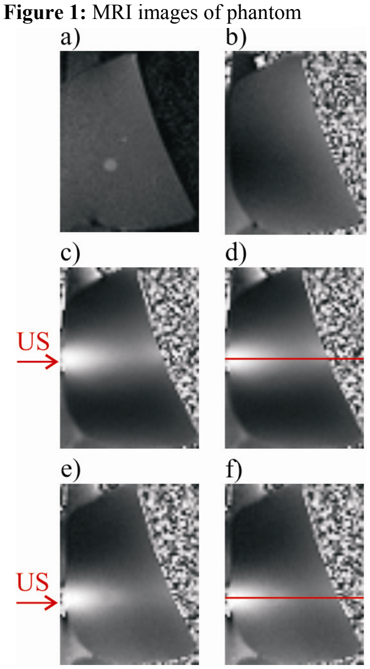
Methods and Materials

Ultrasound (US) waves with a center frequency of 2.5 MHz were coupled into the breast phantom with the focal plane inside it. The acoustic radiation force leads to a displacement of the material inside its path in beam propagation direction. The displacement can be calculated from the phase shift in the phase images according to [2]. It was measured using a modified spin-echo sequence with monopolar gradients added for displacement encoding (sequence parameters: T_E/T_R: 60/400 ms, monopolar gradient length and amplitude: 20 ms and 20 mT/m, voxel: 1.7x1.7x3 mm^3). The 20 ms US pulse was irradiated simultaneously with the second gradient pulse using external triggering. Intensities of 35 W/cm^2 were used and provided by a home-built MR-compatible piezoelectric transducer. The transducer had a diameter of 5 cm and a focal length of 22 cm. The phase images were acquired at a 1.5 T Magnetom Avanto scanner (Siemens Healthcare, Erlangen (Germany)) with a 4 channel breast coil (NORAS MRI products GmbH, Höchberg (Germany)).

The breast elastography phantom (CIRS, Norfolk, Virginia (USA)) accurately mimics the ultrasonic characteristics of tissues found in an average human breast. The lesions are three times stiffer than the background so they can be detected on elastograms [4]. A lesion of 0.9 cm diameter was investigated.

For the finite-element simulations (Marc Mentat, MSC Software Corporation, Santa Ana, CA (USA)) the parameters were adjusted to fit the measurements: US beam diameter: 0.4 cm, US pulse length: 20 ms, US intensity: 35 W/cm^2; geometry: cylinder with diameter: 4 cm, length: 6,4 cm; material parameters: elastic moduli: 10 kPa for the breast tissue [5] and 30 kPa for the lesion, Poisson's ratio: 0.495, density: 1 g/cm^3, absorption coefficient: 0.345 cm^{-1}.

Figure 1: MRI images of phantom



Results

Figure 1 a) & b) show a T_2-weighted amplitude image and a phase image of the breast phantom in sagittal plane without US; direction of displacement detection: A → P. The investigated lesion is located at a depth from 2.8 cm to 3.7 cm. Figure 1 c) shows the phase image with US incident from the left (red arrow), but not on the lesion. The displacement produced by the US is clearly visible as a lighter gray. Figure 2 shows the displacement in micrometers along a horizontal line in the phantom through the center of the US beam plotted against the depth in the phantom. Figure 1 d) shows the position of this line in the phase image (red line). A decrease of the displacement is visible in figure 2. In figure 1 e), the US is incident on the phantom at the horizontal location of the lesion. In figure 3, the displacement is again plotted against the depth in the phantom. The position of the lesion is highlighted by the gray rectangle. We can observe that the decrease of the displacement curve has a dip at the location of the lesion.

Figure 4 and 5 show graphs of the finite-element simulations with and without a lesion in the beam path, respectively. The simulations show good agreement to the measurements. The displacement decreases also in figures 4 & 5 and in figure 5, a dip is observable in the curve.

Discussion

This work presents the first detection of stiff lesions in a realistic breast phantom using ARC in MR phase images. In its present state, the proportionality between Young's moduli can be obtained with the adjustment of finite-element simulation parameters to experimental results. The detection performance can be enhanced by raising the US intensity. The spatial resolution is possible down to the wavelength of US (e.g. 0.7 mm at 2.5 MHz). A line-scan sequence is also a viable tool for displacement detection.

Figure 2: Phantom without lesion

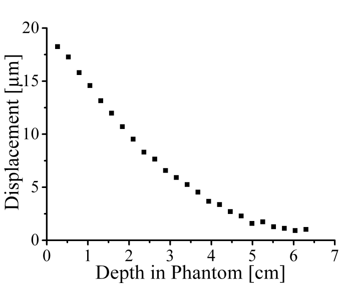


Figure 3: Phantom with lesion

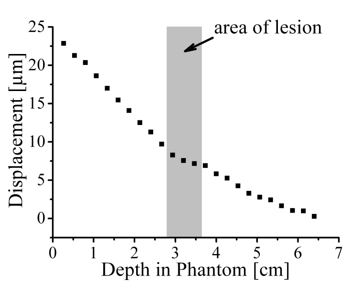


Figure 4: Simulation without lesion

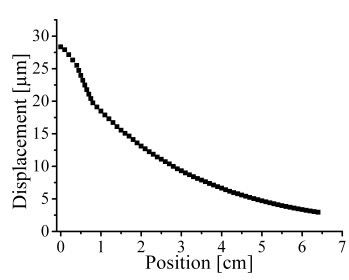
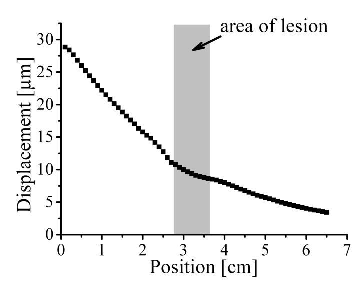


Figure 5: Simulation with lesion



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