Tips and techniques in breast MRI

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Abstract The standard breast MRI protocol includes T2 sequences (anatomy and signal analysis), T1 gradient-echo sequences which can detect markers placed after biopsy, and injected dynamic 3D sequences for performing volume and multiplanar reconstructions, which are particularly useful for locating lesions well. Good patient positioning is essential and is obtained by using foam wedges for small breasts, ensuring there are no folds, and the correct position of the nipples. These aspects limit movement artefacts which alter subtraction sequences, so that it must always be possible for reading these sequences to be assisted by comparing them with the native sequences. New functional imaging sequences are now appearing in an attempt to increase the specificity of MRI, which is one of its main limitations. Of these, magnetic resonance spectroscopy appears to be the most promising, highlighting an abnormal choline peak in malignant lesions. This molecular signature provides early information (24 hours after beginning neoadjuvant treatment) on the chemosensitivity of a breast tumour.

Breast MRI has become an essential examination for investigating the pathological breast. Over the past 10 years or so, a number of papers have described good practice in performing this examination [1,2]. Breast MRI is the imaging of tumour angiogenesis, based on studying dynamic uptake of contrast agent in T1 imaging, which varies with the microvascularisation characteristics of breast tumours. At the beginning of the 1990s, there were two opposite approaches in the literature: some authors advocated high spatial resolution, thus prioritising analysis of the morphology of the lesions (the contours, form, internal characteristics) [3,4], while others favoured high temporal resolution, preferring...
to use information from the dynamic enhancement curve of the lesions [5,6]. Today, with technical progress these two approaches are reconciled, and this compromise is the basis for any sequence optimisation in breast MRI.

**Before beginning the examination...**

**Patient questionnaire**

Apart from the standard contraindications for any magnetic imaging examination (heart stimulator, cochlear implants, ferromagnetic aneurysm clips, etc.), it is desirable to collect a certain amount of other information which will be fundamental for interpreting the results of the examination. Before the examination, it is helpful to have the patient complete a specific questionnaire aided by an experienced breast imaging assistant or a doctor. This should include information on hormonal status (menopause, day of the menstrual cycle, pregnancy, breast-feeding), the personal history of breast cancer (specifying the date of surgery, the date of the end of radiotherapy, the history of axial lymph node dissection, the chemotherapy or hormone treatment) and any family history (Appendix A).

**Positioning the coil**

Correct positioning of the MRI coil is essential to limit a certain number of artefacts (Table 1). The patient must be in a comfortable position with her arms above her head to limit aliasing artefacts and artefacts relating to phase encoding (Fig. 1). In order to limit respiratory movement artefacts, foam wedges should be used inside the coil when the breast volume is low. It must be ensured that any fold that could form when the breast is abnormally compressed by the edge of the coil is avoided (Fig. 2). Attention should also be paid to correctly positioning the nipple directly below the breast to facilitate locating lesions and make it easier to correlate the images with the mammogram and ultrasound.

**Acquisition**

**Standard protocol**

In order to optimise image quality, it is necessary to observe a number of basic points:

- the examination must be performed with a very uniform magnetic field in order to limit artefacts related to non-uniform fat suppression (Fig. 3) [7];
- both breasts must be investigated to allow mirror reading by facilitating detection of the physiological glandular contrast uptake, which can limit the diagnostic value of the examination by masking a certain amount of contrast uptake and limiting aliasing artefacts (this occurs when

Figure 1. Motion artefacts. Because of poor uncomfortable positioning of the patient in the coil (external part of the left breast not within the coil) visible on the T2-weighted sequences (a), the patient moved during injection, which altered interpretation of the subtraction sequences particularly because of blurring in the phase encoding direction (b).

Figure 2. Aliasing artefact and compression because of poor coil positioning. T2 TSE axial sequence with fat saturation: ghost images in the phase encoding direction because of poor positioning of the breast in the coil (folding in the outer quadrants) with lack of fat saturation where there was contact with the coil.

