BLADE Sequences in Sagittal T2-Weighted MR Imaging of the Cervical Spine and Spinal Cord – Lesion Detection and Clinical Value

BLADE-Sequenzen zur sagittalen T2-gewichteten Bildgebung der Halswirbelsäule und des zervikalen Myelons. Läsionsdetektion und klinische Wertigkeit

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Zusammenfassung

Ziel: BLADE (PROPELLER) Sequenzen zur T2-gewichteten Bildgebung der HWS sind geeignet Artefakte zu reduzieren, wie sie für diese Region typisch sind. Ziel war es, zu prüfen, ob BLADE-Sequenzen eine Auswirkung auf die Detektierbarkeit von kleinen und wenig kontrastreichen Myelonläsionen und epiduralen Läsionen haben.

Material und Methoden: T2-gewichtete sagittale Bildgebung der Halswirbelsäule mittels Standard TSE und BLADE-Sequenz bei 33 Patienten mit 46 spinalen und epiduralen Läsionen. Bildschärfe, Abgrenzbarkeit der Dura, Verlässlichkeit der Myelonbeurteilbarkeit und Läsionskontrast wurden von zwei unabhängigen Untersuchern ausgewertet. Zusätzlich wählten zwei weitere erfahrene Neuroradiologen in Konsensusverfahren die Sequenz, die sie für die diagnostische Beurteilung bevorzugen würden. Die Statistik erfolgte mittels Vorzeichentest und $\chi 2$ Test.

Ergebnisse: BLADE wurde für die Kriterien Bildschärfe, Abgrenzbarkeit der Dura und Verlässlichkeit der Myelonbeurteilung gegenüber der TSE-Sequenz als signifikant besser bewertet. Für den Läsionskontrast zeigte sich ein positiver Trend für die BLADE-Sequenz. Sie wurde in 17 von 46 Läsionen besser bewertet als die TSE-Sequenz, während TSE nur bei 10 Läsionen bevorzugt wurde. In der Konsensus-Auswertung wählten die beiden Neuroradiologen in 27 von 33 Patienten BLADE als die bevorzugte Sequenz hinsichtlich der allgemeinen Bildqualität. Für den Läsionskontrast bevorzugten sie bei 10 die BLADE und bei 14 Patienten die TSE-Sequenz, jedoch wurde bei 3 Patienten die TSE-Sequenz für dieses Kriterium als nicht diagnostisch gewertet.

Schlussfolgerungen: Für die Beurteilung von kleinen und wenig kontrastreichen Myelonläsionen sind BLADE-Sequenzen der TSE zumindest gleichwertig. Gleichzeitig liefern sie eine bessere Bild-

Abstract

Purpose: Using the BLADE (PROPELLER) technique for T2-weighted MR imaging of the cervical spine has proven to be a reliable tool for reducing artifacts typically for this region. The aim of this study was to evaluate whether the application of BLADE sequences has an impact on the detection of small or low contrast spinal cord and epidural lesions.

Materials and Methods: A standard TSE and a BLADE sequence were compared in 33 patients with 46 spinal cord and epidural lesions for T2-weighted sagittal imaging of the cervical spine. Image sharpness, visualization of the dura, reliability of spinal cord depiction as well as lesion contrast were evaluated by two independent readers. Additionally two experienced neuroradiologists selected in consensus the sequence they would prefer for diagnostic purposes. Statistical evaluations were performed using the sign and the $\chi 2$ test.

Results: BLADE was significantly superior to TSE regarding image sharpness, visualization of the dura and reliability of spinal cord depiction. Regarding lesion contrast there was a positive trend towards the BLADE sequence. In 17 of 46 lesions, BLADE was judged superior to TSE, while TSE was favored in 10 lesions. In consensus reading both neuroradiologists preferred BLADE for overall image quality in 27 of 33 patients and for lesion contrast in 10 and TSE in 14 of the 33 patients, but 3 TSE sequences were rated as non-diagnostic regarding this criterion.

Conclusion: For the detection of even small and low-contrast spinal cord lesions, BLADE is at least equivalent to TSE, yielding better overall image quality and fewer non-diagnostic images.

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qualität und reduzieren die Zahl diagnostisch nicht verwertbare Bilder.

