

Assessment and Classification of Peripheral Vascular Anomalies by Time-Resolved MRA using TWIST

Ulrich Kramer¹, Ulrike Ernemann², Stephan Miller¹

¹Diagnostic and Interventional Radiology, University Hospital Tübingen, Germany

²Diagnostic and Interventional Neuroradiology, University Hospital Tübingen, Germany

Introduction

Vascular malformations (VM) can be classified into high-flow arteriovenous malformations and/or fistulas (AVM) and low-flow venous or lymphatic malformations. In general, VMs are congenital anomalies, usually caused by an arrest of normal vascular development and failure of resorption of the embryologic primitive vascular elements. VMs can present in any anatomic location, tissue or organ; the most common anatomic locations being the pelvis, extremities (flexor muscles of the forearm and the quadriceps muscle) and the intracranial circulation. Overall prevalence of VMs is estimated to be 1.5% of the general population.

Multiple classifications for vascular abnormalities have been established, but the classification of Mulliken and Glowacki is the most frequently used system [1, 2]. Treatment and prognosis of VMs are based on the type, subtype and architecture of the lesions.

A potential difficulty of making differential diagnoses for the lesions relying only on the above system is that diagnoses may often be incorrect, resulting in turn in inappropriate treatment. Precise imaging evaluation is needed for treatment of the lesions, not only to evaluate the extent of lesions but also to confirm the suspected diagnoses.

Diagnosis and standards of therapy

Magnetic resonance imaging (MRI) and ultrasound (US) are the noninvasive techniques of choice and can be used

for the evaluation of VMs. Because of the limitations of US (small field-of-view, restricted penetration, operator dependency), MRI has emerged as an extremely important modality in the assessment of these lesions. The literature, recognizes that the extent of tissue involvement (muscles, nerves, bone, tendons, subcutaneous tissue and skin) can be accurately determined by MRI, the full extent often being underestimated by physical examination. As a consequence, exact categorization of a VM by MRI guides treatment toward percutaneous embolization, transarterial embolization or a surgical approach. Since the diagnosis of a vascular lesion relies mainly on medical history and clinical examination, diagnostic imaging can be focused on specific structural and functional information required for treatment planning. In general, evaluation of VMs requires delineation of its components:

- (1) location, size, and tissue involvement,
- (2) origin, orientation, and course of feeding arteries, and
- (3) origin, size, and course of the draining veins.

Due to continuous improvements in hard- and software within the last few years, time-resolved MR angiography (MRA) in particular has been gaining acceptance as a practical alternative to digital subtraction angiography (DSA) for the diagnosis and determination of appropriate treatment of VMs [3]. Time-resolved MRA has been shown to be an

accurate technique to distinguish the different types of vascular anomalies [4].

