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BLADE in Sagittal T2-Weighted MR Imaging of the Cervical Spine

C. Fellner, C. Menzel, F.A. Fellner, C. Ginthoer, N. Zorger, A. Schreyer, E.M. Jung, S. Feuerbach and T. Finkenzeller

C. Fellner
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N. Zorger
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BACKGROUND AND PURPOSE: Image quality and diagnostic reliability of T2-weighted MR images of the cervical spine are often impaired by several kinds of artifacts, even in cooperative patients. The aim of this study was to evaluate if BLADE sequences might solve these problems in a routine patient collective.

MATERIALS AND METHODS: TSE and BLADE sequences were compared in 60 patients for T2-weighted sagittal imaging of the cervical spine. Image sharpness, motion artifacts, truncation artifacts, metal artifacts, CSF flow phenomena, contrast of anatomic structures (vertebral body/disk, spinal cord/CSF), and diagnostic reliability of spinal cord depiction were evaluated by 2 independent readers. Another 2 readers selected the sequence they would prefer for diagnostic purposes. Statistical evaluations were performed by using the Wilcoxon and the χ^2 test; differences with $P < .05$ were regarded as statistically significant.

RESULTS: BLADE was significantly superior to TSE regarding image sharpness, image contrast, diagnostic reliability of spinal cord depiction, motion artifacts, CSF flow phenomena, and truncation artifacts; for metal artifacts no significant improvements were found. In 50 of 60 patients, BLADE was preferred for diagnostic purposes, and TSE was favored in 3 patients. The number of examinations that were nondiagnostic due to impaired spinal cord depiction was reduced from 12 in TSE to 3 in BLADE, and nondiagnostic examinations due to overall motion artifacts were reduced from 2 to 1.

CONCLUSIONS: Using the BLADE sequence for sagittal T2-weighted imaging of the cervical spine proved to be advantageous to reduce various kinds of artifacts.

ABBREVIATIONS: CNR = contrast-to-noise ratio; DWI = diffusion-weighted imaging; PROPELLER = periodically rotated overlapping parallel lines with enhanced reconstruction; ROI = region of interest; SNR = signal intensity-to-noise ratio; TSE = turbo spin-echo

Despite several important technical advances in MR imaging during the last 2 decades, imaging of the cervical spine is still demanding. The relevant anatomic structures are very small, and various artifacts, including motion artifacts caused by the pulsatile flow of vessels and CSF or swallowing as well as truncation artifacts, may occur even in cooperative patients.[1,2] Image quality and diagnostic reliability is further impaired by bulk motion if the patient is not able to cooperate to a sufficient extent. For sagittal T2-weighted imaging, TSE or fast spin-echo sequences with gradient moment nulling, a head–feet phase encoding direction, presaturation pulses, and long-term averaging are used today to reduce motion artifacts,[1-4] but there is still need for improvements.

PROPELLER was proposed in 1999 by Pipe to correct for head and heart motion.[5] PROPELLER is based on a TSE sequence with radial *k*-space coverage. In TSE imaging several *k*-space lines are acquired within a single TR interval and to build an echo train. While parallel *k*-space lines are acquired in a rectilinear way in a conventional TSE sequence, in PROPELLER imaging the *k*-space is filled with multiple echo trains that

are rotated around the center of *k*-space. The echo trains cover the *k*-space in a rotating and partially overlapping way, much like overlapping "blades". Therefore, a vendor-specific implementation of the PROPELLER technique is called BLADE (Siemens, Erlangen, Germany). Until now, PROPELLER or BLADE have been applied successfully in MR imaging of the brain to reduce motion artifacts in uncooperative or in pediatric patients[6-9] or to suppress flow artifacts[10,11] after application of contrast agent. Relevant benefits of PROPELLER or BLADE have also been reported in abdominal imaging,[12-15] but to our knowledge there are no data published on its application in spine imaging, except for a pilot study on 5 healthy volunteers.[16] Another important application of this technique is DWI, which is usually based on an echo-planar imaging sequence. PROPELLER or BLADE DWI yielded improved image quality, mainly caused by reduced susceptibility artifacts and increased spatial resolution in comparison with echo-planar imaging DWI.[17-23] In nearly all applications, PROPELLER or BLADE has been used in transverse orientation where the rotating field of view is not a major risk for inducing foldover artifacts in the phase-encoding direction. For sagittal imaging in the brain, BLADE was not as helpful as for the transverse orientation.[10] Another drawback of PROPELLER or BLADE is their increased acquisition time, which is due to oversampling of central *k*-space regions.

