Utility of black-blood MRI sequences in the study of vascular pathology of the CNS

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Abstract

Cerebrovascular diseases are diseases of the central nervous system caused by alterations in the intracranial blood circulation involving an insufficient supply of oxygen to the brain parenchyma. In order to carry out a valid analysis of the vessel wall in recent years, magnetic resonance imaging of the vascular wall has become widespread. (VWMRI, vessel wall magnetic resonance imaging), which has proven to be an effective method with which to characterize pathologies involving the vessel wall and in detecting low-grade stenosis that may evade angiography. VWMRI is based on the use of 'black blood' sequences, i.e. sequences in which the blood signal inside the vessels is suppressed. Contrast medium is often used for this type of study, because it allows any inflammatory changes in the vessel walls to be highlighted. In the past, the main methods for studying intracranial vessels were digital subtraction angiography, i.e. DSA, and CT angiography. Magnetic resonance imaging has proved to be a valid alternative to these methods for detecting stenotic lesions without using ionising radiation, being able to characterise these types of lesions and having the ability to detect lesions that are not stenotic.

Introduction

Cerebrovascular diseases are diseases of the central nervous system caused by alterations in the intracranial blood circulation involving insufficient oxygen supply to the brain parenchyma. A very common pathogenesis of these diseases lies in the vessel wall, which is a structure that is not easy to study with traditional imaging methods (Angiography and Angio-CT).

To perform a valid analysis of the vessel wall, vessel wall magnetic resonance imaging (VWMRI) has become widespread in recent years, and has proven to be an effective method with which to characterise pathologies involving the vessel wall and to detect low-grade stenosis that may elude angiography [1]. This was initially a specific method for the study of cervical carotid atherosclerotic disease, but it has recently been expanded and used for the study of intracranial vascular disease, allowing atherosclerotic plaques to be visualised, their components to be analysed, dissections to be sought, cerebral aneurysms to be assessed, vasculitis to be studied and as a guide to biopsies [2].

Analysing the technical aspect, VWMRI is based on the use of 'black blood' sequences, i.e. sequences in which the signal from the blood inside the vessels is suppressed, so that the vessel walls can be visualised. Contrast medium is often used for this type of study, as it allows any inflammatory changes in the vessel walls to be highlighted. In the past, the main methods for studying intracranial vessels were digital subtraction angiography, i.e. DSA, and CT angiography.

DSA allows optimal visualisation of extra- and intracranial cerebral vessels and an exact localisation and representation of arteriosclerotic processes. It is particularly useful when multiple narrowings (stenoses) are present and in the diagnostic preparation for vascular surgery [4]. Whereas CT-angiography is more widely used in acute stroke situations, given its speed of execution and ability to detect stenotic lesions in the most proximal intracranial arteries and the search for the possible presence of calcifications that led to the stenosis.

However, in recent years, MRI has emerged as a viable alternative to these methods for detecting stenotic lesions without using ionizing radiation, being able to characterise these types of lesions and having the ability to detect lesions that are not stenotic.

Patient preparation

No preparation is necessary for this type of MRI examination; however, it is essential to collect the patient's data by means of a questionnaire form, which the patient must be asked to fill in and sign. In addition to the absolute contraindications to performing MRI examinations, which are claustrophobia, metal objects contraindicated in or on the body, a history of a known allergic reaction to gadolinium or severely impaired kidney function, there are certain situations, such as pregnancy in the first trimester, which will be assessed by the specialist on

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a case-by-case basis when the examination cannot be postponed. The imaging personnel must assess whether the patient is clinically able to undergo the examination. Once this procedure is complete, the patient is asked to undress, keeping their underwear on and wearing a disposable gown; this minimises any artefacts from ferromagnetic components in the clothing. Before the patient is brought to the couch, a venous access is also taken, preferably to the antecubital vein, for the administration of contrast medium. The patient is then asked to position himself on the couch in supine horizontal decubitus with his arms at his sides. The head is placed in the headrest of the encephalon study coil and immobilised with appropriate restraints, as VW imaging sequences are susceptible to motion artefacts due to the relatively long acquisition time and VW visibility decreases rapidly when patients move their heads during acquisition. It is important at this stage to pay close attention to symmetrical head positioning using laser centring.

