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ORIGINAL ARTICLE

Comparison of contrast-enhanced T1-weighted FLAIR with BLADE, and spin-echo T1-weighted sequences in intracranial MRI

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PURPOSE
We compared periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER, BLADE) MR technique with spin echo (SE) technique for evaluation of artifacts, and detection and delineation of brain lesions.

MATERIALS AND METHODS
Contrast-enhanced T1-weighted fluid attenuated inversion recovery (FLAIR) images with BLADE technique (CE T1W-FLAIR BLADE) and contrast-enhanced T1-weighted SE (CE T1W-SE) were performed in 50 patients with intracranial enhancing lesions. These techniques were compared by two neuroradiologists for qualitative analysis of artifacts, lesion detectability, lesion delineation from adjacent structures, and preferred imaging technique; and for quantitative variables, i.e., lesion-to-background and lesion-to-cerebrospinal fluid (CSF) contrast-to-noise (CNR) ratios. Reader agreement was assessed by kappa statistics.

RESULTS
All lesions depicted with the CE T1W-SE were also detected with the CE T1W-FLAIR BLADE technique. Delineation of lesions was better on CE T1W-FLAIR BLADE in the majority of patients. Flow-related artifacts were considerably reduced with CE T1W-FLAIR BLADE. A star-like artifact at the level of the 4th ventricle was noted on CE T1W-FLAIR BLADE but not on CE T1W-SE. The lesion-to-background CNR and lesion-to-CSF CNR did not show a statistically significant difference between the two techniques. CE T1W-FLAIR BLADE images were preferred by the observers over the CE T1w-SE images, indicating good interobserver agreement (k = 0.70).

CONCLUSION
CE T1W-FLAIR BLADE technique is superior to CE T1W-SE for delineation of lesions and reduction of flow-related artifacts, especially within the posterior fossa, and is preferred by readers. CE T1W-FLAIR BLADE may be an alternative approach to imaging, especially for posterior fossa lesions.

Key words: • *PROPELLER, BLADE* • *flow-related artifact* • *magnetic resonance imaging*

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T1-weighted spin-echo (SE) images are widely used to study anatomical details and pathologic abnormalities of the brain. Artifacts can degrade the quality of these images; sometimes they may obscure or mimic pathology. Patient motion, blood flow in major vessels, and metallic clips placed during surgery can induce significant artifacts in magnetic resonance images. The most common source of artifacts is patient motion (1). A unique mode of data acquisition with periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER, BLADE) allows for intrinsic compensation for translational or rotational head motion during data acquisition [BLADE is the Siemens Medical Solutions (Erlangen, Germany) implementation of PROPELLER MRI, allowing PROPELLER data acquisition and reconstruction]. Recent studies have shown that the BLADE technique not only minimizes or even eliminates motion artifacts, it also minimizes other specific artifacts (2, 3). Inversion recovery technique has been reported to have both high tissue contrast and high resolution, and it enables excellent depiction of parenchymal details (4).

We hypothesized that the artifacts would be reduced with BLADE MR imaging (MRI), and that this would lead to improved image quality and lesion detection, compared with SE MRI. The aim of this study was to compare contrast enhanced T1-weighted fluid attenuated inversion recovery images with BLADE technique (CE T1W-FLAIR BLADE), and contrast-enhanced T1-weighted SE imaging (CE T1W-SE) with focus on the evaluation of artifacts, and detection and delineation of lesions.

Materials and methods

Clinical assessment

The criteria for patient inclusion were a clinically indicated contrast-enhanced MRI of the brain for suspected focal brain lesion on the basis of a previous computed tomography (CT) and/or MRI, or clinical suspicion of such a lesion or suspicion of postoperative residual or recurrent lesion. Eighty-four consecutive patients were examined prospectively. Thirty-four patients were excluded from the study because no intracranial enhancing lesion was found. Among the remaining 50 patients, 27 were females and 23 were males; the mean age was 47.3 years (age range, 9 to 77 years).

