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X-ray Elastography: A Feasibility Study

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Abstract—**We propose a new elastography method based on x-ray imaging. After taking two x-ray tomographic images of the breast-mimicking phantom with applying different compressing pressure to it, we calculated displacement and strain maps from the two images using a non-rigid body image registration. The strain maps showed elasticity characteristics of the phantom medium. We expect that the proposed elastography method can be incorporated into breast tomosynthesis or breast CT systems to detect early stage breast cancers.**

I. Introduction

BREAST cancer is the most frequently appearing cancer among women. To reduce mortality of breast cancer and related treatment cost, early screening of breast cancers is strongly recommended to women [1], [2]. Mammography has been the most widely used breast cancer screening device. It is capable of high resolution imaging with spatial resolution of 50-100 μm which enables detection of micro-calcifications, the early sign of breast cancer. However, mammography has limitations that it has high false positive ratio of breast cancer making the following diagnosis procedures, such as ultrasound imaging, MRI and biopsy, in vain. To gain high contrast of cancer tissues in breast imaging using ultrasound or MRI, many kinds of elastography methods were proposed. Ultrasound elastography [3]–[5] and magnetic resonance elastography (MRE) [6] utilize the physical phenomenon that mechanical pressure waves propagate faster in stiffer tissues. Cancerous tissues are known to have much higher stiffness than benign tissues. In both ultrasound elastography and MRE, cancerous tissues appear with much higher contrast in the images acquired with elastography than in the images acquired otherwise. It is expected that elastography might be used for breast cancer screening in the near future.

However, current elastography methods have many limitations for routine use in the clinical field. Ultrasound elastography suffers from low resolution and it is prone to strong artifacts. MRE has better spatial resolution than ultrasound elastography, but it also has strong artifacts. In addition, the mechanical oscillating device to be applied to the human breast to make shear waves inside the breast seems to be inappropriate for clinical use.

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In this paper, we propose a new elastography method based on x-ray tomographic images. Breast x-ray tomographic images can be obtained either by breast x-ray CT or breast tomosynthesis. Breast x-ray CT, a cone-beam CT consisting of a fine-focus x-ray tube and a 2D x-ray detector, can provide full 3D images of a breasts with higher contrast than mammography. Breast tomosynthesis can also provide 3D breast images, but its slice profile is not as good as breast x-ray CT since it acquires projection data in a limited angle [7]. However, recent development of deblurring techniques, such as filtered back-projection (FBP), matrix inversion tomosynthesis (MITS), and iterative image reconstruction techniques, has much improved slice profiles of breast tomosynthesis [8]–[10]. Based on the presumption that small strains in breast tissues caused by breast compression can be detected in x-ray tomographic images, we propose a new x-ray elastography technique.

II. Methods

A. X-Ray Imaging with Varying Compression Pressure

For elasticity imaging, we need to measure strains or velocities of the tissues of interest. Unlike ultrasound elastography or MRE where tissue velocities are mostly measured, x-ray imaging is unsuitable for measuring velocities due to its low sensitivity to velocity. Therefore, we try to measure strains from two x-ray CT images taken with different compression pressures as depicted in Fig. 1.

From conventional mammography images, it is difficult to calculate strains since 3D tissue structure is projected on the 2D image plane. To calculate strains, we need to acquire tomographic 2D images or 3D images. In this study, we presume that tomographic breast images are available through breast tomosynthesis or breast CT imaging.

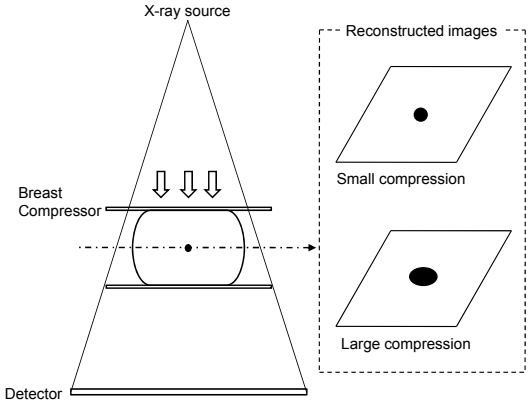

Fig. 1. A schematic diagram of x-ray elastography.

B. Strain Calculation

We presume that tomographic breast images have their particular spatial patterns to be used for image registrations between the two images taken with different compression pressures. Breast surface, mammary glands, malignant or benign tumors have their own unique shapes. When compressed, breast tissues will have different strains depending on their elasticity. We presume that breast cancer tissues would have less strain than normal tissues and the strain difference could be detected from the x-ray CT images of compressed breast.

