Neuroradiology (2001) 43: 254–258

M. Knauth
C. R. Wirtz
N. Aras
K. Sartor

Low-field interventional MRI in neurosurgery: finding the right dose of contrast medium

Received: 14 September 1999
Accepted: 15 February 2000

M. Knauth (✉) · N. Aras · K. Sartor
Department of Neuroradiology,
University of Heidelberg Medical School,
Im Neuenheimer Feld 400,
69120 Heidelberg, Germany
e-mail: Michael_Knauth@med.uni-heidelberg.de
Tel.: + 49-6221-567566
Fax: + 49-6221-564673

C.R. Wirtz
Department of Neurosurgery,
University of Heidelberg Medical School,
Im Neuenheimer Feld 400,
69120 Heidelberg, Germany

Abstract MRI is increasingly being used as an interventional tool in neurosurgery. The field strength of "intraoperative" MR systems is usually lower than that of imagers commonly used for diagnostic purposes. However, lesion enhancement and apparent lesion extent depend on field strength. The aim of this study was to compare the contrast between intracranial, contrast-enhancing space-occupying lesions and the surrounding white matter obtained with low-field (0.2 T) and high-field (1.5 T) MR imaging and to find the contrast medium dosage for low-field MRI that produces the same lesion-to-white-matter contrast as the one obtained with high-field MRI after the administration of a standard dose of the contrast medium. A total of 38 patients with intracranial metastases or high-grade glioma were enrolled in this study. T1-weighted spin-echo sequences were acquired. High-field (1.5 T) studies were performed after the i.v. administration of 0.1 mmol gadolinium-DTPA /kg body weight. For low-field MRI (0.2 T) a dose escalation technique was used. T1-weighted sequences were repeated after each of three i.v. injections of 0.1 mmol gadolinium-DTPA/kg body weight. Thus, at the low-field examinations three T1-weighted sequences with a contrast medium dosage of 0.1, 0.2 and 0.3 mmol gadolinium-DTPA /kg body weight were obtained. Lesion-to-white-matter contrasts were calculated and compared. The average lesion-to-white-matter contrast obtained with high-field MR examinations was 1.63 (standard deviation 0.32). In the low-field MR examinations the average lesion-to-white-matter contrast was 1.34 (0.2) after a single dose, 1.57 (0.2) after a double dose, and 1.71 (.19) after a triple dose of contrast medium. The lesion-to-white-matter contrast of the high-field MR examination after a single dose of contrast medium was significantly higher than that of the low-field study after a single dose ($P < 0.0001$), but did not differ significantly from the low-field studies after a double ($P = 0.28$) or a triple dose ($P = 0.17$) of contrast medium. In a series of patients with contrast-enhancing space occupying brain lesions low-field MRI (0.2 T) after a double dose of contrast medium yielded the same lesion-to-white-matter contrasts as high-field MRI (1.5 T) after a standard dose. This is an important finding to avoid errors in intraoperative MRI due to the immanently lower degree of lesion enhancement in low-field MR imaging.

Key words Magnetic resonance imaging · Contrast media · Neurosurgery

Introduction

MRI is increasingly being used in neurosurgical interventions. In the recent past different concepts for the intraoperative use of this valuable imaging modality have been developed [1, 2, 3, 4, 5]. At present MR imagers with a field strength of either 0.2 T [2, 4, 5] or 0.5 T [1, 3] are commonly being used.

Currently, there are three main indications for intraoperative MRI: stereotactic procedures (e. g. biopsies, cyst drainage) under MRI guidance; MRI monitoring of interstitial therapy (e. g., laser-induced thermal therapy, cryotherapy); and assessment of the completeness of removal of brain tumours. However, use of MRI for these indications is based on the premise that the appearance and extent of the lesion on intraoperative images on low-field imagers is the same as that on diagnostic MRI, for which a high field is commonly used. This is especially critical for the third of these indications, as assessment of the extent of tumour removal may depend on similar demonstration of the margins of a contrast-enhancing tumour.

Image contrast and contrast enhancement depend on field strength [6]. However, previous studies have compared image contrast and intracranial lesion enhancement at 0.5 T and 1.5 T [7, 8] or 2.0 T [9] or used a low field (0.2 T), but focussed on regions other than the central nervous system [10, 11, 12].

