MR Diagnosis of Bone Metastases at 1.5 T and 3 T: Can STIR Imaging Be Omitted?

MRT-Diagnostik von Knochenmetastasen bei 1,5 T und 3 T: Kann auf die STIR-Bildgebung verzichtet werden?

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Zusammenfassung
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Ziel: Bislang gibt es keine prospektive Vergleichsstudie zum diagnostischen Stellenwert der STIR versus T1-gewichteten (T1w) Sequenz sowohl am 1,5 T als auch am 3 T MRT im Hinblick auf die Detektierbarkeit von Knochenmetastasen.

Material und Methoden: 212 onkologische Patienten erhielten eine Ganzkörper-MRT bei 1,5 T und/oder 3 T. Das Standardprotokoll umfasste STIR und T1w-Sequenzen. Alle Patienten, die typische Kriterien von Knochenmetastasen zeigten, wurden in die Studie aufgenommen. Die Bildevaluation erfolgte anhand der Berechnung der Anzahl von Knochenmetastasen durch drei unabhängige Reader und durch visuelle Beurteilung auf einer 4-Punkte-Skala.

Ergebnisse: 86 Patienten erfüllten die Einschlusskriterien. Die Gesamtanzahl der Metastasen war signifikant höher bei T1w als auf den STIR-Bildern bei beiden MRT-Feldstärken (p < 0,05). Die Sensitivität war bei T1w 99,72 % (3 T) und 100,00 % (1,5 T) versus bei STIR 70,99 % (3 T) und 79,34 % (1,5 T). In 53 % (38/72) aller Patienten detektierte die STIR weniger Metastasen im Vergleich zu T1w bei 3 T, bei 1,5 T waren es 37,5 % (18/48) aller Patienten. Die qualitative Analyse ergab eine signifikant bessere Läsionsnachweisbarkeit, Läsionsabgrenzbarkeit und eine verbesserte Bildqualität bei T1w im Vergleich zu STIR an beiden Feldstärken (p < 0,05). Hierbei zeigten sich ähnliche Resultate für T1w bei 1,5 T und 3 T, wohingegen die STIR insbesondere bei 3 T der T1w unterlegen war.

Schlussfolgerung: Besonders bei 3 T kann das Ganzkörper-MRT-Protokoll zur Detektion von Knochenmetastasen bei Erwachsenen auf die T1w-SE-Sequenz beschränkt werden. Eine zusätzliche STIR-Bildgebung ist nicht notwendig. Unsere Studie könnte einen erheblichen Einfluss auf den Workflow einer Abteilung haben, sofern sich die Resultate an einem größeren Patientenkollektiv bestätigen. Insbesondere könnten hier-

Abstract
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Objective: To date, no prospective comparative study of the diagnostic value of STIR versus T1-weighted (T1w) sequences at both 1.5 T and 3 T has been performed with special focus on the detectability of bone metastases.

Materials and Methods: 212 oncological patients had a whole-body MRI at 1.5 T and/or at 3 T. The standard protocol comprised STIR and T1w sequences. All patients who showed typical signs of bone metastases were included in the study. Evaluation of the images was performed by the calculation of the number of metastases by three independent readers and by visual assessment on a 4-point scale.

Results: 86 patients fulfilled the inclusion criteria. The total number of metastases was significantly higher on T1w than on STIR images at both field strengths (p < 0.05). T1w revealed a sensitivity of 99.72 % (3 T) and 100.00 % (1.5 T) versus STIR with 70.99 % (3 T) and 79.34 % (1.5 T). In 53 % (38/72) of all patients, STIR detected fewer bone metastases in comparison with T1w at 3 T. At 1.5 T, STIR showed inferior results in 37.5 % (18/48) of all patients. Qualitative analysis indicated a significantly better lesion conspicuity, lesion delineation and an improved image quality on T1w compared to STIR imaging at both field strengths (p < 0.05) with similar results for T1w at 1.5 T and 3 T, but inferior results for STIR especially at 3 T.

Conclusion: The whole-body MRI protocol for the detection of bone metastases could safely be limited to the T1w sequence in adults, especially at 3 T. There is no need for an additional STIR sequence. These initial results will have a major impact on the department's workflow if confirmed by larger studies as they will help reduce examination time and therefore save financial resources.

