Potential Role of Multi b Factor Diffusion-Weighted Imaging of the Breast*

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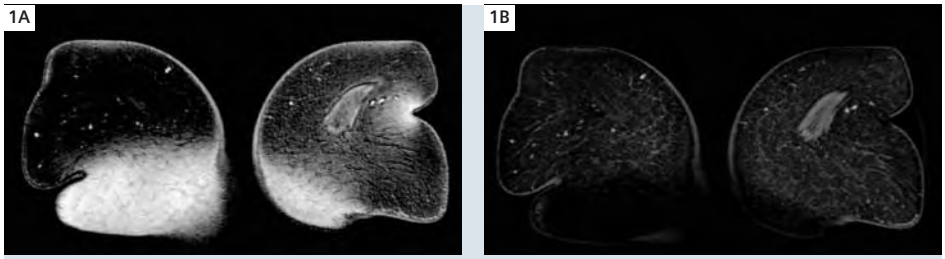
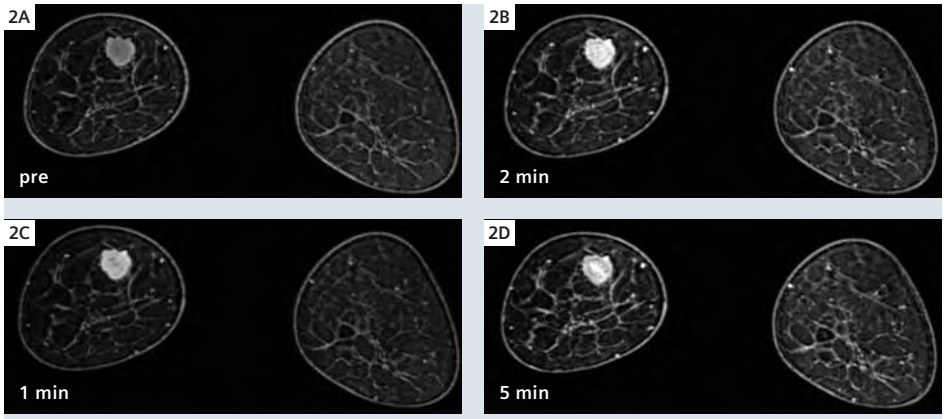
Introduction

Diffusion-weighted imaging (DWI) is characterized by extremely high contrast resolution, and it has been applied to diagnose early-stage cerebral infarction. When used to image the body, however, strong artifacts are created by the non-uniformity of the magnetic field. Recent development of MR technology has nearly overcome this obstacle and enabled the clinical application of diffusion-weighted imaging. DWI has shown great promise in the detection of any tumor type throughout the entire body.

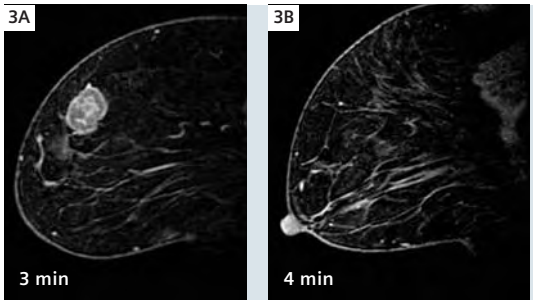
Regarding breast DWI, the potential role of apparent diffusion coefficient (ADC) value in characterizing breast lesions has been reported. In the preliminary results, the ADC value may be an effective parameter in distinguishing between benign and malignant breast lesions because tumor cellularity has a significant influence on the ADC values. On the other hand, the VIBE (volumetric interpolated breathhold examination) sequence with iPAT (integrated parallel acquisition techniques), which allows high-spatial-resolution images with isotropic voxels to be obtained, improves the quality of breast MR examinations dramatically (Table and Figs. 1–3). Following this development, it is debatable whether DWI of the breast is useful or not in routine clinical MR examinations.



1 Breast measurements with the VIBE sequence and Fat Sat using CHESS **(A)** and SPAIR **(B)**. SPAIR utilizes adiabatic fat suppression pulses which have also been optimized with respect to their frequency selective profile. Thus the sensitivity to B1-inhomogeneities is reduced.



