J Neurol (2005) 252 : 1021–1025
DOI 10.1007/s00415-005-0710-6

ORIGINAL COMMUNICATION

Francesco Fera
Francesco Bono
Demetrio Messina
Olivier Gallo
Pier Luigi Lanza
William Auteri
Giuseppe Nicoletti
Giuseppe Santoro
Aldo Quattrone

Comparison of different MR venography techniques for detecting transverse sinus stenosis in idiopathic intracranial hypertension

Received: 4 June 2004
Received in revised form: 15 October 2004
Accepted: 26 October 2004
Published online: 7 March 2005

F. Fera, MD · D. Messina, MD · O. Gallo, RT · P. L. Lanza, MD · W. Auteri, MD · G. Nicoletti, MD · G. Santoro, MD
Institute of Neurological Sciences
National Research Council
Mangone (Cosenza), Italy

Prof. A. Quattrone (✉)
Clinica Neurologica
Policlinico Mater Domini
Via T. Campanella
88100 Catanzaro
Tel.: +39-0961/775322
Fax: +39-0961/777775
E-Mail: a.quattrone@isn.cnr.it

F. Bono, MD · A. Quattrone, MD
Institute of Neurology
University Magna Graecia
Catanzaro, Italy

P. L. Lanza, MD · W. Auteri, MD · G. Santoro, MD
Department of Neurosciences
Azienda Ospedaliera
Cosenza, Italy

Abstract Cerebral venous outflow abnormalities, as transverse sinuses (TSs) stenosis, may underlie a picture of idiopathic intracranial hypertension (IIH). To identify the best non-invasive MR venography (MRV) technique for exploring the disturbance of flow of TSs in IIH patients, we compared three-dimensional phase contrast (3D-PC) MRV images, acquired with different velocity encodings (15 and 40 cm/s) with two-dimensional time-of-flight (2D-TOF) MR images in 6 subjects with IIH and 12 age-matched normal controls. In both groups, we also measured flow velocity in TSs by using single slice 2D-CINE PC acquisitions. In all subjects with IIH, 3D-PC showed marked flow disturbance in the mid-lateral portion of both TSs when velocity encoding (VENC) was set to 15 cm/s while only a slightly irregular flow in TSs was detected when VENC was set to 40 cm/s or when 2D-TOF was used. By contrast, 3D-PC (VENC 15 and 40) and 2D-TOF techniques were comparable in detecting TS signal flow in normal controls. Measures of flow velocity, by using 2D-CINE PC, revealed a three-fold increase of velocity at the level of the flow disturbance in IIH patients compared to normal controls ($p < 0.0001$), suggesting a marked stenosis of mid-lateral portion of TSs in these patients. Setting the VENC to 15 cm/s on 3D-PC MRV may represent the best technical approach for visualizing disturbances of flow in TSs in subjects with symptoms suggestive of IIH.

Key words magnetic resonance venography · idiopathic intracranial hypertension · transverse sinus stenosis

Introduction

There is evidence that idiopathic intracranial hypertension (IIH) may be the consequence of an intracranial venous hypertension due to raised central venous pressure [1] or disturbances of transverse sinuses (TSs) outflow [1–8].

Magnetic resonance venography (MRV) is a noninvasive technique useful for visualization of cerebral venous sinuses [9]. Different MRV sequences offer the capability of investigating cerebral sinovenous outflow from multiple orientations. Two-dimensional time-of-flight (2D-TOF) and three-dimensional phase-contrast (3D-PC) techniques, that do not require contrast injections, have been widely used for MRV imaging [10–13]. All the available MRV techniques, however, suffer from limitations and pitfalls [11–16], and it is unclear which is the best suited for visualizing flow disturbances in TSs in subjects suspected of having IIH, since comparisons of these techniques in patients with IIH and TSs outflow abnormalities are still lacking. Moreover, no data exist in these patients about the optimisation of an MRV protocol, which is especially important in some techniques, as

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3D-PC, where the acquisition of flow data is dependent on the velocity encoding (VENC).

The aim of the present study was to compare two different MRV techniques (3D-PC and 2D-TOF) for detecting TS flow abnormalities in subjects with IIH and normal controls. In both groups, measurements of TSs flow velocity were also obtained.