Key points:

▶ In a routine MR protocol, T1w imaging is sufficient for the detection of bone metastases.

durch Untersuchungszeiten und Untersuchungskosten reduziert werden.

Kernaussagen:

▸ Die T1w ist im MRT-Routineprotokoll zur Detektion von Knochenmetastasen ausreichend.

▸ Bei differentialdiagnostischen Unklarheiten können adäquate Zusatzsequenzen akquiriert werden.

▸ In der Metastasendetektion ist die STIR der T1w insbesondere bei 3 T deutlich unterlegen.

▸ In case of differential diagnostic problems, other appropriate sequences can be added to the protocol.

▸ STIR is inferior to T1w in the detection of metastases, especially at 3 T.

Citation Format:

▸ Ohlmann-Knafo S., Tarnoki A. D., Tarnoki D. L. et al. MR Diagnosis of Bone Metastases at 1.5T and 3T: Can STIR Imaging Be Omitted?. Fortschr Röntgenstr 2015; 187: 924–932

Introduction

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Whole-body MRI has increasingly been used as the preferred method for oncological imaging. As an excellent imaging tool, it shows high sensitivity and specificity for the detection of bone marrow lesions, much more than other modalities such as bone scintigraphy or PET-CT [1 – 4]. Suggested and commonly used standard MRI protocols included a combination of T1-weighted (T1w) spin-echo and fat suppressed short-tau inversion recovery (STIR) imaging [3, 5]. This combination has been shown to be reliable in the detection of bone marrow disorders, e. g. metastases, with a high negative and a high positive predictive value, especially for STIR imaging [2, 5 – 8].

Bone metastases lead to a signal reduction on T1w imaging by a lengthened T1 relaxation time, which contrasts to the surrounding high signal of the bone marrow fat. On STIR imaging, most marrow disorders exhibit high signal intensity, whereas the fat of bone marrow is suppressed and shows a low signal. STIR has been used to improve lesion conspicuity, but in comparison with T1w, STIR has the disadvantage of a lower signal-to-noise ratio and less detailed anatomical information.

However, there has not yet been a definitive consensus as to which MR protocol is the best for evaluating bone marrow lesions. Furthermore, it is uncertain to what degree STIR actually improves lesion detection compared with T1w. Improving MR technology implies a state-of-the-art screening method with MR sequences which are of highest yield for the detection of bone metastases. Furthermore, rapid whole-body screening and a cost-saving work-up are warranted as well.

In view of the above, we conducted the present study to determine the current clinical use of T1w and STIR images for the detection of bone metastases. Over the past decades, the combined use of T1w and STIR for bone metastasis screening has become universally adapted, especially at 1.5 T MRI [1, 6, 9 – 14]. However, to date, no prospective study of the diagnostic importance of T1w compared to STIR imaging at conventional 1.5 T and high-end 3 T has been performed with special focus on the detectability of bone metastases as an indicator of diagnostic value.

Materials and Methods

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Whole-body MRI scans of 212 patients with suspected or known bone metastases were reviewed. Patients underwent examinations at either 1.5 T, or 3 T or both MR systems between February 2010 and October 2014. MR images were obtained on a 1.5 T system until June 2012 (Philips Intera, Philips Healthcare, Eindhoven, The Netherlands) and, from July 2012 onwards, on a 3 T wide bore unit (Discovery MR750w, General Electric Healthcare, Milwaukee, USA). The exclusion criteria for the study group were: inconspicuous MR findings or bone lesions of uncertain malig-

nancy, inhomogeneous bone marrow signal not allowing a differentiation between neoplastic process and bone marrow reconversion, too many image artifacts or incomplete study protocol in case of early termination of scanning.

A routine MR scan was performed to image the whole spine, pelvis, femora, humeri, rib cage, shoulder girdle and sternum. The standardized MR protocol included T1w and STIR sequences of the spine. MR parameters for the spine at 1.5 T and 3 T are shown in ○ **Table 1.**

The final study group consisted of 86 patients (79 females, 7 males, median age ± standard deviation 64 ± 12) with evident vertebral metastases from histologically proven cancer: 78 patients with metastases from breast cancer, 4 patients from lung cancer, 3 patients from plasmocytoma, 1 patient from prostate cancer and 1 patient from a leiomyosarcoma of the uterus.

