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Susceptibility-weighted imaging at 7 T: Improved diagnosis of cerebral cavernous malformations and associated developmental venous anomalies☆

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ABSTRACT

Background and aim: In the diagnosis of cerebral cavernous malformations (CCMs) magnetic resonance imaging is established as the gold standard. Conventional MRI techniques have their drawbacks in the diagnosis of CCMs and associated venous malformations (DVAs). The aim of our study was to evaluate susceptibility weighted imaging SWI for the detection of CCM and associated DVAs at 7 T in comparison with 3 T.
Patients and methods: 24 patients (14 female, 10 male; median age: 38.3 y (21.1 y–69.1 y) were included in the study. Patients enrolled in the study received a 3 T and a 7 T MRI on the same day. The following sequences were applied on both field strengths: a T1 weighted 3D GRE sequence (MP-RAGE) and a SWI sequence. After obtaining the study MRIs, eleven patients underwent surgery and 13 patients were followed conservatively or were treated radio-surgically.
Results: Patients initially presented with haemorrhage (n = 4, 16.7%), seizures (n = 2, 8.3%) or other neurology (n = 18, 75.0%). For surgical resected lesions histopathological findings verified the diagnosis of CCMs. A significantly higher number of CCMs was diagnosed at 7 T SWI sequences compared with 3 T SWI ($p<0.05$). Additionally diagnosed lesions on 7 T MRI were significantly smaller compared to the initial lesions on 3 T MRIs ($p<0.001$). Further, more associated DVAs were diagnosed at 7 T MRI compared to 3 T MRI.
Conclusion: SWI sequences at ultra-high-field MRI improve the diagnosis of CCMs and associated DVAs and therefore add important pre-operative information.

1. Introduction

Cerebral cavernous malformations (CCM) are a heterogeneous group of lesions mostly described as a mulberry like assembly of vascular sinusoids with varying vessel diameter and wall thickness, lined by a thin endothelium lacking smooth muscle and elastin, surrounded by hemosiderin deposits and gliosis (Frischer et al., 2008; Raychaudhuri et al., 2005).

In the diagnosis of CCM magnetic resonance imaging has proven to be the gold standard. However, conventional MRI techniques also have their drawbacks. If CCM lesions are intact and have not bled, they may be almost invisible except for a faint or ill-defined non-specific blush of enhancement after contrast administration. In addition, the lack of flow-related signal intensity makes CCMs undetectable on conventional MR angiographic techniques (Bertalanffy et al., 2002; Tsui et al., 2009).

It is of further importance that according to the pertinent literature an average of 13–30% of cavernomas are associated with venous malformations (Bertalanffy et al., 2002; Porter et al., 1999). However, several studies showed that the prevalence of cavernomas associated with DVAs is underestimated using routine MRI and that small venous malformations are only diagnosed during surgery (Bertalanffy et al., 2002; Kamezawa et al., 2005; Porter et al., 1999; Wurm et al., 2007). Moreover, it has been described that CCMs with associated venous anomalies present with a higher risk of clinically significant

Abbreviations: CCMs, cerebral cavernous malformations; DVA, developmental venous malformation; SWI, susceptibility weighted imaging.

☆ Preliminary data were presented at the EANS conference Rome, Italy October 2011 with an 8 minute oral presentation by J.M. Frischer.

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haemorrhage (Bertalanffy et al., 2002; Porter et al., 1999; Wurm et al., 2007).

The field of magnetic resonance imaging has experienced huge developments in recent years. This especially holds true for a technique formerly known as MR venography. Susceptibility-weighted imaging sequences are highly sensitive for paramagnetic blood degradation products such as desoxyhemoglobin and hemosiderin and enable the exact visualisation even of small vessels. In contrast to conventional MRI sequences that rely on the reading of magnitude information, SWI uses additional phase data. In summary, susceptibility-weighted imaging is a high-spatial resolution, three-dimensional, gradient-echo technique. SWI offers information about any tissue that has a different susceptibility than its surrounding structures such as deoxygenated blood, hemosiderin, ferritin, and calcium. The higher the magnetic field, the higher this susceptibility effect and thus the better the SWI image of e.g. small cerebral white matter veins. This is caused by a higher sensitivity for phase effects, a higher signal to noise ratio and a higher resolution (Haacke et al., 2004, 2009; Ladd, 2007; Mittal et al., 2009).

How or if those effects on ultra-high-field imaging improve the diagnosis of various cerebral pathologies has yet to be evaluated. Few recent studies provide initial data that ultra-high-field magnetic resonance imaging at 7 T improves the detection of cerebral cavernous malformations when compared to 1.5 T (Dammann et al., 2010; Novak et al., 2003; Schlamann et al., 2010). Our study therefore aims to evaluate SWI sequences at 7 T for the detection of CCM and associated DVAs in comparison with SWI at 3 T for the first time in a larger series of CCM patients.