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Introduction

Examination of the spine and spinal cord is one of the major objectives of modern MR imaging. Despite ongoing advances in sequence technique, imaging of the neck region and the cervical spine is still demanding due to several reasons. The anatomical structures are complex and rather small and a variety of artifacts, such as pulsatile flow of vessels and cerebrospinal fluid (CSF) or swallowing, as well as truncation artifacts occur in almost all patients [1 – 3]. Furthermore, many of the patients undergoing MRI of the cervical spine are in a clinical condition which makes it difficult for them to cooperate sufficiently and lie still for the duration of the MR examination. Pain, age, general condition as well as claustrophobic problems sometimes attribute to impaired image quality.

Chemical shift artifacts at the transition between the junction of CSF dura mater and the epidural fat of the spine obscure the dura layer in conventional TSE or fast spin echo images. Therefore, this area often harbors difficulties in the differentiation between epidural and subdural space and impedes lesion detection and location.

Up to now, Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction (PROPELLER) or its vendor-specific implementation, the BLADE technique, has been proposed to reduce motion artifacts in uncooperative or pediatric patients mainly for brain imaging [4 – 7]. The sequence is based on a TSE sequence which uses radial k-space coverage in a rotating and partially overlapping way ("blades") instead of acquiring parallel k-space lines as in conventional Cartesian TSE imaging. In cardiac or abdominal imaging this special way of k-space sampling enables partial compensation of heart or bowel motion [8 – 11]. In diffusion-weighted imaging (DWI), it reduces geometric distortions, diminishes susceptibility artifacts and increases spatial resolution compared to standard echo-planar imaging DWI [12 – 18]. In most of these studies BLADE or PROPELLER was used in transverse orientation.

Recent studies [19, 20] showed that by using the BLADE technique for sagittal T2-weighted imaging (T2WI) of the cervical spine, a significant reduction of several artifacts is possible. Although the overall image quality and depiction of the spinal cord was superior in the BLADE sequence, the diagnostic reliability to detect spinal cord lesions could not be judged due to the low number of spinal cord lesions included.

The aim of this study was to evaluate if in sagittal T2WI of the cervical spine BLADE is equivalent to TSE regarding the detection of spinal cord lesions and epidural lesions. We hypothesized that BLADE will be at least equivalent to TSE in detecting even small and low-contrast cervical spinal cord lesions.

Methods

Patients

We evaluated 33 consecutive patients referred for MRI of the cervical spine at our institution in this prospective study. The average age of the 19 men and 14 women was 53 years (age range: 12 – 86 years). The study was approved by the institutional review board and all patients were included after giving written informed consent.

The MR examinations showed altogether 42 lesions of the cervical spinal cord as well as 4 in the epidural layer. The findings were judged on the complete clinical MR examination performed. The patients suffered from demyelinating lesions due to ED (n = 11 with a total of 22 cervical lesions), myelopathy (predominantly due to degenerative spine disease) (n = 15 with 17 lesions) and funicular myelosis caused by vitamin B12 deficiency (n = 3). 4 patients revealed epidural abscess formation due to spondylodiscitis or parapharyngeal inflammation. The pathologies were all proven by clinical charts, symptoms and/or follow-up examinations.

MR examination

All examinations of the cervical spine were performed on a 1.5 T MRI scanner (Magnetom Avanto Siemens Medical, Erlangen, Germany) using a combination of head, neck and spine array coils. The gradient system had a maximum gradient field strength of 45 mT/m, and a slew rate of 200 T/m/s.

Sagittal T2-weighted TSE was acquired in all patients as the first sequence and sagittal BLADE as the second. For T2WI we applied our routine TSE sequence (rectilinear k-space coverage, head-feet phase encoding direction, flow compensation). Geometrical and contrast parameters of the BLADE sequence were matched (**Table 1**) resulting in a sequence with identical voxel size and acquisition time for optimized comparability. The additional motion correction algorithm of BLADE was not used, but a BLADE-specific high echo-train length and a high readout bandwidth were applied. A "restore" pulse was applied in both sequences to enable a shorter TE for an increased SNR and a shorter TR to reduce acquisition time while maintaining sufficient T2 contrast. In the BLADE sequence cranial and caudal presaturation pulses were applied.

