Feasibility of 7 Tesla breast MRI. Determination of intrinsic sensitivity and high resolution MRI, DWI and 1H-MRS of breast cancer patients receiving neo-adjuvant therapy

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Objectives: To evaluate the feasibility of 7T breast MRI by determining the intrinsic sensitivity gain compared to 3T in healthy volunteers and to explore clinical application of 7T MRI in breast cancer patients receiving neo-adjuvant chemotherapy (NAC).

Materials and Methods: In five volunteers the signal-to-noise ratio (SNR) was determined on proton density MRI at 3T using a conventional 4 channel bilateral breast coil and at 7T using a dedicated 2 channel unilateral breast coil, both obtained at identical scan parameters. Subsequently consecutive breast cancer patients on NAC were included. The 7T breast MRI protocol consisted of diffusion weighted imaging, 3D high resolution (450 μm isotropic) T1-weighted fat suppressed gradient-echo sequences and quantified single voxel ^{1}H-MRS. Morphology was scored according to the MRI BIRADS-lexicon and the images were compared to 3T and histopathologic findings. Image quality was evaluated using a five-point scale.

Results: At 7T a 5.7 fold higher SNR was measured than at 3T, which reflects the advantages of a higher field strength and the use of optimized RF coils (figure 1). Three breast cancer patients were included and received a total of 13 7T MRI exams (table 1). The image quality of the high resolution exams was at least satisfactory, and good to excellent in 9 out of the 13 exams performed. More anatomical detail was depicted at 7T than at 3T. In one case a fat plane between the muscle and tumor was visible at 7T, but not at the clinically performed 3T exam, suggesting that there was no muscle invasion, which was confirmed by pathology (figure 2). Changes in tumor apparent diffusion coefficient values could be monitored in two patients and were found to increase during NAC, consistent with published results from studies at lower field strengths. ADC values increased respectively from $0.33 \cdot 10^{-3}$ mm²/s to $1.78 \cdot 10^{-3}$ mm²/s after NAC and from $1.20 \cdot 10^{-3}$ mm²/s to $1.44 \cdot 10^{-3}$ mm²/s during NAC (table 2). Choline (Cho) concentrations as low as 0.77 mMol/kg$_{water}$ could be detected. In one patient Cho levels showed an overall decrease from 4.2 mMol/kw$_{water}$ to 2.6 mMol/kg$_{water}$ after NAC and the tumor size decreased correspondingly from 3.9x4.1x5.6 cm³ to 2.0x2.7x2.4 cm³ (figure 3). All 7T MRI findings were consistent with pathology analysis.
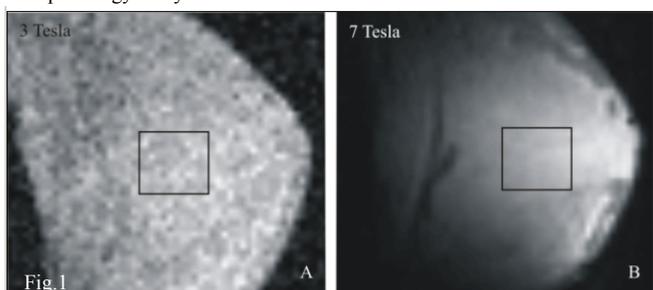
Figure 1. A sagittal combined proton density and noise scan (i.e. flip angle = 0) at 3T **(A)** and at 7T **(B)** in the same healthy volunteer. The SNR, determined in the centre of the breast (black square), at 7T was a factor 5.7 +/- 1.7 higher. Identical scan parameters were: TR=500 ms, TE in phase (2 ms at 7T and 2.3 ms at 3T), flip=10º , 1kHz/pixel, FOV=160x160x2 mm³, resolution = 2 mm isotropic). Similar coil elements were used for the 3T and 7T scans (i.e. 2 elements for one breast of each 15 cm in diameter), however at 3T the elements are positioned in parallel alignment while at 7T in orthogonal alignment.

