Intracranial compliance and pressure measurement based on MR flow quantification and brain circulation model circuit: Sensitivity to hyperventilation and hydrocephalus

K. Kuroda[1], K. Maruhashi[1], M. Ohya[1], M. Honda[2], H. Atsumi[3], K. Oshio[4], and M. Matsumae[3]

[1]Course of Information Science and Technology, Graduate School of Engineering, Tokai University, Hiratsuka, Kanagawa, Japan, [2]Department of Radiology, Tokai University Hospital, Isehara, Kanagawa, Japan, [3]Department of Neurosurgery, School of Medicine, Tokai University, Isehara, Kanagawa, Japan, [4]Department of Radiology, School of Medicine, Keio University, Shinanomachi, Tokyo, Japan

INTRODUCTION

We have proposed a noninvasive technique to evaluate brain compliance index (BCI) and intracranical pressure index (ICPI) based on the inverse analysis of a brain-circulation-equivalent electrical circuit model, in which MR-measured flow rates were given as currents(1). Validity of the technique was assessed by phantom experiments followed by volunteer experiments to compare the BCI and ICPI with the relating results obtained by an approach based on the Navier-Stokes relationship(2,3). In the present study, we have applied our technique to healthy volunteers with different physiological conditions and also to patients with hydrocephalus.

METHODS

In our technique, two major brain circulation systems, blood and cerebrospinal fluid (CSF) flows, were modeled by an electrical circuit shown in Fig. 1. Brain circulation was analyzed by inversely determining the circuit elements (X_2, R_2 and M) at the second-order side of the circuit based on the currents obtained as the arterial blood flow rate (I_1) and CSF flow rate (I_2). The BCI was defined as M/X_2, while the ICPI was defined as the voltage (V_2) of the circuit. All the human studies were approved by the internal review board of our institution and appropriate informed consent was obtained from the volunteers. Quantitative phase-contrast flow measurements were performed by a 1.5T scanner for 6 healthy volunteers (Males, 21-25 years old) with a couple of different physiological conditions. During the flow acquisitions, each volunteer was first requested to relax but to keep awake, and then to have deep and continuous breathing (15~20 times/min) to be slightly hyperventilated, and then to relax and awake again. The acquisition settings were as follows: TR/TE/FA, 20.1 ms / 12.7 ms / 10 degree; slice thickness, 10 mm; FOV, 160 × 160 mm^2; spatial matrix, 256 × 256; VENC, 80-100 cm/s for blood, and 5-10 cm/s for CSF. In order to examine the effect of pre-experimental conditions of the volunteers, each patient was also requested to have walking exercise (stairs up/down, around 400 steps) immediately before scanning in the separate experiments. Moreover, 3 hydrocephalus patients were scanned for the BCI and ICPI measurements to evaluate the diagnostic ability of the technique.

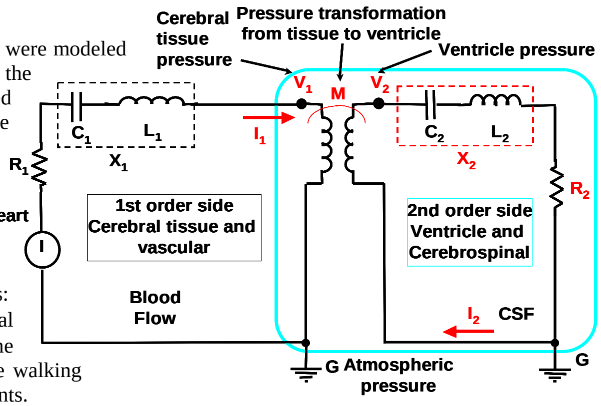

Fig. 1 Electric circuit representing brain circulation.