Besides these sagittal T2-weighted sequences, a T2-weighted sagittal short TI inversion recovery (STIR) and T1-weighted TSE sequences without contrast enhancement as well as T2-weighted images in transverse orientation were acquired in all patients.

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

Tab. 1 Messparameter für die sagittale T2-gewichtete TSE und BLADE-Sequenz.

	TSE	BLADE
TR [ms]/TE [ms]	3000/113	3000/112
echo train length	17	35
bandwidth [Hz/pixel]	140	296
slice thickness [mm]/slice gap [mm]	3/0.6	3/0.6
FOV [mm × mm]	250 × 250	250 × 250
matrix size	384 × 384	384 × 384
phase encoding direction	H-F	rotating
oversampling (phase encoding direction)	85 %	100 %
number of acquisitions	2	1
flow compensation	yes	no
acquisition time [min:s]	4:17	4:20

Depending on the pathology, contrast-enhanced T1-weighted images (with or without fat saturation) in sagittal and transverse orientation were measured additionally.

Image evaluation

Two readers working independently and blinded to the imaging technique as well as to patient data, medical history or additional MR images compared sagittal BLADE vs. TSE images in a randomized order. Reader 1 was an experienced neuroradiologist, while reader 2 was a resident radiologist with 2 years MRI experience. Both readers evaluated images visually. They scored each case on a scale from 1 to 5 (1: excellent, without any impairment of image quality 2: good, with only minimal impairment of image quality 3: moderate, showing artifacts which diminished image quality but still diagnostic 4: poor, with severe impairment of image quality and limited diagnostic reliability 5: non-diagnostic, artifacts/alterations are too severe to make a diagnosis) for the following criteria: Image sharpness, visualization of the dura, diagnostic reliability of spinal cord depiction as well as lesion depiction within the spinal cord.

Additionally the sagittal BLADE and TSE images of every patient were shown simultaneously to another two experienced neuroradiologists who assessed them side-by-side for each patient and selected in consensus the sequence they would prefer for overall image quality and lesion depiction – TSE, BLADE or no preference. Both observers were identically blinded to imaging technique and additional data.

The remaining images and clinical data as well as follow-up examinations were included in the final judgment and classification of the lesions.

Statistical analysis

A statistical analysis was performed using the SPSS software (version 16.0 IBM SPSS Statistics, Armonk, New York, USA). The sign test was used to compare the results of the visual evaluation of TSE and BLADE – for each individual reader as well as for the mean grading of both readers. The $\chi 2$ test was used to evaluate the results of the consensus reading. P-values < 0.05 were regarded as statistically significant for all tests.

Results

Table 2 shows a comparison of the grades given by both readers to TSE and the BLADE sequence for the different criteria. The mean grading of both readers for the BLADE sequence was significantly superior to that of TSE regarding image sharpness, visualization of the cervical spine dura and reliability of spinal cord depiction. Concerning image sharpness and visualization of the dura of the cervical spine, the difference was also significantly better for each individual reader (**Table 2**). The diagnostic reliability of spinal cord depiction just missed significance for one reader, but with an advantage for BLADE even in his judgment.

Regarding lesion depiction, both sequences showed no significant difference, but a positive trend towards the BLADE sequence in the individual and mean grading of both readers for all lesion types (**Table 2**).

As a consequence of the significantly superior visualization of the dura, the detection of epidural lesions (4/33) was considerably easier with BLADE but the overall number of epidural pathologies in the study was very small. Therefore, a reasonable statistical workup of this entity was not possible.

With regard to the reliability of spinal cord depiction, none of the sagittal BLADE sequences was rated as non-diagnostic. 3 of the TSE examinations received this grading and were therefore clinically useless (**Fig. 1**). Although the spinal cord was depicted with high reliability, the number of examinations that were graded as non-diagnostic (grade 5) regarding lesion depiction by at least one reader was 8 with BLADE and 9 with TSE (**Fig. 2**). Difficulties in the exact delineation of the spinal cord and pathologic signal were in most cases due to extensive local narrowing of the spinal canal in high-grade spinal stenosis (**Fig. 3**).

