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Chapter 4
Supine breast MRI using respiratory triggering

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Abstract

Rationale and Objectives
To evaluate if navigator-echo respiratory triggered MR acquisition can acquire supine high-quality breast MRI.

Material and Methods
Supine respiratory-triggered MRI (Trig-MRI) was compared to supine non-triggered MRI (Non-Trig-MRI) to evaluate breathing-induced motion artifacts (group 1), and to conventional prone Non-Trig-MRI (group 2, 16-channel breast coil), all at 3T. A 32-channel thorax coil was placed on top of a cover to prevent breast deformation. Ten volunteers were scanned in each group, and one patient. Acquisition time was recorded. Image quality was compared by visual examination and by calculation of signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and image sharpness (IS).

Results
Scan time increased from 56.5s (Non-Trig-MRI) to an average of 306s with supine Trig-MRI (range: 120-540s). In group 1, median (IQR) of SNR CNR, and IS improved from 11.5 (6.0), 7.3 (3.1), and 0.23 (0.2) cm on supine Non-Trig-MRI to 38.1 (29.1), 32.8 (29.7) and 0.12 (0) cm (all $p < 0.01$) on supine Trig-MRI. All qualitative image parameters in group 1 improved on supine Trig-MRI (all $p < 0.01$). In group 2, SNR and CNR improved from 14.7 (6.8) and 12.6 (5.6) on prone Non-Trig-MRI to 36.2 (12.2) and 32.7 (12.1) (both $p < 0.01$) on supine Trig-MRI. IS was similar: 0.10 (0) cm versus 0.11 (0) cm ($p=0.88$).

Conclusion
Acquisition of high-quality supine breast MRI is possible when respiratory-triggering is applied, in a similar setup as during subsequent treatment. Image quality improved when compared to supine non-triggered breast MRI and prone breast MRI, but at the cost of increased acquisition time.
Introduction

Breast conserving surgery (BCS) can be challenging in patients with small or non-palpable tumors, where tumor palpation is hampered [1]. Therefore, accurate tumor localization during surgery is essential for achieving negative resection margins, avoiding re-excisions and local recurrences. Several technologies have been developed to guide the surgeon, such as wire-guided localization and radioactive seed localization (RSL) [2], [3]. Although both methods have led to a decrease in positive resection margins [4], they only provide surrogate position information about the tumor, not the actual 3-D shape and position information with respect to the tumor border.

Recently, Fichtinger et al. have proposed the use of an electromagnetic (EM) navigation system for intra-operative tumor tracking in combination with wire-guided localization [5]. Pre-operatively, an EM tracked localization needle is placed over the wire-guide under ultrasound guidance. Subsequently, a tracked ultrasound system is used for delineation of the tumor. During surgery, the tracked tumor is shown in combination with a tracked cautery on the navigation screen. This system was found to be safe and feasible by evaluation on 6 palpable tumors. However, non-palpable tumors are often occult on ultrasound [6], challenging tumor visualization and delineation.

An important alternative imaging modality is magnetic resonance imaging (MRI), due to its high soft-tissue contrast [7–9]. Diagnostic MRI of the breast is usually performed in prone position with dedicated breast coils. In this orientation, breathing-induced motion artifacts are minimized, and the breast is elongated. Although this setup is appropriate for diagnosis, the shape of the breast and the position of the tumor is not comparable to the surgical setting [10], where the patient is in supine position. Accurate tumor visualization similar to further treatment could be achieved with supine breast MRI. However, acquisition of supine breast MRI is hindered by breathing-induced motion artefacts that significantly deteriorate image quality. Several attempts have already been made to acquire supine breast MRI of sufficient quality. For example during one or multiple breath holds of the patient or using phase-encode reordering in which positions in k-space are acquired according to the patients breathing cycle [11]. However, these methods have their disadvantages; for example difficulties with reproducible MR acquisition with breath-hold scanning.

