PHASE-CONTRAST-CINE MRI: A NON-INVASIVE QUALITATIVE APPROACH TO THE STUDY OF VARIOUS DISEASES OF THE CENTRAL NERVOUS SYSTEM

Dott. Calligari Dalila, Dott. Corvaglia Martina, Dott. Stringile Michela, Dott. Colombo Giovanni, Dott. Assirelli Angela

Uosd neuroradiologia aorn s. Anna e s. Sebastiano – caserta (it)

KEYWORDS: Magnetic resonance imaging, Sequence phase-contrast, Dynamic CSF, PC velocity

ABSTRACT

The introduction of velocity-sensitive sequences, such as those based on the phase-contrast technique, has recently established a lure for the evaluation of the dynamics of CSF in MRI because it is the only non-invasive method for the study of the CSF flow.
These sequences add to the classic anatomical study of brain, a qualitative functional analysis of his cerebrospinal fluid system studied with sequences acquired in the sagittal plane, maintaining high spatial and temporal resolution despite the small size of the analyzed section and the low speed of the circulating liquor.
The aim of this paper is to illustrate the importance of using amplitude and phase (Phase Contrast) images in Cine-RM, in healthy subjects and in patients with intra-cranial and cervical district diseases.

INTRODUCTION

The brain, notoriously, is dug inside it by some cavities (cerebral ventricles) containing a liquid called cerebrospinal fluid or simply liquor (CSF), a transparent fluid very similar to rock water (which is why it appears to be hyperintense in T2w and hypointense in T1w sequences), with low protein content (for which it appears hypointense in FLAIR sequences).
The CSF is a sort of water-absorbing shock absorbers capable of cushioning any mechanical stress on a soft organ such as the encephalon, but other important trophic and transport functions are also associated. This water content (the first and second ventricles for each cerebral hemisphere, the so-called lateral ventricles, the third and fourth unequal and median ventricles communicating these last through an anatomical narrow called the aqueduct of Silvio) is not static but in continuous, slow movement: the so-called liquor flow.
The development of new sequences sensitive to moving flows has renewed interest in the study of liquor dynamics.
The evaluation of CSF dynamics in magnetic resonance is the only non-invasive method for studying the flow of the cerebral fluid.
This study is necessary when, due to various morbid conditions, there is an increase in cerebrospinal fluid at the level of the cerebral ventricles that dilate, resulting in a pathological condition known as hydrocephalus.
Thanks to the introduction of speed-sensitive sequences, such as those based on the phase contrast technique combined with the latest generation of dedicated software, it is possible with our high-power magnetic field equipment (1.5 Tesla) to perform, in addition to the classic anatomical study of the encephalon, a quantitative functional analysis of the CSF flow, studying it and managing to maintain a high spatial and temporal resolution of the images, despite the small size of the analyzed section and the low velocity of the circulating liquor.
Gradient Echo sequences, especially phase-contrast images have led to major advances in the study of cerebrospinal fluid dynamics. This study assesses this technique in the so-called «third circulation» by dynamically displayed phase and amplitude images (Cine-mode). Technical indications are given on the acquisition of the moving CSF signal together with the results obtained.
This objective was achieved thanks also to the ability of our TSRMs, who have gained an important experience with high-power magnetic field MR equipment.

MATERIALS AND METHODS

For our neuroradiological studies we used a 1.5 Tesla Magnetic Resonance tomography with 33-45 Tesla/mt gradients (Slew Rate 200 T/mt/sec) 16-channel head coil, full-digital.
For all patients, DWI, FLAIR-3D, TSET1, TSET2, BTFFE T2 * and DRIVE sequences were performed on the axial, coronal and sagittal scan planes.
The study of CSF flow was obtained with Gradient-Echo sequences using the phase contrast technique which produces angiographic images of high thickness.
This type of sequence, to obtain only the representation of the vascular structures and the cancellation of the stationary structures, exploits the complex automatic subtraction of two acquisitions: a flow-sensitive reference scan and an acquired with flow compensation by applying a bipolar gradient.