2 Dynamic protocol using VIBE with iPAT: High resolution 3D dynamic acquisitions with fat saturation (SPAIR) using a PAT factor of 2. Both breasts were examined in the coronal plane on the first, second, and fifth-phase dynamic images.

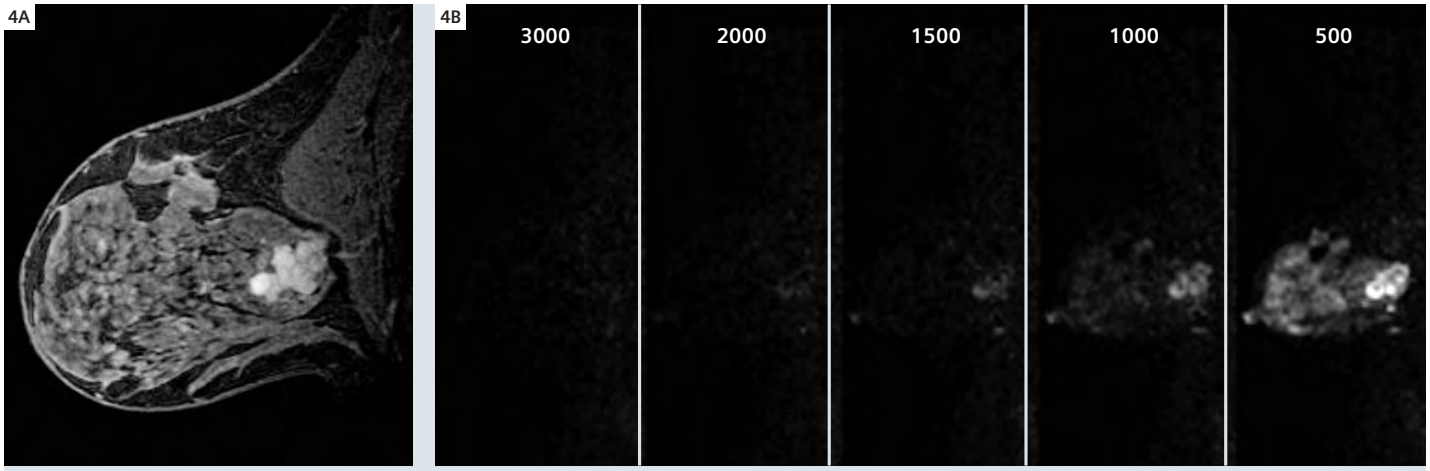


3 High resolution imaging using VIBE without iPAT in the same patient as Fig. 2: Bilateral breasts were sagittally examined on images obtained in the third **(A)** and fourth phases **(B)**. **(A)** Right breast. **(B)** Left breast.

The impact of DWI

Tumor detection

Unfortunately, there was no evidence that sensitivity and accuracy of breast cancer detection by DWI are higher than



4 Sagittal MPR images of diffusion-weighted imaging, showing a fibroadenoma. This benign tumor appears hyperintense on b 500–1500 images.

that by standard contrast-enhanced MRI. In fact, it is insufficient to detect small breast cancer or ductal carcinoma in situ (DCIS). Tumor angiogenesis and increasing cellularity are developed simultaneously in breast cancer. However, the detection of the presence of angiogenesis by perfusion MR imaging using Gd-DTPA contrast agent is more sensitive than that of the degree of increasing cellularity by DWI. In these circumstances, screening MRI without the use of contrast agent has come up for discussion in Japan. Breast cancer is the leading cause of cancer deaths among Japanese women, and among this group it tends to occur in the late forties. Because the limitations of X-ray mammography are well known in dense breast tissue, screening for breast cancer with ultrasound has just started in Japan. One of the current problems of screening ultrasound is that too many benign hypoechoic nodules are depicted. In our hospital, the clinical usefulness of non-contrast MRI that combines DWI and T1-, T2-weighted imaging has been investigated prospectively for the patients with equivocal or suspicious findings on screening ultrasound.