In MR imaging of abdominal organs that undergo breathing-induced motion, e.g. liver, respiratory-triggered MR acquisition is often used [12–17]. The respiratory cycle is monitored during acquisition using a navigator echo which represents the diaphragm position over time [18]. Image acquisition is subsequently triggered at end-expiration. The respiratory motion
in this phase of the breathing cycle is minimal, with subsequent minimal variation in organ position during image acquisition. Navigator-triggered imaging is widely available, but has not been reported for acquisition of supine breast MRI. If supine respiratory-triggered MR of the breast is feasible, it can be used to provide guidance for treatment planning and during actual surgery, and also for better tumor delineation in the setting of preoperative radiotherapy (RT) [19, 20]. The aim of this study was to evaluate if navigator-echo respiratory triggered MR acquisition can acquire high-quality breast MRI in supine position.

Materials and Methods

Imaging protocols

In this study, three T1-weighted imaging protocols were evaluated on a whole-body 3.0T MR scanner (Achieva, Philips Medical Systems B.V., Best, the Netherlands). The first protocol was a standard diagnostic 3-D ultrafast spoiled gradient echo sequence in prone position without contrast agent (prone Non-Trig-MRI). This imaging sequence is used for routine clinical tumor diagnosis in breast cancer patients. A dedicated 16-channel breast coil was used in which both breasts are freely elongated. The imaging parameters of the prone Non-Trig-MRI were as follows: transversal slice orientation, phase encoding from left to right, reconstructed voxel size = 0.88 x 0.88 x 0.90 mm$^3$, TE = 1.97ms, TR = 3.8ms, flip angle $\alpha = 10^\circ$, slices = 200, slice thickness = 1.8 mm, field of view [FOV] = 140 x 384 x 180mm (AP x RL x FH), acquisition matrix = 156 x 416, parallel imaging: SENSE with a phase reduction (LR) of R = 3 and a slice reduction (FH) of 1.2. Fat was suppressed by using a SPAIR pulse with inversion delay of 114.5ms. Total acquisition time was 56.5s, consisting of 84 shots to fully acquire k-space (Cartesian trajectory).

The second protocol was the same Non-Trig-MRI sequence, but then acquired in supine position with the arms up (supine Non-Trig-MRI), using a SENSE 32-channel phased-array thorax coil (coverage of 60cm). The coil was placed on top of a custom-made cover to prevent breast deformation by the weight of the coil (Figure 1). One universal cover was used for all volunteers. We have made a one-size fits all cover with the following dimensions: 40 x 45 x 18 cm (FH x RL x AP). The cover was constructed from a thermoplastic material which is also used in patient immobilization and positioning covers in radiotherapy (Orfit Industries, Antwerp, Belgium). The thorax coil could be placed on top of the cover and there was a small air gap between the breast and the cover. The cover accommodates both arms up and arms down scanning. In our supine protocol, bilateral supine breast scans were acquired with the arms up. Also here, the total acquisition time was 56.5s.
In the third protocol the supine setup was scanned using the navigator echo in order to trigger acquisition at end-expiration (supine Trig-MRI). The navigator is a cylindrical 1-dimensional MR excitation that was applied at the transition between lung and liver (the right hemi-diaphragm) in order to determine the position of the diaphragm. Solely the cranial-caudal movement of the diaphragm was considered and was assumed to move in phase with the breast. Triggering was based on the velocity of the diaphragm visualized with the navigator. Dynamically, the maximum positive directional velocity was determined, which roughly represents the middle between inhale and exhale. In the subsequent navigator data end-expiration should be reached, where the velocity should be close to 0. When the velocity reduced to 30% of the previous maximum velocity, the scanner was triggered to acquire one of the 84 shots needed for the entire scan. The total acquisition time of the supine Trig-MRI scan was 84 breathing cycles, and therefore dependent on the imaging subject. We asked the volunteers to focus on abdominal breathing during image acquisition. Although the total scanning time was increased with Trig-MRI, the actual amount of acquired data is the same between all three protocols.