Study protocol VWMRI:

- **Spatial Resolution:** The normal wall thickness of the middle cerebral artery and basilar artery is 0.2-0.3 mm, which is about one-tenth of the luminal diameter, and is smaller than the voxel size of currently obtainable VWMRI images. However, it is possible to visualise the intracranial artery wall, as the wall generates a detectable MR imaging signal, and the suppression of the signal from adjacent blood and cerebrospinal fluid within the voxel aids its detection. In addition, vascular wall disease often results in a thickening of the vascular wall, which therefore increases its visibility [5]. However, it is easy to find oneself in situations in which partial volume artefacts occur, due to inadequate spatial resolution, because we are in a condition in which the wall thickness range of the intracranial vascular circle is smaller than that of the voxels used for acquisition. In addition, intracranial atheromasic plaques are often too small for compositional characterisation with respect to the spatial resolution obtainable with the MRI study. The resulting exaggeration of the actual wall thickness can be misinterpreted as atherosclerotic plaque or vasculitis, especially if there is a corresponding contrast enhancement. The spatial resolution must also be adequate because it must also resolve those situations in which there are small adjacent vessels, especially veins and cerebral arteries that often flow together, as in the case of Silvio's scissure; in these cases, the presence of small veins can lead to artefacts due to slow flow, which, if inadequate resolution is used, can lead to the localisation of a false atherosclerotic plaque [6].

- **Acquisition times:** Although 3D VWMRI has proven to be a highly efficient signal-to-noise ratio technique, a typical high spatial resolution (isotropic resolution of 0.5-6 mm) VW MRI acquisition with whole-brain coverage acquired in the axial orientation can take more than 10 minutes. An acquisition in sagittal orientation can reduce the imaging time to 5-8 minutes, covering the main intracranial vessels and making the acquisition more easily usable in clinical practice. Recent advances in compressed sensing reconstruction also allow for accelerated MRI by non-linear iterative reconstruction of poorly undersampled k-space data (called incoherent undersampling): i.e. only a portion of the k-space is acquired in a semi-random manner, preferring to sample the central lines of k-space, which are the ones that give contrast to the image. Compressed sensing has been widely implemented in various clinical applications. It has also been used to accelerate carotid plaque imaging and, more recently, for intracranial VWMRI, allowing a substantial reduction in imaging time [7].

- **Acquisition 2D vs 3D:** Accurate interpretation of VWMRI imaging requires visualisation of the vessel wall in both the short and long axis planes.
One option to obtain an optimal image is to use multiple 2D acquisitions
along orthogonal planes, focusing on the specific vessels of interest. A limitation of this approach is that most intracranial arteries have a tortuous rather than linear path, and such obliquities and curvatures in the course of these arteries can cause artefacts that confuse the appearance of the arterial wall. Another, more widely used option is to use a 3D volumetric acquisition that allows isotropic data to be reconstructed for visualisation in multiple planes of space (Fig. 1). In fact, three-dimensional acquisitions with isotropic voxels allow high-resolution reconstruction in the three directions of space, so as to minimise the overestimation of wall thickness as a consequence of the tortuous course of these small

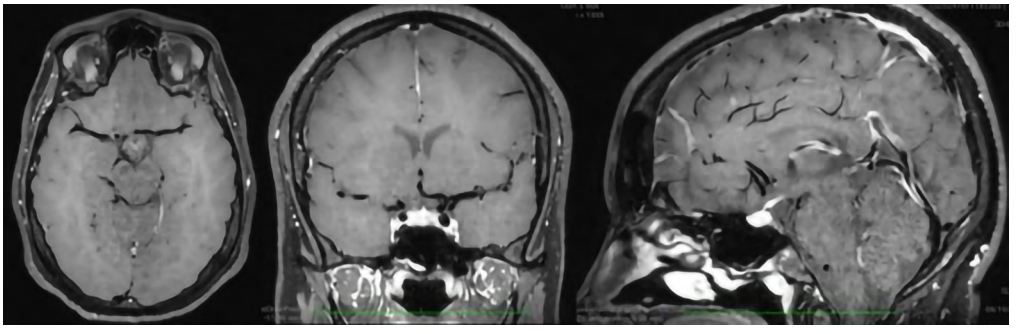

Figure1 3D-T1- Black Blood sequence with related 2D-MPR reconstructions according to multiple plans

