Computer Simulation of Breast Compression Based on Segmented Breast and Fibroglandular Tissues on MRI

T-C. Shih[1,2], D. Liu[3], J-H. Chen[1,4], L. Sun[3], K. Nie[1], H. Yin[5], D. Chang[1], O. Nalcioglu[1], and M-Y. L. Su[1]

[1]Tu & Yuen Center for Functional Onco-Imaging, University of California, Irvine, CA, United States, [2]Department of Medical Radiology Technology, China Medical University, Taichung, Taiwan, [3]Department of Civil and Environmental Engineering, University of California, Irvine, CA, United States, [4]Department of Radiology, China Medical University Hospital, Taiwan, [5]Department of Civil Engineering and Engineering Mechanics, Columbia University, New York, NY, United States

Purpose: Mammographic density is associated with an increased risk of breast cancer [1-2]. Since the density is measured from projection images, it may vary with the projection angle, compression levels, and the patient's position. The effect was illustrated by Kopans [2] using schematic examples, but the impact of these factors on the measured mammographic density has never been demonstrated using realistic human data. Due to the involvement of radiation exposure, it is unethical to study the effect by taking repetitive mammograms varying these factors in humans. In this study we proposed a method to simulate the deformation of a compressed breast, using the 3D model of the breast and fibroglandular tissue segmented from MR images. The compression was applied to acquire cranio-caudal (CC) and mediolateral-oblique (MLO) view projections, and the projection area of the compressed fibroglandular tissue at different compression ratios were calculated and compared.

Methods: A set of 3D MR images from one patient, consisting of 256×256×32 voxels with voxel size of 1.5×1.5×4 mm^3, were used to generate the 3D model of the breast and fibroglandular tissues, shown in **Fig.1**. Only the left breast was studied. The 3D geometry of the segmented breast, including fatty and fibroglandular tissues, was constructed using the Amira® 5 software (Visage Imaging), shown in **Fig.2**. The surface with triangles was created for fatty tissue (**Fig.2a**) and fibroglandular tissues (**Fig.2b**). For simulation of breast compression, the volume mesh of the breast tissue was firstly created, by using the ANSYS ICEM CFD software, shown in **Fig.2c**. The total number of elements was 33,198 for the whole breast, and the corresponding nodes were 6,233. The compression ratio (that is, the level of compression) is defined as 1-(Lf/Li) where Lf is the thickness of the breast after compression by applying an external force, and Li is the original thickness without compression. After compression, the deformed fibroglandular tissue was projected onto a 2D plane, and the density was calculated as the percentage of the fibroglandular tissue area divided by the projection area of the entire breast. Due to the large deformation of the breast, we used a nonlinear elastic model to calculate the breast compression deformation. The Mooney-Rivlin material constants were used for the fatty (C_{01}=1,333 Pa and C_{10}= 2,000 Pa) and fibroglandular tissues (C_{01}=2,333.3 Pa and C_{10}=3,500 Pa). The MSC Marc software was used to simulate the breast compression deformation.

Results: **Fig.3** demonstrates the simulated compression results with the compression ratio varying from 30% (light compression) to 80% (hard compression). For the CC view compression, the deformation of the fibroglandular tissue is clearly noted. The breast tissues are pushed away from the chest wall. A projection image was generated at each compression level, and the dense tissue percentage was calculated, listed in Table 1. The fibroglandular density percentage changed from 0.311 at 30%, increased gradually to 0.349 at 60%, then further to 0.408 at 80%. In mammography it is very likely to reach 70% or 80% compression ratio, therefore, within 40 to 60% compression level, the variation of the measured density percentage was approximately 8%. The MLO compression results are also shown in Fig.3, and the results summarized in Table 1. Within 40 to 60% compression level, the variation of the measured density percentage was approximately 12%.

