Comparing MR Estimate of Intracranial Pressure with Valve Opening Pressure in Shunted Patients

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Introduction

Noninvasive MR measurement of intracranial pressure (MRICP) may have a diagnostic role in several neurosurgical problems related to altered CSF dynamics. For example, MRI based measurement of ICP can assist in the diagnosis of idiopathic normal pressure hydrocephalous, idiopathic intracranial hypertension as well as in hemorrhagic stroke. Initial validation of the MRICP was obtained by comparing the MR derived ICP value with values measured invasively in adult patients with acute subarachnoid hemorrhage who had external ventricular drainage catheter during the time of the MRI scan. Invasive ICP reading was taken immediately before and after the scan while the patient is on the MRI scanner table. A strong linear relationship was found, in these patients, between the invasive ICP value and the MRI derived values of the elastance index [1]. The linear relationship between elastance and ICP is expected due to the monoexponential relationship between intracranial volume and pressure [2]. The elastance index is defined as the ratio of the maximal pressure and volume changes that occur during the cardiac cycle and is obtained from volumetric measurements of the pulsatile blood and CSF flows to and from the cranial vault. The current study evaluates derived MRICP values in patients with various diagnoses who are treated with pressure limiting ventriculo-peritoneal shunt. An MRICP value derived utilizing the previously established linear relationship between elastance and absolute ICP is compared to the shunt opening pressure setting. The aim of the study is to determine the reliability of estimated MRICP values in shunted patients with various CSF related disorders.

Methods

To date, fifteen consecutive shunted patients (median age 11 years; range 4 to 29 years; 6 female) were enrolled in the study. Five were diagnosed with Chiari Malformations type II, five were treated for hemorrhage, three were treated for aqueductal stenosis, and two for arachnid cyst. Two types of gravitational pressure limiting shunts were used, static and programmable pressure valves. The static valves (Miethke PEADI-GAV, B Braun, Melsungen. Germany) were all set to opening pressure of 9 cmH2O or 6.62 mmHg. The programmable valves (Miethke proGAV) were set to opening pressure values ranging from 7 to 16 cmH2O or 5.1 to 11.8 mmHg.

Patients were studied using a 3T MR scanner (Verio, Siemens). Retrospective velocity encoding phase contrast scans with VENC values of 70-90 cm/sec were used for imaging blood flow and 7-9 cm/s for imaging CSF flow at the upper cervical region. Imaging parameters include FOV of 14x11cm, matrix size of 256x160, minimum TE and TR, 2 views per segment, and one average resulting with total scan time of approximately 3.5 minutes. Volumetric flow rate waveforms of total arterial inflow, venous outflow and CSF were obtained using the Pulsatility Based Segmentation (PUBS) technique, which utilizes the velocity waveform at each pixel to differentiate between lumen and background region [3]. Intracranial volume change waveform is derived by integration with respect to time of the net trans-cranial volumetric flow rate waveform, which is simply the momentary difference between arterial inflow, venous outflow, and craniospinal oscillatory CSF flow. Finally the pressure change during the cardiac cycle is estimated from the CSF pressure gradient waveform, which is calculated using the Navier-Stokes relationship between temporal and special derivatives of CSF velocities and pressure gradient. Elastance index is then the ratio of the maximal pressure and volume changes. Derived MRICP values were then compared to the pressure setting of the shunt-valve for all valve types, and separately for the programmable valves. Pearson's correlation coefficient was calculated to assess the strength of the correlation. Differences between the two measures were calculated using Wilcoxon-test.

Results

An example of blood and CSF flow velocity images and calculated intermediate waveforms used for derivation of the MRICP value from one of the patients are shown in Figures 1 and 2, respectively. Strong linear correlation was found between valve pressure setting and MR-ICP values with correlation coefficient value of 0.72 (p < 0.01). A greater R value of 0.86 was found for the programmable shunts where pressure setting spanned a much wider pressure range. Corresponding scatter plots and the linear regression lines are shown in Figure 3 left and right, respectively. The MRICP values were on average higher than the valve opening pressure setting by 1.3 mmHg. Mean MR-ICP was 8.7 mmHg (IQR 1.5 mmHg) and mean setting of the VP-shunt valve was 7.4 mmHg (IQR 1.4 mmHg).