The aim of our study was to apply BLADE for sagittal T2-weighted imaging of the cervical spine and to evaluate if BLADE is helpful in a routine clinical setting. We hypothesized that BLADE will be able to reduce different kinds of motion artifacts typically seen in MR imaging of the cervical

Table 1: Measurement parameters for sagittal T2-weighted TSE and BLADE

	TSE	BLADE
TR (ms)/TE (ms)	3000/113	3000/112
Echo-train length	17	35
Bandwidth, Hz/pixel	140	296
Section thickness (mm)/section gap (mm)	3/0.6	3/0.6
FOV, mm × mm	250 × 250	250 × 250
Matrix size	384 × 384	384 × 384
Phase-encoding direction	Head–feet	Rotating
Oversampling (phase-encoding direction)	85%	100%
No. acquisitions	2	1
Flow compensation	Yes	No
Acquisition time, min:s	4:17	4:20

spine. For this purpose, image quality, contrast of relevant anatomic structures, and various artifacts were evaluated in 60 consecutive patients by using an optimized TSE sequence and a BLADE sequence with identical voxel size and acquisition time.

Materials and Methods

Patients
Sixty consecutive patients, 33 men and 27 women (age range, 19–86 years; mean age, 51 ± 17 years), referred for MR imaging of the cervical spine were included in this prospective study. The study was approved by the institutional review board, and all patients provided written informed consent.

The MR findings in our patients, based on the complete MR examination, were degenerative disk disease ($n = 44$), lesions of the vertebral body ($n = 24$), and lesions of the spinal cord ($n = 10$). Spinal cord lesions included syringomyelia ($n = 2$), myelopathy ($n = 6$), and traumatic spinal cord edema ($n = 2$). Nine patients were examined after vertebral osteosynthesis. In 6 patients no pathology of cervical spine was found.

MR Examination
MR imaging of the cervical spine was performed at 1.5 T (Magnetom Avanto or Magnetom Symphony TIM; Siemens) by using a combination of head, neck, and spine array coils to cover the whole cervical spine. Both MR scanners were equipped with identical coil configuration and software version; the gradient systems had 45 mT/m maximum gradient field strength, 200 T/m/s slew rate, and 30 mT/m and 125 T/m/s, respectively.

Sagittal T2-weighted TSE and BLADE sequences were acquired in all patients with randomized acquisition order of both sequences. None of the sequences was repeated, even if the image quality was insufficient due to motion artifacts. For T2-weighted imaging with conventional rectilinear k-space coverage, we applied our routine TSE sequence with head–feet phase-encoding direction, long-term averaging, and flow compensation to reduce motion and flow artifacts. In long-term averaging all k-space lines of the first acquisition or excitation are measured before acquiring all k-space lines of the second excitation; in conventional short-term averaging each k-space line is consecutively acquired n times (if n acquisitions or excitations are selected) before the following k-space line is acquired.[4] The BLADE sequence was matched regarding geometric and contrast parameters (Table 1). For this purpose, 2 concatenations were selected in the BLADE sequence for signal intensity acquisition together with a BLADE-specific high echo-train length and a high readout band-

width. A "restore" pulse (ie, an additional radio-frequency pulse after signal readout to flip back the remaining transverse magnetization into the longitudinal direction) was applied in both sequences. Using a restore pulse, shorter TE and/or shorter TR can be applied to increase SNR and/or to reduce acquisition time while maintaining sufficient T2 contrast. Phase oversampling was used for the TSE and the BLADE sequence to suppress foldover artifacts, and cranial and caudal presaturation pulses were applied additionally in the BLADE sequence. To increase SNR and to adjust the acquisition time, k-space coverage was increased from 100% to 120% in the BLADE sequence. The additional motion correction algorithm of BLADE was not used.

Due to reduced gradient capability of 1 of the scanners, there were some minor deviations regarding the measurement parameters for this scanner: For the TSE sequence, TE was 112 ms instead of 113 ms and the bandwidth was 130 instead of 140 Hz/pixel. For the BLADE sequence, TE was prolonged from 112 to 113 ms and the bandwidth had to be increased from 296 to 343 Hz/pixel to maintain the remaining acquisition parameters.

Besides the comparison for T2-weighted sagittal imaging, T2-weighted transverse and T1-weighted TSE sequences in sagittal and transverse orientation were acquired in all patients. Depending on the pathology, sagittal short TI inversion recovery, transverse multi-echo data image combination, and contrast-enhanced T1-weighted TSE sequences with or without fat saturation in sagittal and transverse orientation were measured additionally.

Image Evaluation
Visual assessment of image quality was performed by 2 independent readers blinded to the imaging technique as well as to patient data, medical history, or other MR images. Reader 1 (T.F.) was an experienced neuroradiologist; reader 2 (C.M.) was a resident radiologist with 1 year of experience in MR imaging. Image quality was graded on a scale from 1 to 5 (1, excellent; 2, good; 3, moderate; 4, fair, but still diagnostic; 5, nondiagnostic) for the following criteria: image sharpness, overall motion artifacts, truncation artifacts, metal artifacts, CSF flow phenomena, contrast vertebral body/disk, contrast spinal cord/CSF, and diagnostic reliability for the depiction of the spinal cord and lesions within the spinal cord.

