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MAGNETIC RESONANCE

# Feasibility of mapping breast cancer with supine breast MRI in patients scheduled for oncoplastic surgery

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## Abstract

**Objectives** To prospectively determine the feasibility of preoperative supine breast MRI in breast cancer patients scheduled for oncoplastic breast-conserving surgery.

**Methods** In addition to a diagnostic prone breast MRI, a supplementary supine MRI was performed with the patient in the surgical position including skin markers. Tumours' locations were ink-marked on the skin according to findings obtained from supine MRI. Changes in tumours' largest diameter and locations between prone and supine MRI were measured and compared to histology. Nipple-to-tumour and tumour-to-chest wall distances were also measured. Tumours and suspicious areas were surgically removed according to skin ink-markings. The differences between MRI measurements with reference to histopathology were evaluated with the paired-sample *t* test.

**Results** Fourteen consecutive patients, 15 breasts and 27 lesions were analysed. Compared to histology, prone MRI overestimated tumour size by 47.1% ($p = 0.01$) and supine MRI by 14.5% ($p = 0.259$). In supine MRI, lesions' mean diameters and areas were smaller compared to prone MRI (– 20.9%, $p = 0.009$ and – 38.3%, $p = 0.016$, respectively). This difference in diameter was more pronounced in non-mass lesions (– 31.2%, $p = 0.031$) compared to mass lesions (– 9.2%, $p = 0.009$). Tumours' mean distance from chest wall diminished by 69.4% ($p < 0.001$) and from nipple by 18.2% ($p < 0.001$). Free microscopic margins were achieved in first operation in all patients.

**Conclusions** Supine MRI in the surgical position is feasible and useful in the precise localisation of prone MRI-detected lesions and provides a helpful tool to implement in surgery. Supine MRI more accurately determines tumours' size and location and might have an important role to diminish overestimations.

**Key Points**

- *Breath-hold supine breast MRI is feasible using commercially available coils and sequences.*
- *Size and area of lesions on MRI were consistently smaller when measured from the supine position as compared to the prone position.*
- *Supine breast MRI is useful in the precise preoperative localisation of prone MRI-detected lesions.*

**Keywords** Magnetic resonance imaging/methods · Breast neoplasms/diagnosis · Breast/neoplasms/surgery · Humans

**Abbreviations**

| | |
|---|---|
| BCS | Breast-conserving surgery |
| DCIS | Ductal carcinoma in situ |
| IDC | Invasive ductal carcinoma |

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OBCS Oncoplastic breast-conserving surgery
VIBE Volumetric interpolated breath-hold examination

## Introduction

Advances in our understanding of breast cancer biology and management have resulted in a paradigm shift towards more conservative surgical treatment strategies of the disease. Breast-conserving surgery (BCS) with negative margins followed by radiotherapy and adjuvant therapy is nowadays considered the standard of care for early stage breast cancer [1].

Magnetic resonance imaging (MRI) is the most sensitive imaging modalities for detecting breast cancer [2, 3]. Breast cancer is a heterogeneous and often multifocal disease; therefore, preoperative MRI for patients scheduled for BCS may contain a large amount of additional information about the size, shape, location and possible multifocality or multicentricity of the tumour. Previous studies have shown that up to 63% of breast cancers are multifocal, with tumour foci being found more than 2 cm from the reference tumour in 43% of those cases [4]. Intuitively, the preoperative use of MRI can help guide the extent of surgical excision and therefore reduce reoperation rates for positive margins.

Nevertheless, scientific evidence has consistently shown that routine preoperative use of MRI can increase the rate of mastectomies or potentially unnecessary and extensive excisions, and additionally fails to reduce the reoperation rates due to positive margins [5, 6]. MRI is routinely performed in the prone position, while surgery is performed with the patient lying in the supine position. This may result in breast tumours being displaced or deformed secondary to changes in patient positioning. In our opinion, the failure to show the true benefits of breast MRI is not only related to the microscopic tumour burden but also to our inability to translate the information obtained from imaging in the prone position to surgery in the supine position.

Supine MRI is technically challenging for two main reasons. Firstly, breast consistency, shape and size differ between patients and consequently the position of the supine breast cannot be individually predicted on the basis of prone MRI studies alone. Therefore, in the supine position, the coils should be flexible so they can be adjusted to the shape of each individual breast, avoiding breast compression at the same time. Secondly, chest wall movement during breathing requires an ultrafast sequence in order to obtain the needed information in one breath-hold cycle to overcome possible movement artefacts. Further challenges are related to the ability to transfer the information obtained from imaging to the surgeons in the operating theatre.

Thus far, reports dealing with the positioning dilemma are scanty and the number of subjects is limited. Tozaki and Fukuda performed MRIs in 40 patients in the oblique supine position only, using a six-channel body array coil and volumetric interpolated breath-hold examination (VIBE) with acquisition time of 20 s [7]. Carbonaro et al performed supine MRIs in 11 patients using a thoracic four-channel surface coil and VIBE with an acquisition time of 36 s [8]. Siegler et al introduced a flexible unilateral breast coil design and used non-fat-suppressed 3D sequences with an imaging time of 85 s. Fat suppression increased imaging time from 88 s to 190 s [9]. Gombos et al reported intraoperative supine MRI using breath-hold sequences during suspended ventilation to obtain high-spatial-resolution images [10]. They used a 16-channel cardiac coil and 3D fat-suppressed imaging with a scanning time of 24 s. In that study, 12 patients underwent supine MRI after lumpectomy and only six of them had undergone presurgical supine MR imaging.

