**Model Based Fusion of X-ray Mammograms and MR Volumes of the Female Breast**

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**Purpose:**

The most common method of breast cancer detection, next to palpation, is X-ray mammography.
Despite all diagnostic benefits, X-ray mammograms have the disadvantage of displaying a deformed breast. To obtain a mammogram, the breast has to be squeezed between two plates up to 50% decrease in diameter. For further treatment, e.g. biopsy or surgical planning, or for combination with other imaging methods, e.g. Magnetic Resonance Imaging (MRI), it is important to determine the relationship between the undeformed and the deformed breast.

In this paper, a method is proposed for automatic fusion (registration) of two X-ray mammograms and a MR volume of the same, but undeformed breast in prone position, based on a biomechanical model.
The method allows the three-dimensional (3D) position of suspect lesions, which are only visible in X-ray mammograms, to be localized within the MRI, or vice versa.
Our aim is to match X-ray mammograms and MR volumes with a maximal overall inter-modality displacement of 5mm, so that also MRIs with smallest visible lesions can be included.

**Method and Materials:**

Registering images of deformed breast tissue is a difficult task, because the female breast consists of deformable, mobile, inhomogeneous tissue, which deforms varyingly. It offers no internal structures, which are clearly discernible in both multimodal images. In this approach a model of the deformable behavior of the female breast is build, to overcome the problems associated with the huge deformations during mammography. This model makes it possible to deform the breast, as given in the MRI, to have the same configuration as in a corresponding X-ray mammogram.

The geometry of the simulation model is individually constructed based on the MR volume of the breast of a specific patient. The different breast tissues, as imaged in that MRI, are included in the model, by mimicking their particular physical properties. Then the details of the deformation process are expressed, e.g. as plate compression, where two plates are defined, which compress the model to a specific compression thickness. After building this model, the deformation is simulated using the Finite Element Method (FEM). The results of the simulation are subsequently used to generate an artificial MRI of the compressed breast. This artificial MRI can be projected to acquire an image directly comparable to the X-ray mammogram. Figure 1 gives an overview of such a simulation.

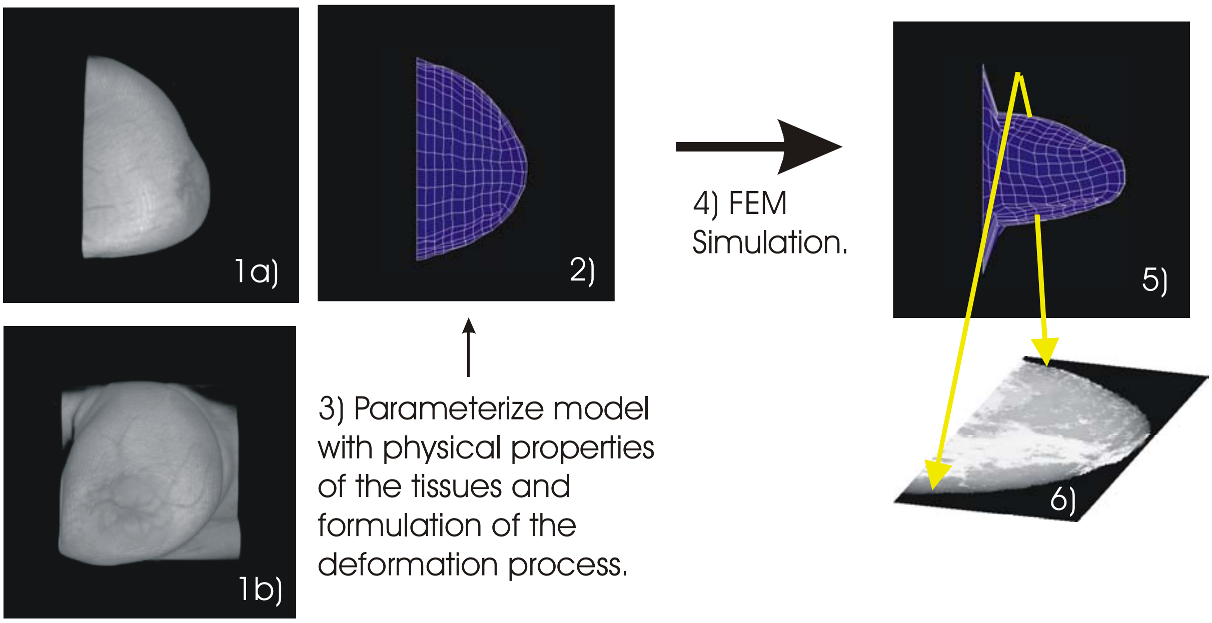

Figure 1: Process of deformation simulation. 1a) and b): Patient specific MRI in different views. 2) Individual geometry of the simulation model, built based on the MRI. 3) Parameter definition for tissues and deformation. 4) FEM simulation. 5) Deformed model. 6) Projection of the generated MRI of the deformed breast. After step 6) the MR projection of the deformed breast can be directly compared to the corresponding X-ray mammogram.

Registration provides the direct comparability of the matched images. In our simulation approach this is ensured by an appropriate formulation of the deformation process, so that the deformed breast in the simulation is similar (ideally equal) to the compressed breast, imaged in the corresponding X-ray mammogram. To achieve this, first the exact projection angle and the imaged portion of the breast of the X-ray mammogram are calculated, using our earlier registration approach [1]. After that the simulation model is built, using the MRI and physical properties of the breast tissues.