Our aim study was to compare the contrast between intracranial contrast-enhancing space-occupying lesions and surrounding white matter (lesion-to-white-matter contrast) at with low (0.2 T) and high (1.5 T) fields and to find the dose of contrast medium for low-field MRI which produces lesion-to-white-matter contrast not significantly different from given by a standard dose of gadolinium-DTPA (0.1 mmol Gd-DTPA/kg body weight) at a high field.

Materials and methods

We studied 38 patients, 15 women and 23 men, mean age 56.3 ± 12.5 years (range 27–75 years). The histologically proven diagnoses were metastases in eight patients and high-grade glioma in 30. Informed consent was obtained from each patient and the study was approved by the local ethics committee.

High- and low-field examinations were performed at 1.5 and 0.2 T, respectively. T1-weighted spin-echo images were acquired with repetition time 674 ms and echo time 20 ms, slice thickness 6 mm, field of view 200–250 mm, and matrix 192 × 256, and three excitations for the low- and two for the high-field studies (this difference does not affect lesion-to-white-matter contrast). All sections were aligned parallel to the intercommissural line for optimum comparability.

High-field studies were performed 5 min after intravenous administration of 0.1 mmol gadolinium-DTPA/kg body weight. For the low-field examinations a dose escalation technique was used: T1-weighted sequences were repeated after each of three intravenous injections of 0.1 mmol/kg body weight, giving three sets of T1-weighted images doses of contrast medium of 0.1, 0.2 and 0.3 mmol/kg body weight.

The signal intensity of the lesion and normal white matter were measured (in the arbitrary units on the manufacturer's console) in identical regions of interest (ROI), minimum size 10 pixels, in each of the four studies. In the cases of multiple metastases or multicentric glioma only one contrast-enhancing lesion was measured to ensure that each patient contributed equally to the statistical evaluation. Lesion-to-white-matter contrast was calculated. Paired, two-tailed Student's *t*-tests were performed for each pair of studies; a P value less than 0.05 was considered significant.

Results

The average lesion-to-white-matter contrast at high field was 1.63 (SD 0.32), and at the low field it was 1.34 (0.20) after a single, 1.57 (0.20) after a double, and 1.71 (0.19) after a triple dose of contrast medium. At the low field, each increase in dose of contrast medium led

Table 1 Lesion-to-white-matter contrasts at different field strengths and contrast medium doses

Lesion-to-white-matter contrast (SD)	1.5 T	0.2 T		
	0.1 mmol/kg	0.1 mmol/kg	0.2 mmol/kg	0.3 mmol/kg
All 38 patients	1.63 (0.32)	1.34 (0.20)	1.57 (0.20)	1.71 (0.19)
Eight patients with metastases	1.74 (0.37)	1.44 (0.21)	1.67 (0.21)	1.76 (0.17)
Thirty patients with high-grade glioma	1.6 (0.30)	1.31 (0.19)	1.55 (0.20)	1.69 (0.19)

Table 2 Summary of statistical results for all 38 patients. The lower left part of the table shows which field strength/contrast medium dose combination yielded the higher lesion-to-white-matter contrast; the upper right part gives the level of significance (Student's *t*-test)

	1.5 T	0.2 T		
	0.1 mmol/kg	0.1 mmol/kg	0.2 mmol/kg	0.3 mmol/kg
1.5 T; 0.1 mmol/kg		< 0.0001	0.28	0.17
0.2 T; 0.1 mmol/kg	<		< 0.0001	< 0.0001
0.2 T; 0.2 mmol/kg	=	>		< 0.0001
0.2 T; 0.3 mmol/kg	=	>	>	