Table 1	Patient A			Patient B	Patient C
Prior to NAC	7T + 3T		Prior to NAC	3T	7T + 3T
Following 1st NAC	7T		Following 1st NAC	7T	7T
Following 2nd NAC	7T		Following 2nd NAC	-	7T
Following 3rd NAC	7T + 3T		Following 3rd NAC	-	-
Following 4th NAC	7T		Following last NAC	7T + 3T	7T + 3T
Following 5th NAC	7T		-	-	-
Following last NAC	7T + 3T		-	-	-

Table 1. Time points at which MRI exams were performed in relation to neo-adjuvant chemotherapy (NAC) courses.

Table 2. Apparent Diffusion Coefficient (ADC) and volume measurements of the tumor of patient A prior to and during neo-adjuvant chemotherapy (NAC).

Table 2	ADC (mm²/s)	volume (cm³)
Prior to NAC	$0.33 \cdot 10^{-3}$	3.9x4.1x5.6
Following 1st NAC	$1.52 \cdot 10^{-3}$	2.5x2.3x2.8
Following 2nd NAC	-	1.8x1.8x2.1
Following 3rd NAC	$2.00 \cdot 10^{-3}$	1.7x2.0x2.0
Following 4th NAC	$1.23 \cdot 10^{-3}$	1.6x2.0x2.0
Following 5th NAC	$1.40 \cdot 10^{-3}$	1.4x1.9x1.8
Following last NAC	$1.78 \cdot 10^{-3}$	2.0x2.7x2.4
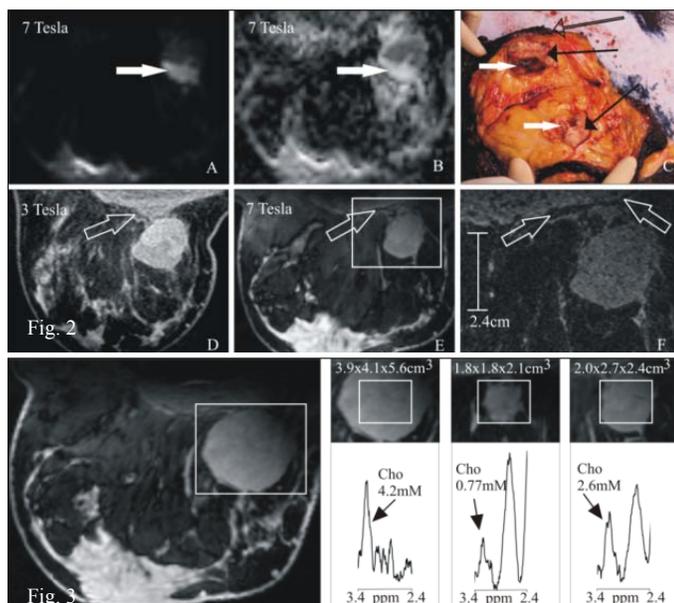
Figure 2. Patient A. **A-C)** Respectively diffusion weighted image at 7T, corresponding apparent diffusion coefficient map and macroscopic pathology assessment of the mastectomy specimen. The tumor consists of a solid component (black solid arrow) and of a cystic component (white solid arrow), visible as a shine through effect in figure A and B. The tumor lies adjacent to the pectoral muscle. The fascia of the muscle is dyed black at pathology assessment (open black arrow).

D-F) Respectively a fat suppressed, clinically performed, non-enhanced fat suppressed 3T T1w image and a low resolution, fat suppressed, 7T image. F is a zoomed in minimum intensity image (slab of 2 slices) of the high resolution 7T image, which depicts the fat plane (open white arrows) between the tumor and the dorsal fascia surface. The fatplane is not visible on the 3T image.

Figure 3. Breast tumor (white large rectangle) in patient A depicted on fat suppressed 3D T1w FFE MRI scans at 7T. Homogenous fat suppression is achieved. Proton spectra of the selected voxel (white small rectangle), depicting the concentration of Choline (Cho) in millimolar (mM) respectively before, after the second and after the final chemotherapy course.

Conclusion: Dedicated 7T breast MRI is technically feasible, can provide more SNR than at 3T, and has diagnostic potential.