Int J Clin Exp Med 2019;12(4):3994-4002
www.ijcem.com /ISSN:1940-5901/IJCEM0077973

Original Article

Effects of goal-directed fluid management with 0.9% normal saline on metabolic acidosis in patients undergoing brain surgery: a prospective and randomized-controlled study

Namo Kim[1], Jae Hoon Lee[1], Do-Hyeong Kim[1], Kwan Woong Choi[2], Eungjin Kim[1], Seung Ho Choi[1]

[1]Department of Anesthesiology and Pain Medicine, Anesthesia and Pain Research Institute, Yonsei University College of Medicine, Seoul, Korea; [2]Department of Anesthesiology and Pain Medicine, National Health Insurance Service Ilsan Hospital, Seoul, Korea

Received April 15, 2018; Accepted November 9, 2018; Epub April 15, 2019; Published April 30, 2019

Abstract: Excessive administration of 0.9% normal saline (NS) can cause hyperchloremic metabolic acidosis during surgery. It was hypothesized that intraoperative administration of 0.9% NS by goal-directed fluid management based on stroke volume variation (SVV) could alleviate metabolic acidosis, compared to central venous pressure (CVP) based fluid management. Forty-eight patients, scheduled for elective craniotomy, were randomly allocated to CVP or stroke volume variation (SVV) groups. Cut-off values to challenge the fluids were set at 5 mmHg in the CVP group and 13 in the SVV group, respectively. Arterial blood samples were taken at T1 (immediately after induction), T2 (4 hours after induction), and T3 (at the end of surgery). The pH, standard base excess, and sum of all anion charges of weak plasma acid values at T2 and T3 were significantly lower than values at T1 in both groups. Apparent strong iron differences at T2 and T3 in the CVP group were significantly lower than those in T1, while there were no significant differences between time points in the SVV group. Lactate levels were significantly greater at T2 and T3 than at T1 in both groups. All measured values at each time point and interactions between the groups were comparable. In conclusion, intraoperative goal-directed administration of 0.9% NS did not alleviate the severity of metabolic acidosis, compared to CVP-guided fluid therapy, in patients undergoing brain tumor surgeries.

Keywords: Central venous pressure, goal-directed fluid management, metabolic acidosis, normal saline, stroke volume variation

Introduction

During brain surgery, intraoperative fluid management must be carefully controlled to preserve cerebral perfusion pressure [1]. Hypovolemia can cause inadequate cerebral perfusion, while fluid overload can result in brain edema and increased intracranial pressure. In general, balanced isotonic fluid is preferred to 0.9% normal saline (NS) for intraoperative fluid management. Administration of large volumes of 0.9% NS can result in metabolic acidosis, primarily caused by hyperchloremia [2]. However, 0.9% NS is still widely used in neurosurgery since it is not expected to contribute to cerebral edema induced by serum hypo-osmolality [3-5].

Static measurements of intravascular pressure, such as central venous pressure (CVP) and pulmonary artery occlusion pressure, generally reflect ventricular preload. However, according to current studies, there is no predictable relationship between these parameters and volumetric preload indices or cardiac performance variables [2, 6]. Additionally, dynamic indices, such as stroke volume variation (SVV) and pulse pressure variation, have emerged as alternatives guiding fluid administration [7]. Previous studies have revealed the efficacy of goal-directed intraoperative fluid therapy based on the use of dynamic indices, showing fewer complications [8] and better outcomes [9] for several surgery types. However, few studies have evaluated acid-base profiles after the use of goal-directed fluid therapy.

This study was designed to test whether intraoperative goal-directed fluid management

using 0.9% NS administration guided by SVV could alleviate metabolic acidosis in patients undergoing craniotomy and brain tumor removal, compared with fluid administration based on CVP. It was hypothesized that a fluid administration strategy based on the dynamic index might prevent either the degree of acidosis caused by hypervolemia with excessive chloride or lactic acidosis caused by hypovolemia with poor tissue perfusion.