As expected, these studies show that tumour size and location differ between the prone and supine position; however, this data has not been previously transferred in detail to the operating theatre for navigation purposes. Pallone et al performed supine MRI with a two-element phased-array receive-only coil to segment tumours and glandular tissue and projected the tumour volume to the skin then compared it to palpation [11]. Image-guided lesion localisation or bracketing is usually needed for nonpalpable lesions, yet they are performed under mammographic or MRI guidance in positions different from surgery [12, 13].

The purpose of the present study was to prospectively evaluate the feasibility of preoperative supine MRI using commercially available coils and breath-hold sequences and to create accurate tools to transfer this tangible information to breast surgeons in the operating theatre using drawing charts and skin ink-mark projections in patients scheduled for oncoplastic breast-conserving surgery (OBCS).

## Materials and methods

### Background

Patients from two screening centres, two district hospitals and all primary health care centres within our catchment area of approximately 250,000 people are referred to our tertiary university hospital for consultation and treatment. Approximately 250 primary breast cancer patients are treated in our hospital annually. Prior to referral, all patients undergo a clinical breast examination, where patients older than 30 years of age undergo a minimum of a two-view mammography and whole breast ultrasound (US). Breast MRI is not performed routinely for all patients preoperatively, but as a problem-solving ancillary examination in accordance with the European Society of Breast Cancer Specialists recommendations [3]. In case additional lesions that would alter the surgical plan are found at MRI, a

second-look US is performed and a core biopsy obtained as needed.

## Patients

This study was approved by the local ethics committee, and written informed consent was obtained from all participated patients. Consecutive patients with core biopsy-proven primary breast cancer and being scheduled for OBCS were invited to participate in this study which included a supplementary preoperative supine breast MRI in addition to the routine diagnostic prone breast MRI (Fig. 1). Patients were excluded if they had any contraindications to contrast-enhanced breast MRI e.g. pregnancy, severe kidney insufficiency (i.e. glomerular filtration rate less than 30 ml/min/1.73m$^2$), MRI-incompatible implants or devices, claustrophobia, age less than 30 years or multiple comorbidities. All patients were evaluated at least three times by a multidisciplinary team: at presentation, after prone MRI and after final histopathology.

## Oncoplastic breast-conserving surgery

Localised breast cancer is routinely treated by wide local excision with a 1-cm macroscopic margin in accordance with national guidelines. If the lesion is too large for conventional breast-conserving surgery, OBCS is offered to the patient. OBCS is a partial reconstruction of the breast with either (1) breast tissue remodelling using reduction or mastopexy techniques or (2) replacing tumour defect with regional or distant tissues.

## MRI protocol

The routine MRI examination is performed in the prone position with a seven-element phased-array coil dedicated to bilateral breast imaging (Philips Achieva 3.0-T TX, Philips). The structural prone breast MRI protocol is presented in Table 1.

The supine MRI was performed on a wide-bore (70 cm) 1.5-T scanner (Siemens Magnetom Aera, Siemens Healthineers) with an 18-channel body-array flexible coil, in combination with opposite elements of a 32-channel spine coil. Patients are positioned at the edge of the scanner's table so that the breast is situated as close to the isocentre as possible. The coil's first edge was placed on foam cushions on the sternum or contralateral chest wall, and the other end was fixed below the patient (Fig. 2). The coil was carefully positioned in close proximity to the breast yet with no contact between the coil and the skin. Patients were scanned with the ipsilateral hand held up and flexed as much as possible to resemble the surgical position.

T1-weighted VIBE with fat suppression was performed as a dynamic study (one native and five enhanced volumes; see details in Table 1) with contrast agent administration (gadoterate meglumine, 0.2 ml/kg, 3 ml/s) injection followed by a saline chaser. The VIBE sequence lasted 19 s and was scanned during a light exhale-phase after a deep breath. The first enhanced sequence was started 30 s after the contrast administration and the subsequent sequences with 40-s intervals. The native image was subtracted from the enhanced images. In case bilateral breast imaging was necessary, patients and coils were repositioned and sequences repeated after a new contrast injection.