The second part of the visual evaluation, the consensus reading of two experienced neuroradiologists, showed significant (P< 0.001) advantages for the BLADE technique concerning overall image quality. BLADE was preferred in 27 of 33 patients, whereas TSE was favored only in 6 patients with regard to this criterion. For lesion depiction the side-by-side comparison of both sequences led to a preference for the BLADE sequence in 10/33 patients and for TSE in 14/33 patients. In 9/33 patients the sequences were graded equivalent (**Fig. 4**). Statistical evaluation showed no significant difference for this criterion.

Table 2 Superior sequence or equivalent grading of BLADE and TSE for the different criteria evaluated by both readers and p-values (sign test).

Tab. 2 Bevorzugte Sequenz bzw. äquvalente Wertung von BLADE und TSE für die verschiedenen Bewertungskriterien, sowie p-Werte (Vorzeichentest).

superior sequence	BLADE		equal		TSE		P	
reader	1	2	1	2	1	2	1	2
image sharpness (n = 33)	17	17	12	14	4	2	0.007	0.002
spinal cord depiction (n = 33)	14	14	15	14	4	5	0.031	0.064
visualization of dura (n = 33)	33	33	0	0	0	0	< 0.001	< 0.001
lesion depiction (all lesions, n = 46)	17	15	20	20	9	11	0.169	0.557
lesion depiction (spinal cord, n = 42)	13	14	20	18	9	10	0.523	0.541
lesion depiction (ED, n = 22)	9	6	9	12	4	4	0.267	0.754
lesion depiction (myelopathy, n = 20)	4	8	11	6	5	6	1.000	0.791

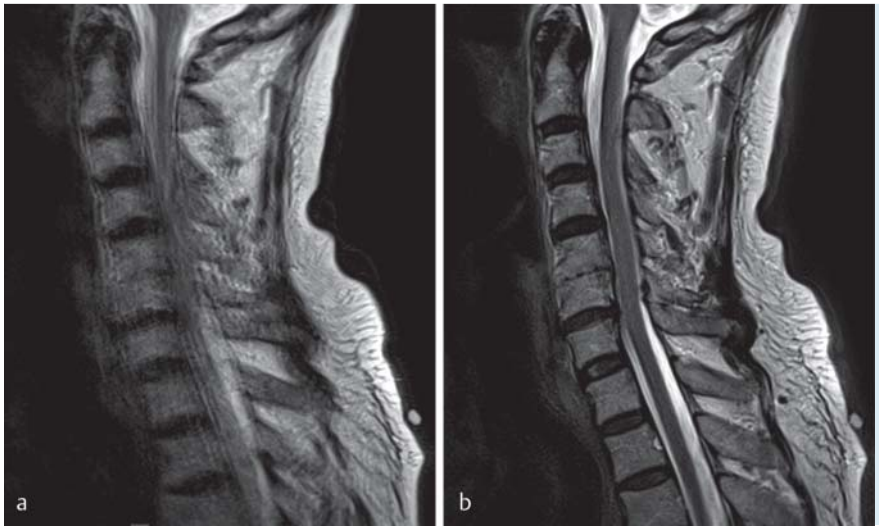

Fig. 1 Sagittal T2-weighted TSE **a** in this patient is rated as non-diagnostic by both readers due to distinctive artifacts. Sagittal BLADE imaging **b** enables sufficient visualization of the cervical spine showing narrowing of the spinal canal at level C5 – 7 with presumed myelopathy, which could be affirmed in axial T2-weighted images (not shown).

Abb. 1 Das sagittale T2-gewichtete TSE Bild **a** dieses Patienten wird von beiden unabhängigen Auswertern aufgrund ausgeprägter Artefakte als nicht diagnostisch gewertet. Die sagittale BLADE Bildgebung **b** ermöglicht eine ausreichende Visualisierung der HWS mit Darstellung einer spinalen Enge auf Höhe HWK 5 – 7 und Verdacht auf lokale Myelopathie, die sich in axialen T2-gewichteten Bildern bestätigte (ohne Abbildung).