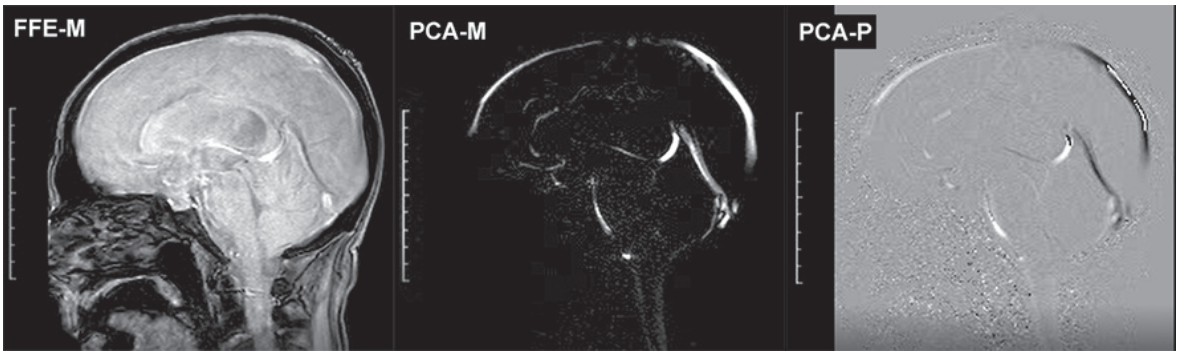

Fig. 1 - Image reconstruction in phase contrast sequences.

At the end of the procedure you will get three different series of images (Fig.1):
1. FFE-M images (fast field echo in form) => soft tissue images
2. PCA-P images (phase contrast in phase) => representation of the flow
3. PCA-M images (phase contrast in Modulo) => background suppression and luminous vessels.

The DRIVE sequence (balance or fast field echo balanced) is used before placing the plan of acquisition of the phase-contrast for a morphological evaluation of the encephalic structures on the midline on the sagittal plane (FIG. 2). For this reason, the acquisition takes place on a sagittal plane a thin layer with an accurate orientation to follow the median line and contain Silvio's aqueduct.

This is a sequence characterized by very short repetition time rates and wide flip angles that generate excellent fluid/tissue contrast in short acquisition times.

For the acquisition of the phase-contrast sequence the parameters to be checked and possibly modified are essentially three:

- Heart rate (heart rate, beats / min);
- PC velocity;
- Heart phases.

Heart rate is the most important parameter to consider because the circulation of the CSF is synchronized with the cardiac contractions and is related to changes in intracranial blood volume: in particular, there is a displacement of the CSF in the cranio-caudal direction in the systolic phase and a caudo-cranial shift in the diastole.

The acquisition therefore envisages the retrospective reconstruction of the images with the use of cardiac gating and, in order to have an optimal study of the CSF throughout the cardiac cycle, the heart rate is monitored with a peripheral pulse detector (PPU). It should be emphasized that, for each patient, the heart rate value is increased by about 10 units, to compensate for any changes in this parameter that may occur during acquisition.

Another parameter to be observed is the PC velocity or venc, expressed in cm/s, which is the maximum speed that should be measured inside of the cerebral aqueduct.

This value should be set based on the flow being studied and expected to be found. Generally, the value of 12 cm/s is set for non-pathological and pediatric patients and 15 cm/s in case of suspected hyperdynamic flow, as in the case of already known hydrocephalus, similarly to what already indicated in the literature (1,15).

This parameter is fundamental for the success of the sequence because if a value is set too high or low artifacts occur that do not allow a correct quantification of the flow as aliasing.

The last parameter to consider is the heart-phases on which the number of phases acquired in a cardiac cycle depends and therefore the number of images in the sequence. In the sagittal plane to have an optimal view in cine mode, it is good to set 24 cardiac phases.

USE AND ANALYSIS OF THE PHASE-CONTRAST CINE-IMAGES

The Phase-Contrast sequences is a non-invasive study technique that allows to document the flow of cerebrospinal fluid in "Cine" mode, while it flows in the ventricles and in the cerebral cisterns in dynamics.

The circulation of cerebrospinal fluid at the level of the ventricular system and of the subarachnoid spaces is a dynamic oscillatory process synchronized with cardiac contractions.

To better define this process, we can imagine that the brain "pulsates" continuously, driven by cardiac contractions. In fact, changes in blood volume resulting from cardiac contractions determine rhythmic bidirectional movements of cerebrospinal fluid along the cerebral spinal axis: during cardiac systole, the increase in cerebral blood volume determines the cranial caudal (systolic) displacement of cerebrospinal

Fig. 2 - The DRIVE sequence is used for a morphological evaluation of the encephalic structures on the midline on the sagittal plane.