Pathologic findings consisted of primary brain tumors [meningioma (n = 13), high-grade glioma (n = 11), oligodendroglioma (n = 4), medulloblastoma (n = 2), thalamic mass (n = 1), pilocytic astrocytoma (n = 1), glioblastoma multiforme (n = 1), hypothalamic glioma (n = 1)], metastatic brain tumors [from lung cancer (n = 8), breast cancer (n = 4)], clivus chordoma (n = 1), intracranial invasion of malignancy [scalp epidermoid carcinoma (n = 1)] and infectious conditions [encephalitis (n = 1), skull base osteomyelitis (n = 1)]. Diagnoses were made on the basis of biopsy findings, clinical history, or imaging studies at presentation or

follow-up. Histological verification was obtained in 33 patients.

This study was approved by the institutional review board of our university hospital. Written informed consent was obtained from all patients.

Imaging parameters

Brain MRI scans were performed in all patients using a 1.5 Tesla MR scanner (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany). Imaging studies included axial CE T1W-SE with fat suppression images (TR/TE/NEX, 429 ms/12 ms/2; imaging time, 3 minutes 16 seconds); and axial CE T1W-FLAIR BLADE with fat suppression images (TR/TE/TI/NEX, 1800/59/860/2; imaging time, 5 minutes 11 seconds; number of blades, 42; *k*-space coverage, 190.9%; and echo train length, 42). BLADE is the Siemens Medical Solutions implementation of PROPELLER MRI, allowing PROPELLER data acquisition and reconstruction. For CE T1W-FLAIR BLADE no correction for translational and rotational movement was applied. All sequences were performed using identical parameters for number of slices, matrix size (256 x 256), field of view (230 mm), slice thickness (5 mm) and intersection gap (1.5 mm).

The scans were initiated 5 minutes after intravenous administration of gadopentetate dimeglumine, adapted to the body weight of the patient (0.1 mmol/kg body weight) as a bolus injection. Akeson et al. showed that the peak enhancement of blood-brain barrier damage occurs around 3.5 min after injection, and the effect does not change during the next 25 min. Thus, scanning should be started 2–5 min after injection of the contrast medium (5). Twenty-five patients were scanned first with T1W-FLAIR BLADE, and then with T1W-SE. Another 25 patients were scanned in the reverse sequence order to avoid delayed contrast enhancement effects of lesions. During the examination, axial and sagittal precontrast spin echo T1W images (TR/TE/NEX, 500/11/2), T2W coronal and axial turbo spin echo images (TR/TE/NEX, 4500/110/2), axial FLAIR images (TR/TE/NEX, 9000/110/2), and T1W coronal and sagittal contrast-enhanced SE images (TR/TE/NEX, 429/12/2) were acquired as part of the routine imaging protocol. The phase-encoding direction was set right-to-left. The comparison between post-contrast T1W-FLAIR BLADE and T1W-SE sequences was made only for the axial images.

Image assessment

CE T1W-FLAIR BLADE and CE T1W-SE images were compared using quantitative and qualitative criteria on a digital multimodality workplace (Siemens Medical Solutions, Erlangen, Germany).

Qualitative evaluation

Two independent, experienced neuroradiologists (Ö.A., T.Y.), blinded to clinical history of the patient, diagnosis, and sequence type, viewed images in random order on a digital work-station. The two image sets of a given patient were presented in random order at three reading sessions. To avoid recall bias of the observers, reading sessions were separated by an interval of at least 2 weeks.

In the first reading session, the location and number of lesions, and the presence of image artifacts (i.e., motion, flow-related, and metallic artifacts) were assessed. Image artifacts were evaluated regarding the influence on image interpretation on a subjective scale (0, no artifact; 1, mild artifact; 2, moderate artifact; or 3, severe artifact).