Data analysis

A lesion-by-lesion analysis between sagittal T1w and STIR images of the spine was performed by three readers in order to ensure the best possible quality and to minimize the interreader variability. First-line reading was performed by a radiology resident (2 – 4 years of experience), followed by two senior radiologists. The three readers evaluated the studies independently from each other. Then the results were discussed in consensus. The evaluation of images was carried out by reviewing the reports and images of the patients. All the numbers of vertebral metastases were calculated and summarized separately in T1w and STIR sequences as well. Qualitative evaluation of images was performed by visual assessment on a 4-point scale with regard to lesion conspicuity, lesion delineation and overall image quality. A standard of reference was established by correlation with clinical outcome (minimum follow-up, 6 months), additional imaging (dedicated MR or CT and CT during the standard diagnostic

Table 1 MRI scan protocol of the spine at 1.5 T and 3 T.

Tab. 1 MRT-Scanprotokoll der Wirbelsäule bei 1,5 T und 3 T.

	1.5 T		3 T	
	T1w	STIR	T1w	STIR
TR (ms)	400	2500	≤ 1000	3000 – 10 000
TE (ms)/TI (ms)	7.4	50/160	10	42/187
FOV (cm)	25	25	36	36
slice thickness/gap (mm)	5/0.5	5/0.5	4/0.4	4/0.4
matrix	336/252	288/216	384/224	288/224
NEX	2	2	2	3
scan time (min, s)	2.30	3.00	2.50	3.00

T1w = T1-weighted, STIR = short tau inversion recovery, TR = repetition time, TE = echo time, FOV = field of view, TI = inversion time, NEX = number of excitations

work-up including the spine or biopsy of the vertebra). In contrast to metastases, round-shaped skeletal lesions with complete signal loss in T1w and STIR images were defined as bone islands.

Statistical analysis

Number of metastases between T1w and STIR and qualitative data between both sequences were compared using a single-tailed paired Student's t-test for each reader. The Wilcoxon signed-rank test was used to calculate the interobserver variability between two readers and Kendall's W test was used among three readers. In addition, interobserver reliability was calculated also as intraclass correlations (ICC) or with Kappa statistic to determine consistency among raters (Cohen`s kappa). Sensitivity and specificity values were calculated for each sequence (with 95 % confidence interval). All analyses were performed with SPSS Statistics 16.0 and Microsoft Excel. Significance was set at $p < 0.05$.

Results
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MR images of 34 patients revealed disseminated, uncountable metastatic deposits to the spine or a diffuse vertebral infiltration. In these cases, an exact number of metastases could not be defined. Two of these patients had countable metastases on the 1.5 T examination and an uncountable status on the 3 T study after significant tumor progression in the time interval between both examinations.

In the group with disseminated infiltration, T1w and STIR subjectively showed the same amount of spine infiltration in 23 patients at 1.5 T and 3 T (○ **Fig. 1**). In 11 patients metastases were more evident on T1w than on STIR at 1.5 T and 3 T and they were depicted less well on STIR images (○ **Fig. 2**).

MR images of 54 patients revealed countable vertebral metastases in 1.5 T and/or 3 T. The number of bone metastases detected by each reader was significantly higher on images obtained with T1w than those obtained with STIR at 1.5 T and 3 T by all three readers ($p < 0.05$). The total number of confirmed lesions was 362 at 3 T and 363 at 1.5 T. The interobserver reliability was high (intraclass correlation ranging between 0.944 and 0.991, $p = 0.000$), indicating almost perfect agreement. Interobserver variability using the Wilcoxon test showed significant differences in case of some variables on 3 T indicating that readers 2 and 3 found more metastases than reader 1, which was not present on the 1.5 T platform. The results are presented in detail in ○ **Table 2, 3.**

In one patient, a solitary metastasis was seen on T1w and missed on STIR at 3 T, but was depicted in both sequences at 1.5 T (○ **Fig. 3**).

In a different case with multiple bone metastases, one lesion was not detected on T1w but was detected on STIR at 3 T. This was the only case in which T1w missed a bone lesion.

STIR was false-positive in 14 patients and 19 detected bone lesions. Confirmed lesions were hemangiomas, a vertebral venous plexus and an intraspongious disk herniation. T1w was not false-positive in any case. T1w revealed 179 additional bone metastases which were missed on STIR.