**Imaging subjects**

Twenty healthy female volunteers were scanned in two groups. In group 1 ten volunteers (mean age: 31 years, age range: 24-36 years) underwent an imaging session during which a supine non-Trig-MRI as well as a supine Trig-MRI were acquired. This data was used to evaluate the difference in breathing induced motion artifacts between triggered and non-triggered scanning in supine position. In group 2 ten volunteers (mean age: 34 years, range: 26 – 60 years) underwent both a prone Non-Trig-MRI and a supine Trig-MRI in one session to
compare the image quality of the new supine protocol to standard imaging in prone position. No contrast agent was injected in the volunteers and none of the volunteers had a history of breast cancer or contra-indications to MRI.

Furthermore, one female patient was included as part of a clinically approved trial in our hospital. The main inclusion criteria were a histologically proven invasive carcinoma in the breast that was visible on prone CE-MRI, acquired as part of routine clinical diagnosis. After tumor visualization was evident on the prone MRI, the patient was asked to participate in our study and informed consent was obtained. On a different day, the patient underwent the supine imaging protocol that consisted of four scans. First a pre-contrast supine Trig-MRI and supine Non-Trig-MRI were acquired. Subsequently, 15 mL gadolinium was injected where after a post-contrast supine Trig-MRI and supine Non-Trig-MRI were acquired. All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Qualitative image assessment

All supine Trig-MRI and supine Non-Trig-MRI of the volunteers in group 1 were independently reviewed by four breast radiologists (C.E.L., G.W., C.A.H.L., and M.V.L.) with 13, 18, 10 and 2 years of experience with breast MRI, respectively. The radiologists assessed the following image parameters: overall image quality, contrast between fibro-glandular and fatty tissue, the possibility to evaluate the breast and axilla for abnormalities and the degree of breathing-induced motion artifacts. The first four image parameters were scored using 1=good, 2=moderate, and 3=poor. The degree of breathing-induced motion artifacts was scored using: 1=absent, 2= moderate and 3=severe visible imaging artifacts. The supine Trig- and Non-Trig-MRI were separately evaluated by the radiologists, but the scans were not blinded from each other. The prone Non-Trig-MRI and supine Trig-MRI of the volunteers in group 2 were not qualitatively assessed by the radiologists.

Quantitative image assessment

Acquisition times of the supine Trig-MRI were recorded. Quantitative assessment of all volunteer scans was performed by calculation of signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Two circular regions-of-interest (ROIs) 1.7 cm in diameter were placed in four consecutive slices: one in the fibro-glandular tissue and one in a homogenous fatty part of the breast. The mean signal intensity (SI) in the ROIs was used for calculation of SNR and CNR. In all three protocols, image-based shimming was applied. With this technique,
the contours of the breast in the whole FOV are auto-segmented and defined as a “mask”. Shimming was automatically applied within the mask region, ignoring the remaining part of the FOV. The intensity values of the voxels outside the mask are set to zero. Therefore, it was impossible to determine the noise levels in the air surrounding the breast. As an alternative, the background noise was defined as the standard deviation of SI in the fatty part of the breast. Before the noise was calculated, images were filtered using a local mean filter with a 3-D kernel size of five voxels to remove gradients caused by the distance of the thorax coil to the tissue. SNR was calculated using: mean (SI_{fibro-glandular tissue}) / noise. CNR was calculated using: (mean (SI_{fibro-glandular tissue}) - mean (SI_{fatty tissue})) / noise.

Image sharpness (IS) was assessed by evaluation of intensity profiles of fibro-glandular and surrounding fatty tissue (Figure 2). The profiles were obtained along a user-defined line that went through both tissues on an axial slice. IS was represented by the standard deviation of the fitted cumulative Gaussian distribution in centimeters along the intensity profile modeling both the transition from fat to glandular tissue and from glandular tissue to fat simultaneously.