In the second session, the images were compared side by side to determine which sequence was better for delineation of lesions from adjacent structures. The same observers were still independent and blinded to the imaging sequence. Observers were asked to make a decision on observation of a single lesion in subjects who presented with multiple lesions. Lesion delineation was graded on a three-point scale: 1, CE T1W-SE superior; 2, sequences equal; 3, CE T1W-FLAIR BLADE superior. Observers were asked to define whether they preferred CE T1W-FLAIR BLADE or CE T1W-SE MR images overall, or whether they had no preference. This decision was made on the basis of overall image appearance (i.e., resolution, artifacts, contrast). The interobserver concordance for preferred image, presence of artifacts, and delineation of lesion was assessed with a κ correlation test.

Finally, a consensus reading was performed by the neuroradiologists, at which time each patient's FLAIR, turbo SE T2-weighted, postcontrast sagittal and coronal SE T1-weighted images as well as clinical information were available. At the consensus reading, the number and location of enhancing lesions were determined to form a standard of reference.

Quantitative evaluation

Region of interest (ROI) analysis was performed for CE T1W-FLAIR BLADE and CE T1W-SE images by a single investigator (Ö.A.). For quantitative interpretation, we measured signal intensities by a ROI analysis of the tumor, the background, the cerebrospinal fluid (CSF), and in the air space for measurement of image noise. Mean tumor signal intensity was measured within a homogenously enhancing region of the tumor. In patients with multiple enhancing lesions, the lesion with the greatest diameter was measured. Background signal was measured in normal-appearing white matter (WM) adjacent to the tumor. CSF signal was measured in a homogenous region within the anterior horn of the lateral ventricles. Noise was defined as the standard deviation of the signal intensity measured in air. From the ROI data, lesion-to-background contrast-to-noise ratios (CNR), and lesion-to-CSF CNR were calculated. Lesion-to-background CNR was defined as the difference between the signals from the lesion and those from WM divided by the standard deviation (SD) of measured image noise. Similar calculations were performed for lesion-to-CSF CNR.

The statistical significance of quantitative data was determined by using the Wilcoxon signed rank test. A P value of <0.05 was accepted as significant.

Results

In all patients, both CE T1W-SE and CE T1W-FLAIR BLADE were able to demonstrate the same lesions. CE T1W-FLAIR BLADE was superior to CE T1W-SE in lesion delineation. Flow artifacts were considerably reduced with CE T1W-FLAIR BLADE. A star-like artifact was noted at the level of the 4th ventricle on CE T1W-FLAIR BLADE, but not on CE T1W-SE. CE T1W-FLAIR BLADE images were preferred by the observers over the CE T1W-SE images. No significant difference in lesion-to-background CNR and lesion-to-CSF CNR values was seen between both sequences ($P > 0.05$).

Qualitative results

At the consensus reading, 140 lesions were detected in 50 patients. Thirty-six

patients had solitary lesions, and 14 patients had multiple lesions. Ninety-eight lesions were found in the supratentorial region, and 42 lesions were found in the infratentorial region. All lesions depicted with the CE T1W-SE technique were also detected with the CE T1W-FLAIR BLADE sequence. When compared with consensus reading, observers noted in their reading sessions 33 false-positive interpretations in 20 patients, and three false-negative interpretations in three patients on CE T1W-SE images. Thirty-one false-positive interpretations were of the infratentorial cranial region, and the other two were of the supratentorial cranial region on the CE T1W-SE images. These false positive interpretations were due to flow-related artifacts and contrast-enhancing blood vessels (Fig. 1). CE T1W-FLAIR BLADE generated six false-negative interpretations in four patients and no false-positive interpretations. The false-negative interpretations were due to localization within the intersection gap, very small size, and delayed enhancement effects.

As presented in Table 1, both neuroradiologists rated lesion delineation to be superior on CE T1W-FLAIR BLADE compared with that on CE T1W-SE (Figs. 2, 3).