Figure 3. Field non-uniformity artefact leading to non-uniformity of fat saturation. Saturation of the left breast has not occurred and that of the right breast is not uniform. This artefact is more common in predominantly fatty breasts.
the field of view is smaller than the area of the patient explored;
- the injection of gadolinium must be reproducible with a dose of 0.1 mmol/kg (or 0.2 mL/kg) and a flow rate of 1–2 mL/sec flushed by 20 mL of physiological saline. The use of an automatic injector is recommended;
- slice thickness should be less than or equal to 3 mm with pixel size less than 1 mm on each side. For multiplanar reconstruction, the voxel should optimally be isotropic and less than 1 mm;
- finally, acquisition time should be less than 2 minutes as the mean enhancement time of a malignant tumour is between 90 and 120 seconds.

For all axial plane acquisitions the phase encoding direction should be from right to left to limit artefacts repeating cardiac and respiratory movement. For sequences in the sagittal or coronal plane, the encoding direction will be anterior-posterior.

Morphological sequences
Historically, breast MRI non-injected sequences were considered as being of little use because of the low diagnostic value of T2 and T1-weighted signals. Since then, several authors have demonstrated the usefulness of T2-weighted sequences for detecting the presence of cysts or microcysts, the presence of which suggests the benign character of enhancement (whether annular enhancement in the case of an inflammatory cyst or stippled non-masslike enhancement in fibrocystic mastopathy). The European recommendations (EUSOBI) advocate undertaking a T2-weighted sequence. According to Kuhl et al., T2-weighted sequences can be performed without fat saturation because a T2 signal greater than that of non-saturated fat has very good predictive value for a cyst being benign [6]. T2-weighted sequences with fat saturation are useful for creating indirect MRI ductography images where there is a discharge and seem to optimise the detection of small cancers.

T1-weighted sequences are useful for detecting the presence of a fatty component within a lesion, which is also a major aspect predicting its benign nature. T1 sequences are therefore performed without fat saturation. They also allow metal markers to be detected which may have been positioned at the end of biopsy. When the biopsy was guided by MRI, T1 sequences can confirm the correct position of the marker in the biopsy site at the end of the procedure [8]. When the biopsy took place using stereotaxic mammography or ultrasound, the marker provides confirmation that the position of the biopsied lesion and of contrast uptake in the MRI is the same. This detection of the biopsy marker is based on detecting the magnetic susceptibility artefact on T1 gradient-echo sequences, created by the metallic nature of the marker. The longer the TE of the sequence the more this artefact is visible. As a corollary, it must be accompanied by an increase in TR to limit the loss in signal-to-noise ratio. If a satisfactory compromise is not found, performing two T1 sequences could be envisaged, one specifically to detect the metal markers and the second to characterise the T1 signal of the lesions (Fig. 4).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The main artefacts and solutions to them.</th>
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<tr>
<td><strong>Main artefacts</strong></td>
<td><strong>Signs</strong></td>
</tr>
<tr>
<td>Movement artefact</td>
<td>Fuzzy lines, Propagation in the phase encoding direction</td>
</tr>
<tr>
<td>Aliasing artefact</td>
<td>Ghost images</td>
</tr>
<tr>
<td>Magnetic susceptibility artefact</td>
<td>Tissue distortion, hypersignal spots, fall in signal</td>
</tr>
<tr>
<td>Non-uniformity artefact</td>
<td>Occurs with a non-uniform field because of non-selection of fatty pixels</td>
</tr>
</tbody>
</table>

**Figure 4.** Special metal marker T1 sequences. The aim of this sequence is to optimise visualisation of metal markers. It is a T1 gradient-echo sequence for which the TE has been increased to maximise the magnetic susceptibility effect. Mammogram produced after biopsy showing two markers (a). Breast MRI; T1 marker sequence showing the two markers in the form of an absence of signal with surrounding distortion (b).
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Dynamic sequences

Dynamic sequences must satisfy the two major classic requirements of perfusion imaging: good temporal resolution (<2 minutes) and good spatial resolution (1 mm isotropic pixel).

2D or 3D?