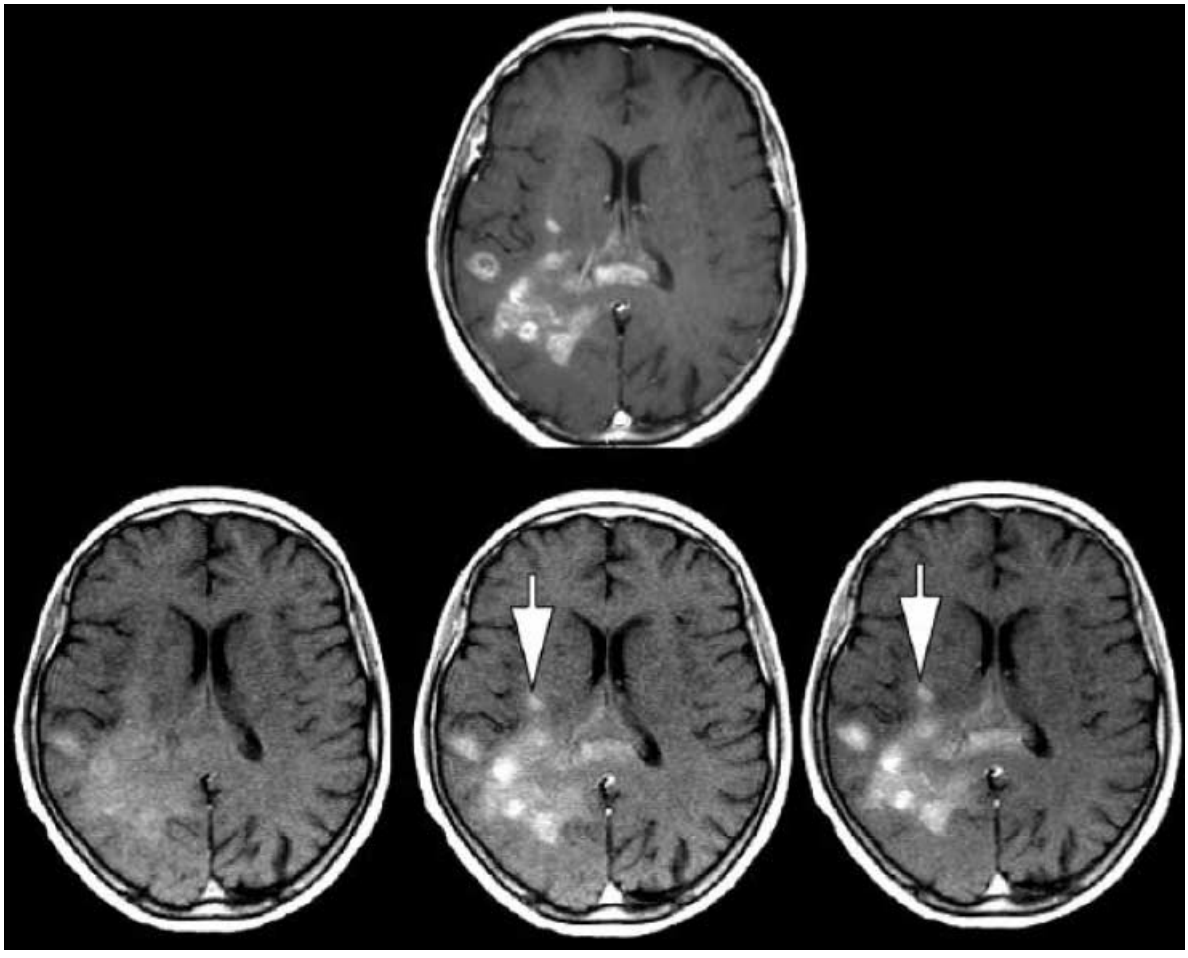

Fig. 1 A 69-year-old woman with a right-hemispheric glioblastoma multiforme involving the splenium of the corpus callosum. *Top* A T1-weighted image obtained at 1.5 T (0.1 mmol gadolinium-DTPA/kg body weight). *Bottom* T1-weighted images obtained at 0.2 T after *left* 0.1, *middle* 0.2 and *right* 0.3 mmol gadolinium-DTPA/kg body weight. At the lower field, parts of the tumour *(arrows)* are seen to enhance only after the double or triple dose

to significantly higher lesion-to-white-matter contrast ($P < 0.0001$). After a single dose, contrast was significantly higher at the high-field than at the low field ($P < 0.0001$), but did not differ significantly between the high- and low-field studies after the double ($P = 0.28$) or triple ($P = 0.17$) dose (Tables 1, 2). Figs. 1 and 2 compare T1-weighted images at the high field imager after a standard dose of contrast medium with those at the different doses at the low field. In our statistical evaluation we included both patients with gliomas and with metastases. When the two groups were assessed separately, the results were almost identical (Table 1), although the levels of significance were lower, because of the smaller number of cases.

Discussion

For a given dose of contrast medium, lesion-to-white-matter contrast was significantly lower at the lower field (other parameters, except the number of excitations, being kept constant); this is neither surprising nor new [7;9].