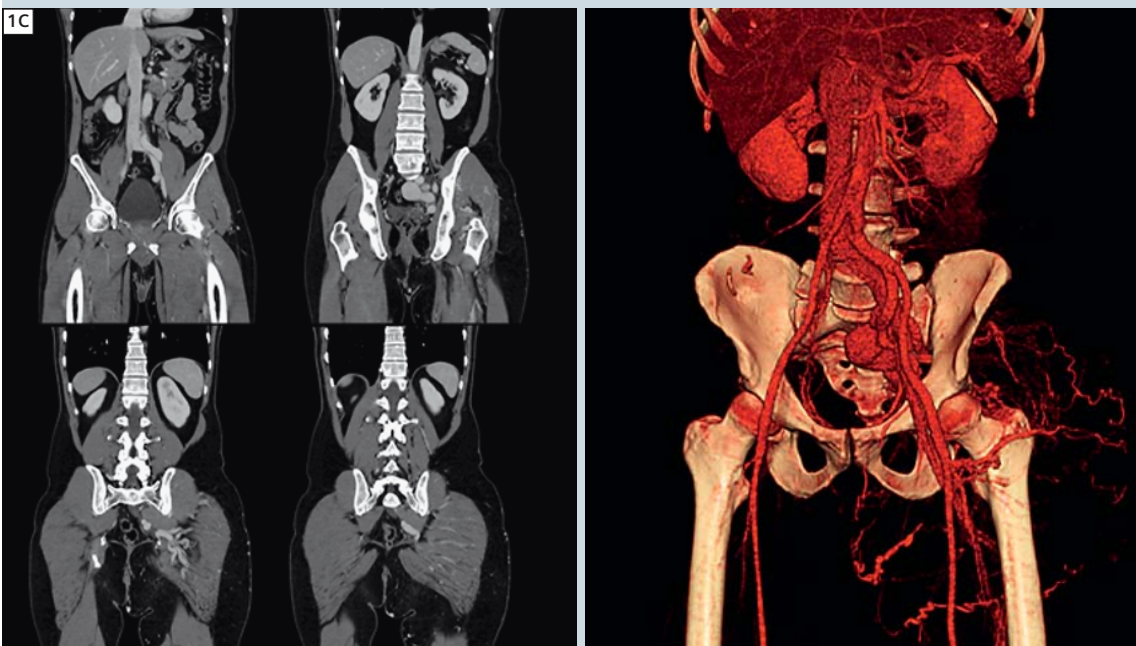
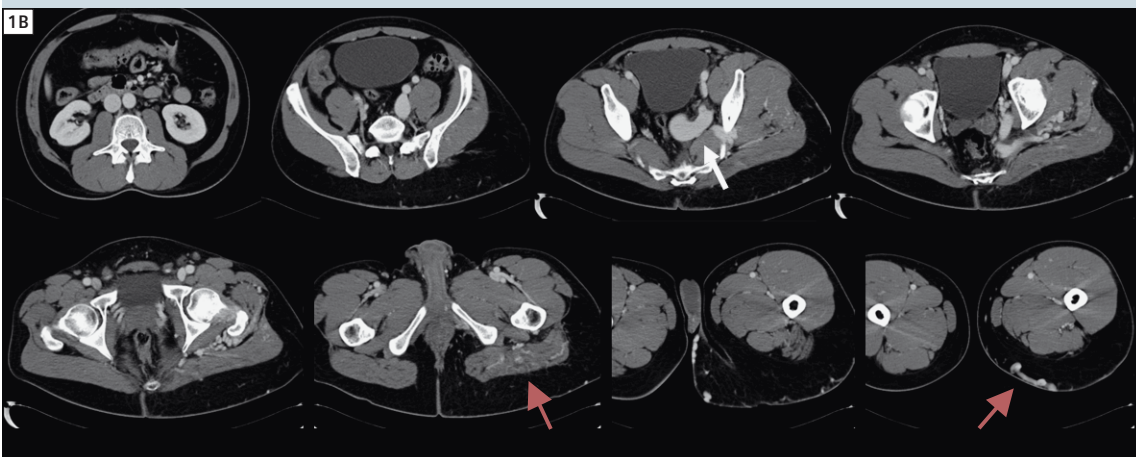
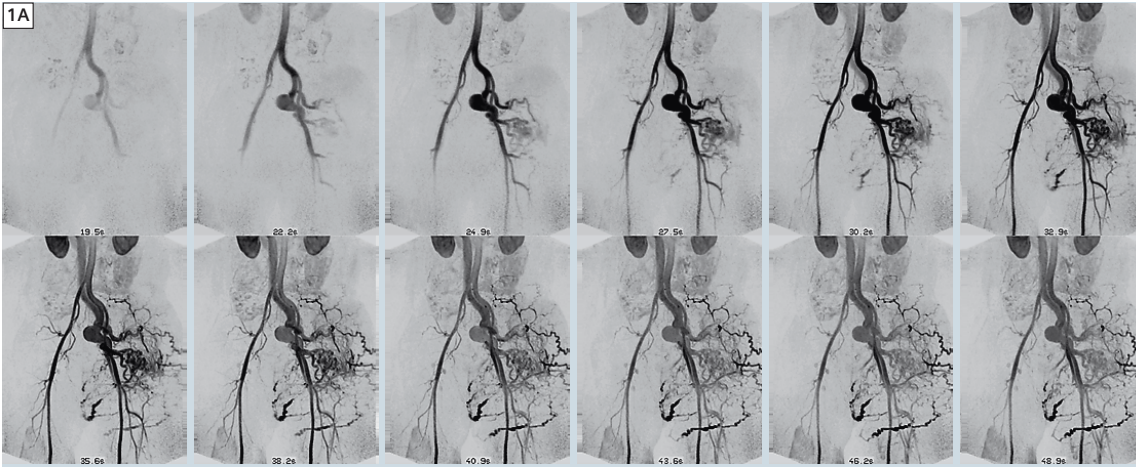
MR imaging

Patients with suspicious or known AVM were studied using a 3D time-resolved contrast-enhanced (ce)MRA which incorporates Generalized Autocalibrating Partially Parallel Acquisitions (GRAPPA) and echo sharing schemes, Time Resolved Imaging with Stochastic Trajectories (TWIST). All patients were examined on a 1.5T MR system (MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany), using a multi-channel phased-array surface coil or dedicated flex extremity coils.