The sensitivity and specificity of the MRI sequences are shown in ○ **Table 4**. T1w and STIR showed a sensitivity of 99.72 % and 70.99 %, respectively, at 3 T, T1w achieved 100.00 % and STIR 79.34 %, respectively, at 1.5 T, indicating that T1w had a higher sensitivity than STIR on both platforms.

In 53 % (38/72) of all patients, STIR detected fewer bone metastases in comparison with T1w at 3 T and in 37.5 % (18/48) at 1.5 T (see also ○ **Fig. 4**).

Qualitative assessment was performed in all patients with bone metastases. The mean ratings for the conspicuity, the delineation of the lesions and the overall image quality were significantly higher on images obtained with T1w compared to STIR ($p < 0.05$ for all). The interrater reliability ranged between kappa = 0.444 and kappa = 0.758 (all $p < 0.05$) indicating moderate to substantial agreement. A significant difference in case of image quality in STIR at 3 T indicates that readers 2 and 3 found it to be worse compared with reader 1 (○ **Table 5**).

Discussion
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To the best of our knowledge, this is the first study to investigate the diagnostic usefulness of T1w compared to STIR at both 1.5 T and 3 T regarding the detectability of bone metastases. Concerning the results of the qualitative analysis including the detected number of metastases, T1w was more effective than STIR imaging. STIR showed a lower diagnostic yield in metastasis detection in comparison with T1w at both field strengths.

These results differ from those of former studies:

In the literature of the 90s and the turn of the millennium, a combination of T1w and STIR has been favored for the evaluation of bone marrow disorders. Studies reported STIR to be superior to T1w [2, 6 – 8] and STIR MRI has been recommended as a screening sequence, especially since it has been more accurate than other screening techniques such as bone scintigraphy [15]. As a consequence, STIR has been included in the appropriateness criteria published by the ACR in 2000 [16].

In more recent studies, the superiority of T1w compared to STIR has been emphasized: In a study in which fast Dixon-based multisequence WB MRI sequences were applied to evaluate the conspicuity of bone metastases, T1w sequence was superior to STIR [17]. In another study with breast cancer patients, T1w was of most value for the detection of bone metastases with a higher sensitivity (98 %) in comparison with STIR, DWI and PET/CT on 3 T. However, the authors concluded that the low specificity of T1w (77 %) could be increased to 95 % with the addition of STIR and DWI [3].

The aforementioned results are supported by our findings.

In our study, the identified number of metastases and the mean rating of the qualitative data (subjective lesion conspicuity, lesion delineation and the overall image quality) revealed significantly better results by all readers using the T1w sequence as compared with STIR at both field strengths. Moreover, the results for T1w sequence were similar at 3 T and 1.5 T, whereas qualitative analysis indicated inferior results for STIR at 3 T compared with 1.5 T. Explanations for these findings might be: first, the higher influence of dielectric effects, pulsation artifacts and image inhomogeneity on STIR imaging at 3 T compared to 1.5 T, as has been reported in the literature [18]. Second, the higher signal-to-noise ratio (SNR) at 3 T with a higher spatial resolution [19 – 21] might particularly affect T1w showing comparable results at 3 T and 1.5 T, but much better results than STIR at both field strengths. In addition, STIR as a low-SNR sequence remains limited in its ability to provide anatomic detail.

Our study clearly indicates that a better performance by the additional use of STIR could not be achieved. In all cases, STIR neither

Fig. 1   62-year-old female with disseminated bone metastases from breast cancer. Sagittal images through the spine are shown using T1w **a** and STIR **b** MRI at 3 T, T1w **c** and STIR **d** MRI at 1.5 T. Vertebral lesions are detected to the same extent on T1w and STIR at 3 T and 1.5 T.

Abb. 1   62-jährige Frau mit disseminierter Knochenmetastasierung bei Mammakarzinom. Dargestellt sind sagittale Bilder der Wirbelsäule mit T1w **a** und STIR **b** MRT bei 3 T, T1w **c** und STIR **d** MRT bei 1,5 T. Die Wirbelsäulenläsionen werden mit der T1w und STIR bei 3 T und 1,5 T in gleichem Maße detektiert.

provided a better differentiation of the lesions nor changed the diagnosis made by T1w imaging alone.

