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


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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 the 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 1.5x1.5x4 mm³, 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−(Lʃ/Li) where Li 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 (C11=2,333.3 Pa and C12=5,500 Pa) and fibroglandular tissues (C11=1,333 Pa and C12=2,000 Pa) and fibroglandular tissues (C11=1,333 Pa and C12=2,000 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%.

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.


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