Materials and methods

Patients

This prospective and randomized controlled study was performed after obtaining approval from the Institutional Review Board of Severance Hospital, Yonsei University Health System in Seoul, Republic of Korea. The study is registered at www.clinicaltrials.gov (Registration number: NCT01738880).

Fifty patients, scheduled for elective craniotomy and brain tumor removal, were enrolled in this study between July 2013 and June 2014. Patients between 20-65 years of age and with American Society of Anesthesiologists physical status scores of I-III were eligible. Patients with New York Heart Association functional classifications of III-IV, severe obstructive or restrictive lung disease, end-stage liver or kidney diseases, diabetes, pre-existing metabolic acidosis, or symptoms and signs of increased intracranial pressure were excluded from the study. Written informed consent was obtained from all patients before enrollment.

Before surgery, each patient was randomly allocated to one of two groups (CVP or SVV group). The anesthesiologist responsible for intraoperative care was aware of the treatment group for each patient. Other members of the research team and participants were blinded to treatment group assignments.

Anesthetic management

Each patient was premedicated with intravenous glycopyrrolate (0.2 mg) before induction of anesthesia. In the operating room, each patient received routine monitoring consisting of non-invasive blood pressure measurement, pulse oximetry, electrocardiography, and capnography. General anesthesia was induced using intravenous propofol (1.5 mg/kg) with remifentanil (1 μg/kg) and inhalation of sevoflurane (2-3 vol%). Endotracheal intubation was performed after ample muscle relaxation, obtained by administration of rocuronium bromide (0.8 mg/kg). Anesthesia was maintained using sevoflurane (1-2 vol%) and infusion of remifentanil (0.05-0.1 μg/kg/min), targeting a Bispectral index (BIS VISTA™, Aspect Medical Systems, Norwood, MA, USA) between 40 and 60. Ventilation was mechanically controlled using a tidal volume of 8 mL/kg of ideal body weight and a respiratory rate of 8-12 breaths/minute to maintain an end-tidal carbon dioxide concentration of 30-35 mmHg. An esophageal temperature probe was inserted and core body temperature was maintained at 36-37°C using a warm air blanket. Muscle relaxation was maintained using rocuronium infusions and train-of-four count monitoring during surgery to prevent patient movement. For continuous blood pressure monitoring and blood sampling, an arterial catheter used was inserted into the radial artery and a central venous catheter was inserted into the femoral vein. In the SVV group, the Vigileo-FloTrac™ System (Edwards Lifesciences, Irvine, California, USA) was connected to the invasive arterial blood pressure monitor for continuous SVV monitoring. The pressure transducer of arterial blood pressure and CVP measurement was zeroed at the level of the mid-axillary line at the beginning of surgery.

Intraoperative fluid management with 0.9% NS or 6% hydroxyethyl starch in 0.9% NS (Voluven®, Fresenius Kabi Deutschland GmbH, Bad Homberg, Germany) was conducted, following standard protocol for each treatment group (**Figure 1**). The maximal limit of 6% hydroxyethyl starch administration was 50 mL/kg. Ephedrine or phenylephrine was administered intravenously in cases of low mean arterial pressure (<65 mmHg) despite appropriate CVP or SVV values. Transfusion of packed red blood cells was performed when hemoglobin declined below 8 g/dL or when an acute massive bleeding event occurred. Before transfusion, compensation of intravascular volume loss due to bleeding was accomplished using the same amount of 6% hydroxyethyl starch solution. Upon the surgeon's request, 0.5-1.0 g/kg of mannitol was administered intravenously.