There were no notable motion artifacts because all patients remained still during the entire examination. Patients were either clinically stable and cooperative outpatients, or sedated children. No flow-related artifacts were present in the 50 patients with CE T1W-FLAIR BLADE. In contrast, CE T1W-SE data showed flow-related artifacts in 92% (n = 46, Observer 1), 88% (n = 44, Observer 2) of patients, respectively. Table 2 summarizes the mean scores for flow-related artifacts. CE T1W-FLAIR BLADE sequence was found to be superior to CE T1W-SE in reduction of flow-related artifacts, especially within the posterior fossa (Figs. 4, 5). Agreement between the observers was average to good ($\kappa = 1$ for lesion detection, $\kappa = 0.56$ for delineation of lesion, $\kappa = 0.64$ for score of flow-related artifact on SE, $\kappa = 1$ for score of flow-related artifact on BLADE, $\kappa = 0.70$ for preferred image).

Magnetic susceptibility artifacts arose from metallic clips in six patients. These artifacts were judged worse on CE T1W-SE by both observers (Fig. 3).

Observers identified a star-like artifact in 35% of BLADE images, while this artifact was not present in any of the SE images (Fig. 6).

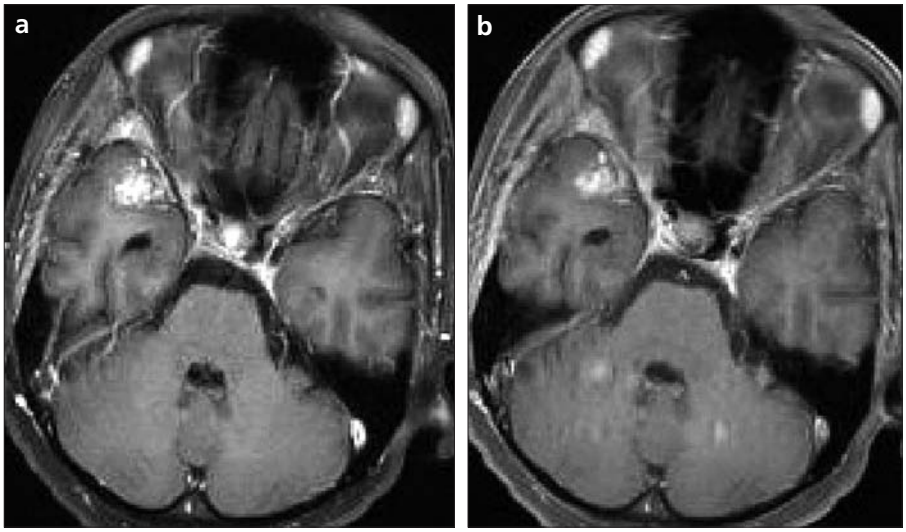

Figure 1. a, b. Axial contrast enhanced (CE) T1-weighted FLAIR BLADE **(a)** and CE T1-weighted SE **(b)** MR images of the posterior fossa in a patient with right temporal lobe anaplastic astrocytoma. CE T1-weighted FLAIR BLADE sequence shows an artifact-free image with no evidence of a lesion, whereas SE imaging shows considerable ghost artifacts mimicking a contrast-enhancing lesion.

Delineation of lesions, and determination of image preference as assessed by the two observers are shown in Table 2. The CE T1W-FLAIR BLADE images were preferred by the observers over the CE T1W-SE images in the majority of cases, with good interobserver agreement ($\kappa = 0.70$).

Quantitative results

ROI analysis of 50 contrast-enhancing lesions was performed in all patients. Quantitative results are summarized in Table 3. Lesion to background CNR and lesion to CSF CNR values were comparable and without statistically significant difference ($P > 0.05$).

Table 1. Qualitative results

	Lesion detection	Lesion delineation	Preferred image
Observer 1	2.00 ± 0.00	2.64 ± 0.59	2.86 ± 0.49
Observer 2	2.00 ± 0.00	2.64 ± 0.59	2.90 ± 0.41
κ^a	1	0.56	0.70

Data are mean ratios ± standard deviation.
Graded on a three-point scale: 1, T1-weighted SE superior; 2, sequences equal; 3, T1-weighted FLAIR BLADE superior.
[a] For the interobserver concordance, κ correlation test was used.

