Enhancing Mass Detection and Classification in Breast Tissue Using Strain-Encoded (SENC) MRI

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Introduction: Early detection of breast lesions using mammography has resulted in lower mortality rates. However, some breast lesions are mammography occult (e.g. dense breasts) and the use of magnetic resonance imaging (MRI) is recommended. MRI has high sensitivity and moderate specificity. Specificity can be increased by incorporating the tissue's stiffness, since masses are 3-13 times stiffer than normal tissue [1]. In this work, we use strain-encoded (SENC) MRI [2] to measure stain, which is inversely proportional to stiffness. We measure the tissues' compression and relaxation response after 10%-30% compression.

Fig.1: Phantom sketch diagram showing masses locations.

Methods: We used the hardware previously described in [3]. The hardware consists of two air-cylinders fitted to standard MR breast coils. We used typical SENC pulse sequence, with the tagging pulses in the slice selection direction and multi-shot acquisition. We operate our hardware in two different modes: compression resulting in SENC-CMP images and relaxation resulting in SENC-REX images. This is achieved by changing the position of tagging and acquisition windows relative to the compression cycle. To obtain SENC-CMP image, we tag the tissue at the normal position, then acquire images after the tissue has been compressed. However, to obtain SENC-REX images, we tag the compressed tissue then acquire images after the tissue has relaxed back to its normal position.

Materials: A custom made phantom was made out of gelatin with medium stiffness having four different groups of material to replicate masses. Groups A and B were stiffer than the background, while groups C and D were softer than the background. All masses were cuboids with 8mm thick and varying sizes (2-10mm) as shown in Fig. 1. We imaged a total of five ex-vivo breast samples from patients that underwent mastectomy. The ex-vivo samples were kept fresh in a 20°C freezer and allowed to thaw before scanning. After scanning, the samples were fixed with formalin and underwent histopathological analysis.
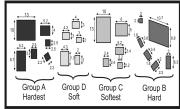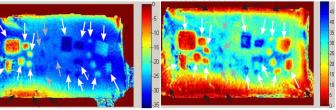

Fig.2: SENC-CMP (Left) and SENC-REX (Right) images of the phantom. White arrows point to masses of groups A, B, and C that are clearly visual, gray arrows point to masses of group D that are barley visual as it is very close to the background stiffness, black arrows point to image artifacts from imperfect compression.
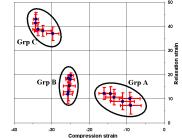
Experiments: We performed our scans on a 3T MRI Philips scanner (Philips Medical Systems, Best, the Netherlands) using a four-channel phased-array breast coil. Alls scans had FOV=192x192mm^2, in-plain resolution=1x1mm^2, slice thickness =5mm. We performed T1W scan (TR=495/TE=10ms) and T2W with fat suppressed spin echo scan (TR=2500/TE=60ms). SENC scans used segmented Cartesian K-space acquisition using TFE=10, EPI=3, $W_0=W_L=0.354$ mm^{-1}, $W_H=0.553$mm^{-1} for SENC-CMP and $W_L=0.4$mm^{-1}, $W_0=W_H=0.6$mm^{-1} for SENC-REX. This enabled us to measure strain ranges of 0 to -36% for SENC-CMP and 0 to 50% for SENC-REX. For visualization, we unified all color pallets such that masses that have low strain values would be colored in red, while normal background is colored in blue for both SENC-CMP and SENC-REX images. A reference SENC scan was performed without compressing. Masses were manually segmented and the masses' cross sectional area, signal-to-noise ratio (SNR), and elastography contrast-to-noise ratio (CNR$_e$) were calculated.

Phantom Results: Since the background and all the masses had almost the same T1, masses with most (group A) and least (group C) water concentration could barely be detected, while group B and D where completely invisible on the T1W image (not shown). SENC images acquired without compression did not show any signs of masses. This indicates that all the contrast in Fig.2 is only due to the difference in stiffness between the masses and the background. Visualization of most of the masses was noted in Fig.2; however, we failed to segment group D due to low CNR. Fig.3 shows the strain (mean±SD) for each of the masses, Groups A, B and C are easily clustered into three separated groups. For all masses, the cross sectional area estimated form SENC-CMP tends to be closer to the ground truth than those estimated from SENC-REX. SNR of T1W was high (300) relative to moderate SENC-CMP (70) and SENC-REX (53); however, CNR$_e$ of T1W was almost zero relative to high SENC-CMP (27) and SENC-REX (18).

Fig.3: Masses' strain (mean±SD) obtained from SENC-CMP (X-axis) and SENC-REX (Y-axis) images.

Ex-Vivo Results: Fig.4 shows ex-vivo breast sample with invasive ductal carcinoma imaged with different sequences. T1W and T2W images are mainly used for anatomical information; therefore the mass was barely identified distinguished from normal tissue (see white arrows in Fig. 4a and 4b). On the other hand, SENC with no compression (Fig. 4d) shows a uniform homogeneous image that is our reference point. Notice that the mass marked with a white ellipse in SENC-CMP and SENC-REX image stayed red indicating stiff tissue (Fig. 4e, 4f), while the rest of the tissue was compressed as indicated by blue color. Quantitative analysis of T1W could not differentiate between the mass and glandular tissue as both had similar intensities (514±30 vs. 502±40), while T2W had small separation (607±43 vs. 470±49), whereas, both SENC-CMP and SENC-REX images had large separation (-7.6±2.6 vs. -20.6±5.4 and 4.2±1.5 vs. 22.6±5). The rest of the ex-vivo samples showed no evidence of tumors on both SENC-CMP and SENC-REX images and histopathological confirmed no tumors.

Conclusion: We have demonstrated that by combining the compression and relaxation properties of the tissue, SENC was able to detect and classify tumors according to their stiffness. Our results show that SENC is sensitive enough to differentiate between both tumors that are stiffer and softer than the background. This will provide a new radiological biomarker for differentiating benign from malignant lesions in the clinical setting.

References: [1] Samani A. *et al*, Phys. Med. Biol. 52:1565 (2007). [2] Osman N. *et al*, MRM 46: 324-10 (2001). [3] Harouni A. *et al*, Academic Radiology. (in press 2011).
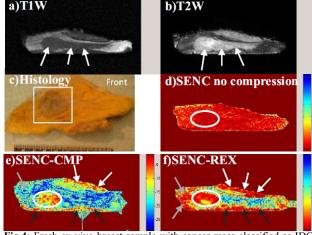
Fig.4: Fresh ex-vivo breast sample with cancer mass classified as IDC. a) T1W, b) T2W with fat suppression. White arrows points to low contrast between mass and normal glandular tissue. c) Histology result, white box indicates the mass. d) SENC with no compression having homogeneous strain throughout the breast. e) SENC-CMP, f) SENC-REX. White ellipse point to mass location. White arrows point to the muscle that appears stiffer than background. Black arrows, point to tissue stuck to the plate under the breast's own weight. Gray arrows point to image artifacts that appear stiff only on SENC-REX image.