Differential analysis: multi b factor DWI

Regarding the differentiation between benign and malignant lesions, the ADC value may be an effective parameter. Up to the present, only the diagnostic cut-off value of ADC has been evaluated and discussed. However, there is the overlap in ADC values. We try to make categorization using multi b factor DWI. In the differen-

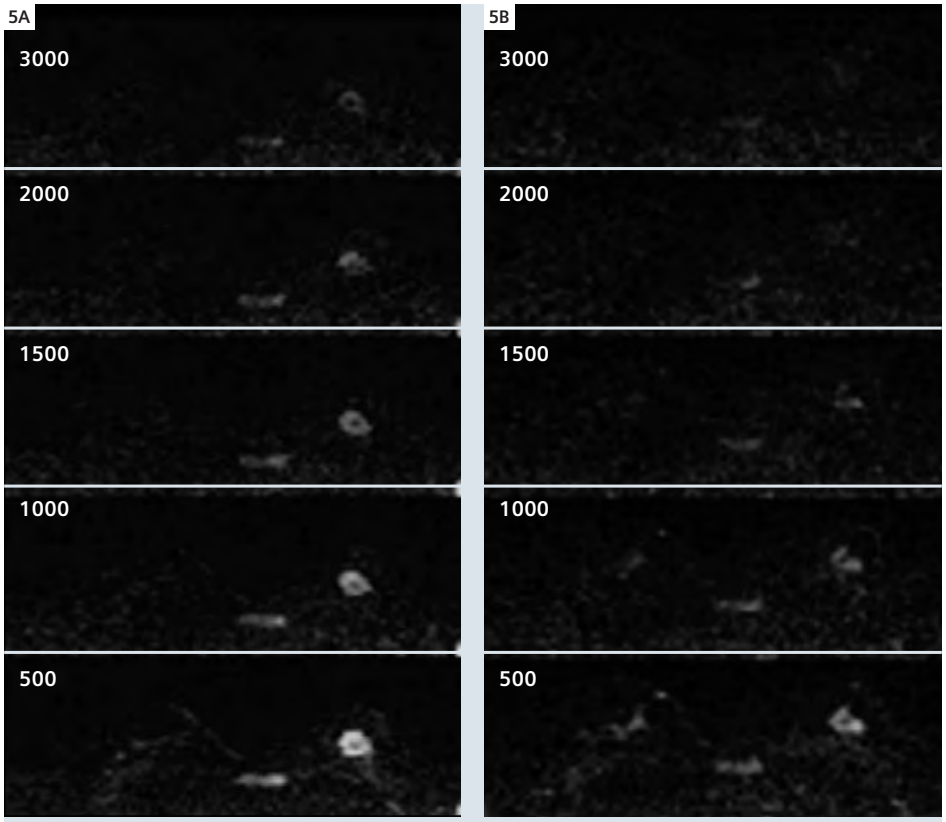
Table 1: Protocols

	sequence	orientation	voxel size	TA	TE	TR
localizer	gre	3 orientation	2.1x1.6x6mm	0:35	4,22	9,2
t1_fl3d_cor_in-phase_FS(-)	fl3d_vibe	coronal	1x1x3mm	0:52	4,76	8
t2_tse_sag_R_fs_SPAIR	tse_rst_ire	sag (right)	0.6x0.6x3mm	1:18	97	4780
t2_tse_sag_L_fs_SPAIR	tse_rst_ire	sag (left)	0.6x0.6x3mm	1:18	97	4780
DWI_ep2d_cor_fs_SPAIR	ep2d_diff_pace	coronal	3x3x3mm	2:24	96	8000
Dyn_t1_fl3d_vibe_cor_fs_SPAIR	fl3d_vibe	coronal	1x0.7x0.9mm	1:00 x 3	2,29	5,23
t1_fl3d_vibe_sag_R_fs_SPAIR	fl3d_vibe	sag (right)	0.6x0.6x1.2mm	1:00	2,22	4:04
t1_fl3d_vibe_sag_L_fs_SPAIR	fl3d_vibe	sag (left)	0.6x0.6x1.2mm	1:00	2,22	4:04
Delay_t1_fl3d_vibe_cor_SPAIR	fl3d_vibe	coronal	1x0.7x0.9mm	1:00	2,29	5,23
svs_se_ub2_270_breast	svs_se_ub2	transversal	15x15x15mm	7:01	270	1620

tial diagnosis of breast lesions, categorization of the lesions, such as ACR-BI-RADS and scoring system (Göttingen score, Jena score, and MARIBS (Magnetic Resonance Imaging in Breast Screening)), is essential. In our hospital we perform categorization visually based on multi-b-factor DWI, always applying the same window level and width (Figs. 4, 5).