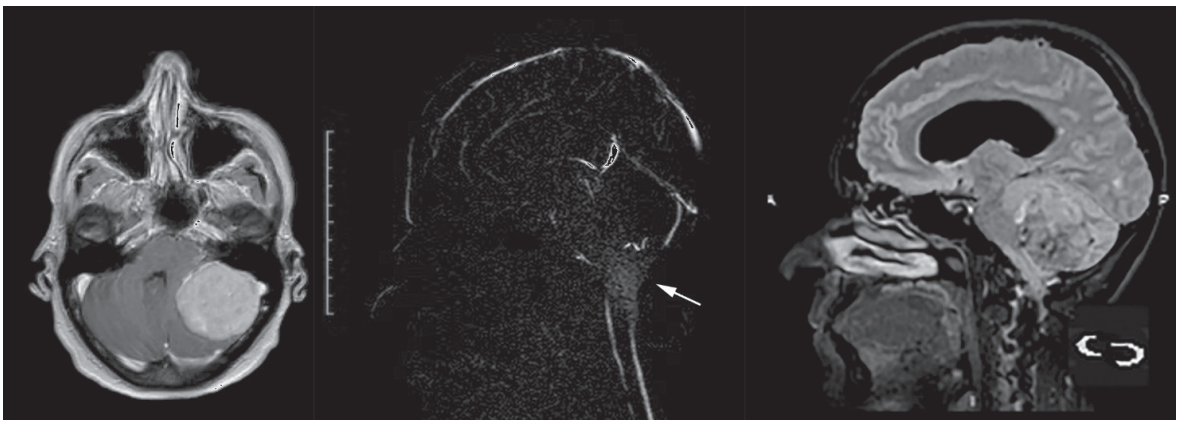

Fig. 3 - A case of a young woman with a meningioma in the left posterior cranial fossa is reported. The tumor causes compression on the cerebellar tonsils that obliterate the foramen magnum. In the phase-contrast sequence (center image) the turbulence of flow is easily noticeable (arrow).

fluid; instead during diastole the reduction of cerebral blood volume conditions the "diastolic return" of the cerebrospinal fluid in the opposite direction.
The described phenomenon is supported by the theory of Monro-Kellie according to which the volumetric modifications of brain, blood and cerebrospinal fluid compensate each other dynamically (which means that they vary in absolute values but, added together, they always maintain a constant volume equal to that of the bone container).
The technique used in our hospital (Phase-Contrast Cine-MRI = Phase Contrast Magnetic Resonance) allows visualization of cerebrospinal fluid movement and determination of its velocity at different anatomical levels; the images are obtained by synchronizing the acquisition of the sequences with the cardiac cycle; in other words the image is "captured" during a known phase of the cardiac revolution.
The exam does not require the use of contrast media; the contraindications to the execution of the exam are the same as those that regulate every magnetic resonance examination; as is known, MRI does not imply the use of ionizing radiation.
The field of application of the Phase-Contrast-Cine MRI is wide and in recent years it has undergone a marked increase in demand as a direct consequence of the development of endoscopic neurosurgery techniques aimed at correcting fluid circulation diseases cerebrospinal, hydrocephalus (endoscopic methods). The examination is performed to evaluate the characteristics of the pulsatile flow in the presence of different pathologies (gliomas, vascular malformations, meningiomas, etc.) located in sites where they can determine alterations of the liquor dynamics with consequent increase of pressure grades on the intracranial structures (FIG. 3).
Another field of application of Phase-Contrast Cine-MRI concerns the diagnosis of cervical cranial hinge diseases (point of transition between the skull and the vertebral column): first of all the Arnold-Chiari malformation type I (descent of the cerebellar tonsils below the large occipital foramen) (FIG. 4), or Dandy-Walker Syndrome (congenital malformation of the brain that involves enlargement of the fourth ventricle due to the absence of a part of the cerebellum) (FIG. 5 - a, b, c).
The Phase-Contrast-Cine MRI in these cases allows to plan the neurosurgical strategy and to evaluate the success of the endoscopic intervention through the study of the permeability of the "neo-communica-