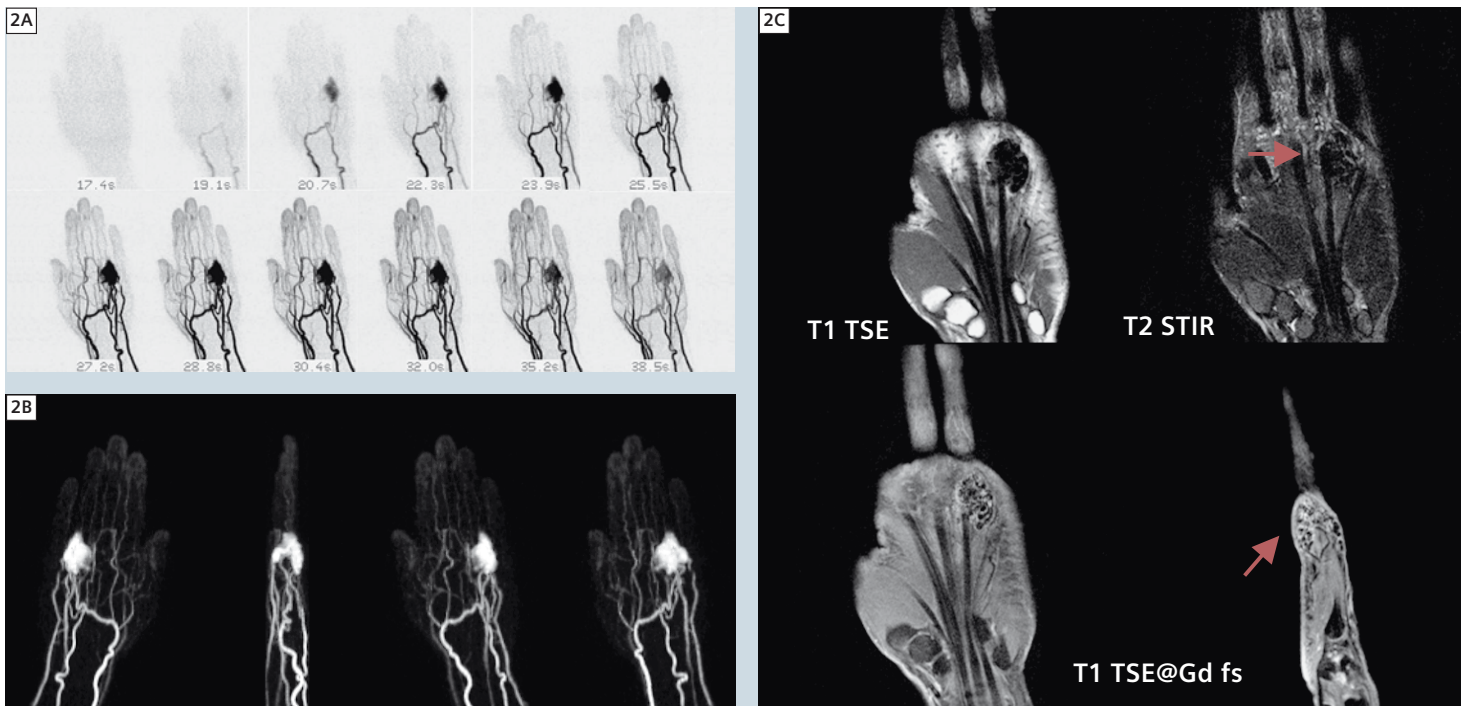
All scans consisted of T1 and fat-suppressed T2-weighted images. Axial conventional spin-echo (SE) and / or turbo spin-echo (TSE) T1-weighted and T2-weighted TSE images were obtained by using 5–10 mm section thickness, 1–2 mm intersection spacing, and variable field-of-view depending on the extremity. Post-contrast images were obtained in axial and sagittal and/or coronal plane following intravenous administration of 0.1 mmol/kg gadobutrol (Gadovist®, Bayer HealthCare, Germany).