2. Patients and methods

2.1. Sample characterisation and ethical approval

Before commencement of the study, ethical approval was granted by the ethics commission of the Medical University of Vienna. All patients admitted to the Department of Neurosurgery of the Medical University of Vienna between March 2010 and June 2011 with the diagnosis of a cerebral cavernous malformation on the initial routine MRI were screened for this study. Patients therefore presented with lesions on their initial routine MRIs resembling popcorn like structures and were hypointense on T2 weighted images and negative on MR-angiography. Signs of intra- or extralesional haemorrhages (hyperintense on T2 weighted and T1 weighted imaging if in the subacute stage) were additionally observed. Inclusion criteria were applied as follows: no prior therapy of the lesions, above 18 years of age, exclusion of pregnancy, exclusion of an allergy to the contrast medium, exclusion of further contraindications for MRI (cardiac pacemaker, metallic cardiac valves, surgical clips, implanted electrical infusion pump, tattoos, piercing, etc.), normal current creatinine level (prevention of nephrogenic systemic fibrosis), exclusion of claustrophobia.

Clinical data were recorded accordingly: age, sex, presenting symptoms, localisation of initial diagnostic lesion(s). After informed consent patients underwent their 3 T and 7 T study MRIs on the same day. Twenty-four patients (14 female, 10 male) with a median age of 38.3 years (21.1 y–69.1 y) were thus included in the study. After obtaining the study MRIs, patients were treated according to the state of the art treatment plan of the Department of Neurosurgery. Thus, 11 patients underwent surgery of their clinically significant lesions, 12 patients were followed conservatively and 1 patient underwent radio-surgery. For all surgical patients the diagnosis of a CCM could be proven histo-pathologically.

2.2. MRI specifics

Routine MRI sequences were a heterogeneous group of 1.5 T and 3 T sequences but in all cases including T2 weighted sequences and T1 weighted sequences with and without contrast enhancement. Still, the routine MRI sequences were only used to include patients in the presented study. In order to directly compare SWI at 3 T and at 7 T for the detection of CCMs, patients were evaluated with our standardised study protocol. Patients underwent a 3 T and a 7 T MRI on the same day. All patients were examined on a 7 T system (Magnetom, Siemens, Erlangen, Germany) using a 32 channel RF coil (Nova Medical, Wilmington, USA). T1-weighted data were acquired using an MP-RAGE sequence. Afterwards a three-dimensional, fully first-order flow-compensated gradient-echo SWI sequence was performed. The same protocol including an MP-RAGE and SWI was performed on a 3 T MR system (Tim Trio, Siemens, Erlangen, Germany). For detailed MR sequence parameters see Table 1.

2.3. Data evaluation

MRI evaluation was performed by a senior radiologist (S.T.) and a junior radiologist (S.G.) in consensus blinded to clinical and initial diagnostic data as has been described before (Pinker et al., 2007). A third co-worker entered the data into the clinical database (J.M.F.). The number of detected lesions on 3 T and 7 T SWI sequences as stated above was recorded. Additionally, the diagnosis of associated venous anomalies was made. Lesion specifics such as localisation and volume were also recorded. For all patients of the surgical group the diagnosis of a CCM could be proven histo-pathologically. The diagnosis of associated venous malformations was also evaluated intraoperatively for all patients of the surgical group. Artefacts on 7 T scans were rated accordingly: none/minor, present but evaluation possible, major evaluation hardly possible. Lesion volume was evaluated on 7 T scans for all lesions in order to enable comparison of lesions. Lesion volume was calculated by using the following formula: $A \times B \times C/2$. (A) is the largest diameter and (B) is the perpendicular diameter of lesion. (C) was obtained by summing up the thicknesses of the slices where the lesion was visible (Pantano et al., 1999).

2.4. Statistical analysis

The presented study was prospectively designed. A prospective cohort study, more accurate a comparative study (3 T vs. 7 T) was applied. Due to the grouping of patients after the state of the art treatment plan, the study was not randomised. Patients' data were administered in an anonymous database. Due to the uneven distribution of our data, statistical analysis was performed with nonparametric tests. Descriptive analysis included median value and range as well as number and percentage. Statistical calculations included Wilcoxon test and McNemar test for paired samples as well as Mann–Whitney test. p-Values<0.05 were considered statistically significant. SPSS

Table 1
MRI specifics.

	7 T	3 T
T1 MP-RAGE:		
Image matrix	320×320	320×308
Resolution	0.7 mm isotropic	0.8 mm isotropic
Slices	208	192
Parallel imaging factor	2	2
TR/TI/TE	3800/1700/3.55 ms	2190/1300/3.02 ms
Acquisition time	7:30 min	11:16 min
SWI sequence:		
TE	15 ms	29 ms
TR	28 ms	42 ms
Image-matrix	704×704 pixels	384×384 pixels
Slices	96	88
Parallel imaging factor	2	2
Acquisition time	10.18 min	11:03 min
Resolution	0.3×0.3×1.2 mm	0.6×0.6×1.5 mm

Table 1 shows detailed MRI specifics for the 7 T and 3 T study images.