Comparison of the noninvasive techniques to evaluate intracranial compliance and pressure based on MR flow quantification

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INTRODUCTION

We have proposed a noninvasive technique to evaluate intracranial pressure (ICP) index and brain compliance (BC) index based on the inverse analysis of a brain-circulation-equivalent electrical circuit model, in which MR-measured flow rates were given as currents(1). Although validity of the technique was assessed by phantom experiments followed by volunteer experiments, the relationships of the indexes of ICP and BC with the relating results obtained by an alternative approach based on the Navier-Stokes relationship(2) have not been examined. In this study, such relationships were evaluated to take advantages of the two different techniques.

METHODS

Quantitative phase contrast flow measurements were performed for 30 healthy volunteers (23-63 years old) and 20 patient volunteers (15-62 years old) with brain tumors by using a 1.5T scanner (Gyroscan, Philips) with the following settings: 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 the equivalent circuit technique, two major brain circulation systems including blood and cerebrospinal fluid (CSF) flows, were modeled by an electrical circuit, as shown in Fig. 1. Detailed relationships between the circuit elements and the fluid components were shown elsewhere(1). Brain circulation was analyzed by inversely determining the circuit elements at the second-order side of the circuit (X_2, R_2, M) based on the currents obtained as the arterial blood flow rate (I_1) and CSF flow rate (I_2). The BC index was defined as M/X_2, while the ICP index was defined as the voltage (V_2) of the circuit.

In the Navier-Stokes technique, the same data sets were used for calculating the pressure gradient in the CSF flow appearing in the following equation;

$$\nabla p = -\rho \frac{\partial \mathbf{v}}{\partial t} - \rho(\mathbf{v}\cdot\nabla)\mathbf{v} + \mu\nabla^2\mathbf{v} \qquad [1]$$

where p is pressure, v is CSF flow velocity, ρ is density and μ is viscosity. Because of the low viscosity and non-convective properties of the CSF flow, the second and third term of the right side of the equation could be neglected(2). Only superior-inferior flow was considered. Correlation between the resultant pressure gradient obtained by this equation and ICP index obtained by the equivalent circuit technique was evaluated.

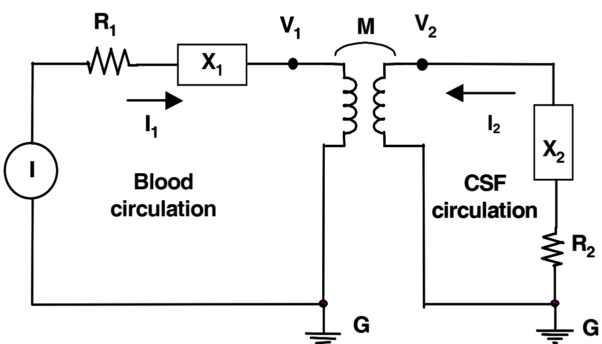

Fig. 1 Electric circuit representing brain circulation.

RESULTS

Relationship between the two different ICP indexes, peak-to-peak amplitude of the pressure gradient calculated by equation [1] and that of the voltage V2 in the equivalent circuit, is shown in Fig. 2. Mapping of the volunteer data for Navier-Stokes-based ICP index and equivalent-circuit-based BC index is shown in Fig. 3.

DISCUSSION

The ICP index defined as the circuit voltage correlated well with that defined as the fluid pressure gradient with correlation coefficients of 0.72 and 0.90 for healthy and patient volunteers, respectively. The high correlation was because both of the ICP indexes were based on the CSF flow. For BC index, venous flow has to be used in the Navier-Stokes technique to calculate total fluid volume change(2). In the equivalent circuit technique, the venous flow is not needed because the index is calculated as the circuit voltage determined by the product of CSF flow rate (I_2) and the reactance (X_2). Based on these considerations, the combination of ICP index obtained by the Navier-Stokes technique and BC index obtained by the equivalent circuit technique seemed to be appropriate for charactering the brain circulation status of the volunteers. Clinical interpretation of the map shown in Fig. 3 is under our current examination.

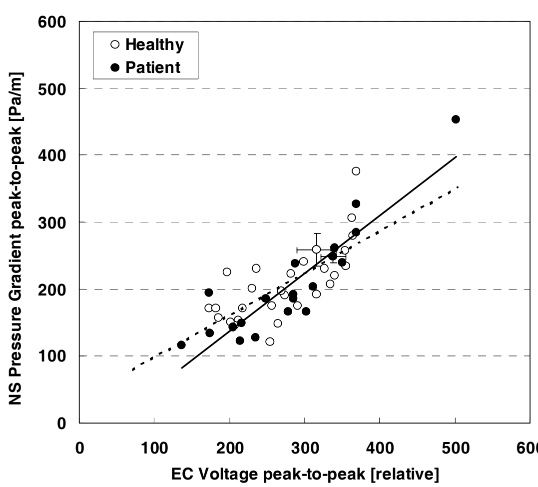

Fig. 2 Relationships between the peak-to-peak pressure gradient obtained by the Navier-Stokes (NS) technique and the peak-to-peak voltage of the second-order side of the equivalent circuit (EC). Correlation coefficients were 0.72 and 0.90 for healthy and patient volunteers, respectively.

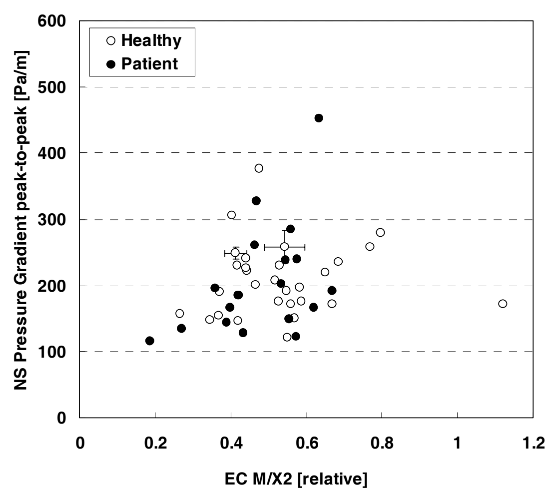

Fig. 3 Map of BC index defined as the M/X_2 ratio in the EC technique and the ICP index defined by the peak-to-peak pressure gradient obtained by the NS technique.

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REFERENCES

1. Kuroda K, Kanno T, Maruhashi K, Tanabe Y, Oshio K, Honda M, Muro I, Matsumae M. Proc Intl Soc Mag Reson Med, 2006; p 1914.
2. Alperin NJ, Lee SH, Loth F, Raksin PB, Lichtor T. Radiology 2000;217:877-885.