We first calculate displacement maps from the two x-ray CT images taken with different compression pressures. To calculate displacements, we used a non-rigid registration algorithm using free-form deformation [11] and its Matlab tool which was coded by Kroon [12]. The non-rigid registration algorithm consists of global and local transformations. The global motion is modeled by an affine transformation, while the local motion is described by a free-form deformation based on B-splines. In the registration, the source image (less compressed image) and the target image (more compressed image) are first smoothed by Gaussian filtering for similarity measure between the two images. Then, the affine transformation is applied through translation, rotation, resizing and shearing of the source image. Finally, affine-transformed coordinates are calculated to match the source image to the target image and transformation grid is made through b-spline interpolation as shown in Fig. 2.

Displacement map, which represents the pixel displacement from the original position (x, y) in the source image to the final position (x', y') in the target image, is calculated as follows:

$$D(i,j) = \sqrt{(x_i' - x_i)^2 + (y_j' - y_j)^2} \ . \tag{1}$$

Strain is defined by the ratio of the expansion length to the original length as follows:

$$s = \frac{\Delta L}{L}. \tag{2}$$

Strain maps are calculated as follows:

$$s_x(i,j) = (x_{i+1}' - x_i')/\Delta x \tag{3}$$

$$s_y(i,j) = (y_{i+1}' - y_i')/\Delta y \tag{4}$$

$$s_{xy}(i,j) = s_x + s_y \tag{5}$$

where s_x and s_y are the x- and y-directional strains, respectively, and s_{xy} is the total strain.

C. Experimental Setups

To figure out the feasibility of the proposed method, we made a breast mimicking phantom as shown in Fig. 3. In a solid epoxy base, we inserted clay spheres and agar branches soaked into the contrast agent (Omnipaque 300, GE Healthcare). The solid epoxy base mimics the entire breast and the agar branches mimic breast tissues as mammary glandular tissues on a slice defined by the breast tomosynthesis or breast CT. To mimic high stiffness cancerous tissues, we put clay spheres in an epoxy base before the solidification of epoxy. We observed that the clay sphere region was less deformative than the other tissues when the solid epoxy base was compressed.

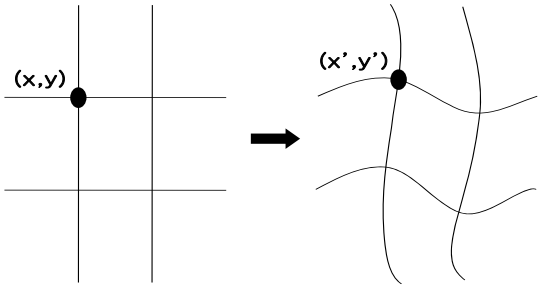

Fig. 2. The initial source grid (left) and the target grid (right) calculated by B-spline interpolation.

Fig. 3. The breast mimicking phantom was consisted of a solid epoxy base, clay spheres mimicking tumors, and agar branches mimicking breast tissues as mammary glands.

We used a micro-focus x-ray source (L8121-21, Hamamatsu, Japan) having a focal spot of 5 μm. For the x-ray image acquisition, we used a CMOS flat panel detector (C7943CA-02, Hamamatsu, Japan) with the pixel pitch of 100 μm and matrix size of 1216 × 1220. The flat panel detector has a 200 μm-thick CsI:Tl scintillator which has columnar structure.

III. Results

Figure 4 shows the two selected CT images taken with two different compression pressures. The upper image was taken with no external compression and the lower image was taken with the compression made the longitudinal strain of 7 % with the displacement of 4mm. The CT images were taken with the tube voltage of 65.5 kV and tube current of 230 μA.

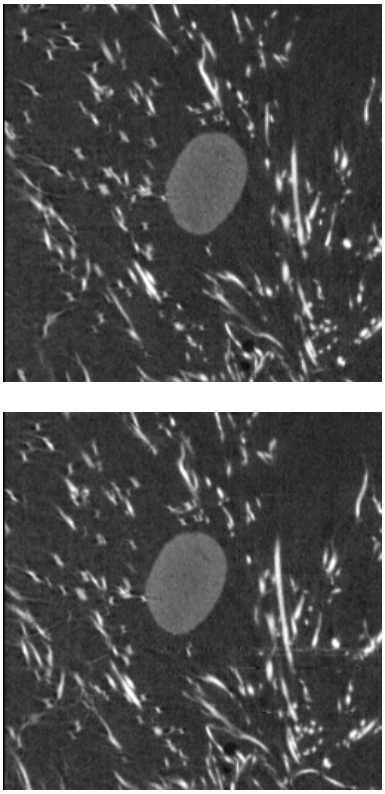

Fig. 4. CT reconstructed images of the phantom with less compression (top) and high compression (bottom)