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However, 3D techniques suffer from long scan times and sub-optimal flux suppression, as the echo train length (ETL) used to suppress flux by deflection effects in 2D turbo spin echo (TSE) sequences is not possible during 3D acquisitions, unless very long scan times are used. In addition, 2D sequences targeted on specific vessels of interest are able to offer better image quality than volumetric sequences.

- **Voxel:** Depending on the choice of two- or three-dimensional acquisition technique, the type of voxel to be used is also chosen. Usually, isotropic voxels are combined with three-dimensional acquisitions and anisotropic voxels with two-dimensional acquisitions. In most cases, isotropic voxels are preferred due to their ability to perform reconstructions to visualise images in different planes. Furthermore, as we have already seen, the intracranial arteries have a tortuous course, so multiplanar assessment plays an important role. Anisotropic voxels, on the other hand, offer high spatial resolution in one plane in shorter acquisition times.

- **Magnetic Field Strength:** In order to perform this type of MRI study, one must also evaluate the type of magnetic field one has available, because for example a magnetic field with a strength of 1.5T would not be able to achieve a sufficient signal-to-noise ratio within a reasonable acquisition time. Therefore, a magnetic field with a strength of at least 3T is required to achieve an adequate SNR and consequently better suppression of the CRL and a wider FOV to cover the entire area of the brain.

Main Protocol Sequence: The main sequence in this protocol is the black blood sequence (Fig. 2), which suppresses the blood signal while allowing visualisation of the vessel wall. The suppression of blood flow is generally achieved by the saturation techniques we described earlier, namely the spin washout technique and the double inversion recovery technique. Of these techniques, DIR has been the most commonly used for 2D black blood MRI.
Flow suppression is most effective when the velocity is high. Blood often has a laminar distribution, with slower flow along the vessel wall; this can lead to inadequate flow suppression. Disordered velocity distributions, such as disturbed or recirculating flow, may render signal suppression incomplete along the periphery of the lumen, mimicking eccentric vessel wall thickening that may simulate plaque, or mimicking concentric wall thickening that may indicate circumferential plaque or vasculitis. Common sites for flow artefacts in VW MRI scans are those with curved vessels and relatively large diameters, because they are more prone to recirculating flow.
Flow suppression occurs more effectively in vessels with small diameters, so flow artefacts are more common in larger vessels; this can be explained by the voxel sensitivity function. In most cases, MRI studies are performed on tissues much larger than the voxel size and the MRI signal intensity is not affected by the position of the protons under examination relative to the voxel. However, for a small structure with a smaller size than the voxel in use, the MR signal strength depends on its position within the voxel. For example, a vessel with a large diameter relative to the size of the voxel will have blood protons located in the centre of a voxel producing a strong signal, being less efficiently suppressed than protons within a small vessel with a smaller size than the voxel, with the protons not necessarily located in the centre of the voxel. Considering that the small size of intracranial vessels can approximate this small size, the blood signal is often adequately suppressed [8].