In group 1, supine Non-Trig-MRI vs. supine Trig-MRI, scans were first registered using in-house developed software. Only rigid registration was performed since breast deformation between the 2 scans was minimal. Mutual information was used for registration of the scans using a region-of-interest that was placed in the glandular tissue, assuring that the same

![Figure 2](image_url)

**Figure 2.** Image sharpness was assessed by placing a profile line (yellow) through fibro-glandular and fatty tissue on the supine non-Trig-MRI (a) and the supine Trig-MRI (b). Next, a cumulative Gaussian distribution was fitted to the intensity profile for the supine non-Trig-MRI (c) and the supine Trig-MRI (d). Note the different scale on the Y-axis in (c) and (d). Trig-MRI, triggered magnetic resonance imaging. By fitting both sides of the profile simultaneously with one Gaussian distribution, IS was less sensitive to local artifacts. A sharp image will result in a smaller standard deviation than a blurry image.
fat to glandular to fat profile was assessed. In group 2, substantial breast deformation was present, and visual assessment was used to sample IS as much as possible on the same region based on anatomical landmarks.

The acquired data of the patient, including the prone CE Non-Trig-MRI as acquired for clinical diagnostic evaluation and the supine CE Trig- and CE Non-Trig-MRI, were subjectively assessed for tumor visualization. One observer (NJ) delineated the tumor on the CE supine Trig-MRI in order to create a supine 3-D anatomical model. The prone CE non-Trig-MRI was used as a guide. The delineation was subsequently evaluated by one radiologist (CL).

**Statistical analysis**

The number of 10 study participants per group was determined before start of the study and was mainly based on practical considerations. We assumed that 10 study participants per group was sufficient enough to assess the feasibility of respiratory triggering for acquisition of high-quality breast MRI in supine position and for a pairwise comparison with prone and supine non-triggered imaging.

The Wilcoxon signed rank test was only used in group 1 to test significant differences in the rated qualitative imaging parameters between supine Trig- and supine Non-Trig-MRI of group 1 (no ratings were available for the prone Non-Trig-MRI and supine Trig-MRI of the volunteers in group 2.). Differences in quantitative image parameters between supine Trig-MRI and Non-Trig-MRI in group 1, and prone Non-Trig-MRI and supine Trig-MRI in group 2 were tested using the paired two-sided \( t \)-test. A \( p \)-value less than 0.05 was considered statistically significant. Statistical analyses were performed using SPSS software package version 20.0 (SPSS Inc., Chicago, IL).

**Results**

Navigator-echo-based respiratory-triggered image acquisition was successful in all cases. The scan time increased from 56.5s (Non-Trig-MRI) to an average of 306s with Trig-MRI (range: 120-540s).

**Group 1**

Qualitatively, the radiologists rated the supine Trig-MRI significantly better than the supine Non-Trig-MRI regarding overall image quality, the possibility to distinguish fibro-glandular
from fatty tissue, and the possibility to evaluate the breast and axilla (Table 1, all $p < 0.01$, Figure 3). Furthermore, breathing-induced motion artifacts were reduced ($p < 0.01$). Quantitatively, median (IQR) values of SNR and CNR increased from 11.5 (6.0) and (7.3 (3.1) on supine Non-Trig-MRI to 38.1 (29.1) and 32.8 (29.7) on supine Trig-MRI (both $p < 0.01$). Furthermore, median IS (IQR) decreased from 0.23 (0.2) cm on Non-Trig-MRI to 0.12 (0) on Trig-MRI ($p < 0.01$) (Table 2). This means that the transition between fat and fibro-glandular tissue was sharper on the triggered images.

**Table 1.** Qualitative evaluation of the supine Trig- and Non-Trig-MRI scans of the 10 volunteers of group 1 by 4 different radiologists.

