# Effectively Improving Accuracy and Reliability in Intracranial Volume Change for MR Intracranial Pressure Measurement

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**[Purpose]** Non-invasive MR intracranial pressure (MR-ICP) measurement shows promising potential for monitoring patients with various central nervous system (CNS) disorders [1]. Currently however, MR-ICP has not been clinically applicable, likely due to limited accuracy and reproducibility as a result of biological and technical variations. Particularly, estimation of the peak-to-peak intracranial volume change ($ICVC_{PP}$) for the derivation of ICP was reported to have a high variance [2]. Heart beat variation between separate scans has been proposed as a major biological cause of ICVC variation [3]. In this study, we investigated whether the distinct internal jugular venous (IJV) flow patterns, conventionally used to represent right atrial hemodynamics [4], as a function of measurement location is a major contributing factor to variations in ICVC calculations that may lead to limited applicability in MR-ICP measurements.

**[Materials and Methods]** Four healthy young volunteers were scanned in a 1.5 T MRI scanner with retrospective ECG-gated cine phase contrast MR imaging. MR-ICP is derived by measuring small fluctuations in intracranial volume and pressure during the cardiac cycle [1]. The intracranial volume change (ICVC) was obtained by summing up the transcranial blood and CSF flow. The spinal CSF pressure gradient was derived using the Navier-Stokes relationship between the temporal and spatial derivatives of fluid velocity.

Blood and CSF flow were measured using velocity-encoding values of 120 and 15 cm/s, respectively, along the slice direction. While the low-venc PC-MRI series were performed on the C2-3 level, the high venc blood-flow series were performed at three different locations: superior sagittal sinus (SSS) and straight sinus (STS), bilateral internal carotid arteries (ICA) below the foramen magnum, vertebral arteries (VA) at C2-3 level near the carotid bifurcations. In such cases, bilateral IJV flow rates could also be obtained at two of these sites ($IJV_{fmag}$, $IJV_{C2-3}$). Time-varying ICVC was then calculated following the method described in the literature [1]. The measurement variability was tested with three consecutive scans, three times with a one-week interval (i.e. 9 scans per subject). An additional experiment was conducted on one subject to further evaluate the changes in IJV flow pattern along the craniocaudal direction, where ten PC-MRI series were acquired, starting from the foramen magnum, shifting 1.5cm caudally per slice. In addition to ICVC, the pulsatility index (Pi) at each venous level was also calculated.

**[Results]** Figure 1 showed the IJV outflow patterns at different locations. Pi of IJV appears to have increased as slice position shifted caudally. $ICVC_{PP}$ also showed the same result. The results presented an exceptionally high correlation between Pi and $ICVC_{PP}$ ($r^2$ = 0.9956), as shown in Figure 2.Table 1 provided the summary of results from all 36 scans. $ICVC_{PP}$s calculated using 3 separate venous outflows showed that $ICVC_{PP}$ obtained using $IJV_{C2-3}$ were significantly higher than those from $IJV_{fmag}$ or from "SSS+STS" ($P < 10^{-5}$). The distinct results were reflected in the ICVC patterns, as shown in Figure 3.

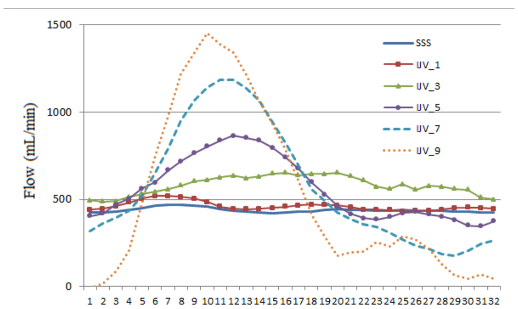


Figure 1. The graph shows venous flow waveform of intracranial sinuses and IJVs on five levels.

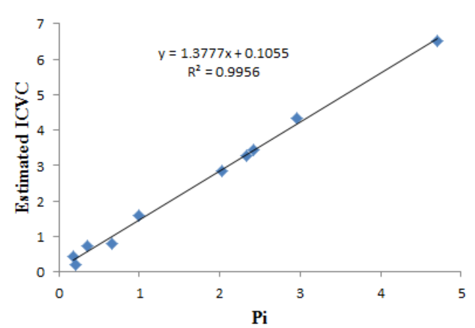


Figure 2. Linear correlation of Pulsatility index and estimated ICVC.

**[Discussion]** Our result showed caudal increase in IJV pulsation, suggesting that estimated $ICVC_{PP}$ lacked accuracy due to the fact that IJV flow patterns at lower positions represented right atrial instead of intracranial hemodynamics [4]. Therefore, the measurement level of IJV alone could contribute to a substantial amount of error in $ICVC_{PP}$ estimations. Cranially positioned slices better present the intracranial hemodynamics, thus show more overall accuracy. As a result, $ICVC_{PP}$ derived using $IJV_{fmag}$ and $IJV_{C2-3}$ showed significantly distinguished results in mean $ICVC_{PP}$ and its coefficient of variation. Although $IJVC_{2-3}$ was commonly used for $ICVC_{PP}$ measurement in past studies, risk of overestimation would be inevitable. In conclusion, measurement of IJV flow for MR-ICP should be properly positioned, preferably as cranially as possible to the level of foramen magnum, in order to acquire accurate and reliable results with minimal interferences from the right heart.

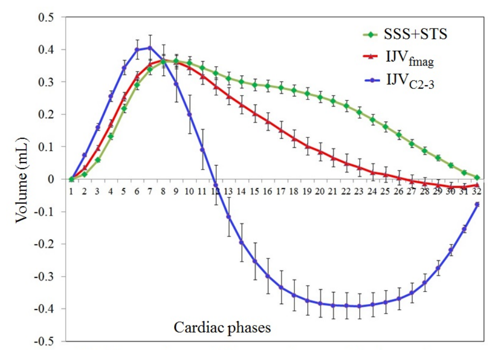


Figure 2. The waveforms of the mean intracranial volume change during 32 phases in a cardiac cycle computed from arterial, venous and CSF flow rates in 36 measurements of 4 volunteers with different venous outflow levels at SSS+STS, $IJV_{fmag}$ and $IJV_{C2-3}$.

**Table 1: Comparison of ICVC and Elastance index from SSS+STS, IJV-fmag, IJV-C2-3.**

| | Peak-to-peak ICVC (ml) | | Peak-to-peak pressure gradient (mmHg/cm) | | Elastance. (mmHg/cm/mL) | |
|---|---|---|---|---|---|---|
| | mean | CV | mean | CV | mean | CV |
| SSS+STS | 0.42±0.15 | 0.26±0.05 | | | 0.14±0.05 | 0.31±0.06 |
| IJV-fmag | 0.46±0.21 | 0.17±0.05 | 0.054±0.011 | 0.12±0.07 | 0.14±0.09 | 0.24±0.12 |
| IJV-C2-3 | 0.94±0.39 | 0.19±0.07 | | | 0.06±0.02 | 0.23±0.08 |

**[References]**

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