Methods

All MRV studies were conducted on a 1.5T scanner (Signa NV/i, General Electric, Milwaukee, USA) using a standard quadrature head coil transceiver. Foam pads were used to stabilize subjects' head within the coil and to minimize head motion during the acquisition. Earplugs were provided for hearing protection against acoustic noise generated by the scanner. Informed consent was obtained from both patients and normal controls before entering the study.

Subjects

Six women with documented IIH and disturbance of flow in both TSs (mean age 37.8 ± 12.5; body-mass index, BMI: 30.8 ± 4.2 kg/m^2) and 12 age-matched normal controls (mean age 36.5 ± 9.0; F/M 10:2; BMI: 29.6 ± 3.9 kg/m^2) were enrolled in the study. Patients underwent lumbar puncture for measuring opening CSF pressure (mean 402 ± 109.4 mmH_2O); both patients and controls underwent brain MRI and MRV (3D-PC and 2D-TOF).

3D-PC acquisition slabs were axially prescribed onto mid-sagittal scout images and were copied onto identical spatial location for the two VENC values of 15 cm/s and 40 cm/s. Forty-two slices with 1.6 mm thickness and no interslice gap were centred as a single volume, over a field-of-view (FOV) of 240 mm, at the internal occipital protuberance, as to cover the torcular region, the transverse and sigmoid sinuses, the jugular bulbs and the initial portion of the jugular veins. Image parameters included TR/TE/α = 26/7.2/20, 256 x 160 frequency/phase encoding matrix, number of excitations (NEX) 0.75, flow compensation. Flow was encoded along all three orthogonal directions, with an inferior presaturation band cancelling for arterial inflow signal, for a total scan time of 6:52 minutes.

2D-TOF coronal acquisitions were prescribed onto midsagittal scout images. One hundred and twenty slices, with slice thickness 1.5 mm and no interslice gap were placed posterior to anterior, as to cover the whole brain, over a FOV of 220 mm. Image parameters included TR/TE/α = 23/4.7/50, 256 x 128 frequency/phase encoding matrix, NEX 1, flow compensation. As for the PC acquisition, a presaturation band was placed inferiorly to cancel for arterial inflow. Total scan time was 4:06 minutes.

Flow quantification procedure

For both IIH patients and controls, three graphically prescribed, single slice, oblique coronal, prospectively cardiac-gated 2D-CINE PC [17] series were obtained at three spatial locations: proximal TS, mid-lateral TS (in IIH patients this slice was placed at the level of the disturbance of flow) and jugular veins, about 2 cm distal to the jugular bulbs. All prescriptions were based on the MRV images that best exposed both TSs and jugular veins, and slices were tilted perpendicularly to the vessel of interest to minimize partial volume effects. Image parameters included TR/TE/α = 11.7/4.7/25, 256 x 224 frequency/phase encoding matrix, NEX 1, flow compensation. A slice thickness of 4 mm was chosen, which is expected to limit quantification errors due to the slow variation in the velocity profile along the vessel. Acquisition of CINE PC data started, at each side singularly, with a VENC of 40 cm/s for the two slices positioned onto TSs and with a VENC of 25 cm/s for the slice passing through both jugular veins. The same neuroradiologist visually inspected all time series right after each single acquisition, to check for image quality. If a corrupted flow signal (aliasing artefact) was identified, VENC was increased linearly at each location in steps of 20 cm/s, and consecutive additional time series were collected, until aliasing resolved. The scan time for each time series was 1:08 minutes.

In controls no time series resulted affected by aliasing at VENC values of 60 cm/s and therefore no additional data sets were collected with higher VENCs.

A variable number of cardiac phases per R-R interval, ranging from 24 to 32 depending on subjects' heart rate, were acquired at each location.

Data analysis

The aliasing unaffected time series with the lowest VENC was selected and underwent a region of interest (ROI) analysis. This criterion was held for both IIH patients and controls. ROIs were manually traced by the same neuroradiologist on the cross-sectional area of targeted vessels. In order to minimize potential bias, due to susceptibility problems or partial voluming artefacts, voxels at the edge of the vessels were not included in the ROIs. Quantification measures of flow velocities were only extracted from voxels contained in each ROI by using a commercial software (CV Flow, General Electric, Milwaukee, USA) and numerical data were exported for further calculations and comparisons. Data are expressed as mean ± SD.