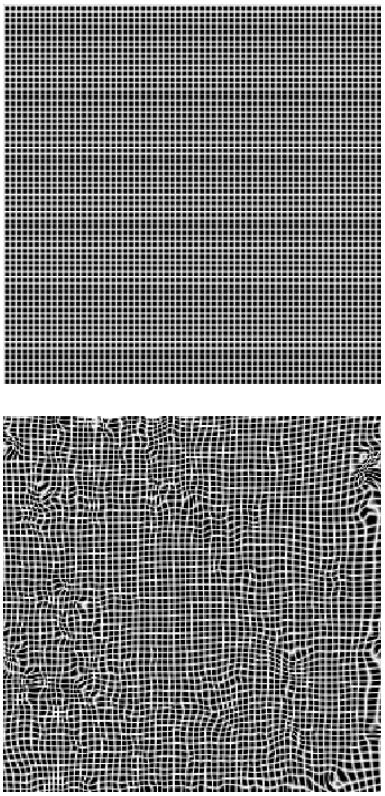

Fig. 5. The grids of source (top) and target (bottom) images

Figure 5 shows the grid maps of the source and target images obtained with the non-rigid body image registration tool. The number of grid points is 64 × 64. As can be seen from the reconstructed images, the clay sphere region shows less deformation due to high stiffness.

Figure 6 shows the displacement map. The right-bottom area shows small displacement since the compression force was not applied evenly to the phantom. The left and top edges have zero displacement because those areas of the source image are out of the interested areas of the target image.

Figure 7 shows the total strain S_{xy} map. Because of the difference operation in strain calculation, noise effects appear heavily. The clay sphere region shows less deformation than the background region due to the higher stiffness. The high strain appears mostly at the edges of the breast mimicking phantom.

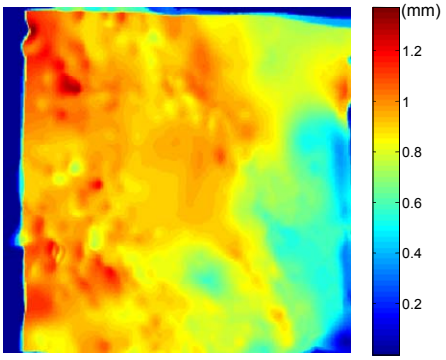

Fig. 6. The displacement map

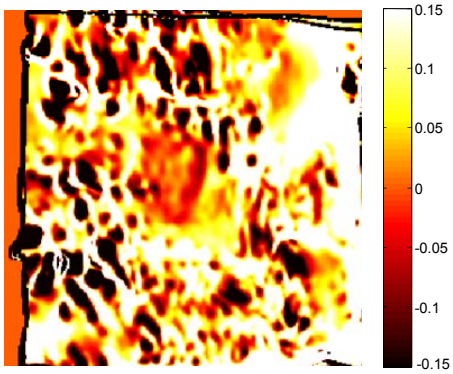

Fig. 7. The strain s_{xy} map

IV. Discussions

In this feasibility study, we used agar structures to mimic breast glandular structures in breast tomosynthesis or breast CT. However, the base phantom material of a solid epoxy has a relatively high elasticity as compared with the real breast tissues. We need more realistic breast phantoms which could be satisfactorily representative the mechanical properties of breast soft tissues. We are now developing 3D breast phantoms which have high stiffness compartments as well as breast tissue mimicking structures. Since x-ray CT elastography uses image registration techniques for strain

calculation, the phantom should have breast tissue mimicking spatial patterns in it. In this paper, we used only two different compressed images from a 3D phantom. We will calculate the strain and elasticity with full 3D CT images in near future. For more accurate diagnoses of breast tumors, we need to acquire 3D elastography. With the phantom, we plan to take 3D tomographic images using a micro-CT with varying compressing pressure. Since a micro-CT is capable of micro-resolution imaging [13], [14], we expect that future studies with micro-CT imaging of a 3D phantom will show the feasibility of x-ray elastography in a quantitative way. Despite the limitations in current experimental setups, we think that the present study shows positive possibility of x-ray imaging as a new elastography modality.

X-ray elastography may have advantages over ultrasound elastography or MR elastography if x-ray elastography can be incorporated into breast tomosynthesis or breast CT. It seems that x-ray imaging keeps its major role in breast cancer screening because it has much higher resolution than MRI and ultrasound scanner to detect micro calcifications. Detection of micro calcifications is crucial in breast cancer screening.

V. Conclusion

Through x-ray CT imaging of a 3D phantom with varying compression pressures, we have shown that strain imaging of a soft structure is possible with x-ray imaging. We expect that the elastography can be further developed for breast cancer diagnosis. We need more experiments with 3D x-ray imaging of breast phantoms for further validation of the x-ray elastography for breast imaging.

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