3D T1 gradient-echo sequences with a moderate flip angle meet these requirements. They allow thinner slices with a better signal-to-noise ratio than 2D sequences [2]. However, classically, if they are acquired without fat suppression, it is preferable to use 2D sequences to limit phase encoding artefacts which propagate in all three directions in 3D sequences, masking the contours and making the detection of these artefacts on the subtraction sequences difficult.

What plane should be chosen?

Working with a small field of view is possible with the sagittal plane (which means a gain in terms of spatial resolution and field uniformity), but the number of slices needed to examine the two breasts means that it is essential to use parallel imaging (or SENSE) to have an acquisition time of less than two minutes. Parallel imaging is based on the principle of partitioned acquisition of the field of view by each of the four to eight coil channels. The image is reconstructed using algorithms which are very sensitive to motion artefacts, particularly in sagittal sequences. For this reason, axial acquisitions are often preferred. In an axial slice, the use of parallel imaging provides improved image quality over acquisitions without a SENSE factor [9].

What fat suppression?

Initially, the use of subtractions was essential for detecting lesions because fat suppression was too costly in terms of time to be performed. With the arrival of parallel imaging, native sequences can be acquired with fat saturation. Undertaking native sequences with fat saturation paired with subtraction improves the detection of lesions and analysis of contrast uptake when the subtractions are degraded by movement. There are several fat saturation techniques: the classic spectral presaturation with inversion recovery (SPIR) fat saturation technique has now been replaced by the technique of selective excitation of the water peak, which gives more uniform suppression of the tissues and improves the contrast of lesions after injection [10].

What are the benefits of 3T imaging?

Appendix B shows the parameters of 3D sequences optimised at 1.5T and 3T. They are applied in an axial plane with a short TR and a very short TE, with fat saturation allowing easy reading of the native sequences and reducing artefacts in the subtraction sequences. When the pixel...
is isotropic, dynamic acquisitions can be reduced to a single plane, preferably the axial plane, since multiplanar reconstruction produces satisfactory images in the sagittal and coronal planes. Theoretically, the use of a 3T magnet increases the signal-to-noise ratio. Kuhl et al. reported improvement in image quality because of possible optimisation of the spatial resolution with a 3T magnet compared with a 1.5T magnet [11]. In our experience, the use of 3T MRI for breast imaging poses the major problem of field uniformity whereas the latter is essential for correct fat suppression. In their experience, Kuhl et al. reported significantly lower enhancement levels at 3T than were obtained with 1.5T acquisitions (Fig. 5). Our clinical impression is the opposite, with enhancement levels which seem to be greater at 3T than those obtained with the 1.5T magnet. These differences from the results of Kuhl et al. are possibly related to differences in sequences used on the Philips magnet because we used a new 3D sequence (Appendix B) which differed from the 2D sequence used by Kuhl et al. in their first paper [11]. In addition, in most editorials written by the same author, she advises caution and warns of the field uniformity difficulties inherent in using 3T for the breast. Finally, with 3T, there is an increase in artefacts, whether they are motion artefacts or of metal, which can result in distortions of the image which adversely affect diagnosis to a considerable extent.

Acquisition is first of all without injection (mask) then dynamic, after injection, with a minimum of four repetitions (the minimal number of points for the enhancement curve) over a minimal period of 7 minutes. Malignant tumours enhance within 1 minute 30 seconds to 2 minutes after injection. Depending on the acquisition time of the sequence, a period of about 20 seconds may be left between the end of the injection and the start of the dynamic sequences so that the first acquisition is at the point of maximum uptake of contrast by malignant lesions.

Specificities of the protocol depending on the clinical indication

Breast implants

The image acquisition protocol must include a sequence where fat and silicone are in hypersignal (T2 TSE with selective water suppression; detection of an intracapsular rupture), a sequence where only the silicone is in hypersignal (water and fat saturation with a STIR sequence with selective water suppression; detection of an extracapsular rupture) and finally a sequence saturating the silicone (water and fat in hypersignal with a T2 TSE with selective silicone suppression; detection of a periprosthetic liquid effusion). Fat suppression is preferably achieved with the STIR sequence because the silicone and fat peaks are close together, which prevents correct fat suppression by a method involving selective suppression of the peak. This STIR sequence produces the best contrast with adjacent tissues (which is fundamental for detecting an extracapsular rupture). On the other hand, analysis of the content of the implant is less precise than with the T2 TSE sequence with water suppression, which is still necessary for detecting and analysing an intracapsular rupture [12]. Acquisition is in the axial and sagittal planes (Fig. 6).