Results

Comparable images with excellent visualization of cerebral venous flow were demonstrated with all techniques in control subjects (Fig. 1a, b and c). In particular, signal from the transverse/sigmoidal regions appeared intense and continuous when 3D-PC with both VENCs at 15 cm/s and 40 cm/s was used. Right or left TS dominance was displayed by six and two controls respectively, whereas the remaining four control subjects showed TSs co-dominance.

TSs were found to be co-dominants in all IIH patients, except one who showed marked hypoplasia of the left proximal TS. In IIH, 12 out of 12 TSs (100 %) displayed images of marked disturbance of flow with a poor signal in their mid-lateral portion when the VENC was set to 15 cm/s (Fig. 2a), whereas slight disturbances of flow were detected in TSs when the VENC was set to 40 cm/s or when 2D-TOF technique was used (Fig. 2b and c).

Quantification of flow parameters in the TSs gave the most striking results (Fig. 3): in IIH patients, the TS flow velocity, measured at the level of the flow disturbance in the mid-lateral portion of the TSs averaged 31.6 ± 16.1 cm/s. This value was significantly higher than both the velocity measured in the proximal portion of TS (12.07 ± 5.44 cm/s, $p < 0.0002$) and the velocity measured 2 cm distal to the jugular bulbs (9.33 ± 2.94 cm/s $p < 0.0001$), demonstrating that the flow disturbance images in the mid-lateral portion of TSs corresponded

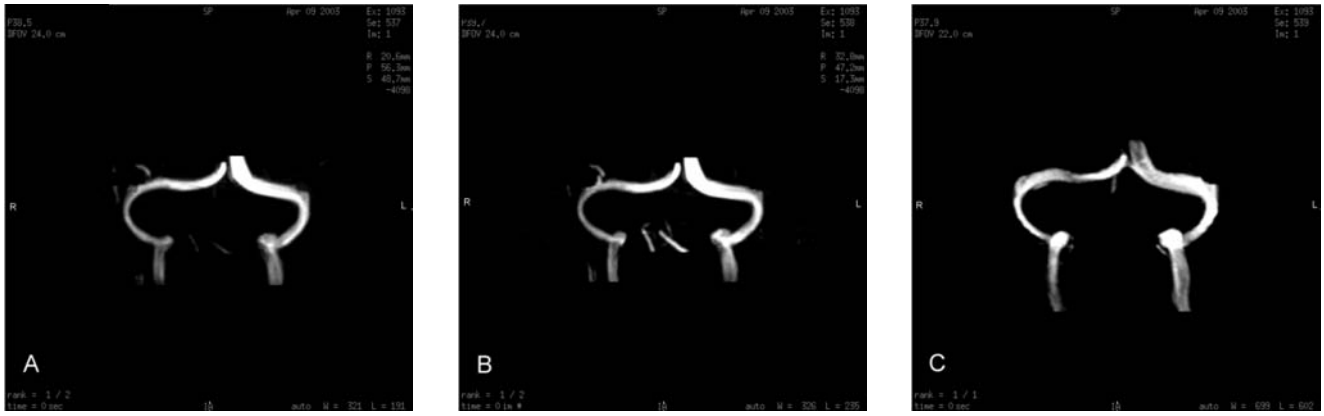

Fig. 1 a, b, c) Coronal MRV images in one normal control acquired with 3D-PC (VENC value of 15 cm/s (**a**), or VENC value of 40 cm/s (**b**)), and 2D-TOF (**c**). Similar intense and homogeneous visualization of TSs is obtained with all techniques