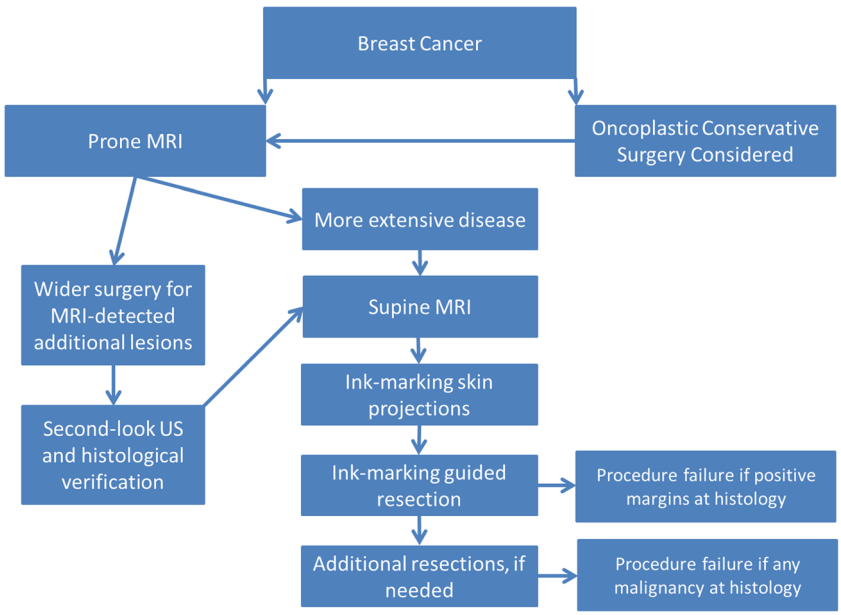


**Fig. 1** Flowchart showing the sequence of events for imaging, surgery and histology

**Table 1** Breast MRI protocol

| Prone MRI | | | | |
|---|---|---|---|---|
| Sequence | TR/TE (ms) | In-plane resolution (mm) | Slice thickness (mm) | Scanning time |
| T1-FFE | Shortest/2.3 | 0.48 × 0.48 | 0.7 | 6 min 11 s |
| T2-TSE | 5000/120 | 0.6 × 0.6 | 2 | 3 min 20 s |
| STIR | 5000/60 | 1 × 1 | 2 | 5 min 40 s |
| T1 dynamic[a] | Shortest/shortest | 0.96 × 0.96 | 1 | 58.5 s |
| DWI | Shortest/95 | 1.15 × 1.15 | 4 | 4 min 8 s |
| Supine MRI | | | | |
| T1-VIBE | 4.54/2.2 | 1.1 × 1.1 | 2 | 19 s |

*FFE* fast field echo, *TSE* turbo spin echo, *STIR* short tau inversion recovery, *DWI* diffusion-weighted echo planar imaging with five respective *b* factors (0, 200, 400, 600 and 800 s/mm2), *VIBE* volumetric interpolated breath-hold examination

[a] eTHRIVE spectrally adiabatic inversion recovery (SPAIR) fat suppression; pre-contrast and six phases after the gadoterate meglumine (0.1 ml/kg, 3 ml/s) injection followed by a saline chaser

Immediately before the supine MRI, self-adhesive 15-mm MRI skin marker capsules (MR-SPOTS®; Radiance® filled, Beekley Corporation) were affixed to the periareolar area in a standardised fashion horizontally at 12, 3, 6 and 9 o'clock positions (Fig. 3). Furthermore, if a palpated tumour was located away from the periareolar area an additional elongated capsule (4 cm) was fixed to the skin above that area.

## Preoperative mapping

Immediately after the supine scanning, a breast radiologist with 25 years of experience in multimodality breast imaging evaluated the locations of the tumours and measured the distances between the tumours and skin markers. According to this data the positions of tumours and other areas to be surgically removed were localised and marked with permanent black ink on the patient's skin according to their relationship to the MRI capsule markers (Fig. 3). During marking, the patients remained in the supine surgical position and the patients' arm was also in the perpendicular surgical position. In cases of larger multifocal lesions, a circle was drawn to visualise the whole area to be removed. All drawings were furthermore photographed and stored in patients' digital records. Furthermore, a drawing of all lesions and distances between them was documented on a special form, which was scanned and stored in the patient's digital records. Additionally, some nonpalpable lesions were bracketed with guidewires as needed according to the resection plan.

## Intraoperative specimen evaluation

The ink-marking guided resected specimens were delivered to the radiology department. Full-field digital specimen radiographs and tomosynthesis views (slice thickness 1 mm, Hologic Selenia Dimensions) were obtained and evaluated in conjunction with an 18-MHz hockey stick US transducer (Logiq E9 class US scanner; GE Healthcare). Removal of demarcated areas was documented and results immediately reported to the theatre. Additional resections performed for aesthetic reconstructive purposes were not evaluated.

## Histology

Palpable lesions were sectioned along their longest axis. Additionally, specimens were sliced at 5-mm intervals and all macroscopically suspicious areas and specimen margins