<table>
<thead>
<tr>
<th></th>
<th>Supine Non-Trig-MRI (n = 40)</th>
<th>Supine Trig-MRI (n = 40)</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Image Quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>0</td>
<td>33</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>Moderate</td>
<td>16</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>24</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Distinction between fibro-glandular &amp; fatty tissue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>0</td>
<td>38</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>Moderate</td>
<td>13</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>27</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Evaluation of breast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>0</td>
<td>32</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>Moderate</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>32</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Evaluation of axilla</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>1</td>
<td>34</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>Moderate</td>
<td>16</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>23</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Breathing-induced motion artifacts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>1</td>
<td>20</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>Moderate</td>
<td>18</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>21</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

MRI, magnetic resonance imaging; Trig-MRI, triggered magnetic resonance imaging. Data are presented as numbers of evaluations.

**Group 2**

In the comparison between prone Non-Trig-MRI and supine Trig-MRI, breathing induced motion artifacts were expected to be absent. This was confirmed in the image sharpness parameter, which was equally good: median 0.10 (IQR=0) cm in prone Non-Trig-MRI versus
0.11 (0) cm in supine Trig-MRI \( (p = 0.88) \). Above expectation, the median (IQR) values of SNR (36.2 (12.2) versus 14.7 (6.8)) and CNR (32.7 (12.1) versus 12.6 (5.6)) of the supine Trig-MRI were both significantly higher than the prone Non-Trig-MRI \( (p < 0.01) \) (Table 2).

**Table 2.** Signal to noise ratio (SNR), contrast to noise ratio (CNR) and Image Sharpness of the MRI of the volunteers in group 1 and 2.

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Median SNR (IQR)</th>
<th>Median CNR (IQR)</th>
<th>Median Image sharpness in cm (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supine Non-Trig-MRI</td>
<td>11.5 (6.0)</td>
<td>7.3 (3.1)</td>
<td>0.23 (0.2)</td>
</tr>
<tr>
<td>Supine Trig-MRI</td>
<td>38.1 (29.1)</td>
<td>32.8 (29.7)</td>
<td>0.12 (0)</td>
</tr>
<tr>
<td>p-value</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
</tr>
<tr>
<td>Group 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prone Non-Trig-MRI</td>
<td>14.7 (6.8)</td>
<td>12.6 (5.6)</td>
<td>0.10 (0)</td>
</tr>
<tr>
<td>Supine Trig-MRI</td>
<td>36.2 (12.2)</td>
<td>32.7 (12.1)</td>
<td>0.11 (0)</td>
</tr>
<tr>
<td>p-value</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(=0.88)</td>
</tr>
</tbody>
</table>

SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio; IQR, interquartile range; MRI, magnetic resonance imaging; Trig-MRI, triggered magnetic resonance imaging

**Figure 3.** Examples of supine non-Trig-MRI (a, c, and e) and supine Trig-MRI (b, d, and f) of three different volunteers. The visibility of normal (a and b) and denser (c and d) fibro-glandular tissue improved on the supine Trig-MRI. The visibility of the axillary region improved on the supine Trig-MRI as well (e and f).
**Patient example**

Informed consent was obtained from the included patient in the study. The patient had a carcinoma in the right breast and underwent acquisition of a prone Non-Trig-MRI (Figure 4A) and a supine Trig-MRI (Figure 4B). As expected, the position of the tumor with respect to the chest wall differed greatly between prone and supine patient positioning. The tumor was located and subsequently delineated on both scans (Figure 4, red line). Figure 4C illustrates that the supine Trig-MRI creates insight in the patient-specific tumor location, extent and shape in a similar patient setup as during subsequent treatment. After volume rendering of the delineated tumor on the supine Trig-MRI, the tumor was visualized in 3-D with respect to the surrounding anatomical structures.