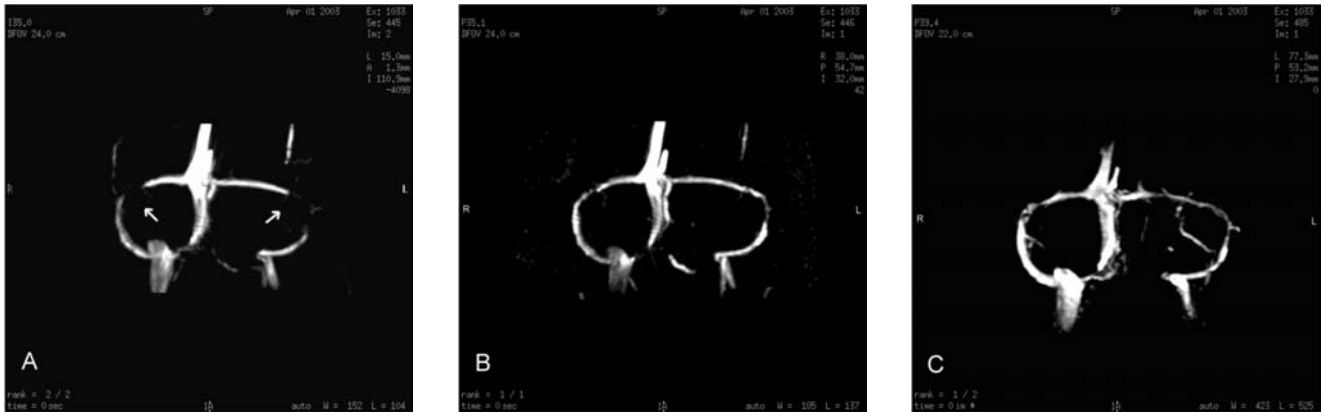

Fig. 2 a, b, c) Coronal MRV images in one representative IIH patient acquired with three different techniques: 3D-PC with VENC value of 15 cm/s shows bilateral disturbance of flow (arrowheads) in the mid-lateral portion of the TSs (**a**). 3D PC acquired with VENC value of 40 cm/s (**b**) and 2D-TOF (**c**) show only slight disturbances of flow at the same anatomical locations

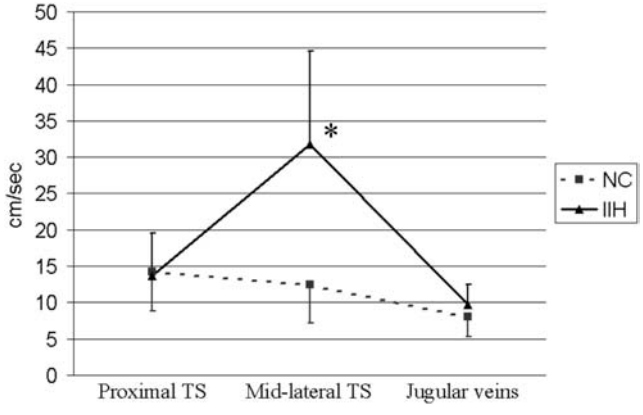

Fig. 3 Plot of flow velocity measured at the three different locations (proximal TS; mid-lateral of TS and jugular vein) in IIH and normal controls. A significant increase of flow velocity occurred in the TS at the level of the flow disturbance in IIH patients in comparison with the corresponding level of TS in normal controls (* $p < 0.0001$). No significant difference was found between patients and controls concerning flow velocity values calculated upstream and downstream to the poor signal in the mid-lateral portion of the TSs

to a marked stenosis in which there was a three-fold increase of flow velocity.

On the other hand no statistically significant differences were found when comparing flow velocity values measured either at the proximal portion of TS or at the jugular level in IIH patients to those calculated at the same levels in control subjects (13.5 ± 5.34 cm/s; $p = 0.34$ and 8.49 ± 2.8 cm/s; $p = 0.29$ respectively).

Discussion

In the current study we found that the 3D-PC MRV technique, with VENC set to 15 cm/s, was the most valuable non-invasive way for detecting disturbances of flow in the TSs of subjects with IIH. We also demonstrated that images of apparent poor signal in the mid-lateral portion of the TSs corresponded to a marked sinovenous stenosis, in which flow quantification measurements showed a three-fold increase of velocity.

There is evidence that disturbances of cerebral venous outflow, especially of TSs, can be associated with idiopathic intracranial hypertension with or without papilledema [1–8]. Detecting flow abnormalities in the TSs may be important for either diagnostic purposes or therapeutic strategy in subjects with symptoms suggestive of intracranial hypertension. Cerebral MRV is the technique of choice for non-invasive visualization of TSs signal, but the optimal sensitivity of the different sequences and applications is still unknown. Despite its well-documented weakness in evaluating the transverse and sigmoid sinuses, due to in-plane saturation and complex blood flow patterns, TOF MRV has been long used to investigate the venous system, due to its capability to visualize the whole cerebral venous system within a reasonable acquisition time.

However, TOF studies [12, 15] conducted in healthy controls or in subjects with dural venous disease gave inconsistent results, suggesting that TOF MRV may underestimate the disturbance of flow in the TSs. Conversely, 3D-PC MRV has been reported to be highly sensitive for visualizing abnormal TS flow signal in patients with IIH with or without papilledema [2–4].