Another 2 experienced neuroradiologists (F.A.F., C.G.) viewed TSE and BLADE images side-by-side for each patient and selected in consensus the sequence they would prefer for diagnostic purposes: TSE, BLADE, or neither or both sequences. These 2 readers were also blinded to patient data and imaging technique.

Quantitative image evaluation was restricted to those examinations with excellent or good image sharpness in TSE and BLADE sequences with agreement of reader 1 and reader 2. A midsagittal section was chosen and circular ROIs were drawn in normal-appearing tissue of vertebral body, vertebral disk, CSF, and spinal cord. ROIs within the vertebral disks were positioned in disks with none or only minimal dehydratation. For the CSF measurements, a position in the cisterna magna free of flow artifacts was selected. Positioning and sizing of these ROIs were identical in TSE and BLADE images to minimize individual variations for sequence comparison. The SNR was then calculated as the mean signal intensity within a ROI divided by its standard deviation. The CNR of 2 tissues was calculated as $SNR_{tissue\ 1} - SNR_{tissue\ 2}$.

Statistical Analysis
All statistical calculations and tests were performed by using SPSS software (version 16.0; SPSS, Chicago, Illinois). Results of the visual
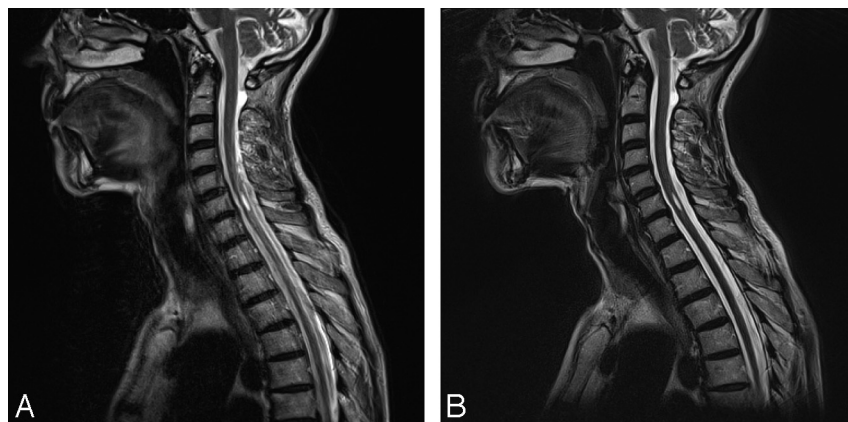
Fig 1. TSE (*A*) and BLADE (*B*) in a 69-year-old woman with syringomyelia C6/C7. Superior grading in BLADE compared with TSE regarding reduced flow phenomena (mean grade BLADE, 2.0; TSE, 4.0) and truncation artifacts (BLADE, 2.0; TSE, 3.5), improved contrast vertebral body/disk (BLADE, 1.5; TSE, 2.5), contrast spinal cord/CSF (BLADE, 1.5; TSE, 4.0), and diagnostic reliability for the depiction of the spinal cord (BLADE, 2.0; TSE, 5.0).
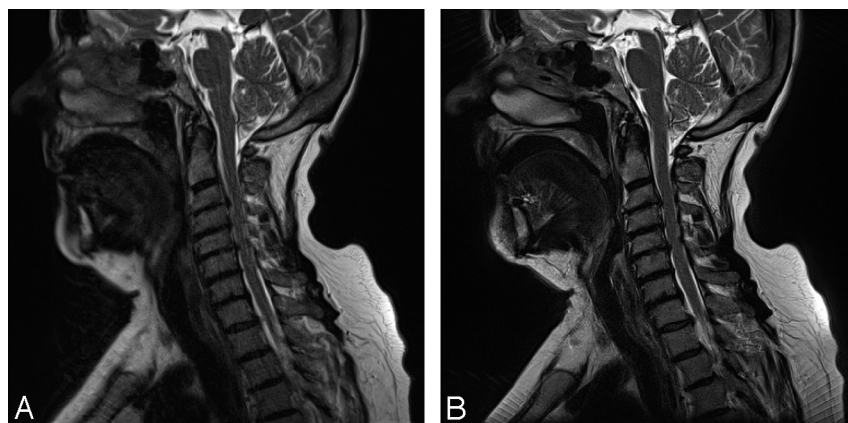

Fig 2. TSE (*A*) and BLADE (*B*) in a 73-year-old woman with degenerative disk disease. Improved image sharpness in BLADE (BLADE, 2.0; TSE, 4.0), reduced motion artifacts (BLADE, 2.5; TSE, 4.0), and improved reliability of spinal cord depiction (BLADE, 2.5; TSE, 5.0) compared with TSE.