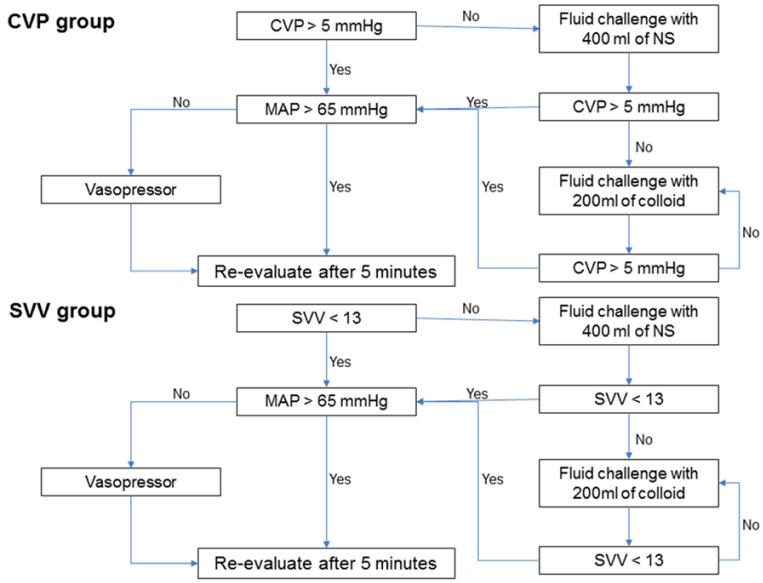

Figure 1. The protocol of fluid management in each group. CVP = central venous pressure; MAP = mean arterial pressure; NS = normal saline; SVV = stroke volume variation.

At 30 minutes before the end of the surgery, each patient received 1 μg/kg of fentanyl for postoperative pain control and 0.3 mg of ramosetron for prevention of postoperative nausea and vomiting. Neuromuscular blockade was reversed at the end of surgery using 0.04 mg/kg of neostigmine and 0.2 mg of glycopyrrolate. If conditions of the patient did not meet the criteria for extubation or the surgeon did not approve of extubation, the patient was transferred to the Neurosurgical Intensive Care Unit without anesthetic emergence and extubation.

Measurements and calculations

An arterial blood sample was taken at three time points: (T1) immediately after induction, (T2) 4 hours after induction, and (T3) at the end of surgery. Samples were analyzed for pH, $PaCO_2$, lactate, Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^- using a blood gas analyzer and for serum concentrations of phosphate and albumin. Values for standard base excess (SBE) and bicarbonate levels were calculated using the Henderson-Hasselbalch and Van Slyke equations, respectively. Since the classical approach often inadequately explains certain causes of acid-base derangement, parameters that determine metabolic acid-base status were calculated using Stewart's approach [10]. Parameters and abbreviations used in this study are presented in **Table 1**.

Statistical analyses

The primary endpoint of this study was to compare differences in SBE at the end of surgery (T3). Based on a previous study regarding SBE, in which a between-group difference of over than 50% was clinically significant [11], 25 patients were required in each group to achieve a two-sided α=0.05 with 90% power and a 10% of drop-out rate.

Distribution of data was assessed using the one-sample Kolmogorov-Smirnov test. Results are presented as mean ± standard deviation (SD) or median (interquartile range). Between-group comparisons were performed using Student's t-test. Mann-Whitney rank-sum test for continuous variables and χ^2 test and Fisher's exact test for categorical variables were applied, as appropriate. A linear mixed model (LMM) was used to assess changes in parameters related to acid-base status over time. All *P* values <0.05 are considered statistically significant. Statistical analyses were performed using SAS® software, version 9.2 (SAS Institute Inc, Cary, NC, USA).

Results

Forty-eight of the 50 enrolled patients completed this study. Two patients (one patient from each treatment group) had metabolic acidosis (SBE <5.0 mEq/L) at baseline and were excluded. Patient characteristics were similar between the two groups (**Table 2**). Intraoperative results are presented in **Table 3**. Colloid and ephedrine were administered to more patients in the CVP group than the SVV group. There were no other significant differences between the two groups.