Table 2. Grading of flow related artifact

	SE	BLADE
Observer 1	1.86 ± 0.94	0.00 ± 0.00
Observer 2	1.84 ± 1.03	0.00 ± 0.00
κ^a	0.64	1

Data are mean ratios ± standard deviation.
Subjective scale (0, free of artifact; 1, mild artifact; 2, moderate artifact; or 3, severe artifact).
SE, spin-echo; BLADE, periodically rotated overlapping parallel lines with enhanced reconstruction, PROPELLER.
[a] For the interobserver concordance, κ correlation test was used.

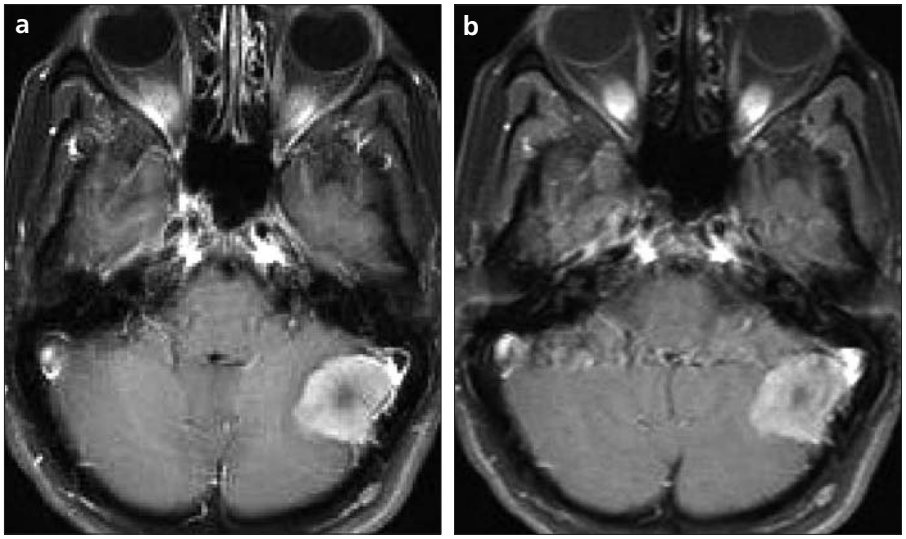

Figure 2. a, b. Axial contrast enhanced (CE) T1-weighted FLAIR BLADE **(a)** and CE T1-weighted SE **(b)** MR images in a patient with meningioma in the left side of the posterior fossa. Both readers judged BLADE images superior to SE images for the delineation of the lesion. Prominent flow-related artifacts are seen on SE imaging, while BLADE imaging shows no artifact.

