MAGNETIC RESONANCE VESSEL WALL IMAGING IN CEREBROVASCULAR DISEASES

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ABSTRACT

Cerebrovascular diseases are abnormalities of the intracranial vascular system, affecting its ability to carry blood to the brain. The pathogenesis of many of these begins in the wall of the vessel and actual imaging techniques are not able to visualize the vascular wall. Moreover, perfusion imaging techniques do not provide adequate information on the differentiation, onset or progression of the disease. Recently, imaging of vessel walls with magnetic resonance imaging (VWI) allowed to visualize sub-millimeter structures of the arterial wall, emerging as a valuable technique for understanding and evaluating cerebrovascular diseases. Localization of the lesion and characteristic aspects with contrast medium provide therefore new information on the inflammatory etiology of cerebrovascular diseases, such as intracranial steno-occlusive disease, identification of atherosclerotic plaques, localization of vessel pathology in areas with minimal or zero waist to luminal imaging and stability of the aneurysm allowing early diagnosis and treatment. In recent years, intracranial vessel wall (VW) magnetic resonance (MR) imaging has been an exponential increase in popularity and clinical applicability. However, increasing evidence shows that also the intracranial atherosclerosis might be a potential cause of ischemic stroke, focusing the toward the imaging of the intracranial vasculature. The following descriptive study has been carried out on some patients of the University Hospital "San Giovanni di Dio e Ruggi d'Aragona", using a 3-T MR. This study describes the effectiveness of the magnetic resonance vessel wall imaging in cerebrovascular diseases.

INTRODUCTION

Cerebrovascular diseases are abnormalities of the intracranial vascular system, affecting its ability to carry blood to the brain. The pathogenesis of many of these begins in the wall of the vessel and actual imaging techniques are not able to visualize the vascular wall. Moreover, perfusion imaging techniques do not provide adequate information on the differentiation, onset or progression of the disease. Recently, imaging of vessel walls with Magnetic Resonance imaging (VWI) has facilitated visualization of sub-millimeter structures of the arterial wall, emerging as a valuable technique for understanding and evaluating cerebrovascular diseases. Localization of the lesion and characteristic aspects with contrast medium provide therefore new information on the inflammatory etiology of cerebrovascular diseases, allowing to identify intracranial steno-occlusive diseases and atherosclerotic plaques, to localize vessel pathologies with minimal or zero waist to luminal imaging and to assess the stability of brain aneurysms, guiding its diagnostic and therapeutic process. In recent years, intracranial vessel wall (VW) magnetic resonance (MR) imaging has been an exponential increase in popularity and clinical applicability. Initially, it was restricted to extracranial arteries, such as the carotid arteries, in which atherosclerotic plaques are prone to cause embolism ischemic stroke.

Patient's preparation

Proper patient preparation plays an important role in the acquisition of high- quality intracranial VW images. The patient (or legal representative) needs to be informed about the MR imaging examination, and the MR imaging staff needs to asses if any possible contraindications for MR imaging (claustrophobia, contraindicated metal objects in or on the body, pregnancy) or for gadolinium- containing contrast agents (known allergic reaction to gadolinium severely impaired renal function) exist. Imaging staff needs to assess whether the patient is clinically able to undergo the examination. It may be challenging to lay still for a long period of time especially for neurologically impaired patients. Prior to imaging a peripheral intravenous catheter is placed in the antecubital vein for contrast agent administration. VW imaging sequences are susceptible to motion artifacts because of the relatively long acquisition duration, and visibility of the VW decrease rapidly when patients move their head during acquisition, therefore is positioned foam cushions around the patient's head to aid in limiting movement artifact.

MR Angiography's sequences

MR Angiography (MRA) is based on resonance sequences that exploit the chemical and physical properties of the protons contained within the blood allow