![Figure 4](image)

**Figure 4.** Example of a prone non-Trig-MRI (a) and a supine Trig-MRI (b) of a patient with a carcinoma in the right breast (delineated in red). Notice the reduced contrast in signal intensity between the tumor and the surrounding fibro-glandular tissue in the supine Trig-MRI; this reduced contrast is probably due to the prolonged acquisition time resulting in less optimal timing of the contrast agent. (c) Use of supine Trig-MRI for visualization of patient-specific tumor location, extent, and shape with respect to the surrounding anatomic structures in 3-D space. The tumor model was created by volume rendering based on tumor delineations.
Discussion

This study has shown that respiratory-triggered MR acquisition can provide high-quality images of the breast in supine position, which is similar to the patient setup during surgery and RT and therefore will enable improved translation of the MRI findings to the treatment setting. With respiratory triggering image quality improved both quantitatively and qualitatively. The supine Trig-MRI also resulted in improved SNR and CNR compared to the current standard prone non-Trig-MRI. Although the same amount of data is acquired in supine Trig-MRI and supine/prone Non-Trig-MRI, the total scanning time of supine Trig-MRI is prolonged since it is dependent on the patient specific breathing cycle.

Comparison of the supine Trig-MRI image quality to other methods of supine MRI acquisition, such as the phase-encode reordering methods [11, 21] or the breath hold techniques [22] is difficult, since SNR, CNR or IS are not reported in these studies. Both the breath hold technique and the phase-encode reordering methods will be faster than the acquisition of Trig-MRI. Other studies, in which deformable image registration of a high quality prone breast MRI to a supine breast MRI is investigated result in registration errors of more than 0.5 cm [23, 24]. Errors of such magnitude can have a large impact on resection margins, and should therefore be reduced.

We proposed navigator echo-based respiratory triggered image acquisition to minimize motion artifacts on MRI scans. There were significantly less breathing-induced motion artifacts in the supine Trig-MRI in comparison to the supine Non-Trig-MRI. Despite the triggering, two radiologists rated 2 different supine Trig-MRI scans as having severe breathing-induced motion artifacts (3 ratings in total). The presence of these artifacts can have several causes. First of all, there could be a discrepancy between diaphragm motion and breast motion. Also, the acquisition is triggered at end-expiration, but acquisition of one shot takes 0.67s in which breathing motion can still take place. Quantitatively, supine Trig-MRI resulted in significantly improved IS compared to supine non-Trig-MRI. As a positive control, the IS was comparable between the prone non-Trig-MRI and the supine Trig-MRI.

The SNR and CNR of the supine Trig-MRI scans were significantly increased in comparison to the prone non-Trig-MRI. This difference could partly be explained by the use of a 16 channel breast coil in prone imaging versus a 32 channel thorax coil during supine imaging. However, differences between supine non-Trig-MRI and supine Trig-MRI were of similar magnitude, indicating that other causes might be present. During the supine Trig-MRI acquisition, only one shot is acquired per breathing cycle, allowing full recovery of the longitudinal magnetization before a new shot is acquired in the next breathing cycle. In the
Non-Trig-MRI acquisition (both prone and supine), 84 shots are repeated in a time frame of 56.5s until k-space is fully acquired. A consequence of the continuous scanning is that the longitudinal magnetization will not fully recover before a new shot is acquired, which in turn leads to a decreased signal intensity in comparison to the triggered MRI acquisition. Therefore, besides reduction of breathing artifacts, respiratory triggering also results in more signal intensity while having a similar noise level. This was especially represented in group 1 in which the SNR was increased when triggering was applied.

The improved SNR and CNR with supine Trig-MRI came at a cost of a longer acquisition time. As the same amount of data is acquired in all scans, triggering is also SNR and CNR efficient. However, since 84 breathing cycles are needed for full acquisition, the 4-5 fold image quality improvement comes at a cost of a 2-9 fold increase in acquisition time, making it time-wise less efficient. With the 32-channel thorax coil, parallel imaging could be used to increase the amount of data acquired during end-expiration, reducing the amount of needed breathing cycles, improving the CNR and SNR efficiency. If further use of parallel imaging could result in a speedup of more than twofold, actual acquisition of all data in a single breath hold of less than 30 seconds becomes possible.