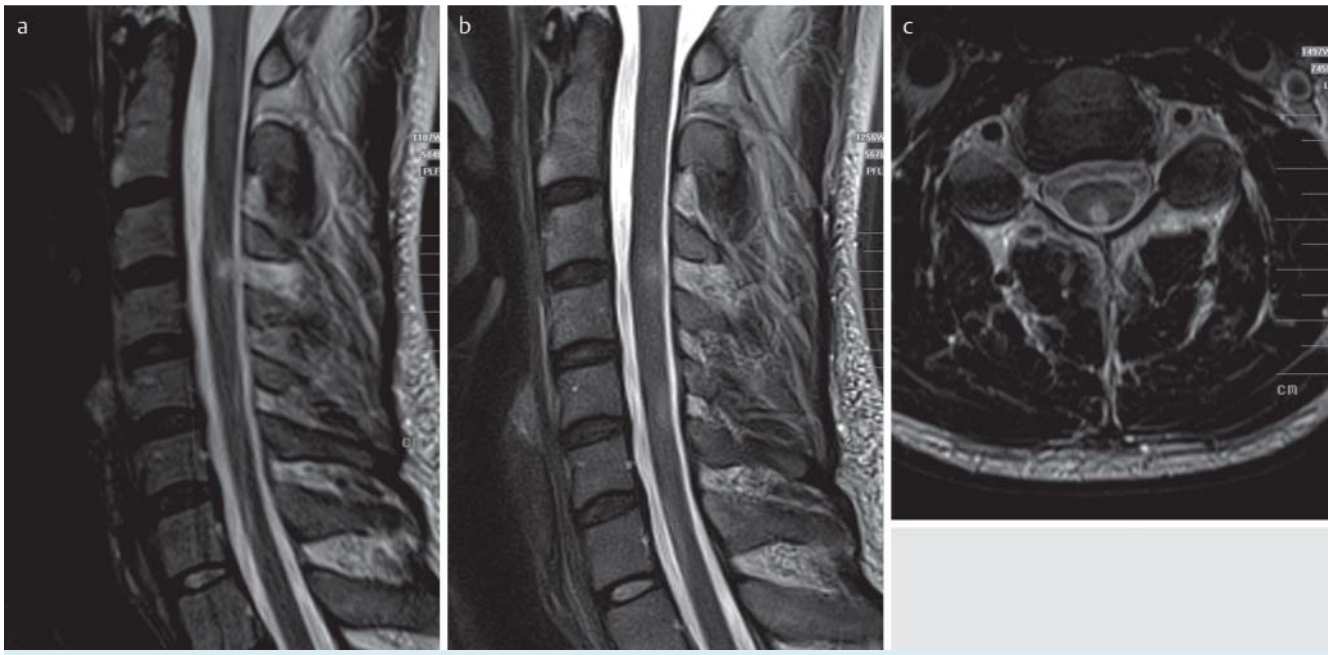

Fig. 2 Sagittal T2-weighted TSE **a** shows significant artifacts with reduced image sharpness and spinal cord depiction. A dorsal midline lesion at level C3/4 is misjudged in sagittal T2 TSE **a** as artificial but is clearly confirmed in BLADE **b** and axial T2 **c**. Furthermore, additional lesions at level C5/6 and C7 can be identified in BLADE and on axial T2 (not shown).

Abb. 2 Sagittales T2-gewichtetes TSE-Bild **a** mit deutlichen Artefakten und eingeschränkter Bildschärfe sowie Beurteilbarkeit des Myelons. Eine Läsion in der Mittellinie des Myelons auf Höhe HWK 3/4 wird in der sagittalen TSE-Sequenz als artifiziell fehlgedeutet, kann aber in der sagittalen BLADE **b** gut abgegrenzt und in der axialen T2 **c** verifiziert werden. Zusätzliche Läsionen zeigt die sagittale BLADE auf Höhe HWK 5/6 und HWK 7 die in axialen T2-Schichten (ohne Abbildung) bestätigt werden.