Table 2: Results of the visual evaluation on a scale from 1 (excellent) to 5 (nondiagnostic): means and standard deviations

	Reader 1		Reader 2		Mean (reader 1, reader 2)	
	TSE	BLADE	TSE	BLADE	TSE	BLADE
Image sharpness	2.20 ± 1.04	1.62 ± 0.76***	2.45 ± 1.11	1.50 ± 0.73***	2.32 ± 1.02	1.56 ± 0.68***
Artifacts						
Motion	2.23 ± 1.24	1.55 ± 0.91***	2.30 ± 1.18	1.55 ± 0.87***	2.27 ± 1.17	1.55 ± 0.83***
Truncation	2.77 ± 0.99	2.42 ± 0.72*	2.53 ± 0.65	2.12 ± 0.49***	2.65 ± 0.73	2.27 ± 0.52***
Metal	3.78 ± 0.44	3.89 ± 0.33ns	4.00 ± 0.00	3.44 ± 0.53ns	3.89 ± 0.22	3.67 ± 0.35ns
Flow phenomena	2.93 ± 0.82	1.98 ± 0.77***	3.00 ± 0.92	2.18 ± 0.62***	2.97 ± 0.79	2.08 ± 0.62***
Contrast						
Vertebral body/disk	2.38 ± 0.96	2.12 ± 0.80*	1.93 ± 1.02	1.18 ± 0.47***	2.16 ± 0.86	1.65 ± 0.54***
Spinal cord/CSF	2.42 ± 0.98	1.97 ± 0.80**	2.62 ± 1.08	1.62 ± 0.78***	2.52 ± 0.93	1.79 ± 0.69***
Diagnostic reliability						
Spinal cord	3.03 ± 1.26	2.70 ± 0.89**	2.93 ± 1.19	2.38 ± 0.78***	2.98 ± 1.16	2.54 ± 0.77***

Note:—Wilcoxon rank sum test; ns indicates no significant difference between TSE and BLADE ($P \geq .05$); *, $P < .05$; **, $P < .01$; ***, $P < .001$.

evaluation for TSE and BLADE were compared with the 2-sided Wilcoxon rank sum test for each individual reader as well as for the mean grading of both readers. The 2-sided *t* test was applied to the results of the quantitative evaluation (SNR, CNR). To assess the results of the consensus reading for the preferred sequence, the χ^2 test was used. For all tests *P* values <.05 were considered statistically significant.

Results

Qualitative Results
The BLADE sequence was superior to TSE regarding image sharpness, motion artifacts, truncation artifacts, flow phenomena of the CSF, contrast between vertebral disk and vertebral body, contrast between spinal cord and CSF, as well as diagnostic reliability for the depiction of spinal cord and spinal

cord lesions (Figs 1 and 2). The difference was statistically significant for each individual reader as well as for the mean grading of both readers (Table 2). Metal artifacts, however, were graded very similarly in both sequences; there was no statistically significant difference between TSE and BLADE (Table 2 and Fig 3).

The number of examinations that were graded as nondiagnostic by at least 1 reader was clearly lower with BLADE than with TSE (Figs 4 and 5). TSE images were nondiagnostic due to reduced image sharpness and severe overall motion artifacts in 2 patients, due to flow artifacts in 2 patients, due to reduced vertebral body/disk contrast in 1 patient, and due to reduced spinal cord/CSF contrast in 2 patients. BLADE images were diagnostic in all of these patients taking into account the cri-
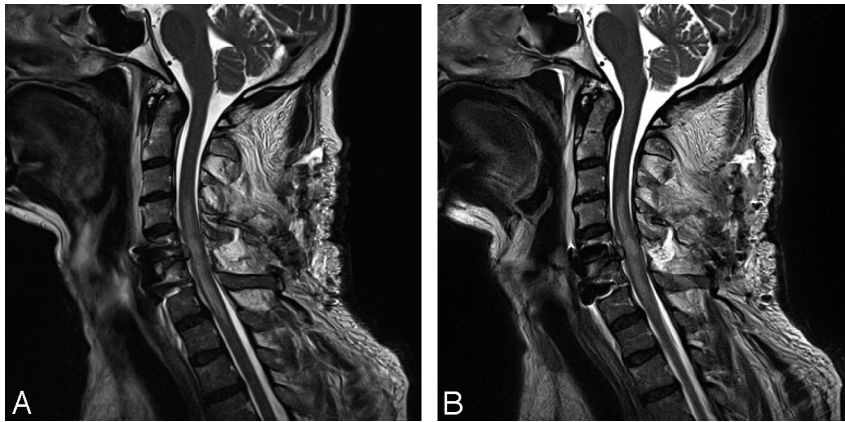
Fig 3. TSE (A) and BLADE (B) in a 60-year-old man with myelopathy following cervical osteosynthesis. Similar metal artifacts (mean grade, 4.0) in TSE (A) and BLADE (B).
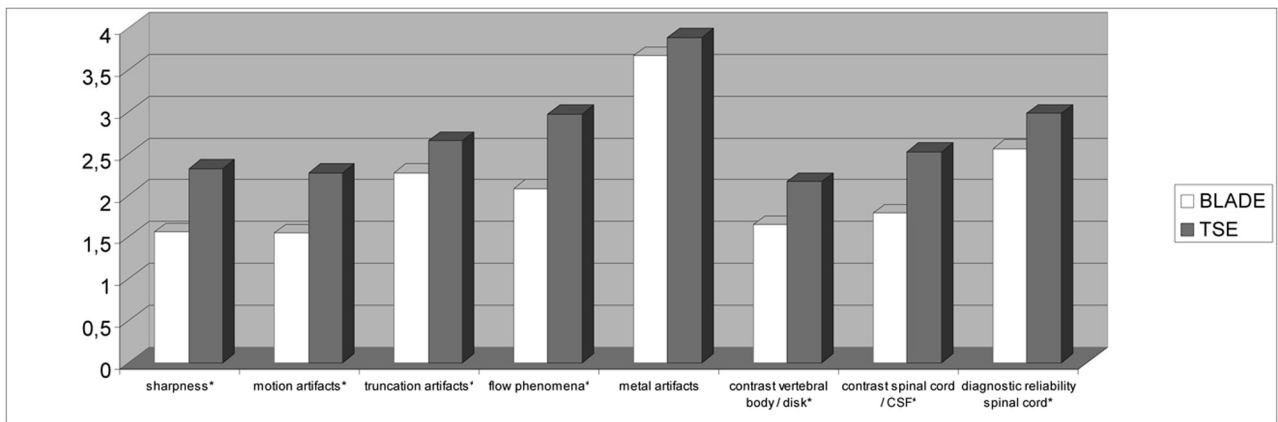