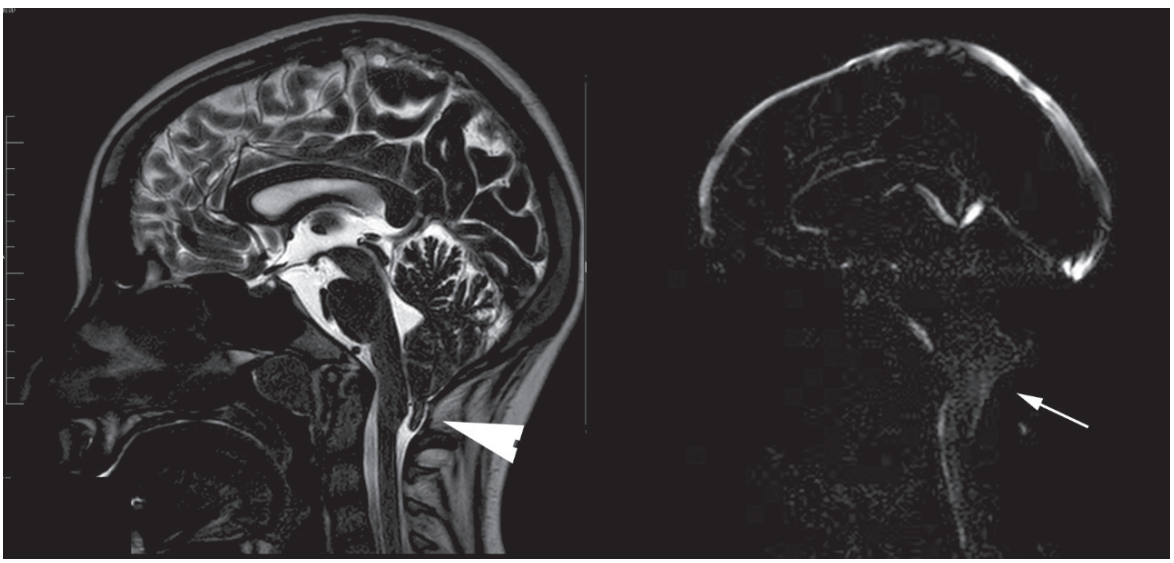

Fig. 4 -A case of a young man with Arnold-Chiari malformation type I (descent of the cerebellar tonsils below the large occipital foramen; image left - head arrow). In the phase-contrast sequence (right image) the turbulence of flow is easily noticeable (arrow).

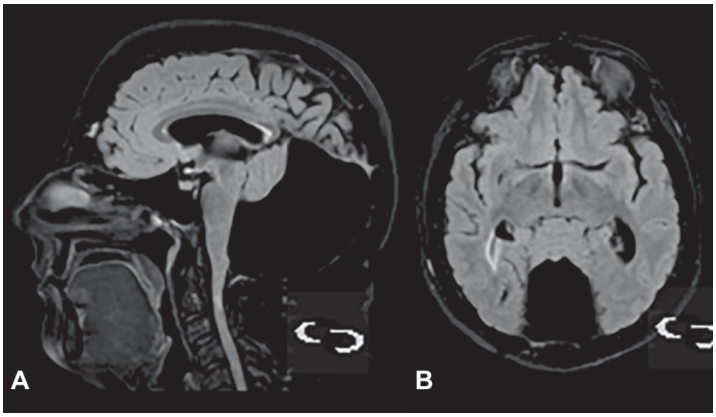

Fig. 5a - A case of a young girl with Dandy-Walker Syndrome (congenital malformation of the brain that involves enlargement of the fourth ventricle due to the absence of a part of the cerebellum). The FLAIR images are shown in sagittal to the right and in axial to the left.

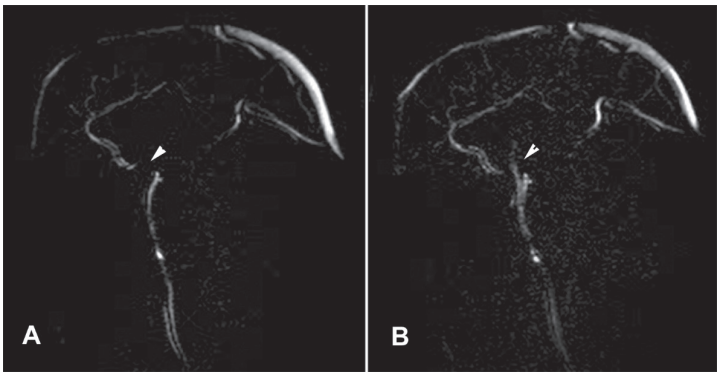

Fig. 5b - The Phase-Contrast Cine-MRI allowed this case to evaluate the success of the endoscopic intervention through the study of the permeability of the "neo-communication" created between the third ventricle and the interpeduncular cistern (as in sequence images A before surgery and B after surgery; arrow head).

tion" created between the third ventricle and interpeduncular cistern (as in images in sequence) (FIG. 5 b). Further indications for the execution of the exam are represented by the evaluation of the flow dynamics in syringomyelia (cavitation of the central portion of the spinal cord associated with congenital malformations or secondary to spinal trauma or tumors), useful for a better surgical approach, and the study of formations medullary and intracranial cysts.