Discussion

MR imaging of the cervical spine and spinal cord is a main element of the modern diagnostic workup of numerous neurological pathologies including disc herniation, spinal stenosis, and inflammatory or demyelinizing disease. Thereby T2-weighted sequences in sagittal orientation produce the most essential images for anatomic overview of the region and lesion depiction. These images should be free of artifacts and with sufficient contrast of anatomical details to be able to show even tiny lesions with poor contrast. Furthermore, the dural layer in the cervical spine region is often impaired by artifacts, calling for new MR sequence designs to solve these problems. BLADE sequences proved their value to overcome some of the above named problems in head and spine imaging in former studies, but clear statements concerning spinal cord lesion detection with these sequences are not available to our knowledge. To assess the value of the BLADE technique in comparison to the regular TSE technique in the overall image quality for the cervical spine, image sharpness as well as visualization of the dura mater of the cervical spine were judged qualitatively by visual evaluation. Furthermore, the quality of lesion depiction within the spinal cord and in the epidural space was evaluated.

Geometric as well as contrast parameters were matched in TSE and BLADE to yield sufficient comparability of both sequences (▶ **Table 1**). The BLADE sequence was designed with a nearly

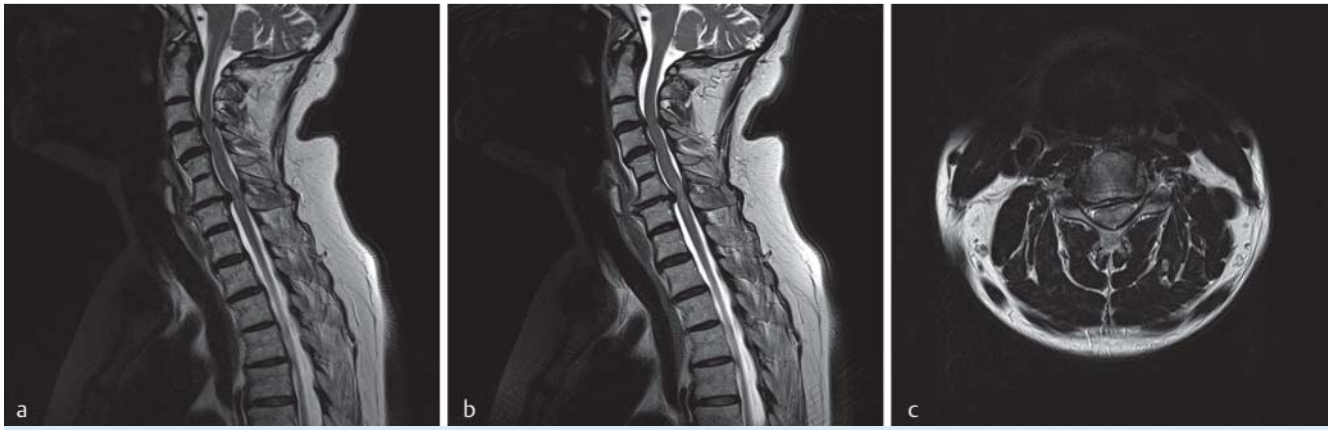

Fig. 3 Sagittal T2-weighted TSE **a** in good image quality but reduced spinal cord depiction at the level of spinal canal narrowing at level C3/4 and C6/7 in this patient with a Klippel-Feil segmentation anomalia involving C5 and C6. In sagittal BLADE **b** lesion detection and assessment of spinal cord status corresponds to axial T2-weighted **c** images showing predominately left-sided myelopathic signal at the level of the herniated disc C6/7.

Abb. 3 Sagittales T2-gewichtetes TSE-Bild **a** in guter Qualität aber reduzierter Myelonbeurteilbarkeit auf Höhe der spinalen Stenose HWK 3/4 und 6/7, bei diesem Patienten mit einer Klippel-Feil-Anomalie HWK 5 und 6. In der sagittalen BLADE **b** korrespondiert die Läsionsdetektion und die Abbildung des Myelons gut mit der axialen T2-gewichteten Sequenz **c**, die ein linksbetontes Myelopathiesignal auf Höhe des Diskusprolaps HWK6/7 zeigt.