Fig 4. Number of examinations with nondiagnostic quality regarding all evaluation criteria in TSE and BLADE (nondiagnostic grading by at least 1 reader). *, Highly significant difference between TSE and BLADE (P < .001).

Fig 5. TSE (A) and BLADE (B) in a 72-year-old man with paresthesia of the left hand. Nondiagnostic image quality (image sharpness, motion artifacts, diagnostic reliability spinal cord: mean score, 5.0) in TSE (A) compared with fair, but still diagnostic quality in BLADE (B) (image sharpness, 4.0; motion artifacts, 4.0; diagnostic reliability of spinal cord, 4.5).

teria mentioned above. In 1 patient, TSE images were graded as poor, but still diagnostic (grade 4), because of motion artifacts, whereas BLADE images of this patient were scored as nondiagnostic (grade 5) by 1 reader and as poor (grade 4) by the other reader. Diagnostic reliability of spinal cord and spinal cord lesion depiction was insufficient in 12 patients with TSE (for 5 patients, mean grade, 4.5; for 7 patients, mean grade, 5.0), but only in 3 patients with BLADE (mean grade, 4.5). In 2 of the 12 patients that were graded as nondiagnostic in TSE, a spinal cord lesion was diagnosed based on the complete MR examination.

The consensus reading resulted in a significant advantage for the BLADE technique, too. BLADE was the preferred se-

quence in 50 of 60 patients, in 3 patients TSE was favored, and in 7 patients both sequences were graded as equivalent. In 1 of the patients in which TSE was judged superior to BLADE, atypical artifacts were seen in some of the BLADE images that were not present in TSE images (Fig 6).