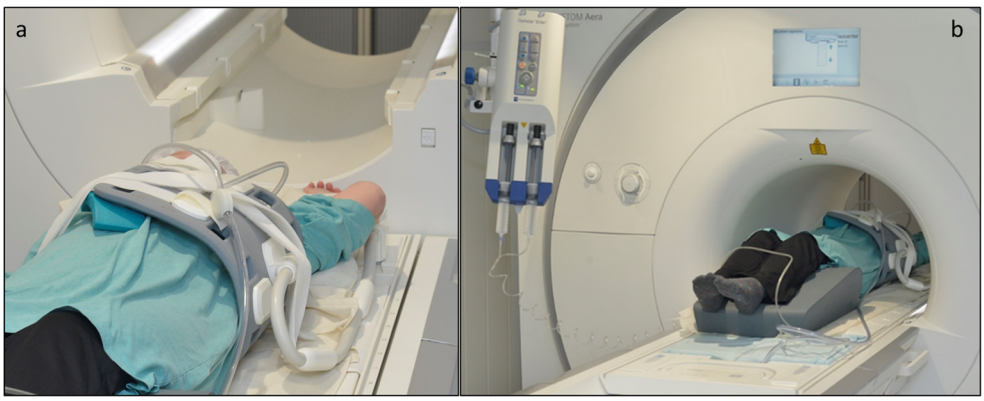


**Fig. 2** Patient and coil positions in supine MRI. Patient ready before (**a**) and after (**b**) entering MRI tube

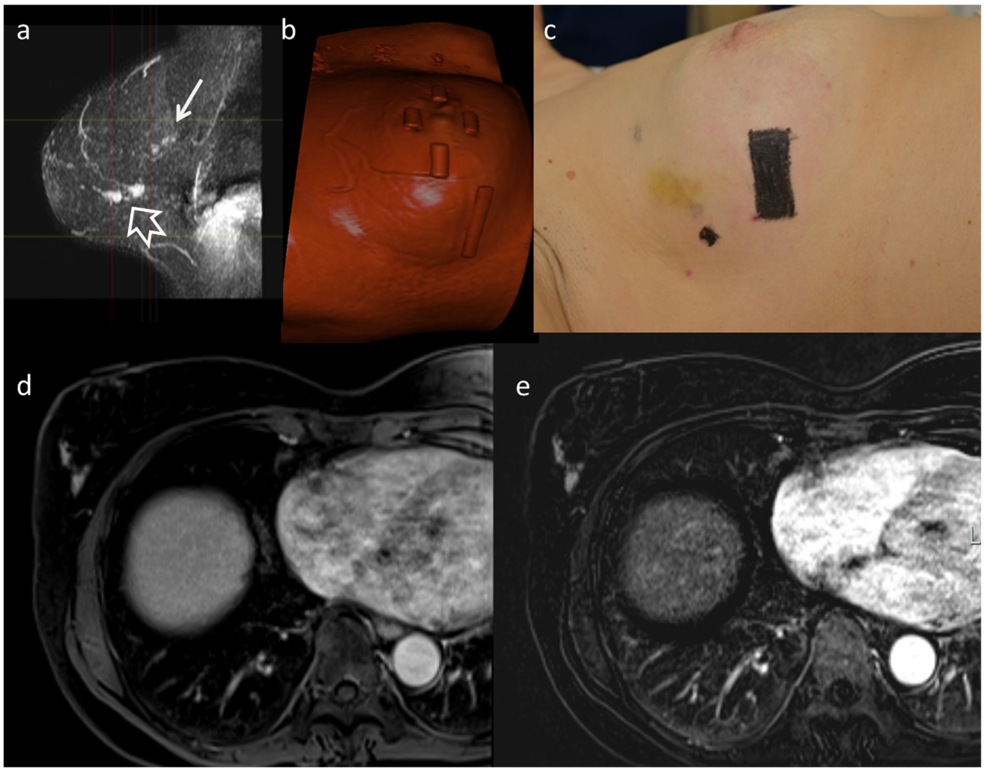


**Fig. 3** Patient no. 13 had a palpable invasive cribriform carcinoma (open arrow) in the lower lateral quadrant. A second suspicious tumour area was diagnosed with prone MRI (**a**, arrow) and proved to be invasive ductal carcinoma at targeted US-guided core biopsy. Shaded volume rendered reconstruction image of supine MRI (**b**) shows the position of the MRI-visible capsules positioned on the skin. **c** Shows the positions of the tumours inked on skin based on the preoperatively performed supine MRI. The additional lesion was further bracketed with guidewire (not shown). Supine MRI axial source (**d**) and subtraction images (**e**) at the level of the palpable tumour show good tumour visibility and image quality

were histologically verified. Serial sectioning was performed, as needed, especially in non-palpable lesions to determine the largest diameters of any given lesion, and sizes were routinely reported in three dimensions according to a structured standardised institutional protocol. Furthermore, all findings at imaging were correlated to histopathology.

## Image analysis

All images were retrieved and analysed from a picture archiving and communication system (Sectra Workstation IDS7 Sectra AB). Tumours' 3D largest diameter and surface area were measured from the same area from both prone and supine MRIs (second postcontrast sequences, reported and interpreted in a similar manner as in the preoperative setting) and these were compared to the final histological measurements. Similarly, the second largest additional MRI finding was measured in the same fashion. Furthermore, the tumour's posterior distance from the chest wall was compared between the prone and supine MRIs. Multiplanar reconstructions were used to measure the distances of the anterior margins of the tumour from the base of nipple in the sagittal orientation.

Primary resection was deemed successful if the resected area was primarily fully removed with macroscopic margins as evaluated by intraoperative specimen imaging and no tumour-on-ink at histopathology.

## Statistical analysis

The differences between the MRI measurements and the corresponding dimensions in histopathology as the golden standard were evaluated with the paired-sample *t* test. The statistical analysis was performed with SPSS software (IBM SPSS Statistics for Windows, Version 23.0. IBM). Differences between groups were considered significant if the *p* value was less than 0.05.