Breast discharge

T2-weighted sequences, with fat saturation and without the use of a contrast agent, produce an ‘indirect’ ductography image of the dilated lactiferous ducts, which appear in T2 hypersignal relative to the saturated fat, whereas the mammary tissue is in hyposignal (Fig. 7). Some teams have suggested performing direct MR ductography, which consists of injecting gadolinium (gadopentate, MAG-NEVIST) into the lactiferous ducts then performing VIBE or FLASH rapid sequences, depending on the constructors. When conventional ductography has failed, this technique could thus provide an alternative for identifying and then
targeting a breast abnormality for undertaking a biopsy or pinpointing it preoperatively. In a population of 62 patients referred for nipple discharge, this technique produced diagnostic accuracy close to that of conventional ductography (85%) [13].

**Post-treatment**

**Analysis of the morphology of the lesions**

**Multiplanar reconstruction**

This is one of the fundamental phases of the examination, allowing lesions to be located in the three axes. It is thus particularly useful for analysing the shape and contours of a mass, and the distribution of non-masslike enhancement by providing its possible orientation relative to the nipple, for calculating the distance to the nipple from the area of contrast uptake, for evaluating possible pectoral extension or determining the quadrant in which the lesion is situated (making the task easier for second-line targeting a breast abnormality for undertaking a biopsy or pinpointing it preoperatively. In a population of 62 patients referred for nipple discharge, this technique produced diagnostic accuracy close to that of conventional ductography (85%) [13].

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**Figure 7.** The usefulness of T2-weighted sequences with fat saturation in cases of nipple discharge. T2 TSE axial sequence with fat saturation showing predominant unilateral duct ectasia at the junction of the inner quadrants of the right breast in a patient with juvenile papillomatosis or “Swiss cheese disease”.

**Figure 8.** Multiplanar reconstruction. Isotropic axial sequences (a) allow multiplanar reconstruction of excellent quality (b), virtually equivalent to acquisition in the native plane (c). This reconstruction is very useful for assessing distance relative to the nipple and for correlating MRI data with the data of the mammogram or mammary ultrasound (quadrant on coronal reconstructions) (d).
ultrasonography looking for the lesions detected by MRI) [14] (Fig. 8).

Multiple intensity projection (MIP)
This rapidly detects areas of maximum enhancement (a tumour, a lymph node) and their relationship with the arteries or veins (Fig. 9). It must be undertaken from early dynamic sequences following injection of gadolinium. It can be useful to the surgeon if there are multiple lesions for assessing the relations of each of the lesions. On the other hand, in no case can it be used for measurement (particularly not for measuring distance relative to the nipple).

Analysis of enhancement dynamics
In contrast enhanced-MRI, the principle is common to all tissues: the slice is selected where the tissue to be studied is located, then areas of interest to be analysed are positioned. The correct position of the area of interest within the enhancement area on the different acquisition phases must be systematically checked. If an area of enhancement is detected on subtracted sequences, analysis of the enhancement dynamics should be confirmed on the native sequences to eliminate all artefacts linked to the subtraction (Fig. 10). Several types of analysis of contrast uptake can be performed:

- descriptive analysis is the simplest and consists of describing types of curves (type 1 benign, progressive, type 2 intermediate with a plateau, or type 3 malignant, with secondary washout);
- semi-quantitative analysis involves determining more reproducible parameters describing the enhancement curve, such as the initial enhancement slope, the time to peak, washout and the area under the curve. These parameters are the basis for the colour-coded parametric maps offered by various constructors or CAD programs. Thus there are maps of washin, washout, a combination of the two, time to peak or of area under the curve. These maps can help detect maximum areas of contrast uptake in order to determine regions where an area of interest should be applied (Fig. 11);
- quantitative analysis, the last type of analysis, is based on compartmental analysis. The principle of this analysis is to follow the changes in concentration of the contrast agent in each tissue compartment using differential equations which define the compartmental model used. In breast imaging, the most commonly used model is the extended Tofts-Kety model [15]. It is suitable for low temporal resolution acquisitions because it uses a mean arterial input function. It describes the blood volume, the interstitial volume and a transfer constant between these two compartments ($K_{trans}$). Quantitative analysis is the most reproducible analysis because, unlike the first
two analyses, it is independent of measurement conditions (sequence, machine, coil, etc.). However, this type of post-treatment is still in the development stage even if some semi-automatic programs are beginning to appear.

**Work in progress: diffusion and spectroscopy**

The sensitivity of breast MRI is excellent (higher than 95% for invasive carcinomas) but its specificity is very variable depending on the experience of the reader (37 to 86% depending on the study, according to the literature) despite the different multiparametric approaches which take into account both morphological and dynamic criteria [6,16,17]. Several techniques are also currently being developed in an attempt to increase the specificity of this examination.

**Magnetic resonance spectroscopy**

Magnetic resonance spectroscopy (1H MR spectroscopy) is a molecular imaging method based on detecting an abnormal choline peak in malignant tumours (resonance at 3.2 ppm) [18]. Bartella et al. have shown that adding this sequence to the standard protocol increases the PPV of biopsies from 35 to 82% (P<0.01) and avoids a biopsy in 57% of lesions without any cancer going unrecognised [19]. In addition, several preliminary studies have recently demonstrated the usefulness of this imaging technique for showing up an early response (after 24 hours) to neoadjuvant chemotherapy [20]. There are two broad types of analysis technique: monovoxel acquisition, targeted on the lesion enhancing after gadolinium injection, is the most widespread. Few studies have produced acceptable results with multivoxel sequences because the signal-to-noise ratio at 1.5T is too low. Additional studies will be necessary with the development of 3T magnets. Of the sequences available, the Point REsolved Spectroscopy Sequence (PRESS) is usually preferred because, for the breast, it provides a better signal-to-noise ratio than the STimulated Echo Acquisition Mode (STEAM) sequence. Acquisition takes between 6 and 12 minutes with a 5-minute preparation phase, allowing shimming, to check the homogeneity of the coil. Any difficulty is in post-treatment which requires an expert in spectroscopy to interpret the molecular profiles obtained.
Diffusion imaging is a method based on quantification of the motion of water molecules in the tissues. There are two objectives in using diffusion sequences: to optimise characterisation of lesions (to differentiate benign from malignant tumours) and to improve detection of small lesions, which requires an optimal signal-to-noise ratio. It has been shown in breast imaging that there is a reduction in the apparent diffusion coefficient (ADC) in malignant tumours with a threshold value of $1.13 \times 10^{-3}$ mm$^2$/s [21]. The ADC of malignant tumours is between 0.95 and $1.02 \times 10^{-3}$ mm$^2$/s, of benign tumours between 1.35 and $1.66 \times 10^{-3}$ mm$^2$/s and of normal tissue between 1.51 and $1.9 \times 10^{-3}$ mm$^2$/s. A wide variety of ADC values can be found in the literature [22]. When combined with morphological data and the type of enhancement, this technique allows breast MRI to achieve diagnostic accuracy of 91% [23]. Initially, diffusion was mainly assessed for masses larger than 1 cm [24,25] but with the recent technical improvements, several authors have shown that this technique is relevant for smaller masses (5 mm) and even for non-masslike enhancements [26,27]. At 3T, there is no difference in value of the ADC coefficients but small lesions are detected better as there is a better signal-to-noise ratio which is optimal for a $b$ value of 850 [28]. Nothing is gained by increasing the $b$ values above 1000 because the signal-to-noise ratio falls. Two $b$ values are enough to calculate a correct ADC. At 1.5T this is the pair 0 and 750 [29] and at 3T the pair 50 and 850 [28]. Diffusion MRI seems also to be of use for evaluating the response to neoadjuvant chemotherapy with a rise of more than 10% in the ADC coefficients at the end of the first cycle of chemotherapy [30]. Certain authors have shown that the mean ADC value before neoadjuvant chemotherapy could be a good predictive factor of response to the treatment [31]. This was a preliminary study which must be confirmed on larger series. A recent study has shown the usefulness of diffusion imaging for differentiating between tumour recurrence and scarring, which is one of the classic questions asked in breast MRI (Fig. 12) [32]. Finally, the diffusion tensor provides a new parameter predicting malignancy independent of the ADC: fractional anisotropy [26].
Figure 12. Diffusion sequence at 1.5T. T2-weighted sequence (a). Dynamic sequence with injection (2nd phase after injection): presence of architectural disorganisation due to a history of surgery without detectable suspect contrast uptake (b). b750 weighted diffusion sequence showing the absence of a hypersignal anomaly in the scar area (c). There is a hypersignal in front of the scar which is a T2 shine-through effect (no lowering of the apparent diffusion coefficient [ADC] coefficient). ADC map showing an ADC coefficient of 1.34 confirming the absence of evidence of tumour recurrence (d).