DISCUSSION

The evaluation of CSF dynamics with the MRI exam has limits that cannot always be exceeded.
Beyond all the common contraindications to any Magnetic Resonance examination (patients with pacemakers, metal splinters or other objects that cannot enter a magnetic field), this type of study requires synchronization with the electrocardiographic signal (ECG) so it cannot be performed if the patient has an irregular heart rhythm over time.
Then there are other problems related to the protocol used. The main sources of imprecision are represented by the effect of partial volume between parenchyma and liquor, possible systematic errors caused by imperfect suppression of induced currents and by the presence of aliasing artifact.
Image quality can be increased by reducing the effect of partial volume using thinner sections.
Add to all this the difficulty of estimating the liquor flow not only due to the limits linked to the method, but also for all the possible variations of the anatomy of the liquor spaces, of the size of the blood vessels, of the pressure of the arteries in diastole and systole, of the heart rate and flow in the jugular veins.

CONCLUSIONS

The phase-contrast sequence, with all its advantages and limitations, represents a new method of Magnetic Resonance capable of provide important diagnostic information on liquor dynamics, so far studied with procedures such as ventricular catheterization, exter-

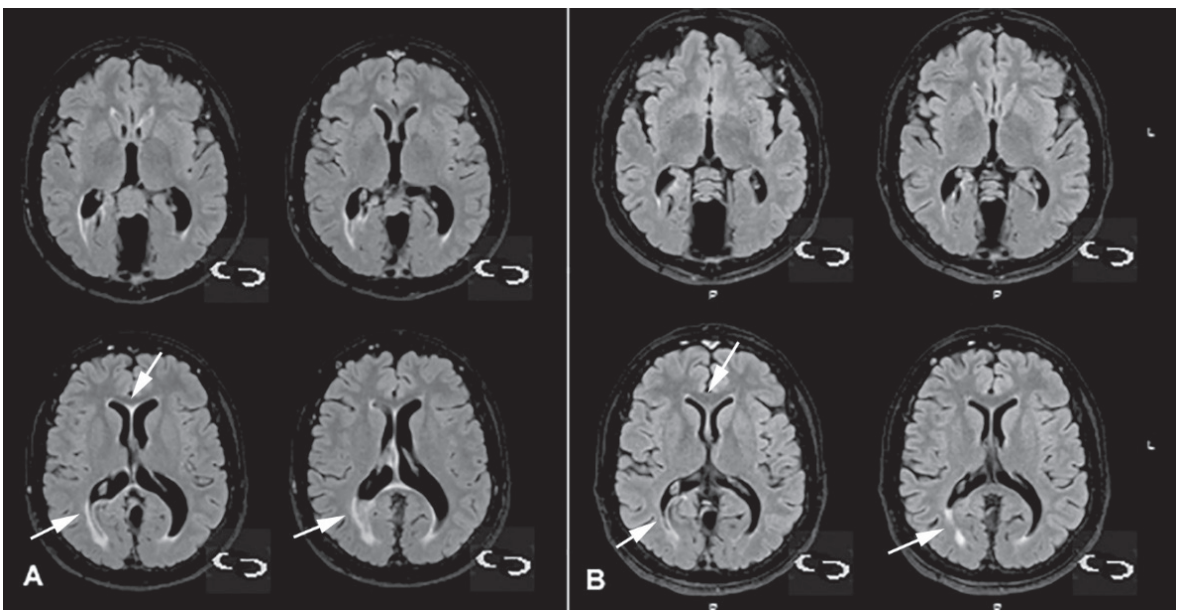

Fig. 5b - The Phase-Contrast Cine-MRI allowed this case to evaluate the success of the endoscopic intervention through the study of the permeability of the "neo-communication" created between the third ventricle and the interpeduncular cistern (as in sequence images A before surgery and B after surgery; arrow head).

nal ventricular drainage or ventricular-cisternal perfusion.
The non-invasiveness of these methods explains the constant diffusion of this type of MR study, which due to its characteristics of non-invasiveness, simplicity of execution and reproducibility is already becoming for some years a point of reference in the diagnostic-therapeutic pathway of patients suffering from alterations in the cerebrospinal fluid liquor.

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