Quantitative Evaluation

SNR and CNR were assessed in 30 patients with excellent or good image sharpness for TSE and BLADE images. SNR of vertebral disk and CSF were very similar in TSE and BLADE, and SNR of vertebral body and spinal cord were significantly higher in TSE. No statistically significant difference was found
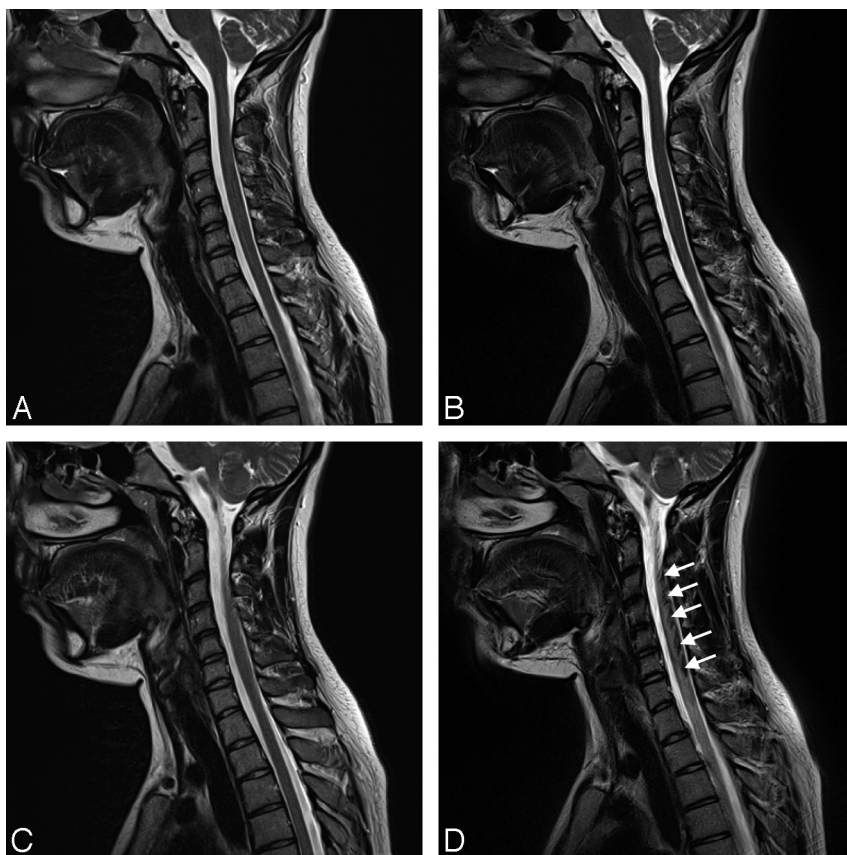
Fig 6. TSE (*A, C*) and BLADE (*B, D*) in a 19-year-old woman with paresthesia of both hands and feet after a traffic accident: no pathologic findings of the spinal cord or vertebral bodies. No motion artifacts are seen in TSE (adjacent section positions, *A, C*) (mean grade, 1.0); indentation artifacts (*arrows*) were detected on some of the BLADE (*B, D*) images.

Table 3: Results of the quantitative evaluation: SNR and CNR

	TSE	BLADE
$SNR_{vertebral\ body}$	11.13 ± 2.93	9.43 ± 1.93***
$SNR_{vertebral\ disk}$	5.61 ± 2.86	5.11 ± 2.50^{ns}
SNR_{CSF}	41.93 ± 15.23	41.29 ± 14.06^{ns}
$SNR_{spinal\ cord}$	16.79 ± 4.54	12.99 ± 2.56***
$CNR_{vertebral\ body/vertebral\ disk}$	5.52 ± 4.42	4.32 ± 3.02^{ns}
$CNR_{CSF-spinal\ cord}$	25.14 ± 13.40	28.30 ± 13.62^{ns}

Note:—t test: ns indicates no significant difference between TSE and BLADE ($P \geq .05$); *, $P < .05$; **, $P < .01$; ***, $P < .001$.

between TSE and BLADE for $CNR_{vertebral\ body/vertebral\ disk}$ and $CNR_{CSF/spinal\ cord}$ (Table 3).

Discussion

Sagittal T2-weighted images are an essential part of MR imaging in the cervical spine. Therefore, sufficient contrast of anatomic structures and sharp images free of artifacts are important requirements. To assess the potential role of the BLADE technique in comparison to the traditional TSE technique, contrast of relevant anatomic structures was studied qualitatively by visual evaluation and quantitatively by SNR and CNR measurements. Furthermore, artifacts that typically occur in this anatomic region were assessed visually. Geometric as well as contrast parameters were matched in TSE and BLADE to yield sufficient comparability of both sequences. The BLADE sequence was designed with a very similar acquisition time to evaluate a technique that might be applicable in clinical routine. Specific characteristics of TSE (flow compensation, head–feet phase encoding direction, and long-term averaging to reduce motion artifacts, as well as shorter echo-train length

and lower bandwidth in TSE compared with BLADE) were not transferred to the BLADE sequence. This was done to apply both sequences in an optimized fashion. In BLADE, a long echo train is selected to cover a relatively large area of the k-space center with each blade and to yield sufficient information for motion correction. On the other hand, short echo spacing is necessary to keep the acquisition time for a single blade short enough (to shorten the total acquisition time and to freeze motion during data acquisition of a blade). To realize short echo spacing, a high readout bandwidth has to be chosen.

BLADE was superior to an optimized TSE sequence concerning image sharpness and overall motion artifacts in a routine patient collective consisting of mainly cooperative patients and a few patients with restricted ability to cooperate. Although the dedicated motion correction algorithm was switched off in this study, minor motion artifacts were sufficiently corrected by the altered k-space coverage in the BLADE technique with its repeated measurement of central k-space areas. This result is in good agreement with prior studies of the PROPELLER or BLADE technique in MR imaging of the brain.[5,10,11] In 2 patients with severe motion artifacts in TSE, the BLADE sequence yielded sufficient image quality, in 1 patient, the BLADE sequence was not successful in solving this problem.

Besides overall motion artifacts, truncation artifacts, CSF flow phenomena, and CSF pulsation artifacts as well as artifacts caused by metal implants can severely impair image quality of the cervical spine.