RESULTS

Changes in the arterial blood and CSF flows induced by hyperventilation are demonstrated in Fig. 2. Effects of the hyperventilation and exercise to the BCI and ICPI are compared in Fig. 3. The BCI-ICPI plot is shown in Fig. 4 for the healthy volunteers including those who were scanned in the past, , and the hydrocephalus patients.

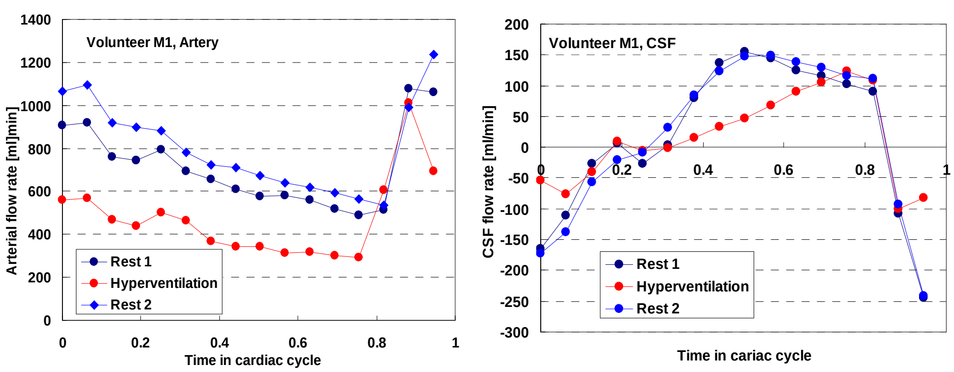

Fig. 2 Typical changes in the arterial and CSF flows induced by hyperventilation.

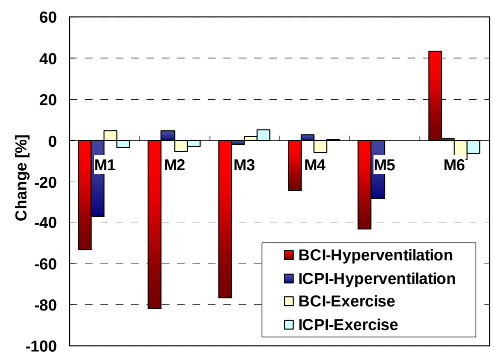

Fig. 3 Change in the BCI and ICPI for hyperventilation and exercise conditions.

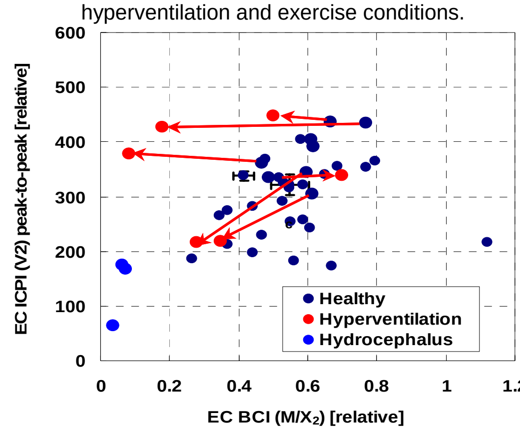

Fig. 4 BCI-ICPI plot for the healthy and patient volunteers. The red arrows indicate the changes of the indexes with hyperventilation.

DISCUSSION

It is known that hyperventilation reduces the cerebral and peripheral arterial blood flows through vasoconstriction induced by blood alkalization with decrease of CO_2 concentration. This physiological response is recognized in the blood and CSF flows shown in Fig. 2. The marked negative changes of BCI in the 5 volunteers may be interpreted to be caused by the "deflation" of the cerebral tissue with vasoconstriction. The BCI changes in the exercise task were obviously smaller than those in the hyperventilation task. These observation suggested that the proposed technique is sensitive to the brain compliance change. In the BCI-ICPI plots shown in Fig. 4, the hydrocephalus data located at the low BCI and IPCI region remote from the normal volunteers. These results agreed with the diagnostic findings of two experienced neurosurgeons in our group.

REFERENCES

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