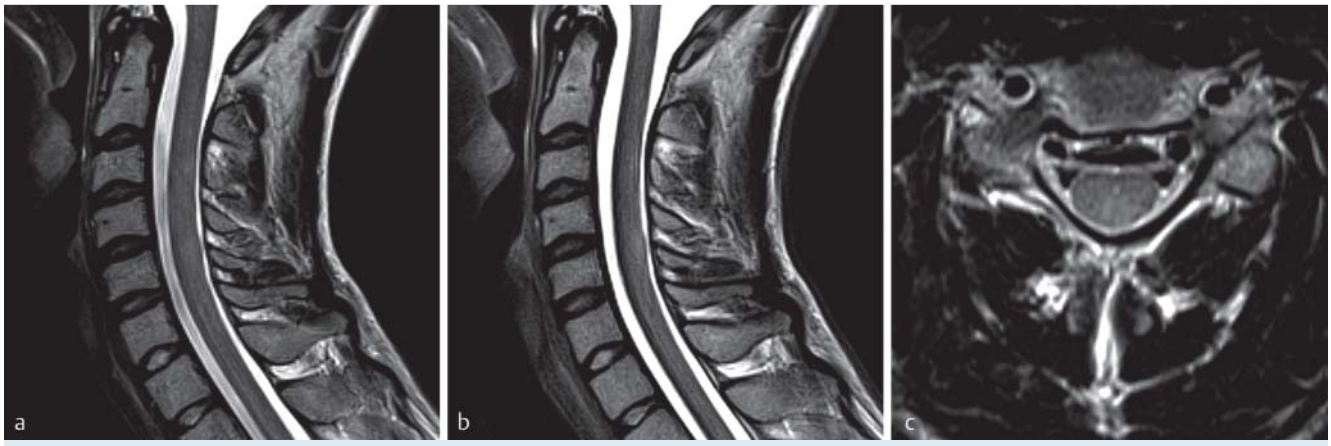

Fig. 4 Low-contrast lesion in the cervical myelon at the C4/5 level in a patient with ED. Sagittal T2-weighted TSE **a** and sagittal BLADE (4b) are rated as equal by both independent readers and in consensus reading. Axial T2-weighted images **c** confirm the low-contrast dorsal, midline lesion

Abb. 4 Läsion der Zervikalmarks auf Höhe HWK4/5 mit sehr geringem Kontrast bei einem Patienten mit ED. Sagittale T2 TSE **a** und BLADE **b** wurden sowohl in der unabhängigen Auswertung, als auch in der Konsensusbewertung als gleichwertig eingeschätzt. Axiale T2-gewichtete Bilder (4c) bestätigen das Vorliegen der diskreten Läsion dorsal paramedian im Myelon.

identical acquisition time to make it applicable in the daily clinical routine. Specific characteristics of TSE and BLADE – longer ETL and higher bandwidth in BLADE, flow compensation, head-feet phase encoding direction and long-term averaging to reduce motion artifacts in TSE – were not transferred to the other sequence. In our routine patient collective consisting of mainly cooperative patients and a few patients with restricted ability to cooperate, motion artifacts were sufficiently corrected by the rotating k-space coverage in the BLADE technique with its repeated measurement of central k-space areas, although the dedicated motion correction algorithm was switched off in this study. This result is in good agreement with prior studies of the PROPELLER or BLADE technique in MRI of the brain [21 – 23] and spine [19, 20]. In the clinical routine motion artifacts often require repeated sequence acquisitions, thus prolonging the overall time of the examination and impairing patient comfort and departmental workflow. As detailed in the Results section, the intrinsic motion correction of BLADE has the potential to save time by avoiding repetition of sequences thereby improving patient comfort and workflow.

Spinal cord depiction and visualization of spinal cord lesions are the main objective of most neurological and neurosurgical clinical issues and demand high standards of MR image quality. However, diagnostic reliability for the depiction of the spinal cord and spinal cord lesions is influenced by several factors: contrast between the spinal cord and CSF, motion artifacts including artifacts caused by swallowing and pulsatile CSF motion, and truncation artifacts (▶ **Fig. 1, 2**). Most of these factors have been evaluated separately in former studies [19, 20], which showed improved spinal cord/CSF contrast in BLADE by reduced overall motion artifacts and improved image sharpness. The better and clearer the spinal cord is visualized, the easier spinal lesions can be identified. Although the results of BLADE for the diagnostic reliability of spinal cord depiction (▶ **Table 2**) were not always statistically significant for each individual reviewer, a trend of su-

perior scores for the BLADE sequence as well as the absence of non-diagnostic BLADE examinations indicate an important advantage compared to TSE.