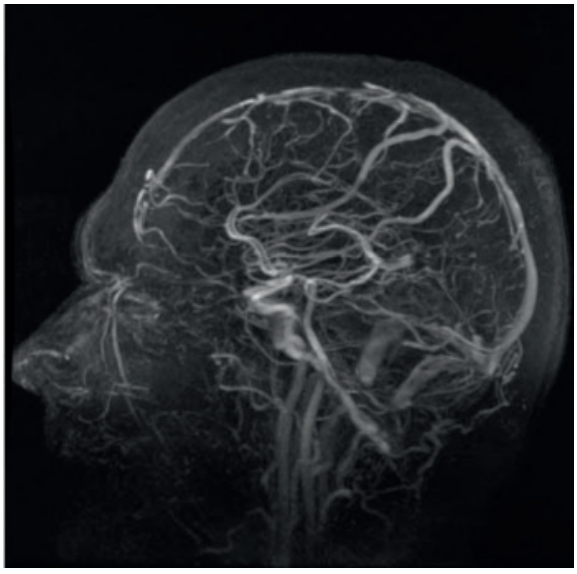

Fig. 1 - *Sagittal section of an MRA acquisition*

to visualize the vascular component (FIG. 1). Blood has more free water than all tissues in the body and its signal strength is influenced by its high proton density and high iron content. The signal intensity of the blood can be altered through various MRA techniques, that according to the iconographic result, can be divided into two main categories: Black Blood and Bright Blood.

In the Black Blood category blood has no signal, while in the Bright Blood category it is hyperintense. Bright Blood sequences are angiographic sequences used in Magnetic Resonance to study the contents of the vessels. Those sequences are basically based on the blood flow, like:

- TOF (Time of flight) that can visualize flow within vessels, without the need to administer contrast. It is based on the phenomenon of flow-related enhancement of spins entering into an imaging slice. With 2-D TOF, multiple thin imaging slices are acquired with a flow-compensated gradient-echo sequence. These images can be combined by using a technique of reconstruction such as maximum intensity projection (MIP), to obtain a 3-D image of the vessels analogous to conventional angiography. With 3-D TOF, a volume of images is obtained simultaneously by phase-encoding in the slice-select direction (FIG. 2). An angiographic appearance can be generated using MIP, as is done with 2-D TOF.
- Phase Contrast Imaging is an MRI technique that can be used to visualize moving fluid. Spins that are moving in the same direction as a magnetic field gradient develop a phase shift that is proportional to the velocity of the spins. This is the basis of phase-contrast angiography. In the simplest phase-contrast pulse sequence, bipolar gradients (two gradients with an equal magnitude but opposite direction) are used to encode the velocity of the spins. Stationary spins undergo no net change in phase after the two gradients are applied. Moving spins will experience a different magnitude of the second gradient compared to the first, because of its different spatial position. This results in a net phase shift. This information can be used directly to determine the velocity of the spins.

The Black Blood sequences also called Dark Blood are not properly angiographic sequences that are useful for the evaluation of vessel walls and related diseases such as plaques, dissections and thrombus (FIG. 3). The main disadvantage of this sequences is the need of Cardiac Gating, which results in long acquisition times and limitation in the number of layers. Currently the main fields of application are the study of the Heart, the Aorta and its secondary branches, the Carotids and the intracranial circle. The main features for the MRI study of the vessel wall are the high spatial resolution (high field, 3 Tesla), the 2D or 3D multiplanar acquisition, multiple weighing sequences with blood and liquor suppression. Today many techniques exist to provide an excellent spatial resolution and a precise delimitation of the wall of the vessels surrounded by blood and liquor flows and are both 2D and 3D: 2D techniques are very common and generally a 2D image in a plane perpendicular to the plane of the lumen is the most important because it allows a detailed assessment of the damage of the lumen and the morphology of the lesion. The advantages of 3D techniques, on the other hand, are related to the increased field width resulting in increased brain coverage and the ability to obtain isotropic acquisitions. The most used 3D technique is the Variable Refocusing Flip Angle (VRFA) performed with T1-T2 and Proton Density sequences after administration of contrast agent. Contrast-enhanced sequences are mandatory for the VW imaging. As general rule, optimal timing of sequence acquisition is between 5 and 10 minutes after contrast agent injection; contrast enhancement may be weak outside this time window. The choice of acquire pre-contrast images depends on both specific setting and clinical question. Indeed, most VW lesions, even if not enhancing, can be detect on the post contrast sequence. However, acquiring only post-contrast images may miss important findings such an intraplaque hemorrhage or intracranial arterial dissections. Other MR sequences also add helpful information when used in combination with the intracranial VW imaging. With the relativity long acquisition time of these VW sequences, most of the currently used intracranial VW imaging protocols rely on T1- weighted imaging, because of its benefits in the detectability of contrast enhancement after contrast agent administration and favorable imaging characteristics when distinguish