Further, the torso coil geometry has much more spatially variable SNR when compared to the prone breast coil, especially in women with different breast sizes. The thorax coil is closer positioned to the breasts in women with smaller cup size, resulting in higher intensity values of the fibro-glandular tissue. This effect was also seen in three women in group 1, explaining the higher average and spread of SNR and CNR values when compared to group 2. To avoid such spatially variable SNR, we tried to position the thorax coil as reproducible as possible by using the custom-made cover.

In diagnostic breast MRI, dynamic contrast enhanced MRI is used to discriminate tumor from healthy breast tissue [25]. Because of the prolonged scan time, respiratory-triggered imaging in combination with contrast enhancement is challenging. Therefore, this implementation of supine Trig-MRI should not be seen as an alternative for diagnostic prone CE MRI. If tracer kinetics is still necessary in the supine setup, multiple fast MRI scans can be acquired immediately after contrast agent injection, followed by a supine Trig-MRI. An example of such a fast MRI is a DIXON sequence [26], which at a reasonable resolution is fast enough (±15s) to be performed in breath hold.

The rationale for acquisition of supine breast MRI in this study was to acquire high quality images of the breast in a patient setup comparable to surgery and RT. This scan can be acquired after diagnosis of the tumor, when the prone MRI has already been acquired. As
a proof of principle, we have performed manual tumor delineation on the supine CE Trig-MRI of the patient that was included in this study. Using the prone CE Non-Trig-MRI as a guide, it was easy to recognize the tumor shape in the supine CE Trig-MRI. The resulting 3-D tumor and breast model with the patient lying in supine position can be beneficial for the anatomical insight of the surgeon. This might be beneficial in combination with an image-guided navigation system used for intra-operative tumor tracking [27]. Furthermore, the supine MRI can be used for planning of implantation of one or multiple tumor markers or radioactive seeds (RSL) in the tumor, in order to locate the tumor pre-operatively [28]. In the RT application, several studies investigated the beneficial value of supine MRI for target volume delineation in pre- and post-operative breast RT [19, 20, 27]. Beneficial value of MRI was seen for tumor detection and the visualization of irregularities and spiculations. However, in the used MRI protocols breathing motion during image acquisition was not taken into account. Therefore, we can speculate that further improvement is possible, as was shown in the comparison of the presence of breathing-induced motion artifacts between supine non-Trig-MRI and supine Trig-MRI in group 1.

The limitations of this study are the small study population that included only healthy volunteers and one patient. The volunteers were relatively young and therefore not directly representative for the average breast cancer patient. Therefore, these results are only preliminary and should be verified on a larger population including more patients. We would like to emphasize that patient positioning between acquisition of supine MRI and subsequent surgery and radiotherapy is similar but not exactly the same. For example, the study participants were scanned with the arms up, different from the surgery setup and could result in different breast shapes. Furthermore, supine MRI acquisition was performed on a standard curved MR table while a flat table will be used during surgery or radiotherapy.

We do however think that the image quality will not be dependent on the shape of the anatomy. A wide-bore scanner could be used to achieve comparable positioning of all imaging subjects [20]. Future studies could be directed towards the use of different parallel imaging techniques and non-Cartesian sampling of k-space, with or without compressed sensing, to further decrease acquisition time. The acquisition parameters for the supine Non-Trig-MRI were directly copied from the standard prone MRI protocol, and are therefore not fully optimized for minimizing the breathing motion artefacts.

In conclusion, we have shown that acquisition of high-quality supine breast MRI is possible when respiratory-triggering is applied. Supine Trig-MRI results in minimization of breathing induced artifacts, to a level comparable to prone scanning, and in a doubling of signal-to-noise and contrast-to-noise compared to prone scans. Therefore, the breasts can be imaged
with the patient in a similar setup as during breast-conserving surgery and radiation therapy. The use of respiratory triggering entails a larger scanning time of approximately 5 minutes. Future studies will be focused on the application of supine MRI in treatment planning and guidance.
Chapter 4

References