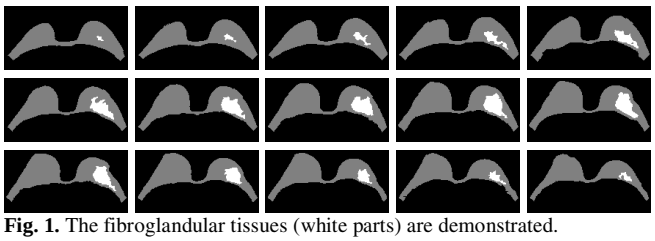

Fig. 1. The fibroglandular tissues (white parts) are demonstrated.

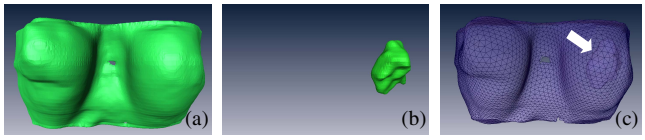

Fig. 2. The 3D geometry was reconstructed by Amira® 5 software. (a) the surface of the whole breast, (b) the surface of the fibroglandular tissue, (c) the volume mesh of the whole breast created by ANSYS ICEM CFD software. The fibroglandular tissue is in the left breast (indicated by arrow).

Table 1. Comparison of fibroglandular tissue projection area percentages for CC and MLO view at different compression ratios

	Compression ratio (%)					
	30	40	50	60	70	80
CC	0.311	0.323	0.333	0.349	0.374	0.408
MLO	0.299	0.304	0.316	0.342	0.380	0.381

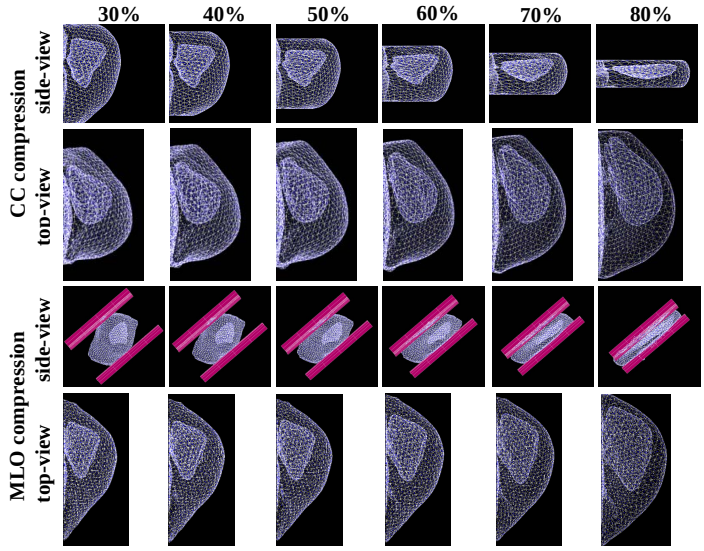

Fig. 3. Demonstration of the compression deformation at different compression ratios varying from 30% to 80%. The CC view and MLO view compression are shown. The side view illustrates the compression level, and the top view illustrates the 2D projection results (normalized to show relative deformation).

Discussion: In this study we presented a simulation method for three-dimensional modeling of breast compression using a realistic human data set of breast and fibroglandular tissue segmented from MRI. This method can be applied to simulate the effect of different compression levels (as demonstrated here), and can also be easily applied to study the effect of different projection angles. The case selected for development of this simulation program was one with confined fibroglandular tissue with relatively smooth surface, so a small number of elements can be used to reduce the computational complexity. For a case with irregularly shaped fibroglandular tissue the variation due to different compression level is expected to be higher. We are planning to apply this method to gain more in-depth understanding of the dependence of mammographic density on the potential technical factors that may contribute to the high variation, and to estimate the measurement variation.

References: [1] Boyd N.F. *et al.*, The New England Journal of Medicine, Vol.356, 2007, pp.227-236. [2] Kopans D.B., Radiology, Vol. 246, 2008, pp.348-353.

Acknowledgments: This study was supported in part by a grant CMU97-161 from China Medical University, the Distinguished Professor Research Project.