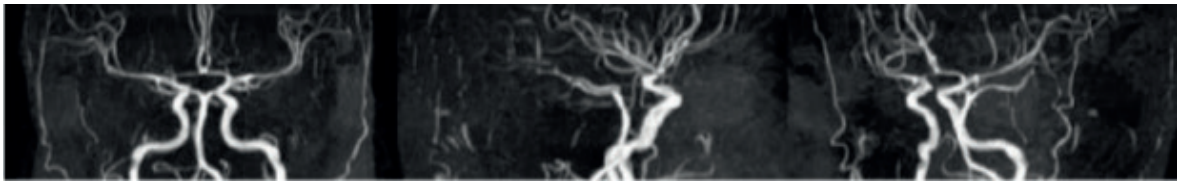

Fig. 2 - *3D reconstructions TOF with MIP algorithm of intracranial arterial circle (without contrast agent).*

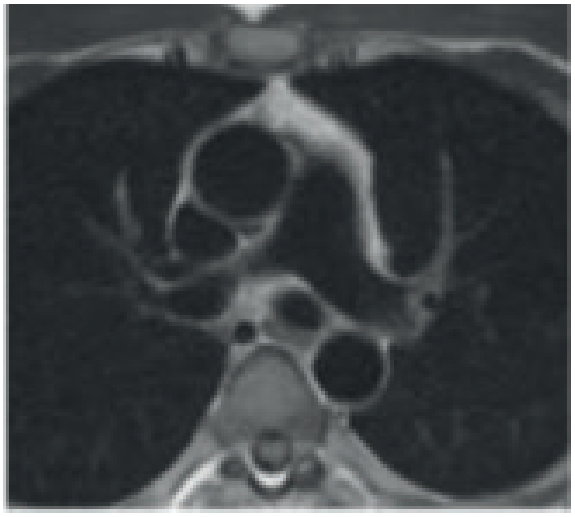

Fig. 3 - *"Black Blood" spin echo image*

the VW from its surrounding tissue and plaque components.

Contrast-enhanced MR Angiography during first contrast agent passage clearly shows the arterial vasculature and is less sensitive to slow-flow artifacts compared with TOF MR angiography. Other pulse sequences that can be of additional value in VW imaging assessment, depend on the specific clinical question and include:

- T2-weighted TSE sequence that can confirm the absence of a flow void in the arterial lumen in a patient with an arterial occlusion.
- T1 weighted anatomic sequence for both assessment of normal anatomy and for use as precontrast sequence for mainly tissues enhancement.
- T1 weighted fat-suppressed sequence that can depict a subintimal hematoma in patients with an arterial dissection that involves both the extracranial and intracranial segments.
- Fluid Attenuated Inversion Recovery and Diffusion-weighted imaging sequence for localizing white matter lesions and old and recent ischemia possibly associated with VW disease.

MATERIALS AND METHODS

This descriptive study has been carried out on some patients of the University Hospital "San Giovanni di Dio e Ruggi d'Aragona", using a 3D T1-weighted volumetric isotropically reconstructed TSE acquisition, VIRTA or SPACE, sequence that is performed after contrast material administration only (Gadobutrol, Gadovist 1.0 mmol/mL, single dose, adjusted to patient weight; Bayer Schering Pharma, Newbury, England). Images are acquired at an anisotropic spatial resolution of 0.5x 0.5 x 1.0 mm3 that is subsequently reconstructed to 0.5 x 0.5 x 0.5 mm3 isotropic resolution. This particular spatial resolution was chosen because is considerably above the "ideal" spatial resolution of 0.18 x 0.18 x 0.18 mm3, because of the limitations regarding acquisition time and SNR. Also, in a recent small study, it was found that sequences with a lower spatial resolution (0.5 mm x 0.5 mm x 1.0 mm) and a short imaging duration (6 minutes 42 seconds) have a good subjective quality score and good performance with respect to lesion detection. An anisotropic sequence was chosen for two main reasons:

- assessment of the in-plane sections, planned in a transverse oblique plane to image the circle of Willis in the classic anatomic way (FIG 4), most often will suffice for detection of larger lesions;
- mainly it was used this sequence to detect VW enhancement, which is less dependent on partial volume effects. In this regard, an anisotropic voxel size can be a good compromise between an increased SNR and shorter acquisition times. However, the above-mentioned drawbacks of anisotropic sequences always need to be taken into account when assessing the images.