Time-resolved MRA using TWIST

The TWIST sequence divides k-space into a central (A) and a peripheral (B) region. The central region (low frequencies) defines the contrast in the image and the peripheral region (high frequencies) accounts for the detail information in



1 39-year-old male patient presented with a painful pulsating mass in the left buttock soft tissue. There is an increase in local skin temperature and a thrill when the lesion is palpated. (1A): On time-resolved MRA an aneurysm of the intern iliac artery as well as a large VM involving the left upper thigh, buttock and lumbar region is found. Multiple feeding arteries and an early opacification of dilated out-flow veins can be seen. Additional CT scan was performed in order to evaluate extent of disease and tissue involvement prior to treatment. CT images in axial (1B) and coronal (1C) orientation confirmed diagnosis demonstrating a number of prominent arteries and arterioles mainly in the left gluteus muscle and multiple huge dilated and early draining veins in the subcutaneous layer, compatible with a high-flow arteriovenous malformation.



2 46-year-old female patient presenting with a high-flow AVM of the right hand. **(2A)** On time-resolved MRA (2.7 s/frame) feeding arteries of the radial and ulnar artery as well as an enlarged dorsal draining vein can be observed. **(2B)** Due to high-spatial resolution (in-plane resolution $(1.3 \times 1.3) \text{ mm}^2$, slice thickness 1.3 mm), multiplanar reformatted views obtained from a single dataset allow for more precise evaluation of vascular pathology in addition to viewing the standard MIP in the acquired plane. **(2C)** Morphological images showed subcutaneous hypointens mass on T1w as well as T2w sequences. Fast flow vessels are also identified by the presence of flow voids within the mass (open arrow). There is no enhancement after application of gadobutrol (lower row).

the images. While region A is completely sampled for every measurement repetition, region B is undersampled by a factor of n , which can be varied by the operator. The larger the undersampling factor the shorter the time difference for two consecutive acquisitions of the central region. The k -space trajectory within region B follows a spiral pattern in the k_y - k_z plain with every trajectory in B slightly different, depending on the undersampling factor n . During reconstruction, the missing data points in region B for a particular time frame t_i will be copied from the corresponding k -space trajectories in other time frames. The following sequence parameters were used: TR 2.27-3.46 ms, TE 0.8-1.29 ms (depending on patient adjustment), flip angle (FA) 25° , sampling bandwidth (BW) 650-950 Hz/pixel; in-plane resolution $1.1 \times 0.8 \text{ mm}^2$, slice thickness 1–3 mm. In our study we have used a value of 15% for region A, and an undersampling factor of 25% for region B.

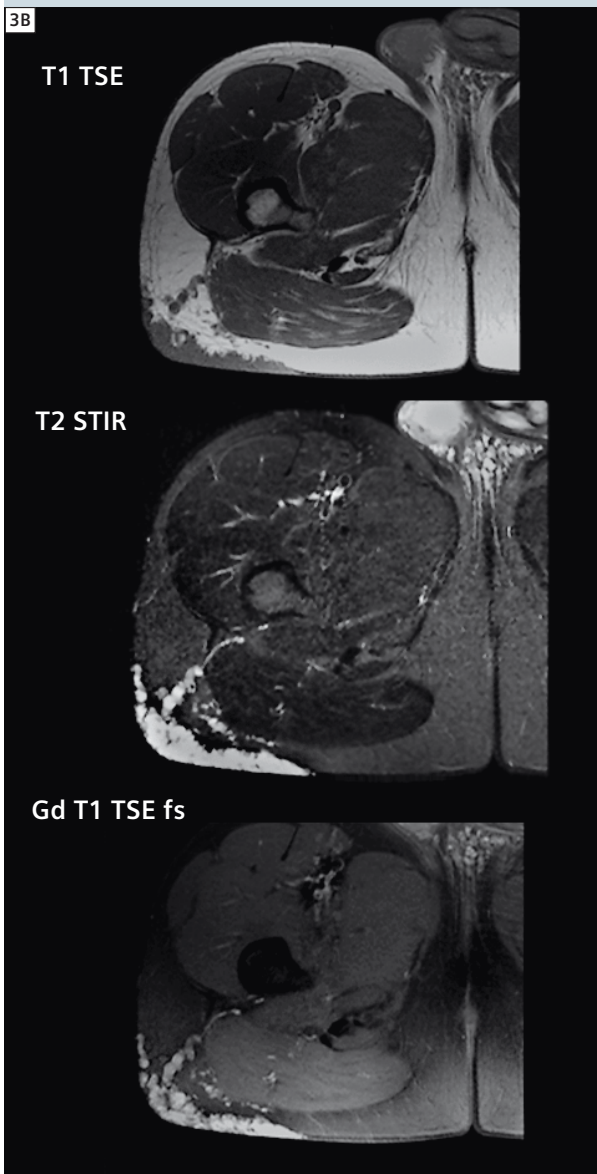
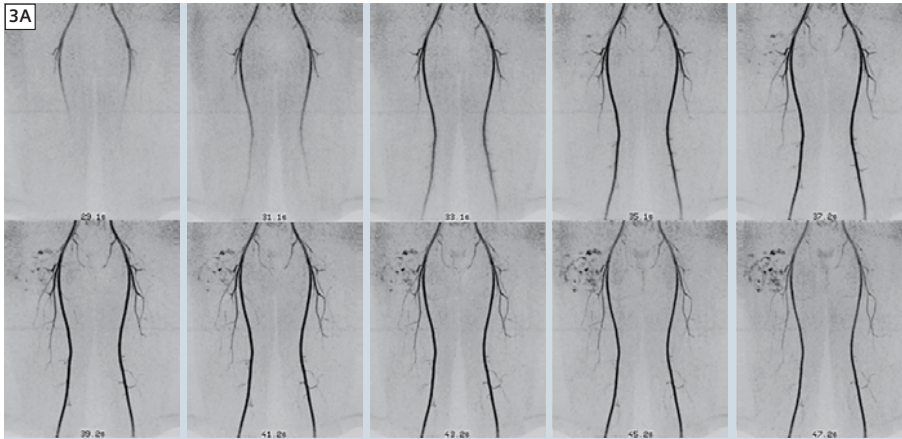
Discussion