Conclusion

Overall there is a good correspondence between the valve opening pressure setting and the MR estimate of ICP. The statically significant strong linear correlation between the two variables supports the validity of the previously established linear relationship between elastance index and absolute ICP. Two possible interpretations for the higher MRICP values are: 1) MRICP value overestimates the true ICP by approximately 1.3 mmH, and 2) ICP is slightly higher than the shunt pressure setup due to the resistance for CSF outflow through the shunt. Additional studies are warranted to further assess the reliability and robustness of the MRICP measurement across different pathologies.

References

[1] Alperin et al, Radiology, 2000; 217:877-885.
[2] Marmarou et al, J Neurosurgery, 1975; 43:523-534.
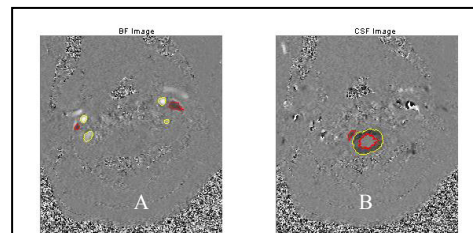[3] Alperin and Lee. Mag. Reson. Med., 2003; 49: 934-944.

Fig. 1 Blood (A) and CSF (B) velocity images with superimposed segmented lumens.
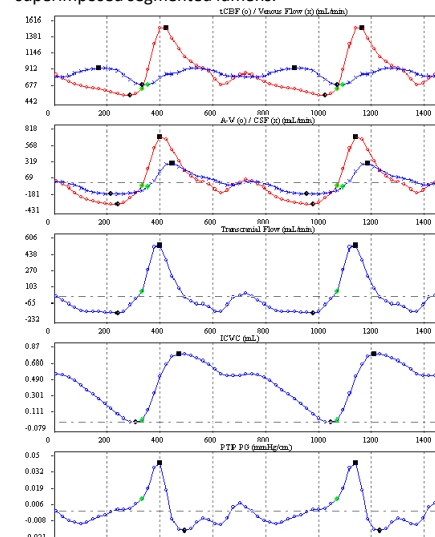

Fig. 2 Waveforms used for derivation of MRICP: Arterial inflow (A) and venous outflow (V), A-V and CSF, net – trans-cranial flow, intracranial volume change and CSF pressure gradient.
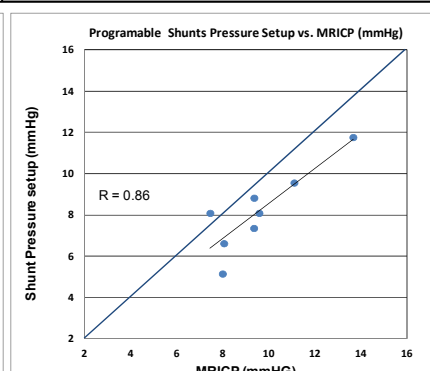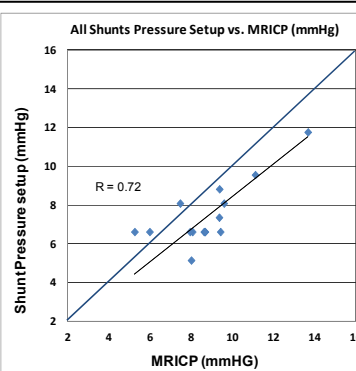

Fig 3. Relationship between shunt valve pressure setting and MRI derived measurements of ICP in 15 consecutive shunted patients studied to date. A strong linear correlation was demonstrated. On average MRICP values were 1.3 mmHg higher than vulvae pressure setting.