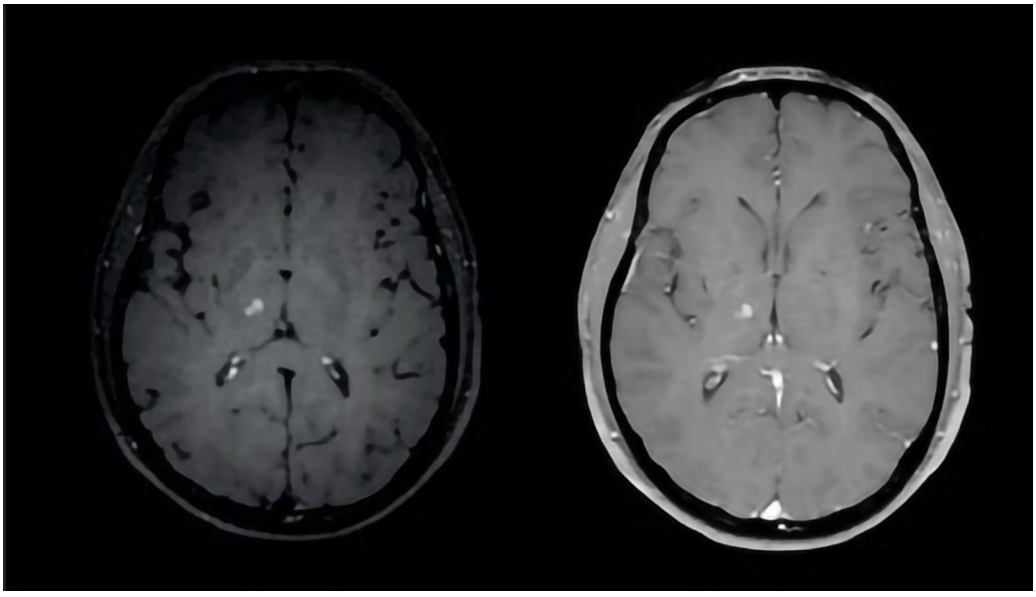

Figure 2 on the left the Black Blood sequence; on the right the corresponding conventional axial T1.

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Other sequences: In combination with the specific sequences of the VWMRI protocol, conventional sequences such as Angio-RM techniques are usually used. Mainly contrast-enhanced MR angiography, known as CEMRA or time-of-flight (TOF) MR angiography, is used, as these sequences are particularly useful for assessing the arterial lumen and specifically identifying the arteries to which the vessel walls visualised in the other sequences belong. Furthermore, in the case of using a small FOV, these techniques can help the positioning of the FOV centred on the circle of Willis or a specific stenotic wall lesion. Contrast-enhanced MR angiography during contrast medium passage clearly shows arterial vascularisation and is less sensitive to slow-flow artefacts than TOF MR angiography, which is sensitive to the same haemodynamic factors that generate artefacts in black-blood sequences. However, TOF MR angiography is the optimal sequence for the detection of stenotic lesions and vascular disease, including aneurysms of the intracranial vasculature, as there is no need to wait for the contrast medium to pass first, so acquisition time can be invested to increase spatial resolution [9,10].

Other sequences that may be of additional value in the evaluation of VW imaging depend on the specific clinical question and include:

- T2-weighted TSE sequence that can confirm the absence of a flow gap in the arterial lumen in a patient with an arterial occlusion;
- T1-weighted anatomical sequence, both for anatomy assessment and for use as a precontrast sequence for tissue enhancement. It would also be possible to use proton-density-weighted sequences to get a better signal-to-noise ratio, but this weighting has the disadvantage that it would bring the contrast of the CSF closer to that of the vessel wall, making differentiation more difficult;
- T1-weighted fat-suppression sequence, very useful for visualising a possible subintimal haematoma in patients with an arterial dissection involving both extracranial and intracranial segments;
- fluid-attenuation sequences such as FLAIR sequences or other methods; this is because the visualisation of the wall of an intracranial arterial vessel in VW MRI scans can be optimised by suppressing the signal of the CSF surrounding these vessels in order to highlight their outer wall. The signal strength of the CSF can be attenuated using a short repetition time due to the long T1 value of the CSF; however, the loss of signal from T1-weighting of the vessel wall is an unfavourable consequence that limits the ability to visualise the thin walls of intracranial arteries. Another method to reduce the signal of the CSF is the addition of a flip-down radiofrequency pulse module to the 3D VW MRI. It uses a 90° positive radiofrequency pulse at the end of the echo train to tilt the transverse magnetisation into the negative longitudinal plane, thus suppressing transverse magnetisation and minimising the signal of tissues with long T2 values, such as the CSF;
- diffusion-weighted imaging (DWI) sequence to highlight ischaemic lesions of recent onset often associated with vascular disease. In the case of evaluation for ischaemia in the acute phase, it may be useful to combine the DWI sequence with the FLAIR sequence, so as to highlight a possible mismatch: if the hyperintensities that we obtain in DWI, are also present in the FLAIR sequence, it will mean that that tissue is necrotic, while if a lesion is visualised in DWI and not in FLAIR it will mean that the tissue has not yet gone into necrosis.