In the current study we demonstrated that all IIH patients displayed disturbance of flow in both TSs on 3D-PC MRV images when VENC was set to 15 cm/s, whereas only slight disturbances of flow in the mid-lateral portion of TSs were found when the VENC was set to 40 cm/s, suggesting that VENC plays a pivotal role for detecting disturbance of flow in the TS. Likewise, a slight irregular flow was found in IIH patients when 2D-TOF was used, demonstrating that this technique underestimated disturbances of flow in the TSs. By contrast, the visualization of TSs flow signal in control subjects was similar with both 3D-PC and 2D-TOF techniques. In particular 3D-PC images acquired with VENC of 15 cm/s paralleled those acquired with VENC of 40 cm/s, suggesting that under physiological flow conditions, VENC may not be as important as in subjects with disturbance of flow in TSs.

Compared to TOF, the 3D-PC technique offers several advantages when investigating the dural sinuses. Firstly, it is sensitive to flow in all directions, which allows imaging of insidious regions with complex flow geometry. Its excellent background suppression greatly improves the sensitivity to slow flow. Secondly, it does not suffer from mimicking flow due to incorporation of methemoglobin within a thrombus. Thirdly, for a given a-priori estimate of flow velocity, it allows optimal visualization of flow-sensitive images through adaptation of VENC. Within a fixed range of VENCs, the venous blood flowing with that VENC will accumulate the maximum of phase shift (180°) and it will be encoded with the brightest signal.

Moreover, the quantification of flow velocity in arterial and venous vessels is allowed by the 2D-CINE PC acquisition technique. Since it is well known that flow velocity is inversely related to the vessel calibre [18], 2D-CINE PC flow measurements are important for evaluating possible vessel stenosis in which high velocity values can be measured. In our series, flow velocity measured in TSs of normal subjects was in good agreement with measures obtained by other authors by ultrasound methodologies [19]. Indeed, the mean value of 13 cm/s, measured by sonography in TSs of healthy controls [19], was strikingly similar to that obtained by 2D-CINE PC in the TSs of our control subjects (13.5 ± 5.4 cm/s), indicating the strong reliability of the latter technique for quantification of cerebral venous flow. In patients with IIH, the average flow velocity strongly increased at the level of the disturbance of flow, suggesting the presence of a severe sinovenous stenosis in the midlateral portion of TSs. Flow velocity at the intrastenotic level was significantly higher than the velocity measured proximally or distally to the stenosis, thus underlining the functional importance of the rapid accelerating jet occurring at the intrastenotic level. As expected, flow velocities did not differ between IIH patients and control subjects when measurements were performed over vessels with normal calibre, as the proximal TS and the jugular vein. The current data are in accordance with a previous study conducted in subjects with IIH without papilledema, showing that the flow disturbance images in the TS on MRV corresponded to a high-grade vessel stenosis on conventional digital angiography [3]. Similar findings have also been reported in a patient with IIH and MRV evidence of sinovenous obstruction in both TSs by using cerebral venography with manometry. In this patient, some authors [4] found a pressure gradient between the proximal and distal portion of TS, demonstrating that the poor flow signal detected on MRV corresponded to a severe sinovenous stenosis.

In conclusion, in subjects with IIH, 3D-PC with VENC set to 15 cm/s showed an image of poor signal in the mid-lateral portion of TSs, which disappeared when VENC was set to 40 cm/s, indicating that a faster VENC may mask the disturbance of flow, making the diagnosis difficult. 2D-CINE PC measurements showed a strong increase of velocity at the level of mid-lateral portion of TSs in subject with IIH, thus confirming that the disturbance of flow observed with slow VENC is not artifactual in nature, because they underlie a severe TSs stenosis, which is functionally coupled to focal abnormal vascular hydraulics. PC images acquired with a VENC of 40 cm/s and 2D-TOF images tend to bias the interpretation of MRV flow signal toward normality, underestimating the hemodynamic significance of the above-mentioned flow disturbances.

Acknowledgements The authors gratefully acknowledge Dr. Piero Ghedin (General Electric Medical Systems, Italy) for technical application support and Mrs. Gemma Di Palma (Institute of Neurological Sciences, Cosenza) for patients' assistance.

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