Monitoring the therapeutic response

After one or two cycles of chemotherapy there are substantial changes in the contrast enhancement pattern, which are observed even before measurable changes of the tumor size occur. However, contrast enhancement patterns may lead to misleading findings and false-negative results due to the effects of chemotherapeutic agents. In contrast, DWI and ^{1}H MR spectroscopy show great promise in the observation of the direct effects of chemotherapeutic agents. ^{1}H MR spectroscopy is a promising molecular-based method, although the chemotherapeutic changes can be observed within a limited region (single voxel) that, in advanced cases, may be smaller than the breast cancer itself. We believed that DWI has additional information in monitoring the therapeutic response of locally advanced breast can-



5 Transeverse MPR images of diffusion-weighted imaging, showing a breast cancer in the left breast. DWI before **(A)** and after **(B)** chemotherapy. Signal intensity and size of the tumor are reduced after chemotherapy.

	FA	FoV read	FoV phase	slice thickness (mm)	matrix (base resolution)	matrix (phase resolution)	iPAT (Acce)	Fat Sat	band width
	20	400	100	6	256	75%	off	off	230
	25	330	100	3	320	100%	GRAPPA (2)	off	320
	150(refo)	160	100	3	256	100%	off	SPAIR	300
	150(refo)	160	100	3	256	100%	off	SPAIR	300
	3scan-trace	330	100	3	110	100%	GRAPPA (2)	SPAIR	1684*
	12	330	100	0,9	448	71%	GRAPPA (2)	SPAIR	430**
	15	160	100	1,2	256	100%	off	SPAIR	390
	15	160	100	1,2	256	100%	off	SPAIR	390
	12	330	100	0,9	448	71%	GRAPPA (2)	SPAIR	430
	90							spectral suppresion	1000