# Results

During a 14-month period (December 2016–January 2018) a total of 14 female patients were included in the study. In one patient MRI showed a large additional non-mass segmental enhancement which proved to be a carcinoma in situ at preoperative biopsy (Fig. 4). Altogether 15 breasts in 14 patients were evaluated; of these, 12 patients had one or multiple additional lesions defined as separate mass or non-mass lesion enhancements not in contact with the index tumour. Only the largest additional lesion was further evaluated in the same manner as the index lesion. A total of 27 (19 mass and 8 non-mass) lesions were evaluated. Patients' and tumours' characteristics are presented in Table 2. In all patients, prone MRI showed more extensive findings than were previously evaluated by conventional imaging modalities. Prone MRI was

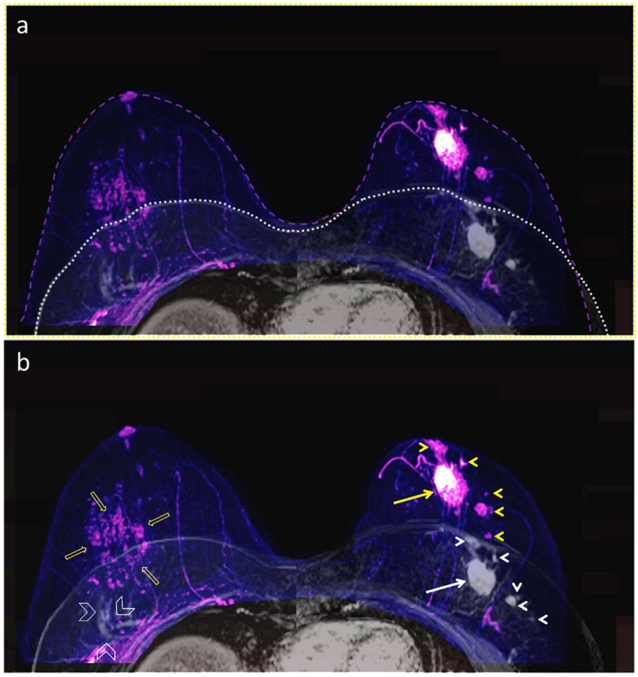


**Fig. 4** Patient no. 3 with multifocal invasive papillary carcinoma in the left breast and carcinoma in situ in the right breast as an incidental MRI finding. Fusion images of bilateral maximum intensity projection prone and supine MRI images. Tumours are shown pink colour-coded in the prone position and light grey in the supine position. **a** Shows the contours of the merged breasts, the purple dashed line indicates the contours in prone MRI and the white dotted line in supine MRI. **b** The main position of the tumour in the left breast (arrow) remained constant relative to the nipple. Minor changes are depicted in the other multifocal tumour positions (arrowheads). However, in the right breast the 6-cm non-mass lesion in the prone position (open arrows) shrunk antero-posteriorly to a 2-cm area in the supine position (open arrowheads)

considered to change the primary surgical plan in 5 out of 14 patients (35.7%). In these patients, histological verification was obtained with core biopsy at second-look US examinations.

All supine MRI examinations were deemed technically successful. Ink-marking guided resection was performed in all cases with clear margins at final histopathology. The size of lesions at histology and changes in breast lesion characteristics compared to MRI both in prone and supine positions are presented in Tables 3 and 4. Tumour sizes differed significantly when imaged in the prone and supine positions and were more accurately measured from supine MRI. The nipple-to-lesion distances also differed significantly, the mean change being less than 1 cm in all lesions. On a clock position was stable in 16/27 (59.3%) lesions. In one patient (no. 14) prone MRI showed a non-mass enhancement at the planned resection margin that was not visualised at supine MRI. Intraoperative frozen-section and final histology showed no malignant changes. All resections were successfully performed with free macroscopic and microscopic margins.

## Discussion

The results of our study show that supine breast MRI is feasible using commercially available coils and sequences. Furthermore, supine MRI enables the lesions detected in prone MRI to be demarcated and projected on the skin in the same position used in surgery. This practically ensures the proper estimation of the resection area and consequently the total resection of all MRI-visible lesions with the needed macroscopic margins. Intuitively, supine MRI might reduce the number of reoperations due to possible positive margins.

Oncoplastic breast-conserving surgery is an oncologically safe option for the mobilisation and surgical removal of large amounts of tissue. One of the major drawbacks of oncoplastic surgery is the increased probability of positive margins at final histology, which in turn would most probably lead to mastectomy as re-resections are more challenging in this patient population [14]. Therefore, efforts to reduce the reported high positive margin rates are needed and supine MRI, in our opinion, might play an important role in this aspect.

Breast MRI in the prone position was previously shown to be undoubtedly the most sensitive imaging modality in the detection of invasive breast cancer. Breast MRI is also considered to be the most sensitive method in the assessment of tumour size [3]. Nevertheless, considerable over- and underestimation of tumour sizes are reported [15–18]. Overestimation of tumour sizes in MRI, both invasive and DCIS, is a recognised drawback and can result in unnecessarily large excisions or mastectomies [19]. Behjatnia et al reported overestimation of tumour size with MRI in 70% of their cases and in up to 81% in invasive ductal carcinoma (IDC) [18]. A similar result of overestimation in 68.4% of the cases was reported by Leddy et al [17]. Esserman et al reported a more than twofold overestimation in DCIS patients [20]. In a study by Carin et al, in cases where MRI overestimated the size of the main tumour, there was an associated DCIS in 56.5% of cases [21].