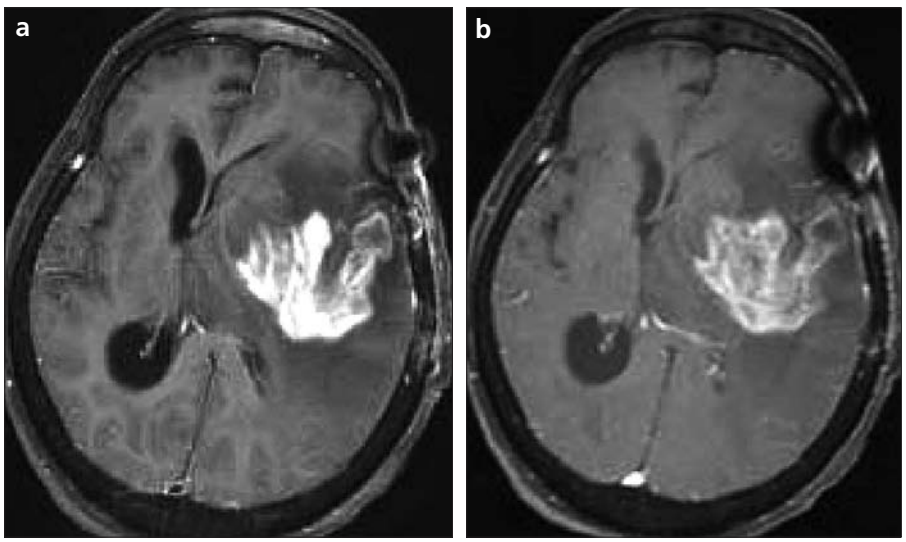

Figure 3. a, b. Axial contrast enhanced (CE) T1-weighted FLAIR BLADE **(a)** and CE T1-weighted SE **(b)** MR images in a patient with high-grade glioma. The delineation of the lesion is better on BLADE than on SE. Magnetic susceptibility artifact is less prominent on BLADE than on SE.

Table 3. Summary of contrast-to-noise ratio results

	Lesion to background		Lesion to CSF	
	SE CNR	BLADE CNR	SE CNR	BLADE CNR
Mean ± SD	55.40 ± 0.70	48.35 ± 50.59	135.73 ± 48.9	136.96 ± 36.6
Median ± SD	39.6 (55.7–296.0)	31.2 (1.1–239.9)	120.0 (78.7–381.0)	113.0 (77.2–380.6)
P	0.162		0.973	

SD, standard deviation; CSF, cerebrospinal fluid; CNR, contrast-to-noise ratio; SE, spin-echo; BLADE, periodically rotated overlapping parallel lines with enhanced reconstruction, PROPELLER.
For statistical analysis, Wilcoxon signed rank test was used ($P < 0.05$).

Discussion

PROPELLER MR technique proposed by Pipe sought to reduce artifacts induced by in-plane rotation and translational head motion, using an alternative method of sampling k-space (6). Unlike rectilinear k-space sampling, this method acquires multiple echo trains (so-called "blades") of a turbo spin echo in a rotating, partially overlapping fashion. Because the central region of k-space is sampled multiple times, this approach offers improved artifact suppression. Data within this central region can be compared between consecutive blades. If motion has occurred between the acquisitions of consecutive blades, the data can be transposed and rotated to its estimated stationary position, before final image reconstruction (7). It is known from previous investigations that the PROPELLER k-space acquisition scheme is beneficial in non-cooperating patients with artifact-inducing motion during data sampling (8). In this study, we focused primarily on a cooperative, outpatient population. The potential for specific motion correction using the BLADE technique was not evaluated in our study.

Flow artifacts are typically seen on images of the posterior fossa, and are caused by blood flow in the dural sinuses, particularly the transverse sinus. In young patients in whom the flow of the CSF is relatively rapid, the inflow artifacts may also be more prominent. Flow-related artifacts, either image blurring or discrete ghosts, severely impair evaluation of posterior fossa structures. Reduction of flow artifacts may considerably improve the visibility of small posterior fossa lesions (9, 10). Flow-related artifacts may be excluded by performing an additional section orientation, or by changing the phase-encoding direction (11). Various efforts have been made to reduce flow-related artifacts on contrast-enhanced images. The presaturation and the flow-compensation technique cannot suppress this artifact completely after injection of contrast media (12, 13).

Another method is the black-blood technique, whose limitations include a reduced number of slices, and a longer scan time (14). High spatial resolution T1W techniques such as 3D spoiled gradient-echo (SPGR), 3D volume interpolated breath-hold examination (VIBE), and 3D magnetization-prepared rapid acquisition gradient echo

(MP RAGE) sequences can reduce flow-related artifacts (10, 15, 16). However, studies have demonstrated that contrast-enhanced lesions might be less conspicuous, and can be missed on MP RAGE images, compared with T1W SE images. Wintersperger et al. showed that BLADE minimizes flow-related artifacts (2). Naganawa et al. showed that T1W-FLAIR BLADE is less susceptible to flow-related artifacts than is T1W SE (3). In the present study, no flow-related artifacts in the posterior fossa were observed with CE T1W-FLAIR BLADE technique.