As an important point, in the past, STIR had an advantage as the edema-sensitive search sequence, but nowadays T1w imaging might be more useful for imaging bone metastases at higher field strengths because of a better image quality and higher metastases yield.

Fig. 2   A 73-year-old breast cancer patient with multiple vertebral lesions. The lesions are more clearly seen and more conspicuous on T1w than on STIR. Lesions were depicted to a lesser extent or not seen at all on STIR images (T1w **a**, STIR **b** at 3T; T1w **c**, STIR **d** at 1.5 T).

Abb. 2   Eine 73-jährige Brustkrebspatientin mit multiplen Wirbelsäulenläsionen. Die Läsionen sind deutlicher zu sehen und auffälliger in der T1w als in der STIR. Die Läsionen wurden auf den STIR-Bildern in einem geringeren Ausmaß abgebildet oder waren überhaupt nicht sichtbar (T1w **a**, STIR **b** at 3T; T1w **c**, STIR **d** at 1.5 T).

Table 2   Number of detected bone metastases by different readers on T1w and STIR at 3 T and 1.5 T.

Tab. 2   Anzahl detektierter Knochenmetastasen nach unterschiedlichen Readern bei T1w und STIR bei 3 T und 1.5 T.

	reader 1			reader 2			reader 3		
	T1w	STIR	p	T1w	STIR	p	T1w	STIR	p
3 T									
number of metastases	361	264	0.00	377	283	0.00	373	265	0.00
(mean ± SD)	8.02 ± 9.12	5.80 ± 6.95		8.38 ± 9.31	6.29 ± 7.41		8.29 ± 9.31	5.89 ± 6.91	
1.5 T									
number of metastases	363	300	0.00	368	287	0.00	364	285	0.00
(mean ± SD)	10.00 ± 11.94	7.77 ± 9.79		10.19 ± 11.9	7.58 ± 8.67		10.06 ± 11.9	7.51 ± 8.63	

SD indicates standard deviation, p < .05 was considered statistically significant

Fig. 3 A 63-year-old breast cancer patient with a single metastasis to the fifth lumbar vertebra. Metastasis was depicted on T1w **a** at 3 T, but not on STIR **b**. T1w **c** and STIR **d** at 1.5 T show good delineation of the metastasis.

Abb. 3 Eine 63-jährige Mammakarzinompatientin mit einer solitären Metastase im fünften Lendenwirbelkörper. Die Metastase stellt sich in der T1w dar **a** bei 3 T, nicht aber in der STIR **b**. T1w **c** und STIR **d** bei 1,5 T zeigten eine klare Abgrenzung der Metastase.

Table 3 Interobserver variability in the detection of metastases on T1w and STIR at 3 T and 1.5 T.

Tab. 3 Interobserver Variabilitäten in der Metastasendetektion bei T1w und STIR bei 3 T und 1.5 T.

sequence	Z-score and p-value between raters (Wilcoxon) 1 and 2	Z-score and p-value between raters (Wilcoxon) 2 and 3	Z-score and p-value between raters (Wilcoxon) 1 and 3	Kendall's W among 3 raters with p-value (Kendall's W test)
interobserver variability at 3 T				
T1w	Z = −2.645 p = 0.008	Z = −1.265 p = 0.206	Z = −2.762 p = 0.006	W = 0.124 p = 0.004
STIR	Z = −2.200 p = 0.028	Z = −2.496 p = 0.013	Z = −1.213 p = 0.225	W = 0.060 p = 0.071
interobserver variability at 1.5 T				
T1w	Z = −1.200 p = 0.230	Z = −1.300 p = 0.194	Z = −0.816 p = 0.414	W = 0.032 p = 0.353
STIR	Z = −0.226 p = 0.821	Z = −0.816 p = 0.414	Z = −0.241 p = 0.809	W = 0.004 p = 0.889

Table 4 Sensitivity and specificity of T1w and STIR for the detection of bone metastases of the spine at 3 T and 1.5 T.

