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Supine breast MRI and assessment of future clinical applications

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1. Introduction

Dynamic contrast enhanced (DCE) MRI has high sensitivity for the detection of breast cancer [1–3] and provides accurate assessment of the extent and presence of multi-focal disease [4–6]. DCE breast MRI is an attractive and powerful three-dimensional tool for the breast surgeon, because it results in excellent selection of patients for breast conserving surgery and low rates of positive histologic margins [7]. Usually, breast MRI is performed in the prone position to overcome motion artifacts from respiration thereby providing high resolution imaging. However in this configuration, the breast shape and tumor location are significantly altered when compared to the actual configuration found in the surgical setting where the patient is supine on the operating room table.

In order to match the breast configuration to the surgical setting, breast MRI with supine positioning of the patient has been suggested [8,9]. In studies performed on patients with known breast abnormalities, supine breast MRI is able to depict the lesion of interest and the corresponding contrast enhancement dynamic [9]. Supine positioning simplifies the registration of supine MR images to the operating room and therefore aids breast conserving surgery using MRI.

The biggest change of the breast conformation between a supine breast MRI and the later situation in the OR is expected to be caused by the different arm positions in the two settings. While the arm of the patient is parallel to the body during the supine MRI, it is commonly positioned perpendicular to the body axis during the surgery. Any registration algorithm should correct for the corresponding positional changes of the breast which may occur. Because the breast is highly deformable, this could be a challenging task.

In this preliminary study, supine MRI images were acquired with the arm of the patient adjacent to the body and the arm placed above the head. Since the arm position during surgery is an intermediate of these positions, the result of the registration between these two data-sets provides a first measure of the tumour localization accuracy during surgery using image-guidance based on supine breast MRI.

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2. Materials and methods

2.1. Supine breast MRI

To achieve good SNR, a four-element receive unilateral coil for supine breast MR imaging was built for a 1.5T whole body MR scanner (GE Signa Excite) on a flexible Teflon sheet [9]. A set of gimbaled joints (Loc-Line system, Modular Hose) permits a smooth flexing of the coil array so that it can conform as closely as possible to different breast geometries. A coil fixture was designed to support the coil above the breast of the patient on the standard bed of the scanner [9]. The coil is never in contact with the breast during imaging and an air gap with a minimal width of 1 cm is always kept between the coil and the breast surface which allows the supine patient's breast to remain in its native configuration that would be expected in subsequent surgical or supine interventional procedures.

In this study, unilateral supine breast MRI images were acquired with a fast 3D SPGR sequence, which is frequently used for DCE breast MRI [9]. An oblique coronal slice orientation minimizes the number of necessary slice acquisitions and measurement time. The frequency encoding direction was chosen in the left-right direction in order to avoid artifacts arising from the arm and the contra-lateral breast. During the entire procedure, a pneumatic respiratory belt was used to monitor the respiratory state of the free-breathing patient. Zonal Motion-adaptive Acquisition and Reordering Technique (ZMART), a combination of phase-encode reordering and spin-conditioned gating [10], was used to compensate for the respiratory motion of the breast.

2.2. Patient study

All human supine breast MRI scans were conducted under a protocol approved by the Human Ethics Review Board. Six patients with diagnosed breast abnormalities, which were clearly visible in previous diagnostic breast MRI, were included in this study.

Prior to the MR-examination, the patient was requested to place MR-visible position-markers (PinPoint, Beekley) over the surface of her breast. The number of markers used was dictated by the patient's specific breast geometry (15 to 32 markers per patient). The IV line used for the injection of the contrast agent was placed in the contralateral arm.

The patient was prepared for the first supine breast MRI with her lateral arm placed adjacent to her body. Before the injection of the contrast-agent, the imaging settings and parameters for the motion compensation were adjusted by acquiring test supine

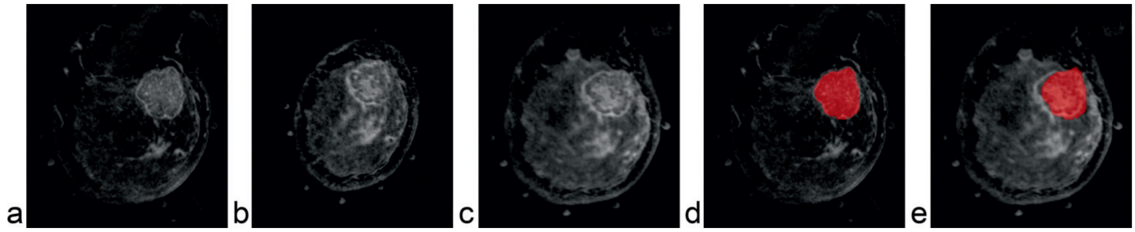

Fig. 1. Images with (a) the arm adjacent to the body (reference) and (b) the arm placed above the head (template). Result of the registration of the template to the reference (c). Segmented tumour in the reference (d) shown in red and as a color-overlay on the registered template (e).

