Acute Stroke Imaging:

Feasibility and Value of MR Angiography with High Spatial and Temporal Resolution for Vessel Assessment and Perfusion Analysis in Patients with Wake-up Stroke

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Rationale and Objectives: Magnetic resonance (MR) imaging (MRI) provides information that can be used to estimate the symptom onset in patients with wake-up stroke (WUS). Time-resolved MR angiography (MRA) is the fastest available MR sequence technique for vessel assessment, and the different phases acquired can provide information about cerebral perfusion. The aim of this study was to evaluate the diagnostic performance of time-resolved MRA both for the assessment of vessel morphology and for the feasibility of perfusion.

Materials and Methods: Nineteen patients with WUS were included. Image quality and vessel pathologies were evaluated and correlated to time-of-flight–MRA ($n = 14$), computed tomography–angiography ($n = 4$), sonography ($n = 12$), and conventional angiography ($n = 6$). The temporal delay of signal enhancement in all pixels of the time-resolved MRA measurement after contrast injection was evaluated and compared to dynamic susceptibility contrast-enhanced (DSC) perfusion imaging ($n = 13$).

Results: Time-resolved MRA resulted in the diagnosis of large vessel disease in 14 of 19 patients, involving the internal carotids ($n = 4$), the vertebral arteries ($n = 3$), and the circle of Willis ($n = 10$). All severe vascular pathologies which influence patients' acute stroke therapy were obtained by time-resolved MRA. Overestimation of stenoses in two of 14 patients resulted in sensitivity and specificity of 100% and 71%, respectively. Time-to-peak (TTP) estimations were hampered by movement artifacts in four patients (31%). Compared to DSC, the area of TTP delay was comparable in size and localization without relevant overestimation or underestimation.

Conclusions: Time-resolved MRA is a valuable technique in patients with WUS with high sensitivity and high negative predictive value. Cerebral perfusion estimation can be performed in selected cases for therapy decision but can be hampered by patient movement.

Key Words: MRA; time-resolved MRA; wake-up stroke; thrombolysis; MR perfusion.

Noncontrast brain computed tomography (CT) is considered the first line of imaging in patients with suspected acute stroke because of its broad availability and acquisition speed. Because intravenous tissue plasminogen activator (tPA) is the most important therapy for acute ischemic stroke, any contraindications—notably intracranial hemorrhage—have to be ruled out as fast as possible before starting thrombolytic therapy. Noncontrast CT is often combined with CT-angiography (CTA) and CT-perfusion (CTP) imaging to evaluate the underlying stroke cause. Recent technological advances have contributed to more widespread use of new neuroimaging modalities and strategies such as diffusion-weighted (DWI) magnetic resonance (MR) imaging (MRI), cerebral perfusion imaging, and MR angiography. Although DWI is only available in MRI, perfusion imaging and angiography are available in both CT and MRI, which can be beneficial to patient evaluation and management in special cases. MRI is more sensitive than CT for the detection of early infarction, small infarcts, and those in the brain stem and posterior fossa (1).

In some instances, MRI may be the first imaging test performed, for example, in patients with unknown symptom onset, such as patients with wake-up stroke (WUS). Patients with WUS have often been excluded from thrombolysis because of the unknown time of symptom onset. However, stroke severity is similar in both patient groups, and it has been reported that patients with WUS may benefit from thrombolysis (2). In WUS, comprehensive stroke evaluation is more important as tPA is still under evaluation in this setting.

The fluid attenuated inversion recovery (FLAIR) signal provides information that can be used to estimate the age of the stroke. Diffusion restriction without FLAIR hyperintensity indicates with a high positive predictive value (PPV) that the delay between stroke onset and MRI is <4.5 hours (3). Many groups therefore proposed to differentiate between

Acad Radiol 2015; 22:413–422

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http://dx.doi.org/10.1016/j.acra.2014.11.013

hyperacute stroke (<4.5 hours) and acute stroke >4.5 hours using the DWI–FLAIR mismatch which describes a lesion with a DWI hypersignal and an absence of FLAIR hypersignal (3,4). The time from onset of the symptoms to initiation of therapy is a major factor, as intra-arterial thrombectomy has longer window periods for treatment compared to intravenous thrombolysis (5,6). Interventionalists also look for thrombus in the carotid arteries and proximal intracranial vessels when considering intra-arterial therapy, and a very fast MR protocol is required for making the individual therapy decision in selected cases.

The fastest MR sequence technique for assessing extracranial and intracranial vessels is time-resolved MR angiography (MRA); it is therefore proposed for the assessment of vascular disease in patients with acute stroke by some groups (7). It can easily be planned and enables the assessment of both extracranial and intracranial vessels in <90 seconds (7) without the need for accurate contrast timing. In theory, the original data of time-resolved MRA can also provide information about tissue perfusion (8), and several parameters, such as time-to-peak (TTP) estimations, can be extracted (9).