In the SPACE (or VIRTA) sequence, black blood is obtained by means of low- flip-angle refocusing pulses. To optimize CSF suppression, it also used the antidriven-equilibrium method. Because CSF suppression is not optimal with use of this method, could be implemented with DANTE for better CSF suppression. Because the FOV of the sequence is restricted in the through-plane direction– measuring 45 mm thickness–care must be taken to plan the FOV correctly (FIG. 4).

By the way, key parameters of 3-T protocol are shown in Table 1.

Case example

Male, 29 y.o. admitted with headache and cervical pain. The brain MR showed the occlusion of the supraclinoid segment of the left internal carotid artery (ICA) and the stenosis of the M1 segment of the left middle cerebra artery (MCA; Fig 5A). The VW-MRI documented a concentric thickening and enhancement of the left ICA and eccentric enhancement of the superior wall of the left MCA. We decided to treat the patient with intracranial stent obtaining the complete recanalization of both the ICA and the MCA.

RESULTS AND DISCUSSIONS

imaging of vessel walls with magnetic resonance imaging (VWI) has facilitated visualization of sub-millimeter structures of the arterial wall, emerging as a valuable technique for understanding and evaluating cerebrovascular diseases. Localization of the lesion and characteristic aspects with contrast medium provide therefore new information on the inflammatory

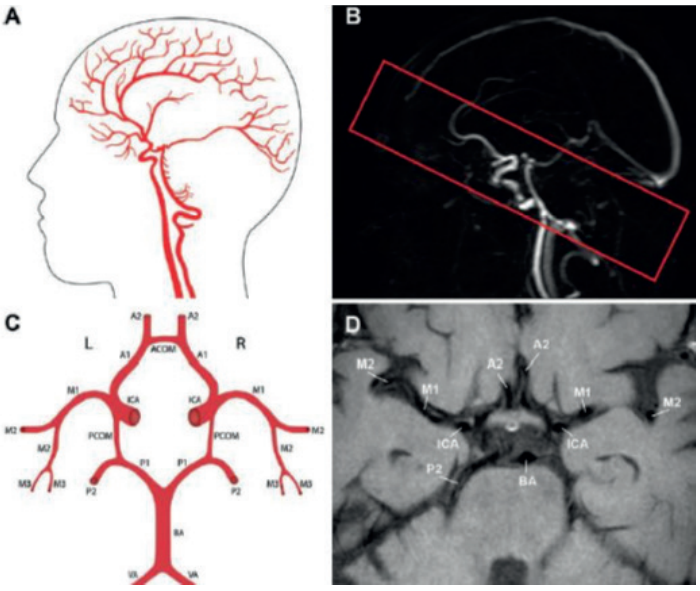

Fig. 4

Table 1

3-T VW Imaging Protocol Used at Our Institution

Imaging Parameter	Diffusion-weighted Imaging	3D TOF MR Angiography	2D T2 FLAIR	3D T1 VIRTA with Contrast Agent
FOV (mm^3)	230 × 230 × 140	200 × 200 × 70	230 × 183 × 140	200 × 167 × 45
Acquisition orientation	Transverse	Transverse	Transverse	Transverse oblique
Acquisition spatial resolution (mm^3)	0.96 × 1.22 × 4.0	0.4 × 0.7 × 1.0	0.65 × 0.85 × 4.0	0.5 × 0.5 × 1.0
Reconstructed spatial resolution (mm^3)	0.45 × 0.45 × 4.0	0.36 × 0.36 × 0.5	0.41 × 0.41 × 4.0	0.5 × 0.5 × 0.5
TR/TE/TI (msec)	4056/68/-	22/3.5/-	10000/120/2800	1500/32/-
Flip angle (degrees)	90	18	120	90
Echo spacing (msec)	...	...	9.6	4.5
MPIR TSE factor	...	...	24	56 + 4
Oversampling factor	...	...	...	1.8
Readout bandwidth (Hz)	15.1	522.7	218.1	643.4
No. of signals acquired	2	1	1	1
Sensitivity encoding factor	3 (AP)	2 (RL)	2 (RL)	1.5 (RL)
Acquisition time	1 min 25 sec	5 min 12 sec	5 min 0 sec	8 min 3 sec

Tab. 1

etiology of cerebrovascular diseases, such as intracranial steno-occlusive disease, identification of atherosclerotic plaques, localization of vessel pathology in areas with minimal or zero waist to luminal imaging and stability of the aneurysm allowing early diagnosis and treatment. In recent years, intracranial vessel wall (VW) magnetic resonance (MR) imaging has been an exponential increase in popularity and clinical applicability. This descriptive study has been carried out on some patients of the University Hospital "San Giovanni di Dio e Ruggi d'Aragona", using a 3-T MR. This study shows the effectiveness of the magnetic resonance vessel wall imaging in cerebrovascular diseases.