The precise definition of the radiological tumor margins, and the possible delineation of the enhancing tumor regions are essential for planning treatment, biopsies, and radiation therapy (11). The detection and delineation of brain lesions with MR imaging is affected by a number of factors including lesion size, image contrast (lesion-to-background CNR), and lesion location (17). T1W SE images are primarily used for postcontrast brain MR imaging. T1W-FLAIR BLADE provides superior image contrast between white matter and gray matters, probably due to greater contrast provided by the inversion recovery technique (4). The reason for the improved delineation was most likely the superior contrast between gray and white matter. In the present study, all lesions depicted with the CE T1W SE technique were also detected with the CE T1W-FLAIR BLADE, and delineation of lesions was better with CE T1W-FLAIR BLADE.

The disadvantages of BLADE are minimal compared with those of SE. Imaging time of BLADE is longer than that of SE. The increase in scan time is caused by oversampling of the center of k-space. On the other hand, oversampling of the center of k-space offers improved artifact suppression and higher signal-to-noise ratio (2).

Unlike rectilinear k-space sampling, this method acquires multiple echo trains of a turbo spin echo. A longer echo train lengthens the effective TE time, resulting in changes of imaging contrast. A pre-inversion pulse is used to obtain T1-weighted contrast. A previous phantom study showed CE T1W-FLAIR BLADE due to the presence of the pre-inversion pulse was more sensitive to lower concentrations of Gd-DTPA than CE T1W SE (3). Regarding this fact further investigation

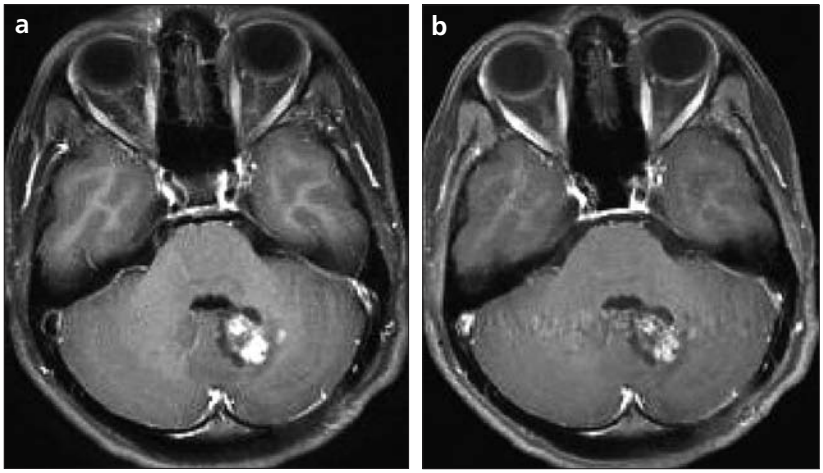

Figure 4. a, b. Axial contrast enhanced (CE) T1-weighted FLAIR BLADE **(a)** and CE T1-weighted SE MR imaging in a patient with astrocytoma. The flow-related artifacts obscure the satellite lesion on CE T1-weighted SE imaging, while CE T1-weighted FLAIR BLADE clearly depicts the satellite lesion.