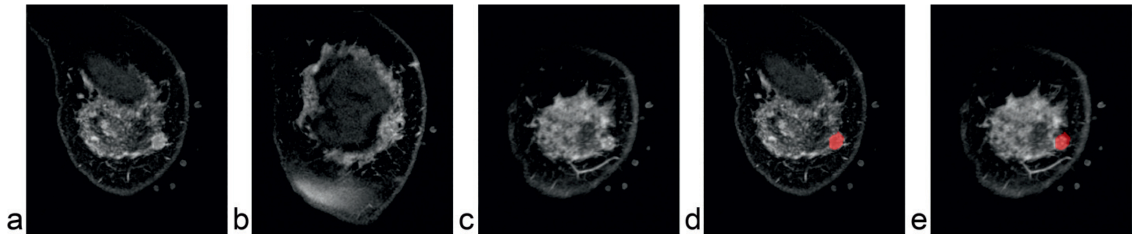

Fig. 2. Registration results for a patient, which placed markers only on the side of the breast next to the tumor. (a) Arm position adjacent to the body (reference). (b) Arm placed above the head (template). (c) Registered template. (d) Tumour segmentation in the reference and (e) color-overlay on the registered template.

breast MRI scans. After the injection of the contrast agent, the first supine contrast-enhanced breast MRI was acquired. The patient was then quickly repositioned with the arm placed above the head after which a second MRI data-set was acquired. All scans were performed using fat-saturation.

2.3. Image registration

The position of the MR-markers was manually detected in all supine data-sets. A thin-plate spline (TPS) registration scheme [11] was used to register the second data-set (template) to the first data-set (reference) based on the spatial position of MR-markers. To evaluate the registration, the tumour masses were segmented on the first acquired data-set and color-overlayed on top of the registered second acquired data-set.

3. Results

3.1. General experiences

Only phase-encode reordering was used for the ZMART motion compensation for all of the patients as verified by the pre-contrast scan. However, one patient changed her respiration pattern after changing the arm position for the second supine scan so that the second scan had to be repeated with a repositioned respiratory belt. In another patient, markers covered only one side of her breast close to the tumor. A third patient experienced coughing during MRI data acquisition so that the motion-compensation based on the respiratory belt failed. The acquired supine data-sets of this patient were not suitable for inclusion in this study.

3.2. Registration results

Placing the arm adjacent to the body and around the head allowed the acquisition of two 3D data sets of two different breast configurations. Using only the surface positions of the MR visible markers and the TPS registration permitted the successful co-registration of the tumour between the two arm positions as shown in Fig. 1. The method was also able to register the two data-sets for the patient in whom markers were placed on only one side of her breast (see Fig. 2). The processing time for the registration was around 2 minutes in MATLAB.

4. Discussion

Previous volunteer studies showed that the registration result improves, if the last oblique coronal slice towards the anterior direction contains MR-markers. The patients placed the MR-markers on their breast by themselves, but were instructed to ensure that some markers were present around their nipple. In addition, they were requested to uniformly cover the rest of the breast with markers. To avoid patient confusion with the instructions in the future, a handout will be prepared for the patients with some simple sketches and lay language.

Phase encode reordering achieved satisfactory motion compensation for five out of the six patients and time consuming gating is not necessary. However, more stable and reliable motion tracking than using the respiratory belt would be preferable, which could be achieved using other respiration tracking techniques like MR-navigators or micro-coils.

The registration based on the MR-marker position achieved an alignment of the tumour regions (see Figs. 1e and 2e). However, some differences in the tumour margins were detected, which are currently under further investigation. Possible reasons for these discrepancies may be inaccuracies in the detection of the MR-marker location or the registration method. As only one injection of contrast-agent was used, the two data-sets were acquired at two different phases of the contrast agent uptake, which presented a different tumor contrast for the two data-sets. Similar measurements of the tumour region at different phases of the contrast agent dynamic should be done on the available diagnostic scan for comparison.

Despite of these experimental limitations, the results of this preliminary study show that localization of a tumour for image-guided surgery based on supine breast MRI and registration based on breast surface marker detection is feasible and may aid in improving the accuracy of breast conserving surgery in the future.

Competing interests: Gilbert Thevathasan is an employee of Hologic (Sentinelle). The other authors have no conflict of interest to report.

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