The deformation process is formulated using the following approach. We showed (see results), that simulations driven by deformation formulations based on the 3D shape of the deformed breast give the best overall similarity. However, the 3D shape of the deformed breast is not recoverable from the X-ray mammograms, as they are 2D projections. This problem is solved using a two-step approach. First, the model of the breast is subjected to a deformation mimicking plate compression. Second, the shape of this deformed breast and the circumference of the corresponding X-ray mammogram are used to estimate the 3D shape of the breast during mammography. In the second step the deformation formulation is based on this 3D shape. The subsequent simulation results in a MR projection with exactly the same circumference as the X-ray mammogram.

To recover the volume in the MRI containing a lesion of the X-ray mammograms, the registration approach described above has to be accomplished for each X-ray mammogram. After the registration of the X-ray mammograms and the MR volume, the position of the lesion in the mammogram can be directly superimposed onto the MR projection. Knowing the applied deformation process to obtain the registration, the position of the lesion in the undeformed breast can be calculated straightforwardly.

**Results:**

To obtain the best configuration for our simulation model, which satisfy the requirements of simulation accuracy, different physical models for breast tissues and different deformation process formulations were applied. A specially acquired dataset was used for evaluation, consisting of two MR volumes, one displaying an undeformed breast of a healthy volunteer, the other showing the same breast, subjected to mammographic compression. We demonstrated, that a simulation model using the same physical tissue properties for all breast tissues is sufficient, and more complex models do not increase the simulation accuracy [2]. As an example, figure 2 displays the comparison of the original MRIs and a generated MRI, based on simulation results.

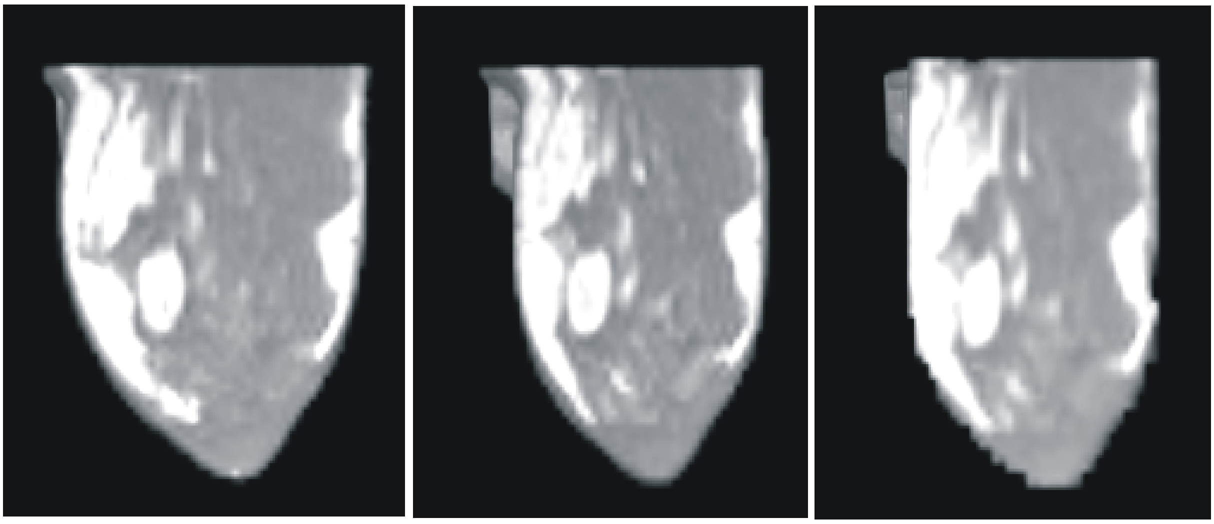

Figure 2: Lineup of original and artificially generated MR volumes. All volumes have been cut open in a transversal plane. Left: original undeformed MRI. Middle: original deformed MRI. Right: generated deformed MRI.

Simulations using only plate compression for deformation formulation gave an overall displacement error of 3.7mm, with a standard deviation of 1.3mm. The maximal displacement was slightly larger than the accuracy limit of 5mm displacement. Therefore they do not completely fulfill the rather stringent requirements. Simulations using the 3D surface deformation to drive the compression had an overall accuracy of 2.6mm (standard deviation 1.1mm). The maximal errors were below the limit of 5mm.

The registration approach based on the simulation model is actually evaluated using clinical data, where lesions are visible in both modalities. Therefore the position of a lesion in the MRI can be calculated and then compared to the real position of the lesion in the X-ray mammogram. First results are very promising and showed a displacement of the lesion’s center point of 3.8mm in a cranio-caudal and 0.8mm in an oblique X-ray mammogram.

**Conclusions:**

We proposed a method to fuse X-ray mammograms and MR volumes of the breast. This enables to automatically determine the relationship between the mammographically deformed breast and the undeformed breast. Possible applications of this approach are to support and to facilitate biopsy or surgical interventions, e.g. MRI guided biopsy of lesions only visible in X-ray mammograms, or to combine the diagnostic information of X-ray mammograms and MRI, e.g. diagnosis support or comparative studies. Even diagnostic information acquired with ultrasound could be fused with X-ray and MRI data in future, using an Ultrasound Computer Tomograph as proposed in [3].

Our simulation model has been developed using only one, specially acquired data set. The maximal deviation of the simulations is smaller than the diameter of the smallest resolvable lesion and hence enables the estimation of the location of these tumors in the MRI.
In a strict sense, the results are only valid for the dataset used to build the model. However, first evaluations based on clinical data showed that it is possible to retrieve similarly accurate results with other data. More evaluation is necessary to generalize this conclusion and will be done in the future studies.

**References:**

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