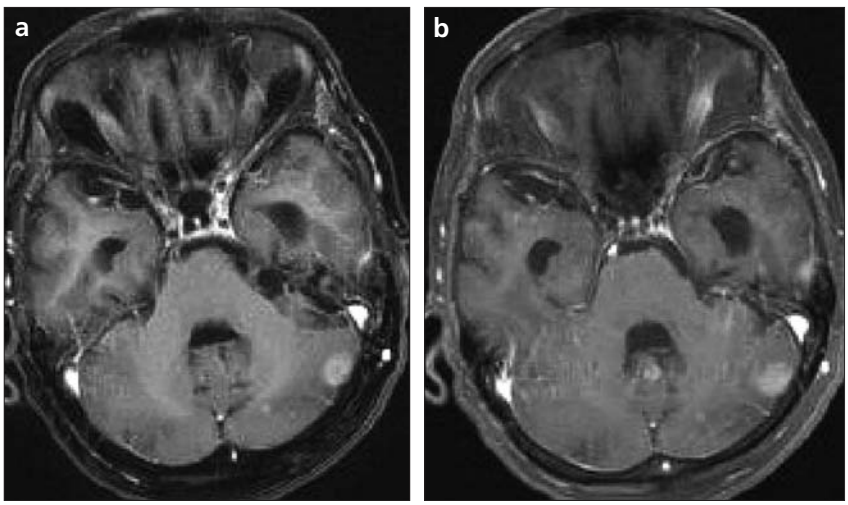

Figure 5. a, b. Axial contrast enhanced (CE) T1-weighted FLAIR BLADE **(a)** and CE T1-weighted SE MR imaging of the posterior fossa in a patient with brain metastases of lung cancer. With BLADE technique **(a)** these artifacts are eliminated, whereas SE **(b)** shows considerable ghost artifacts along the phase-encoding direction from the dural venous sinus.

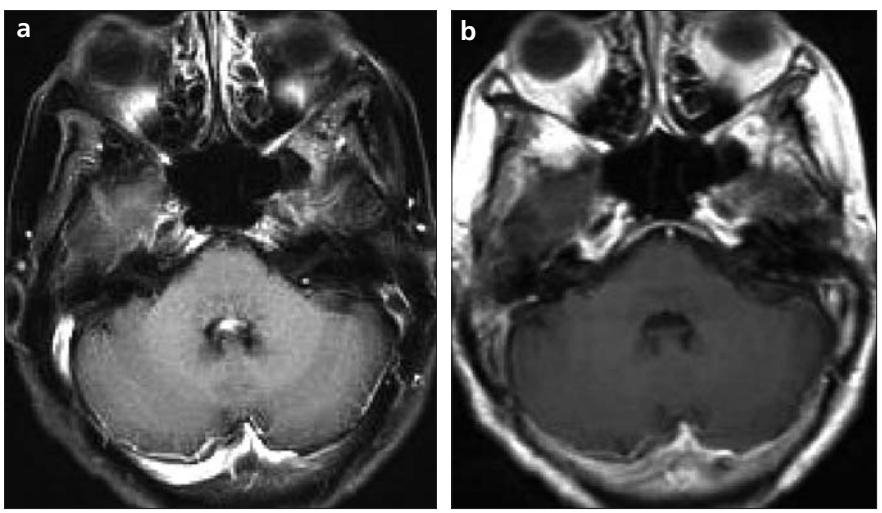

Figure 6. a, b. Axial contrast enhanced (CE) T1-weighted FLAIR BLADE **(a)** and CE T1-weighted SE MR imaging of the posterior fossa. CE T1-weighted FLAIR BLADE imaging **(a)** shows a star-like artifact at the entrance of the aqueduct into the 4th ventricle, whereas CE T1-weighted SE **(b)** shows no artifact.

in patients with multiple, small, faint or strongly contrast-enhancing lesions are needed.

A star-like flow artifact may arise in the 4th ventricle due to CSF inflow at the entrance of the aqueduct into the 4th ventricle. In our study, a star-like artifact was noted only on CE T1W-FLAIR BLADE, and is in concordance with the data of Wintersperger et al. (2), but did not degrade the image quality.

There are limitations of the present study. First, the two sequences were not matched for scan time. Different scan times may affect both SNR and artifacts. Second, in our study, it is not clear whether it is BLADE or T1-FLAIR that contributes most to better lesion delineation as compared with CE SE T1-weighted sequence—we believe that both contribute to it. This could be investigated by comparing CE T1W FLAIR with and without BLADE technique.

In conclusion, our study demonstrates that contrast-enhanced T1W-FLAIR BLADE imaging is superior to CE T1W SE in lesion delineation and reduction of flow artifacts. On the basis of these results, axial CE T1W-FLAIR BLADE might be an alternative approach to brain MRI, especially in patients with or suspected to have posterior fossa lesions.

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