Impact of Aneurysm Location on Cardiopulmonary Dysfunction after Subarachnoid Hemorrhage

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Background: Cardiopulmonary dysfunction may occur after aneurysmal subarachnoid hemorrhage (SAH), but its characteristics have not been fully clarified. We investigated the impact of aneurysm location on systemic hemodynamics after SAH. *Methods:* This multicenter prospective cohort study measured hemodynamic parameters in relation to aneurysm location in patients with SAH using a single-indicator transpulmonary thermodilution system (PiCCO) on days 1-14. *Results:* Of 204 subjects enrolled, 58 had aneurysms of the anterior communicating artery (ACA), 61 of the middle cerebral artery (MCA), 57 of the internal carotid artery (ICA), and 28 of the vertebrobasilar artery (VA/BA). Patient characteristics were similar except for predominance of coiling in the VA/BA. Patients with ACA aneurysm had a lower systemic vascular resistance index (SVRI) in the acute phase and afterload mismatch (lower cardiac index [CI] and higher SVRI) in the spasm phase. Those with ICA aneurysm had a lower CI in the acute phase, and those with VA/BA aneurysm had a warm shock-like condition (higher CI and lower SVRI) in the spasm phase. Patients with MCA aneurysm showed no specific characteristics in CI and SVRI with a significant improvement in B-type natriuretic peptide. Extravascular lung water index was high independent of left cardiac dysfunction. In multivariate analysis, age and ACA were independently related to poor global ejection fraction after SAH. *Conclusions:* Aneurysm location affects cardiac output, vascular resistance, and pulmonary edema in biphasic fashion. Patient age and location of aneurysm in the ACA may be risk factors for cardiac failure after SAH. **Key Words:** Subarachnoid hemorrhage—aneurysm location—systemic hemodynamics—cardiopulmonary dysfunction.

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Cerebral vasospasm is a leading cause of morbidity and mortality in patients with aneurysmal subarachnoid hemorrhage (SAH), and volume management is a critical component of its assessment. SAH is often associated with cardiopulmonary complications, including arrhythmia,[1] cardiac dysfunction (neurogenic stunned myocardium),[2-4] and neurogenic pulmonary edema,[5-7] which also contribute to post-SAH morbidity and mortality. It is therefore important to develop reliable assessment modalities for close monitoring of systemic hemodynamic status after SAH. It has been reported that marked sympathetic activation is linked to cardiopulmonary complications,[8,9] and studies have identified predictors of neurogenic manifestations based on chest

x-ray, electrocardiogram, or cardiac ultrasound.[10-12] However, little is known about cardiopulmonary complications based on systemic hemodynamic parameters after SAH.[13-16]

Because transpulmonary thermodilution (PiCCO; Pulsion Medical Systems, Munich, Germany) can measure important hemodynamic parameters without the need for cardiopulmonary catheterization,[16,17] it has gained increasing acceptance in many intensive care units[18,19] and for volume management in patients with SAH.[13-16,20] Therefore, PiCCO monitoring may provide new insights into the characteristics of cardiopulmonary dysfunction after SAH and real-time hemodynamic status.

This study aimed to determine whether location of the ruptured aneurysm has an impact on systemic cardiopulmonary hemodynamics after SAH and to assess the predictors of initial cardiopulmonary dysfunction after SAH based on hemodynamic parameters prospectively collected by the SAH PiCCO study group.

Methods

Study Population

Patients were included if they had a ruptured cerebral aneurysm diagnosed by cerebral angiography or 3-dimensional angiography. The exclusion criteria were the following: (1) <15 years of age; (2) absence of brainstem reflexes; (3) pregnancy; and (4) severe cardiopulmonary dysfunction requiring percutaneous cardiopulmonary support. Patients with rebleeding during the postoperative study period were also excluded because the accuracy of diagnosis of delayed cerebral ischemia (DCI) and the degree of pulmonary edema could be affected by rebleeding. The SAH PiCCO study was a multicenter prospective cohort study of SAH patients admitted to the 9 participating Japanese university hospitals. The study was approved by the appropriate ethics committees of all participating institutions, and written informed consent for treatment was obtained from all patients or their next of kin. The study was registered with the University Hospital Medical Information Network (UMIN) Clinical Trials Registry (http://apps.who.int/trialsearch/trial.aspx?trialid=JPRN-UMIN000003794): UMIN-CTR ID UMIN000003794.

All patients admitted to the 9 participating institutions with aneurysmal SAH between October 2008 and March 2012 were screened for eligibility. Patients who were monitored using the PiCCO system during the perioperative period were included in the study. All patients underwent aneurysm treatment (clipping or coiling) within 48 hours of the onset of symptoms of SAH. Treatment decisions were at the discretion of the attending physician.

Single-indicator Transpulmonary Thermodilution (PiCCO) Monitoring

All patients were monitored using PiCCO Plus on days 1-14 after SAH. A 4-French thermistor-tipped arterial catheter (PV2014L16; Pulsion Medical Systems, Munich, Germany) was inserted into the femoral or brachial artery. The arterial catheter and a central venous catheter were connected to pressure transducers and to the PiCCO Plus system for monitoring. Cardiac index (CI; normal range [NR], 3-5 L/minute/m^2) and systemic vascular resistance index (SVRI; NR, 1700-2400 dyn/second/m^2) were measured to assess afterload as left cardiac function and cardiac output. Global end-diastolic volume index (GEDI; NR, 680-800 mL/m^2) was measured to assess preload as right cardiac function. Extravascular lung water index (EVLWI; NR, 3.0-10.0 mL/kg) and pulmonary vascular permeability index (PVPI; NR, 1.0-3.0) were also measured to assess pulmonary edema. Finally, global ejection fraction (GEF; NR, 25%-35%) was measured to assess cardiac contractility as a marker of cardiac failure. The parameters were determined by continuous cardiac output (CO) calibration by triplicate central venous injections of 15 mL of ice-cold saline (<8°C). CO was calculated by analysis of the thermodilution curve followed by pulse–contour analysis for continuous monitoring. Details of the PiCCO monitoring protocol have been described elsewhere.[13,14]

Postoperative Management

Perioperative care was performed according to the standardized protocol for SAH provided by current American Heart Association guidelines.[21] Postoperative B-type natriuretic peptide (BNP), a marker of cardiac failure, was measured on day 1 (acute phase) and days 12-14 (delayed phase), and laboratory testing of the blood was performed until day 14. Cardiopulmonary function was monitored throughout the analysis until day 14. Intracranial and cerebrospinal fluid pressure were controlled by ventricular, cisternal, or spinal drainage. Blood transfusion was performed when hemoglobin and hematocrit levels were below the lower limit of the normal range. Triple-H (hypervolemia, hypertension, and hemodilution) therapy was administered for symptomatic vasospasm at the discretion of the attending physician.

Statistical Analysis

Data are presented as median values with 95% confidence intervals. Data were tested for normality of distribution and equal standard deviations using GraphPad InStat Version 3.10 (GraphPad Software, La Jolla, CA) to determine whether parametric or nonparametric assumptions should be used for each statistical method. Comparisons between groups were performed using the Mann–Whitney test for continuous variables and the χ^2 test for categorical