Tab. 4 Sensitivität und Spezifität für T1w und STIR in der Detektion von Knochenmetastasen der Wirbelsäule bei 3 T und 1.5 T.

sequence	sensitivity (%)	specificity (%)
3 T		
T1w	99.72	100
STIR	70.99	89.55
1.5 T		
T1w	100	100
STIR	79.34	74.47

In addition to the above-mentioned drawbacks of STIR, another disadvantage is its longer acquisition time compared to T1w. An optimal MR protocol should not only focus on high-yield MR sequences, but it should also been performed within an acceptable scan time to improve patient throughput and department productivity.

It should be noted that it is not clear to which degree post-therapeutic effects of irradiation or chemotherapy influenced the detectability of the lesions on T1w and STIR imaging. It is known that treatment induces edema, return of marrow fat, sclerosis or fibrosis [22], resulting in MR signal changes of the bone marrow which are time- and dose-dependent [23]. While T1w reflects marrow replacement and is rather independent of associated sclerosis, STIR reflects more the lesion composition (water content, fibrosis and sclerosis) and shows variable signal [24, 25].

Fig. 4 A 65-year-old woman with extensive metastatic breast cancer. At 3 T, T1w **a** shows an increased number of skeletal metastatic deposits and better image quality than STIR **b**. At 1.5 T, metastases are equal in extent on T1w **c** and STIR images **d**.

Abb. 4 Eine 65-jährige Frau mit ausgedehnter Brustkrebsmetastasierung. Bei 3 T zeigt T1w **a** eine größere Anzahl an Skelettmetastasen und eine bessere Bildqualität als die STIR **b**. Bei 1,5 T sind die Metastasen gleichermaßen auf den T1w- **c** und STIR-Bildern **d** vorhanden.

Table 5 Qualitative assessment criteria on a 4-point scale for T1w versus STIR at 3 T and 1.5 T: 1 (not diagnostic), 2 (poor), 3 (good), 4 (optimal).

Tab. 5 Qualitative Bewertungskriterien anhand einer 4-Punkt-Skala für T1w und STIR bei 3 T und 1.5 T: 1 (nicht diagnostisch), 2 (schwach), 3 (gut), 4 (optimal).

	lesion conspicuity			lesion delineation			overall image quality		
sequence	mean ± SD	p	interrater varia-bility (Kendall's W test)	mean ± SD	p	interrater varia-bility (Kendall's W test)	mean ± SD	p	interrater varia-bility (Kendall's W test)
3 T									
T1w	3.66 ± 0.46	0.002	W = 0.044 p = 0.157	3.34 ± 0.63	0.000	W = 0.007 p = 0.564	3.46 ± 0.48	0.000	W = 0.022 p = 0.317
STIR	2.86 ± 0.97		W = 0.07 p = 0.564	2.39 ± 0.82		W = 0.067 p = 0.083	2.20 ± 0.67		W = 0.133 p = 0.014
1.5 T									
T1w	3.67 ± 0.52	0.026	W = 0.028 p = 0.317	3.33 ± 0.62	0.000	W = 0.028 p = 0.317	3.52 ± 0.54	0.000	W = 0.000 p = 1.000
STIR	3.14 ± 0.94		W = 0.028 p = 0.317	2.63 ± 0.8		W = 0.111 p = 0.046	3.08 ± 0.54		W = 0.028 p = 0.317

Furthermore, all cases without definite bone marrow changes and with unclear differential diagnosis (e.g. metastases versus hematopoietic red marrow) were excluded from the study. This may possibly affect our study results as well.

In conclusion, our data suggest that the exclusive use of T1w MRI, especially at 3 T, represents a safe and sufficient method for the detection of bone metastases in adults. The combination of T1w and STIR was not more accurate than T1w imaging alone. As a consequence, additional STIR imaging might be redundant in the assessment of skeletal metastases. If osseous lesions remain unclear, for example in case of very inhomogeneous bone marrow, additional pulse sequences, e.g. contrast-enhanced T1w, may still be added.

These initial results will have a major impact on the department's workflow if confirmed by larger studies and help to save financial resources as well.

Clinical relevance of this study

1. As a rule, a new oncological state-of-the-art MR protocol limited to T1w is as effective as a combined T1w and STIR protocol, especially at the increasingly used higher magnetic field strengths (3 T).
2. By confining the MR protocol to T1w, examination and reporting times can be significantly reduced.
3. In times of economic constraints, cost-efficient MRI is warranted, without impairing the diagnostic accuracy.

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