The appearance of metal artifacts was somewhat different in TSE and BLADE images, which might be explained by the
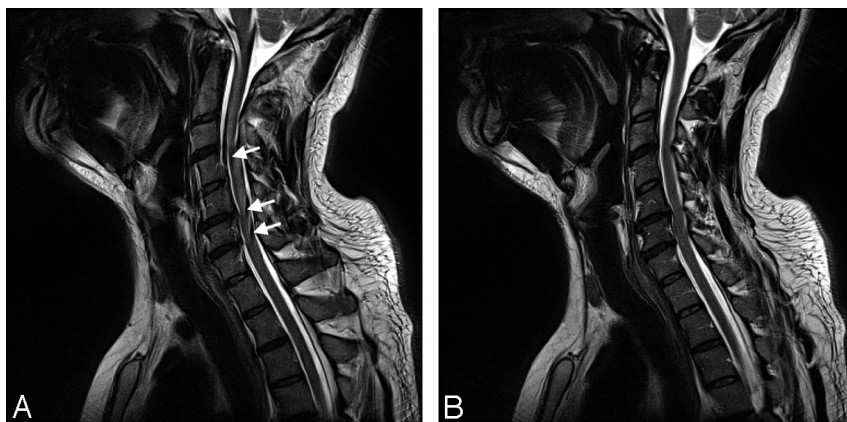
Fig 7. BLADE sequence during 2 types of brief head motion (*A, B*) in a volunteer without pathologic changes of the spinal cord: nodding (*A*) during the first half of the data acquisition (ie, during the first concatenation) results in similar indentation artifacts (*arrows*) as in the patient shown in Fig 6; no relevant artifacts appear by shaking his head (*B*) during the second half of the data acquisition.

rotating frequency and phase-encoding directions in BLADE compared with the constant encoding directions in TSE. Further imaging parameters that influence metal artifacts in MR imaging,[2,24] such as sequence type, voxel size, and TE, were identical in TSE and BLADE, and there was only a relevant difference regarding the readout bandwidth. However, despite the increased bandwidth in BLADE, no significant improvement concerning metal artifacts could be detected. According to our experience with T2-weighted TSE sequences and metal artifacts, a much larger increase in readout bandwidth would be necessary to reach a relevant reduction of metal artifacts.

Truncation artifacts occur at tissue boundaries with large differences of signal intensities between both tissues. Improving the spatial resolution is known to decrease truncation artifacts,[25] because the signal intensity of the "ripples" is decreased. Voxel sizes of BLADE and TSE sequences were identical; nevertheless, truncation artifacts were less pronounced in BLADE images. Once again, this advantage might be caused by the rotating phase-encoding direction of BLADE imaging and is in agreement with previous results in the brain.[10]

Flow phenomena of the CSF result in local spin dephasing and, therefore, cause hypointense areas within the CSF. In MR imaging of the cervical spine these CSF flow phenomena sometimes can cause diagnostic problems, especially for a reader with only minor MR experience. Using the BLADE *k*-space trajectory, flow phenomena were significantly reduced compared with the rectilinear trajectory in TSE, similar to the reduction of flow phenomena or pulsation artifacts seen with PROPELLER or BLADE sequences in other anatomic regions.[10,11,15]

Diagnosis of spinal cord lesions demands high standards of MR image quality. However, diagnostic reliability for depiction of spinal cord and spinal cord lesions is influenced by several factors: contrast between spinal cord and CSF, motion artifacts including artifacts caused by swallowing and pulsatile CSF motion, and truncation artifacts. Most of these rather technical criteria have been evaluated separately in our study. The criterion "diagnostic reliability of spinal cord depiction" was added to the visual assessment because of its clinical importance. Furthermore, it is sometimes difficult to differentiate the influence of single parameters. Statistically superior results of BLADE for the diagnostic reliability of spinal cord as well as the reduced number of nondiagnostic examinations (3

of 60 in BLADE versus 12 of 60 in TSE) indicate an important advantage of BLADE over TSE.

The dedicated visual assessment of BLADE and TSE was done by 2 readers with very different experience in MR imaging. While reader 1 was an experienced neuroradiologist, reader 2 was a resident with only 1 year of experience in MR imaging. Nevertheless, their independent image evaluation gave similar results for all criteria in favor of the BLADE technique (except for metal artifacts; see above).