To our knowledge, there are no studies that analyze the feasibility and clinical value of time-resolved MRA in patients with acute stroke. The aim of this study was to evaluate the diagnostic performance of time-resolved MRA both for the assessment of pathologies in the extracranial and intracranial vessels and for the feasibility and reliability of perfusion information calculated from time-resolved MRA source data. Based on this information, the feasibility of an ultrafast MR stroke protocol should be assessed.

MATERIALS AND METHODS

Patient Population

In this retrospective study, 61 clinically indicated MR examinations of patients with symptoms of WUS between October 2011 and March 2014 were screened. Inclusion criteria for study evaluation were signs of acute stroke with unknown time of onset. Among these, 19 patients were examined with a protocol including time-resolved MRA. The decision to perform MRI and time-resolved MRA was made individually by an interdisciplinary team consisting of at least one neurologist and an interventional neuroradiologist to allow intravenous thrombolysis therapy or local thrombectomy/thrombolysis as fast as possible. The 42 excluded examinations were either performed without contrast application (eg, when the therapy decision was made after FLAIR and DWI imaging) or when other MRA techniques were performed, for example, conventional contrast-enhanced MRA. Figure 1 shows the diagnostic approach and applied sequences as well as the scan duration of MRI in patients with WUS in our institution. All patients gave their informed consent, and the institutional review board approved the study design.

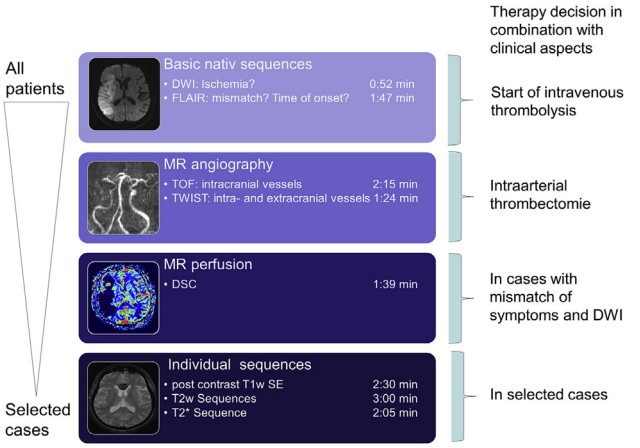

Figure 1. Diagnostic approach and applied sequences as well as the scan duration of magnetic resonance (MR) imaging in patients with wake-up stroke in our institution. All 62 screened patients underwent the basic diffusion-weighted imaging and fluid attenuated inversion recovery sequences, whereas time-resolved MR angiography was performed in the 19 included patients (inclusion criteria). Additionally available sequences in the included patients were time-of-flight (n = 14) and dynamic susceptibility contrast-enhanced image (n = 13). DSC, dynamic susceptibility contrast-enhanced image; DWI, diffusion-weighted imaging; FLAIR, fluid attenuated inversion recovery; MR, magnetic resonance; TOF, time-of-flight; T1w SE, T1-weighted spin echo; T2w, T2-weighted; TWIST, time-resolved magnetic resonance angiography with interleaved stochastic trajectories.

Imaging Protocol

MRI was performed on a 1.5-T scanner (MAGNETOM Aera or Avanto, Siemens, Erlangen, Germany) using a 12-channel head matrix coil. All the 19 included patients underwent the basic DWI, FLAIR, and time-resolved MRA sequences. Additionally available sequences in the included patients were time-of-flight (TOF; n = 14), dynamic susceptibility contrast-enhanced (DSC) imaging (n = 13), CTA (n = 4), and digital subtraction angiography (DSA; n = 6).

Time-resolved MRA

We used an ultrafast time-resolved MRA with interleaved stochastic trajectories (TWIST). On the standard three-plane localizer, a sagittal 3D block was planned. Imaging parameters were as follows: repetition time (TR), 2.34 ms; echo time (TE), 0.89 ms; field-of-view (FOV), 230 × 230 mm^2; voxel size, 1.0 × 1.0 × 1.0 mm^3; flip angle (FA), 10°; 160 slices, slice thickness, 1.0 mm; the scan protocol consisted of 28 phases; temporal resolution, 2.5 seconds; scan duration, 1:24 minutes; bandwidth (BW), 600 Hz/pixel; central region A, 15%; sampling density B, 20%; acceleration factor 4 (extended parallel acquisition technique [ePAT]). The dosage of contrast agent was 0.05 mmol/kg bodyweight gadobutrol for the time-resolved MRA (Gadovist; Bayer HealthCare, Leverkusen, Germany). The bolus injection of the contrast agent was at a rate of 3.0 mL/s (Spectris Solaris; Medrad Inc., Bayer Medical Care) followed by 20-mL saline. Contrast injection