The TWIST technique has special advantages for MR imaging of VMs, because it provides information on the hemodynamics of the malformations, demonstrating the early filling of the lesion during the arterial phase of the acquisition as well as – where relevant – the feeding artery. The use of parallel imaging techniques in association with the variable rate k -space sampling allows a reduction of acquisition time, improving the temporal resolution while maintaining and even improving the spatial resolution. In our study protocol the temporal resolution was varying from 4.8 to 1.4 seconds per single frame and the spatial resolution ranged from $(1.1 \times 0.8 \times 1.0) \text{ mm}^3$ to $(1.1 \times 1.1 \times 3.0) \text{ mm}^3$. A high acceleration factor of 3 was used for parallel imaging in most applications. Thus, we have been able to obtain detailed anatomical and hemodynamic information similar not only to conventional high-spatial resolution MRA but

also to that obtained with DSA, but without the risks associated with ionizing radiation exposure, iodizing contrast agents, or catheterization itself.

Clinical implication

In general, whilst differentiation between a vascular malformation and a hemangioma can often be obtained clinically, MRI will be useful in this regard in several cases. Diagnostic imaging is often required for the evaluation of deeper lesions or in the setting of an atypical history to allow differentiation from other malformations or non-malformation lesions. As a result, MRI has become the imaging modality of choice in the assessment of morphological issues of VMs, e.g. extent of the lesion, tissue involvement and flow characteristics (signal voids in high-flow lesions). At our institution, based on these initial results, time-resolved MRA will influence therapeutic decision making by defining the internal architecture of a VM and its



3 Ten consecutive coronal time-resolved inverted MIP images (2.0 s/frame) in a 25-year-old male patient presenting with a vascular malformation of right upper thigh. An early enhancement of dilated vessels in the subcutaneous layer can be seen. **(3B)** Corresponding morphological images in an axial orientation. T1-weighted pre- and post-contrast as well as T2-weighted images show multiple dilated vessels in the subcutaneous tissue. No involvement of the right gluteus maximus muscle was found.

relationship to adjacent critical structures. Moreover, TWIST allows highly sensitive and specific discrimination between high-flow and low-flow malformations. Furthermore, time-resolved MRA can also serve as an objective method to quantitatively assess therapeutic outcomes through serial MRI scans (size of treated lesion, signal characteristics).

Conclusion

Vascular malformations are complex lesions with a variety of clinical manifestations. Time-resolved MRA combined with parallel imaging and echo sharing schemes represents a reasonable alternative to more invasive DSA for the evaluation of VMs. Therefore, time-resolved MRA can play an important role in categorizing these lesions and determining their extent in order to correctly guide treatment.

References

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Contact

Ulrich Kramer, M.D.
 Diagnostic and Interventional Radiology
 University Hospital Tübingen
 Hoppe-Seyler-Str. 3
 72076 Tübingen
 Germany
 Ulrich.Kramer@med.uni-tuebingen.de