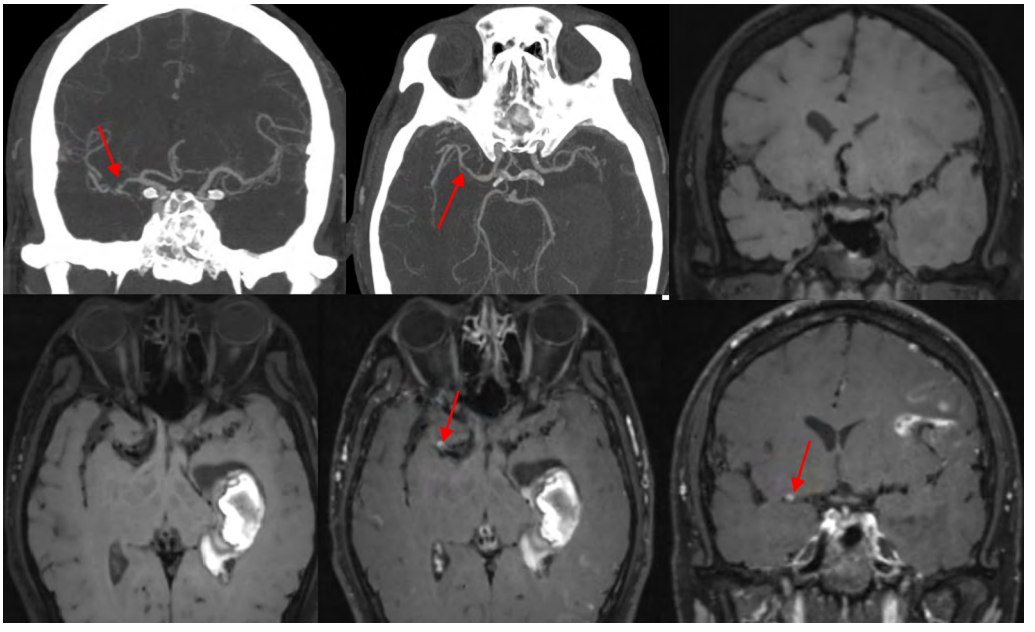

Figure 3. *Patient with cerebral haemorrhage. Atheromatous plaque at the CT angiography study characterized by impregnation after MDC at the VWMRI study, in relation to inflammation, is documented at the right middle cerebral artery.*

Use of contrast medium: Sequences with contrast are mandatory for VW imaging. The best time for sequence acquisition is between 5 and 10 minutes after contrast medium injection; outside this window the contrast may have a suboptimal effect. The choice of acquiring pre-contrast images is not always necessary, because most vessel wall lesions, even without enhancement, can be detected in post-contrast sequences. However, acquiring only post-contrast images may miss important findings such as intraplaque haemorrhage or intracranial arterial dissections. The use of contrast medium is also important to better assess vessel patency (Fig. 3).

Conclusions

MRI of vessels using the Black Blood study technique has facilitated the visualisation of sub-millimetre structures of the arterial wall, emerging as a valuable technique for understanding and evaluating cerebrovascular disease [11-13]. Lesion localisation and characteristic features with contrast medium provide information with high sensitivity and specificity of vessel pathologies, identification of atheromasic plaques, allowing early diagnosis and effective treatment, with the main advantage of not using (unlike other diagnostic methods) ionising radiation potentially harmful to the patient.

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