The advantage of BLADE was also confirmed in the consensus reading of 2 experienced neuroradiologists. In only 3 of 60 patients TSE was preferred over BLADE for diagnostic purposes. In 1 of those 3 patients "indentation artifacts" were seen with BLADE in the spinal cord (Fig 6), which severely impaired diagnostic reliability (mean grade, 4.5). Their appearance is different from BLADE- or PROPELLER-specific wrap-around artifacts, which were very discrete in our BLADE images and were typically located in the lower right (and left) corner of the image (Figs 1*B*, 3*B*, and 5*B*). To our knowledge no comparable artifacts have been described in the literature until now. Severe overall motion artifacts seemed to be unlikely in this otherwise cooperative patient, because no motion artifacts were present in the remaining sequences of this patient. Nevertheless, very similar artifacts were reproduced in a volunteer by a special kind of head motion. The volunteer was instructed to hold still except for 2 short periods of head motion: during the acquisition of the first concatenation of the BLADE sequence he was told to nod (like saying "yes") and during the second concatenation was told to shake his head (like saying "no"). Both movements were performed with a quite large movement amplitude but short duration. Shaking his head did not influence the image quality (Fig 7*B*), but nodding resulted in these unusual indentation artifacts in the spinal cord (Fig 7*A*), very similar to those seen in the patient in Fig 6. Due to their typical appearance the indentation artifacts can be easily discriminated from real spinal cord lesions. Furthermore, the frequency of those artifacts was very low in our patient collective (1/60). Nevertheless, indentation artifacts are a disadvantage in the current implementation of the BLADE sequence.

The visual evaluation revealed improved image contrast with BLADE, but there was no statistically significant difference regarding CNR values, and SNR was even lower for some tissues in BLADE. These inconsistent results might be ex-

plained by the following considerations. The visual impression seems to be dominated by reduced overall motion artifacts and improved image sharpness resulting in improved vertebral body/disk and spinal cord/CSF contrast in BLADE. For SNR and CNR some physical aspects have to be taken into account: PROPELLER or BLADE k-space trajectories yield a prolongation of acquisition time by a factor of $\pi/2$ while increasing the SNR.[5] Another parameter to increase SNR (and acquisition time) in the BLADE sequence of our study was a k-space coverage of 120%. On the other hand, the lower number of acquisitions or excitations in BLADE (= 1) compared with TSE (= 2) as well as the higher bandwidth in BLADE result in a decrease of SNR. If the acquisition time of BLADE and TSE is matched, as was done in our study, SNR will be somewhat reduced in BLADE compared with TSE. The effect of decreased SNR was seen for the vertebral body and the spinal cord, but there was no statistically significant difference between TSE and BLADE concerning the SNR of the vertebral disk and the CSF. For both tissues the standard deviation was quite high. Importantly, when discussing SNR and CNR, note that quantitative SNR and CNR evaluation is a demanding task when using array coils, because the noise is no longer distributed evenly over the complete field of view.[26] Calculating SNR in a traditional way as the mean signal intensity in a tissue ROI divided by the standard deviation of signal intensity in the air (in a ROI free of artifacts in the background) is therefore critical. For this reason, signal intensity and noise were measured in a local approach within the same ROI. Although this kind of analysis includes tissue-related inhomogeneities it may be a possible solution for the evaluation of patient data, because SNR and CNR are compared for 2 sequences by using identical ROIs.

By combining the results of qualitative and quantitative contrast assessment, the BLADE sequence can be assumed to be at least equivalent to the conventional TSE sequence. The most important advantages of BLADE are significant reduction of motion artifacts, flow phenomena, and truncation artifacts along with improved image sharpness and improved diagnostic reliability for delineation of spinal cord and spinal cord lesions. In contrast to these relevant advantages there are only some minor disadvantages. Although we were able to present a BLADE sequence with adequate SNR and spatial resolution, the acquisition time of 4 minutes 20 seconds is relatively long for a sagittal T2-weighted sequence of the cervical spine. Indentation artifacts, which occurred in only 1 of 60 patients, are another disadvantage of BLADE, but they might not be a relevant problem for an experienced reader.

Despite the relatively large patient collective and its prospective design, our study has some limitations. The number of patients with spinal cord lesions (10 of 60) was too low to yield a reliable result concerning the depiction of spinal cord lesions. All spinal cord lesions in our patient collective were very extensive and/or showed high contrast in T2-weighted images. Therefore, the diagnostic value of BLADE for spinal cord lesions has to be confirmed in a larger number of patients and especially for small lesions. Furthermore, the current implementation of the BLADE technique for the cervical spine might not be optimal. While it seems to be helpful in compensating minor motion artifacts (including swallowing, flow phenomena, and CSF pulsation), gross motion is not compensated for sufficiently in all cases. For this purpose the dedicated motion correction algorithm, which can be performed based on the repetitive acquisition of the central k-space area, might be helpful.

Conclusions

Sagittal T2-weighted imaging by using the BLADE technique is a reliable tool to reduce artifacts that are typically seen in MR imaging of the cervical spine in a routine patient collective. Applying a BLADE sequence with the same spatial resolution and acquisition time as in an optimized TSE sequence, our preliminary results indicate that imaging of the spine as well as diagnostic reliability for the depiction of the spinal cord and of spinal cord lesions is significantly improved. For delineation of very small lesions or lesions with very low contrast, however, further studies are necessary to settle this question.

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