It is noteworthy that the comparison of results between different studies is difficult because of the different study designs used. Some studies included DCIS in the analysis while others did not [18]. Differences in previous results can also be attributed to the inconsistency in corrections for specimens' shrinkage-effect after fixation or to the different concordance thresholds adopted within the studies [16]. Furthermore, comparable measurements from three-dimensional ducts in different imaging modalities and two-dimensional histology sections are difficult to standardise [20].

Our results consistently show significantly smaller lesion sizes when measured from supine MRI as compared to prone MRI. Factors that have been previously attributed to the overestimation dilemma in the MRI literature include the presence of peritumoural DCIS and/or benign proliferative lesions with increased angiogenesis in continuation to DCIS [15, 16, 18, 20, 21]. On the basis of observations from the present study,

**Table 2** Patient, tumour characteristics and additional findings at final histopathology

| Patient no. | Side | Age (years) | Histology and grade | TN classification | Stage | ER/PR/Ki67 (%) | HER2 + or – | Multifocal | Additional lesions |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Left | 57 | IDC gr 2 | pT2N0 | IIB | 100/80/30 | – | Yes | DCIS gr 2, Paget disease |
| 2 | Left | 72 | IDC gr 3 | pT2N0 | IIA | 100/20/60 | – | Yes | DCIS gr 3 |
| 3 | Left | 58 | IPC gr 2 | pT2N2a | IIIA | 100/100/20 | – | Yes | IDC, DCIS gr 1, LCIS, papilloma |
| | Right | | LCIS | NA | NA | NA | NA | No | NA |
| 4 | Left | 49 | IDC gr 2 | pT2N1a | IIB | 90/100/10 | – | Yes | DCIS gr 3 |
| 5 | Right | 41 | IDC gr 2 | pT1cN0 | IA | 95/100/30 | – | Yes | DCIS gr 3 |
| 6 | Left | 60 | IDC gr 2 | pT1cN0 | 0 | 100/10/20 | – | No | Multiple fibroadenomas, LCIS |
| 7 | Left | 41 | IDC gr 2 | pT2N3a | III C | 100/100/20 | – | Yes | IDC, DCIS |
| 8 | Left | 70 | IDC gr 3 | pT1cN1a | 1a | 100/100/20 | – | Yes | IDC |
| 9 | Right | 67 | DCIS gr 3 | pTisN0 | 0 | NA | NA | No | – |
| 10 | Right | 39 | IDC gr 3 | pT2N1a | IIB | 1/0/60 | – | No | Radial scar, papillomatosis |
| 11 | Left | 65 | ILC gr 2 | pT2N1a | IIB | 100/90/5 | – | Yes | ILC |
| 12 | Right | 52 | IDC gr 1 | pT1cN0 | IA | 100/100/5 | – | Yes | IDC |
| 13 | Right | 62 | ICC gr 2 | pT2N0 | II A | 100/0/15 | – | Yes | IDC, DCIS |
| 14 | Left | 68 | IDC gr 2 | pT1cNo | IA | 100/100/20 | – | No | Fibrocystic changes |

*IDC* invasive ductal carcinoma, *ILC* invasive lobular carcinoma, *ICC* invasive cribriform carcinoma, *IPC* invasive papillary carcinoma, *DCIS* ductal carcinoma in situ, *LCIS* lobular carcinoma in situ

we further propose an additional "accordion-like" mechanism: breasts consist of differing amounts of fibroglandular and fat tissues and these have variable biomechanical properties such as expandability and intrinsic elasticity [22]. In the prone position, closely located ductal structures broaden out and track surrounding tissues resulting in discontinuous and fragmented areas of enhancement as seen in Fig. 2. The amount and behaviour of these tissues result from complex interactions of collagen fibres, elastin, proteoglycans and water within the tissue and also depend on the stiffness of the area of concern. Apparently, this behaviour cannot be predicted and varies between different individuals as the amplitude is dependent on the breast-specific elastic variability and structural properties. Furthermore, enhancement due to the intraductal benign proliferative lesions is not equally depicted in the supine position and therefore overestimation is further diminished. In this context, supine MRI might have a role in the proper preoperative evaluation of patients with larger tumours. Solid breast tumours are much stiffer than the normal breast parenchyma, and therefore this "accordion effect" occurs mainly in the peritumoural area. Therefore, size changes are minimal in solid lesions (mean 9.2%) as compared to non-mass lesions (20.9%).