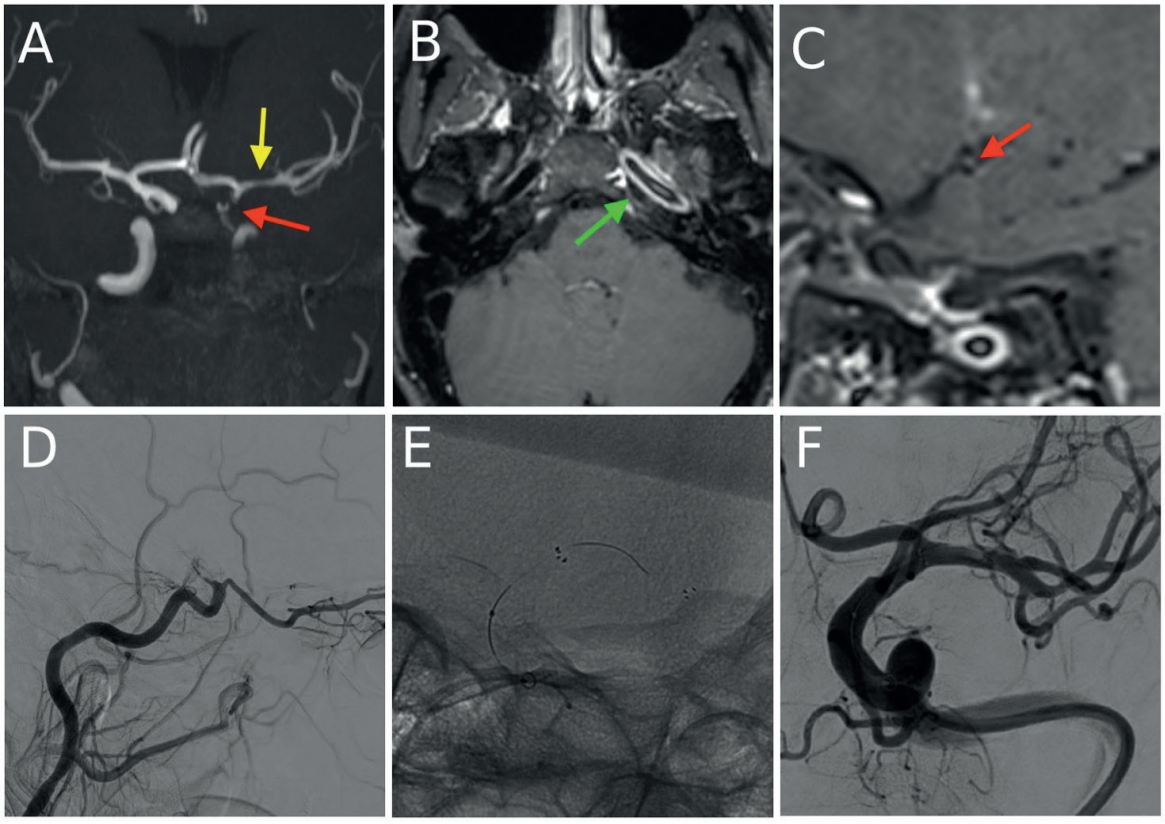

Fig. 5 - *A) 3D-TOF showing the left supraclinoid ICA occlusion (red arrow) and the left M1 narrowing (yellow arrow); B) T1 SPACE-C+ showing the left ICA wall thickening and enhancement (green arrow); C) T1 SPACE-C+ sagittal plane showing the enhancement of the superior wall of the left M1 segment (red arrow); D) DSA injecting the left ICA confirming the occlusion of the supraclinoid segment; E-F) deployment of two self expanding stent allowing the recanalization of both the ICA and M1.*

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