Elster [6] worked out the physics underlying this phenomenon: The change in tissue relaxation rate and thus contrast enhancement, is proportional to the concentration of the contrast medium and inversely proportional to its to the relaxation rate of the tissue prior to its administration. Relaxivity of both the contrast medium and the tissue is a function of field strength. The functions are both nonlinear and nonintuitive [6], and the tissue concentration of the contrast medium is not known. Therefore, there is practically no way of calculating the dose of contrast medium which gives the same lesion-to-white-matter contrast at high and low fields after of a standard dose.

Previous studies have either compared image contrast and intracranial tumour enhancement at 0.5 T and high fields [7, 8, 9] or lesion enhancement in low

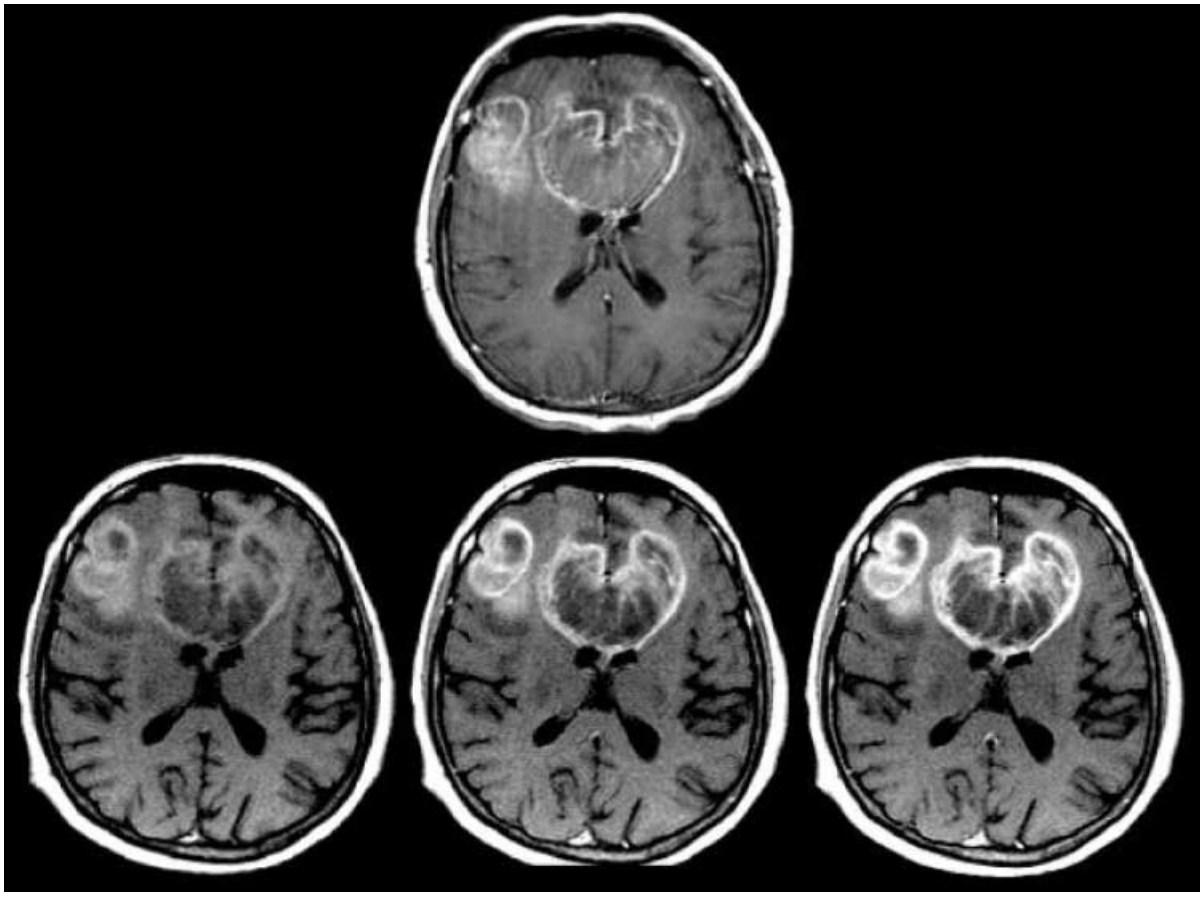

Fig. 2 A 61-year-old woman with a bifrontal glioblastoma multiforme involving the rostrum of the corpus callosum. Images as in Fig. 1: at the lower field, the full extent of the tumour can seen only after the double or triple dose of contrast medium

(0.2 T) and high fields in other parts of the body [10, 11, 12]. In our study, there were no significant differences in lesion-to-white-matter contrasts between low-field MR examinations after a double dose of contrast medium and high-field MR examinations after a standard dose. This finding is valid for both patients with intraparenchymal metastases or high-grade glioma. It is reasonable to assume, but scientifically not proven, that this finding can be transferred to other intracranial enhancing tumor entities.