**Table 3** Size of lesions at histology compared to MRI both in prone and supine positions

| | Histology | Prone | Supine | *p*1 | *p*2 | *p*3 |
|---|---|---|---|---|---|---|
| Mean (mm) | 19.04 | 28.00 | 21.81 | 0.01 | 0.259 | 0.003 |
| Mass (mm) | 16.29 | 21.12 | 19.18 | 0.222 | 0.441 | 0.009 |
| Non mass (mm) | 24.22 | 41.00 | 26.78 | 0.013 | 0.069 | 0.031 |

*p1 p* value of statistical differences between histology compared to prone MRI, *p2* histology vs. supine MRI, *p3* prone vs. supine MRI

As expected, in this study, all tumours were significantly closer to the chest wall on supine images because of the effect of gravity, which is in line with previous results [10]. Although prone-to-supine tumour displacement in the breast can be occasionally predicted depending on the tumour's location in a given quadrant [23], the exact displacement can vary greatly according to the location of the lesion and to the size of the breast. In this study the nipple-to-lesion distances differed significantly, and the mean change was less than 1 cm in all lesions irrespective of the tumour's morphology, mirroring the results of Carbonaro et al. The authors suggested that the lesion-to-nipple distance may be the most reliable measure to be used for second-look breast US in a study including 11 patients [8]. Furthermore, the change of tumour location according to its position on a clock in relation to the nipple had a small mean range of 8.5°, also indicating that the dislocated lesions might be located in close proximities to these positions evaluated from the prone MRI. Nevertheless, not all lesions can always be visualised with targeted US and clearly supine MRI is an additional useful examination that might also have an important role for the proper localisation and evaluation of lesions detected by MRI only.

Tumour relocation inside the breast from the prone to supine positions seems to be minimal when measured from

**Table 4** Changes in breast lesion characteristics comparing prone and supine MRIs

| | | | Prone | Supine | Proportion | *p* value |
|---|---|---|---|---|---|---|
| Area ($mm^2$) | Lesions combined | | 329.42 | 203.12 | – 38.3% | 0.016 |
| | Mass | | 224.76 | 189.41 | – 10.7% | 0.027 |
| | Non mass | | 527.11 | 229.00 | – 56.6% | 0.042 |
| Distance from chest wall (mm) | Lesions combined | | 50.65 | 15.50 | – 69.4% | < 0.001 |
| | Mass | | 54.71 | 14.76 | – 73.0% | < 0.001 |
| | Non mass | | 43.00 | 16.89 | – 60.7% | 0.002 |
| Distance from nipple (mm) | Lesions combined | | 38.29 | 31.32 | – 18.2% | < 0.001 |
| | Mass | | 45.71 | 37.82 | – 17.2% | 0.004 |
| | Non mass | | 26.82 | 21.27 | – 20.7% | 0.036 |
| Changes in lesions' position on a clock in relation to nipple in supine MRI | Changes in lesions' position in relation to the nipple in supine MRI[a] | 0–37.5°<br>8.5°<br>11/27<br>(range 15–37.5°) | | | | |

[a] Proportion of change was visually estimated as the relative change of direction of the lesion from the nipple using the analogy of a 12-hour clock, where every hour corresponds to an angle of 30°

the nipple as well as when evaluated on a clock position. Therefore, these two measurements, in our opinion, offer a useful tool in the evaluation of MRI-detected occult lesions. Furthermore, in addition to the preoperative staging and mapping of breast cancer, supine MRI provides new insights into the direct visualisation and accurate localisation of the enhancing process. These issues warrant further research. Furthermore, although we have preferred to use breath-hold dynamic imaging with subtractions, the optimal protocol for supine MRI is yet to be determined

Our study is not without limitations. The small sample size is the major limitation of this study, yet the results nevertheless showed a statistically significant difference between morphological measures in prone and supine MRI. Although the use of a wide-bore MRI scanner has reduced the degree of hand elevation, the position of the elevated arm in supine MRI was still somewhat higher than the perpendicular position at surgery because of size limitations of the MRI tube, which is another limitation of this study. Changes in the arm's position might result in tumour relocation which was reported to be small on average, yet it can be occasionally significant [24, 25]. Consequently, the skin of the breast will be pulled and its markers relocated along with the superoinferior movement of the hand, yet the relationship between these changes is not yet defined. Although according to our limited experience this did not affect the marking protocol, the possible drawbacks of this issue need to be acknowledged and addressed in studies with larger patient populations.

To conclude, supine MRI performed in the surgical position using commercially available coils and sequences is feasible and useful in the precise preoperative localisation of prone MRI-detected lesions in patients undergoing oncoplastic breast-conserving surgery. Supine MRI more accurately determines the size of the tumours compared to prone MRI and might have an important role in diminishing overestimations.

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## Compliance with ethical standards

**Guarantor** The scientific guarantor of this publication is Dr Mazen Sudah MD, PhD.

**Conflict of interest** The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

**Statistics and biometry** One of the authors has significant statistical expertise.

No complex statistical methods were necessary for this paper.