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.
Appendix A. Example of MRI questionnaire developed by the CHUM

Have you already had breast MRI: ☐ No ☐ Yes Where? _______________When? _______________
Date of your last mammogram: _______________

A. If you are not post-menopausal, which of these options describes your situation?
☐ Regular menstrual cycle: _______________Date of the 1st day of your last period: _______________
☐ Irregular menstrual cycle: _______________Date of the 1st day of your last period: _______________
☐ Hysterectomy with one or two ovaries in place
Are you taking oral contraceptives? ☐ No ☐ Yes Which and since when? _______________

B. If you are post-menopausal, please give us the following information:
1. ☐ Natural menopause: _______________At what age: _______________
2. ☐ Surgical menopause (bilateral ovariectomy): _______________How many years ago _______________
3. ☐ Menstrual cycle stopped by chemotherapy: _______________Date of last period: _______________
Are you taking hormones? ☐ Yes, which and since when? _______________
☐ No, never taken OR ☐ No, stopped since: _______________

We would like to know your personal medical history:
To which category do you belong?
A. ☐ Never been diagnosed as having breast cancer
B. ☐ Breast cancer already diagnosed Date: _______________

Site: ☐ Right ☐ Left
Treatment: 1. ☐ Surgery Date of surgery: _______________
☐ Partial ☐ Total ☐ Prosthesis reconstruction ☐ TRAM
2. ☐ Radiotherapy ☐ Conventional OR ☐ Brachytherapy
3. ☐ Chemotherapy
If treatment is on-going, please tell us the treatment you have already received: _______________
4. Have you had axillary or sentinel lymph node dissection? ☐ Yes, number of lymph nodes affected: _____ ☐ No

Are you taking tamoxifen, Arimidex or other anti-oestrogens?
☐ Yes, since when? _______________
☐ No

C. Have-you already had mediastinal radiotherapy (e.g. for a lymphoma)?

D. What is your family medical history?

Breast cancer ☐
✓ Mother age: ___ ☐ Daughter age: ___
✓ Sister age: ___ ☐ Aunt age: ___
✓ Others: _______________

Ovarian cancer ☐
✓ Mother age: ___ ☐ Daughter age: ___
✓ Sister age: ___ ☐ Aunt age: ___
✓ Others: _______________

Please give us the name of
Your family doctor: _______________
Your surgeon/oncologist: _______________

Appendix B. Optimised sequence parameters (GE, Siemens, Philips)

<table>
<thead>
<tr>
<th></th>
<th>GE (1.5T)</th>
<th>Siemens (1.5T)</th>
<th>Philips (1.5T)</th>
<th>Philips (3T)</th>
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<tr>
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<td>BW (Hz)</td>
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<td>Slice thickness</td>
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<td>Duration (sec)</td>
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<td>82</td>
<td>81</td>
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