Prompted by our results, we use a double dose of contrast medium to perform intraoperative MRI in patients with contrast-enhancing intraparenchymal tumours of the central nervous system [2] and strongly recommend this approach. The danger of using a standard dose of contrast medium at low field is obvious: because of the lower lesion-to-white-matter contrast, the more weakly enhancing parts of a tumour might not be detected and therefore erroneously not resected.

Acknowledgements We thank the MRI technicians, Bettina Bittmann and Sabine Unterwaldt, for their collaboration.

References

1. Black PM, Moriarty T, Alexander E, Stieg P, Woodard EJ, Gleason PL, Martin CH, Kikinis R, Schwartz RB, Jolesz FA (1997) Development and implementation of intraoperative magnetic resonance imaging and its neurosurgical applications. Neurosurgery 41: 831–842
2. Knauth M, Wirtz CR, Tronnier VM, Staubert A, Kunze S, Sartor K (1998) Intraoperative magnetic resonance tomography for control of extent of neurosurgical operations. Radiologe 38: 218–224
3. Dietrich J, Schneider JP, Schulz T, Seifert V, Trantakis C, Kellermann S (1998) Intraoperative appearance of the resection area in brain-tumor operations in an open 0.5 MRT. Radiologe 38: 935–942

4. Tronnier VM, Wirtz CR, Knauth M, Lenz G, Pastyr O, Bonsanto MM, Albert FK, Kuth R, Staubert A, Schlegel W, Sartor K, Kunze S (1997) Intraoperative diagnostic and interventional magnetic resonance imaging in neurosurgery. Neurosurgery 40: 891–900
5. Steinmeier R, Fahlbusch R, Ganslandt O, Nimsky C, Buchfelder M, Kaus M, Heigl T, Lenz G, Kuth R, Huk W (1998) Intraoperative magnetic resonance imaging with the Magnetom open imager: concepts, neurosurgical indications, and procedures: a preliminary report. Neurosurgery 43: 739–747
6. Elster AD (1997) How much contrast is enough?. Dependence of enhancement on field strength and MR pulse sequence. Eur Radiol 5: 276–280
7. Lindsey RO, Yetkin FZ, Prost R, Haughton VM (1994) Effect of dose and field strength on enhancement with paramagnetic contrast media. AJNR 15: 1849–1852
8. Lee DH, Vellet AD, Eliasziw M, Vidito L, Ebers GC, Rice GP, Hewett L, Dunlavy S (1995) MR imaging field strength: prospective evaluation of the diagnostic accuracy of MR for diagnosis of multiple sclerosis at 0.5 and 1.5 T. Radiology 194: 257–262
9. Chang KH, Ra DG, Han MH, Cha SH, Kim HD, Han MC (1994) Contrast enhancement of brain tumors at different MR field strengths: comparison of 0.5 T and 2.0 T. AJNR 15: 1413–1419
10. Kersting-Sommerhoff B, Gerhardt P, Golder W, Hof N, Riel KA, Helmberger H, Lenz M, Lehner K (1995) MRT des Kniegelenks: erste Ergebnisse eines Vergleichs von 0,2-T-Spezialsystem mit 1,5-T-Hochfeldmagnet. Rofo Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr 162: 390–395
11. Hittmair K, Turetschek K, Gomiscek G, Stiglbauer R, Schurawitzki H (1996) Field strength dependence of MRI contrast enhancement: phantom measurements and application to dynamic breast imaging. Br J Radiol 69: 215–220
12. Gehl HB, Lorch H, Amblank OB, Engerhoff B, Weiss HD (1998) Comparative magnetic resonance imaging of renal space-occupying lesions with a high and low field MRI system. Rofo Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr 169: 484–489