Compression Effects in Breast MR Elastography

Jun Chen1, Kathleen Brandt1, Karthik Ghosh1, Roger Grimm1, Kevin Glaser1, Jennifer Kugel1, Kay Pepin1, and Richard Ehman1

1Mayo Clinic, Rochester, MN, United States

Introduction: MR Elastography (MRE) has shown promising results in differentiating breast cancer from benign tumors by measuring tissue stiffness [1-3]. Breast MRE measures tissue stiffness in three steps: 1) a mechanical driver (transducer) sends low-frequency probing mechanical waves into the breasts, 2) a MRE imaging sequence records the wave field in the breasts, finally 3) an algorithm is used to calculate breast tissue stiffness maps (elastograms) from the breast wave images. In conventional breast MRE, the driver requires compression of the breasts to maintain mechanical coupling for wave transmission. In the ultrasound literature, compressions have been documented changing substantially the patient breast tissue stiffness measured by both strain and shear wave elastography [7], but this compression effect in MRE has not been thoroughly studied. Since compression could be a significant source of measurement variation, the goal of this study was to assess the effects of breast compression on tissue stiffness measured by MRE in healthy volunteers. Our hypothesis was that breast tissue stiffness increases with breast compression.

Methods: (1) Subjects: Our Institutional Review Board approved the study. Four subjects without known breast disease underwent MRE (prone position, feet first) performed in a 1.5-T MRI scanner (GE, Signa HDxt, Wisconsin, USA). (2) Breast Compression: In this study, we used a commercial breast RF coil (Liberty 9000 8-ch. breast coil, USA Instruments, Inc., Aurora, OH), which included a set of biopsy plates (Fig. 1.6). The inside plate was fixed in the middle of the coil and the lateral plate was fixed on an adjustable positioning frame (Fig. 1.7). The lateral plate could be moved toward or away from the target breast by a measurable distance for the adjustment of breast compression. The displacement $d_0$ was determined by a desired compression rate, $d_0/d_0$, where $d_0$ was measured with the lateral plate lightly touching the breast (Fig. 1). We performed breast MRE three times: 1) prior to the compression, 2) with a 20% compression, and 3) after the compression was removed. (3) Breast Driver: We have developed a noncompressive breast MRE driver that does not require breast compression. It offers many advantages when compared with the conventional compressive drivers, as described in [4]. In this study, the noncompressive driver (2 x 0.6 x 22 cm, width x thickness x length), was positioned in between the subject’s sternum and the bridge of the breast RF coil. (4) MRE Imaging Sequence: We used a 3D 3-direction GRE MRE sequence similar to the one previously reported [4]. The parameters included vibration frequency = 40 Hz, FOV$_{x/y/z}$ = 32-38/32-38/6.4 cm, 13 cycles of motion per 12 TRs, motion-encoding gradient (MEG) amplitude = 2.8 G/cm, TR = 27.1 ms, TE = 22.7 ms (fat/water in-phase), flip angle = 15°, BW = 15.6 kHz, axial imaging plane, acquisition matrix = 96X96X20, reconstruction matrix = 256X256X16, SENSE acceleration factor = 2 (right-left), frequency-encoding direction = anterior-posterior, scan time = 4’34” (free breathing). (5) Calculation of Elastograms: The vector curl of the measured wave data was calculated using 3x3x3 derivative kernels [5]. A 3D local frequency estimation inversion was performed on the curl data with 2D directional filters (2-128 cycles/FOV) to calculate the volumetric elastograms of the two breasts [6]. Regions of interest were drawn in the adipose and glandular tissue for stiffness measurements.

Results: The 4 subjects in this study had an age range of 24 to 45 years, and body mass indexes (BMIs) ranging from 20.8 to 26.5 kg/m². Fig. 2 shows the stiffness of glandular tissue and adipose tissue versus the breast compression status for each individual subject. For the group, glandular tissue stiffness = 0.80 ± 0.09 kPa (prior-compression), 1.23 ± 0.22 kPa (with 20% compression), and 0.85 ± 0.15 kPa (after the compression was removed); adipose tissue stiffness = 0.52 ± 0.15 kPa (prior-compression), 1.06 ± 0.45 kPa (with 20% compression), and 0.58 ± 0.21 kPa (after the compression was removed). With 20% breast compression, glandular tissue stiffness increased by 53.8%, while adipose tissue stiffness increased by 103.8%. As expected, the stiffness of both tissues returned to the normal range after the compression was removed. Fig. 3 shows an example of the compression effect in one subject. Only the compression-tested breast changed its tissue stiffness significantly between the two MRE scans (prior-compression vs. 20% compression). Discussions and Conclusions: For the first time, this study has demonstrated strong evidence of breast compression effects on breast MRE stiffness measurements. The adipose tissue stiffness increased at a higher rate than the glandular tissue did with compression. Also, the adipose tissue under compression could be even stiffer than glandular tissue with or without compression (as in v13d, v13c). These findings are consistent with the observations in a breast cancer compression study done on patients using ultrasound elastography [7]. Therefore, true breast tissue stiffness can be measured only when there is no additional tissue compression, such as using the noncompressive breast MRE technique utilized in this work.

Acknowledgement: Diane Sauter, Jacqueline Holm, and Pamela Trester for assistance in performing the breast MRE exams.