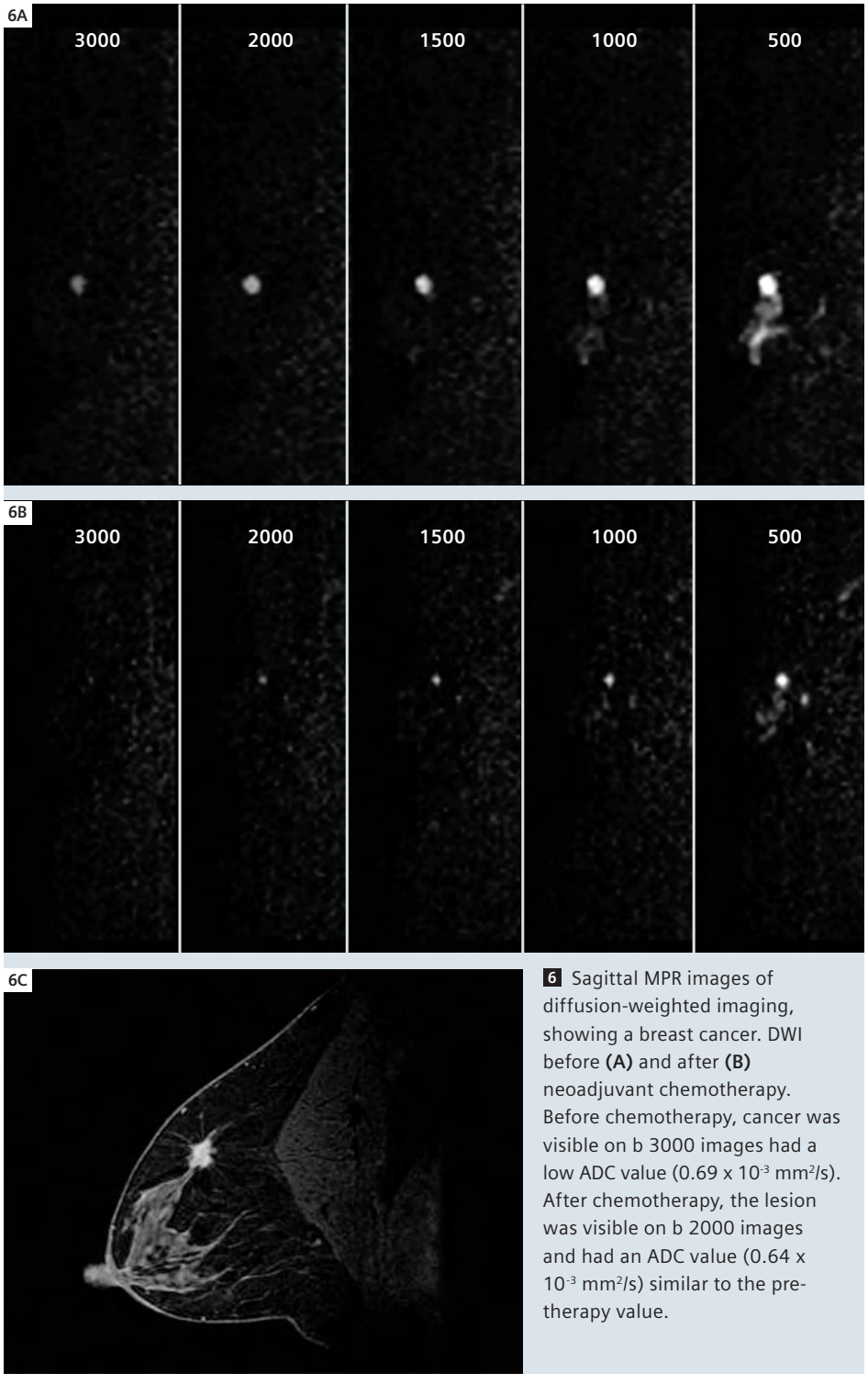
*b1=500,b2=1000,b3=1500,b4=2000,b5=3000; **pre+ 2 measurements

cer patients (Fig. 5). In addition, diffusion-weighted images are thought to be a useful guide for placing a volume of interest (VOI) within a breast tumor in order to measure the 1H MR spectrum.
There is, however, a pitfall in the use of ADC values. Figure 6 shows a patient with breast cancer before and after neoadjuvant chemotherapy. Before chemotherapy, cancer was visible on b 3000 images and had a low ADC value (0.69 x 10^{-3} mm^2/s). After chemotherapy, the cancer decreased in size as observed on both contrast-enhanced MRI and DWI. The lesion was visible on b 2000 images and had an ADC value (0.64 x 10^{-3} mm^2/s) similar to the pre-therapy value. Despite the decrease in tumor size due to the chemotherapeutic effect, cellularity changes within the lesion were of variable degree (Fig. 6). In short, decreasing cellularity of breast cancer has occurred inhomogeneously within the tumor and may be independent useful information, compared with morphology and vascular permeability.

Conclusion

It is debatable whether DWI of the breast is useful or not in the clinical MR examinations. However, DWI is the only sequence able to visualize breast cancers with a high rate on non- or pre-contrast enhanced MRI. We should continuously evaluate the potential role and limitations of this Cellularity-weighted Imaging. Further investigation and prospective study incorporating the visual assessment of multi b factor DWI is necessary.

*Some of the concepts and information presented in this paper are based on research and are not commercially available in the U.S.



6 Sagittal MPR images of diffusion-weighted imaging, showing a breast cancer. DWI before **(A)** and after **(B)** neoadjuvant chemotherapy. Before chemotherapy, cancer was visible on b 3000 images had a low ADC value (0.69 x 10^{-3} mm^2/s). After chemotherapy, the lesion was visible on b 2000 images and had an ADC value (0.64 x 10^{-3} mm^2/s) similar to the pre-therapy value.