**Informed consent** Written informed consent was obtained from all patients in this study.

**Ethical approval** Institutional review board approval was obtained.

**Methodology**
- prospective
- case-control, diagnostic study
- performed at one institution

## References

1. Litière S, Werutsky G, Fentiman IS et al (2012) Breast conserving therapy versus mastectomy for stage I-II breast cancer: 20 year follow-up of the EORTC 10801 phase 3 randomised trial. Lancet Oncol 13:412–419
2. Leithner D, Wengert GJ, Helbich TH et al (2017) Clinical role of breast MRI now and going forward. Clin Radiol. https://doi.org/10.1016/j.crad.2017.10.021

3. Sardanelli F, Boetes C, Borisch B et al (2010) Magnetic resonance imaging of the breast: recommendations from the EUSOMA working group. Eur J Cancer 46:1296–1316
4. Holland R, Veling SH, Mravunac M, Hendriks JH (1985) Histologic multifocality of Tis, T1-2 breast carcinomas. implications for clinical trials of breast-conserving surgery. Cancer 56: 979–990
5. Turnbull L, Brown S, Harvey I et al (2010) Comparative effectiveness of MRI in breast cancer (COMICE) trial: a randomised controlled trial. Lancet 375:563–571
6. Houssami N, Turner RM, Morrow M (2017) Meta-analysis of preoperative magnetic resonance imaging (MRI) and surgical treatment for breast cancer. Breast Cancer Res Treat 165:273–283
7. Tozaki M, Fukuda K (2006) Supine MR mammography using VIBE with parallel acquisition technique for the planning of breast-conserving surgery: clinical feasibility. Breast 15:137–140
8. Carbonaro LA, Tannaphai P, Trimboli RM, Verardi N, Fedeli MP, Sardanelli F (2012) Contrast enhanced breast MRI: spatial displacement from prone to supine patient's position. Preliminary results. Eur J Radiol 81:e771–e774
9. Siegler P, Holloway CM, Causer P, Thevathasan G, Plewes DB (2011) Supine breast MRI. J Magn Reson Imaging 34:1212–1217
10. Gombos EC, Jayender J, Richman DM et al (2016) Intraoperative supine breast MR imaging to quantify tumor deformation and detection of residual breast cancer: preliminary results. Radiology 281:720–729
11. Pallone MJ, Poplack SP, Avutu HB, Paulsen KD, Barth RJ Jr (2014) Supine breast MRI and 3D optical scanning: a novel approach to improve tumor localization for breast con-serving surgery. Ann Surg Oncol 21:2203–2208
12. Kuhl CK, Strobel K, Bieling H et al (2017) Impact of preoperative breast MR imaging and MR-guided surgery on diagnosis and surgical outcome of women with invasive breast cancer with and without DCIS component. Radiology 284:645–655
13. Hayes MK (2017) Update on preoperative breast localization. Radiol Clin North Am 55:591–603
14. Macmillan RD, James R, Gale KL, McCulley SJ (2014) Therapeutic mammaplasty. J Surg Oncol 110:90–95
15. Schouten van der Velden AP, Schlooz-Vries MS, Boetes C, Wobbes T (2009) Magnetic resonance imaging of ductal carcinoma in situ: what is its clinical application? A review. Am J Surg 198:262–269
16. Lai HW, Chen DR, Wu YC et al (2015) Comparison of the diagnostic accuracy of magnetic resonance imaging with sonography in the prediction of breast cancer tumor size: a concordance analysis with histopathologically determined tumor size. Ann Surg Oncol 22:3816–3823
17. Leddy R, Irshad A, Metcalfe A et al (2016) Comparative accuracy of preoperative tumor size assessment on mammography, sonography, and MRI: is the accuracy affected by breast density or cancer subtype? J Clin Ultrasound 44:17–25
18. Behjatnia B, Sim J, Bassett LW, Moatamed NA, Apple SK (2010) Does size matter? Comparison study between MRI, gross, and microscopic tumor sizes in breast cancer in lumpectomy specimens. Int J Clin Exp Pathol 3:303–309
19. Fancellu A, Turner RM, Dixon JM, Pinna A, Cottu P, Houssami N (2015) Meta-analysis of the effect of preoperative breast MRI on the surgical management of ductal carcinoma in situ. Br J Surg 102: 883–893
20. Esserman LJ, Kumar AS, Herrera AF et al (2006) Magnetic resonance imaging captures the biology of ductal carcinoma in situ. J Clin Oncol 24:4603–4610
21. Carin AJ, Molière S, Gabriele V et al (2017) Relevance of breast MRI in determining the size and focality of invasive breast cancer treated by mastectomy: a prospective study. World J Surg Oncol 15: 128-017-1197-1
22. Ramião NG, Martins PS, Rynkevic R, Fernandes AA, Barroso M, Santos DC (2016) Biomechanical properties of breast tissue, a state-of-the-art review. Biomech Model Mechanobiol 15:1307–1323
23. Satake H, Ishigaki S, Kitano M, Naganawa S (2016) Prediction of prone-to-supine tumor displacement in the breast using patient position change: investigation with prone MRI and supine CT. Breast Cancer 23:149–158
24. Ebrahimi M, Siegler P, Modhafar A, Holloway CM, Plewes DB, Martel AL (2014) Using surface markers for MRI guided breast conserving surgery: a feasibility survey. Phys Med Biol 7:1589–1605
25. Conley RH, Meszoely IM, Weis JA et al (2015) Realization of a biomechanical model-assisted image guidance system for breast cancer surgery using supine MRI. Int J Comput Assist Radiol Surg 10:1985–1996