# A noninvasive technique to evaluate intracranial compliance and pressure using MR flow quantification and inverse circuit analysis

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## INTRODUCTION

Noninvasive techniques (1, 2) to measure intracranial pressure (ICP) and brain compliance have been developed based on intracranial volume changes calculated from MR flow measurements and volume-pressure relationships approximated by the Navier-Stokes theorem. To further extend such noninvasive methodologies, an alternative technique using inverse analysis of a brain-circulation-equivalent electrical circuit model, in which MR-measured flow rates were given as currents, was proposed (3). In this paper, preliminary results with healthy and patient subjects are presented.

## METHODS

Two major brain circulation systems including blood and cerebrospinal fluid (CSF) flows, were modeled by an electrical circuit, as shown in Fig. 1. Relationships between circuit components of the fluid and the electrical systems are shown in Table 1. Brain circulation was analyzed by inversely determining circuit elements at the second side circuit ($X_2$, $R_2$, M) based on currents obtained from arterial blood flow rate ($I_1$) and CSF flow rate ($I_3$). The estimation function corresponded to the sum of the square error of the estimated CSF flow rate from the measured one. Parameters $X_2$, $R_2$ and M were estimated using the simplex method (4). One thousand sets of initial conditions were allocated to the parameters, and estimated values were mapped in the $X_2$-$R_2$-M space. Flow phantom experiments were performed using a 1.5T scanner (Gyroscan, Philips), and a phase-contrast sequence with the following settings: TR/TE/FA, 20.1 ms/12.7 ms/10$^{o}$; slice thickness, 10 mm; FOV, 160 $\times$ 160 mm$^2$; spatial matrix, 256 $\times$ 256; VENC, 8 or 70 cm/s. Studies using 26 healthy (22-63 years old) and 21 patient (27-78 years old) subjects were performed with identical settings as above, except for VENC of 80-100 for blood, and 5-10 for CSF.

## RESULTS

Numerical simulations and phantom experiments revealed that the estimated circuit parameters converged to line-like shapes, from which ratios of parameters were obtained. Indexes for ICP and brain compliance, ICPI and BCI, were defined as $1/(M \cdot I_3)$ and $M/X_2$, respectively. Typical flow velocity images in a healthy subject are shown in Fig. 2. Data in the human subjects were mapped within the two-dimensional space formed by the indices. Healthy and patient groups were distributed in significantly different regions as shown in Fig. 3.

## DISCUSSION

Results demonstrated that the proposed technique had feasibility and viability for classifying intracranial biomechanical properties of the subjects. An important advantage of this technique is that the venous flow rate, which is usually difficult to precisely measure based on MR flow images because of high elasticity of veins, is not required for the entire process. Quantitative evaluations of absolute ICP and brain compliance are under examination.

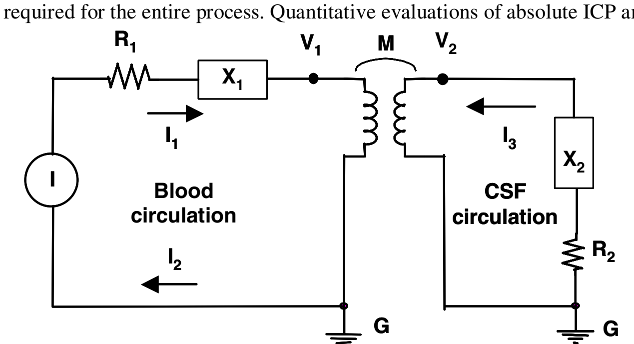


Fig. 1. Electric circuit representing brain circulation.

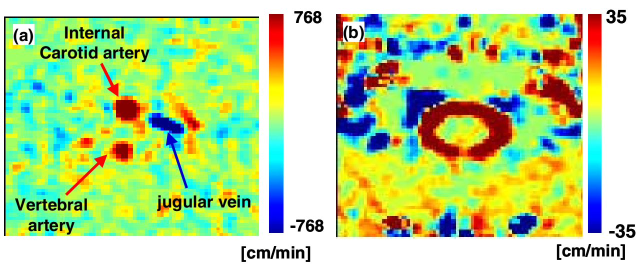


Fig. 2. Typical flow velocity maps of a healthy volunteer. (a) Blood flow and (b) CSF flow. Up-flows in the inferior-to-superior direction are shown as positive values, while down-flows in the opposite direction are shown as negative values.

Table 1. Fluid, electrical elements, and variables (refer to Fig. 1 for circuit configuration.)

| Fluid | Electrical |
|---|---|
| Blood circulation | 1st order circuit |
| CSF circulation | 2nd order circuit |
| Ventricle wall | Transformer |
| Heart | Current source |
| Arterial flow rate<br>Venous flow rate<br>CSF flow rate | Current, $I_1$<br>$I_2$ (= $I_1$)<br>$I_3$ |
| Atmospheric pressure | Ground voltage, G |
| Pressure on the brain tissue side<br>Pressure on the ventricle side | Voltage, $V_1$<br>$V_2$ |
| Compliance and intertance<br>for blood circulation<br>for CSF circulation | Reactance<br>$X_1$<br>$X_2$ |
| Resistance<br>for blood circulation<br>for CSF circulation | Resistance<br>$R_1$<br>$R_2$ |

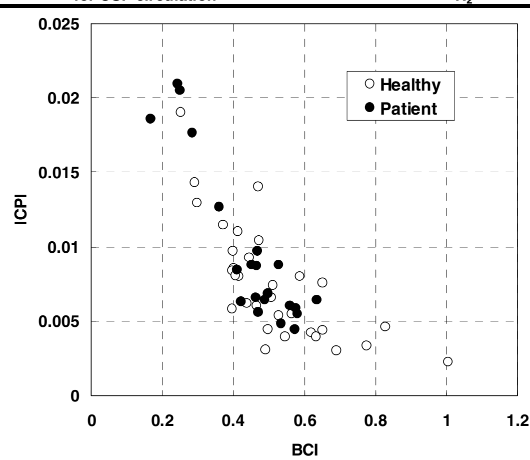


Fig. 3. Volunteer data plot in the ICPI-BCI space. Bottom right represents the low-pressure, high compliance region relevant to healthy brain circulation, while the top left corresponds to the high pressure, low compliance region relevant to possible brain circulation disorder.

## ACKNOWLEDGEMENTS

This work was supported by a Grant-in-Aid for Scientific Research, Japanese Society for the Promotion of Science, #15500325.

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