Besides motion and flow artifacts lesions within the spinal cord can be "masked or blurred" by low contrast or size of the lesion itself as well as narrowing of the spinal canal with partial volume effects. The BLADE sequence showed improved or at least equivalent lesion depiction for all evaluated pathologic entities (MS, myelopathy, epidural lesions and overall lesion grading) even in very tiny, low-contrast lesions, which was one of the major objectives in this study.

Visualization of the dura mater at the cervical spine is difficult in TSE sequences for several reasons. Flow phenomena of the CSF result in local spin dephasing and, therefore, cause hypointense areas within the CSF, which often disturb proper delineation of the small linear dural structure. 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 pulsations artifacts seen with PROPELLER or BLADE sequences in other anatomical regions [21 – 23].

Even more relevant, chemical shift artifacts at the junction between epidural fat layer and CSF blur the dural structures to a major extent so that they can rarely be differentiated in T2-weighted TSE sequences. BLADE with its radial k-space coverage and a high readout bandwidth eliminates chemical shift artifacts and enables good visualization of the dural layer at the cervical and upper thoracic spine. In all examinations BLADE showed the dural layer better than TSE and as a consequence the differentiation of epidural pathologies was easier with BLADE. Although the number of epidural pathologies in our study was rather small (n = 4), we would suggest that BLADE is a useful tool to visualize epidural inflammatory processes and to determine in which compartment of the cervical spine a pathology is located.

The dedicated visual assessment of BLADE and TSE in all categories was done by two independent readers with different levels of MRI experience. While reader 1 was an experienced neuroradiologist, reader 2 was a resident with two years of general MRI experience. Nevertheless, their independent image evaluations gave similar results for all criteria in favor of the BLADE technique (**Table 2**). This confirms that T2-weighted BLADE imaging at the cervical spine is a reliable and robust technique with good agreement to clinically proven T2-weighted TSE sequences and better overall image quality, which can be judged even with less experience at a good level of confidence. Compared to shorter TSE sequences used in uncooperative individuals, BLADE images result in a better overall image quality with good depiction of spinal discs, bony structures and the spinal cord [19]. We would recommend its clinical use especially in uncooperative patients but even see the potential to replace TSE in standard imaging protocols at least for the Magnetom Avanto system.

Despite its prospective design, our study has some limitations: The number of patients with epidural lesions (4 of 33) was too low to yield a reliable result concerning the depiction of these lesions. Therefore, the diagnostic value of BLADE for epidural lesions has to be confirmed in a larger number of patients. Furthermore, randomized sequence acquisition with an alternating order of TSE and BLADE would be optimal to overcome the drawbacks of increasing patient motion with prolonged examination duration. As we evaluated our patients in a clinical setting, we used TSE for first-line imaging to ensure standard validated clinical imaging. This resulted in the acquisition of the BLADE sequences 4 to 5 minutes after TSE with potentially increasing patient motion.

A major limitation of this and of most clinical studies concerning intramedullary lesions is that a true gold standard such as histological verification is missing and is rarely achieved. Therefore, the clinical workup and history as well as follow-up examinations are often the only way to substantiate and confirm a suspected pathology.

Finally, all results reported in this study represent the findings on a 1.5 T Siemens Magnetom Avanto with its specific gradient system, array coils and optimized measurement parameters. Scanners of different producers or with higher/lower field strengths as well as vendor-specific sequences (e. g. PROPELLER, MULTIVANE) might yield different results. Therefore, the results of this study should be validated on the specific scanner before use.

Conclusion

Sagittal T2-weighted imaging of the cervical spine using the BLADE technique in a routine patient collective significantly improves overall image sharpness and visualization of the dural layer compared to TSE. A BLADE sequence with the same spatial resolution and acquisition time as in an optimized TSE sequence is at least equivalent with respect to spinal cord depiction and the delineation of even small or low-contrast spinal cord lesions and more importantly the number of non-diagnostic examinations can be reduced. We therefore could even recommend BLADE sequences as a routine application for sagittal T2-weighted imaging of the cervical spine replacing T2-TSE.

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