Results for acid-base status, including pH, $PaCO_2$, and SBE, are presented in **Figure 2**. There were no significant changes in $PaCO_2$ over time in either group (**Figure 2B**). However, in both groups, pH values at T2 and T3 were significantly lower than those at T1 (**Figure 2A**). SBE values were significantly decreased at T2 and T3 in both groups, compared with baseline

Table 1. Abbreviations and calculations

Abbreviation	Definition	Calculation
SIDa	Apparent strong iron difference	$Na^+ + K^+ + Ca^{2+} + Mg^{2+} - Cl^- - Lactate^-$
SIDe	Effective strong iron difference	$HCO_3^- + Alb^- + Pi^-$
SIG	Strong iron gap	SIDa - SIDe
A_{TOT}	Sum of all anion charges of weak plasma acid	$Alb^- + Pi^-$
Alb^-	Negative charges of serum albumin	Serum albumin concentration [g/L] X (0.123 X pH - 0.631)
Pi^-	Negative charges of inorganic phosphate	Serum phosphate concentration [mmol/L] X (0.309 X pH - 0.469)

Table 2. Patient characteristics

	CVP group (n=24)	SVV group (n=24)	*P*-value
Age (y)	54 (43-60)	50 (39-57)	0.445
Height (cm)	159 (155-170)	164 (158-172)	0.142
Weight (kg)	62 (56-74)	64 (57-70)	0.820
Body mass index (kg/m^2)	25 ± 2	24 ± 2	0.115
Sex (M/F)	7/17	9/15	0.760
ASA (I/II)	10/14	13/11	0.564
Tumor type (M/C/G/S)*	13/2/8/1	16/2/6/0	0.814
Preoperative mannitol (n)	13 (54.2%)	9 (37.5%)	0.385

Values are expressed as a median (IQR), mean ± SD, or number of patients (percentage). *M, meningioma; C, craniopharyngioma; G, glioma; S, schwannoma.

Table 3. Intraoperative data

	CVP group (n=24)	SVV group (n=24)	*P*-value
Anesthesia time (min)	505 (465-550)	467 (393-571)	0.201
Surgery time (min)	395 (360-467)	373 (327-510)	0.523
Crystalloid (mL)	3900 (3000-4400)	3725 (3138-5175)	0.992
Colloid (mL)	400 (0-500)	0 (0-150)	0.027
Packed RBC transfusion (mL)	0 (0)	0 (0)	0.704
Urine output (ml)	1590 (1310-2490)	1865 (1158-3072)	0.934
Estimated blood loss (ml)	700 (500-1250)	615 (313-915)	0.140
Phenylephrine dose (mg)	0 (0-1.8)	0 (0-6)	0.245
Ephedrine dose (mg)	12 (6-24)	5 (0-16)	0.028
MBP (mmHg)			
T1	76.1 ± 13.8	73.8 ± 12.5	0.549
T2	73.1 ± 6.3	74.1 ± 9.9	0.666
T3	74.0 ± 8.5	75.0 ± 9.0	0.706
HR (beats/min)			
T1	64.5 ± 11.3	66.9 ± 12.8	0.484
T2	73.8 ± 11.4	68.3 ± 11.2	0.096
T3	76.0 ± 14.6	70.7 ± 8.8	0.130
Hemoglobin (g/dL)			
T1	12.1 ± 1.0	12.4 ± 1.2	0.438
T3	10.9 ± 0.9	11.3 ± 1.3	0.163
Intraoperative mannitol (n)	18 (75%)	23 (95.8%)	0.097

Values are expressed as a median (IQR) or mean ± SD or number of patients (percentage). T1: immediately after induction; T2: 4 hours after induction; T3: at the end of the surgery.

values (**Figure 2C**). SBE values in the CVP group were greater than those in the SVV group, especially at T3. However, there were no differences in any parameter at each time point between the groups. Changes in SBE over time were not significantly different between the two groups. Results for other variables that can affect acid-base status are presented in **Table 4**. Although there were changes in Na^+, Cl^-, and albumin values at each time point for each group, there were no significant between-group differences.

In **Figure 3**, changes in parameters that can determine acid-base status are presented. Apparent strong iron difference (SIDa) values at T2 and T3 in the CVP group were significantly lower than at T1. However, there were no significant changes in SIDa for any time points in SVV group patients (**Figure 3A**). The sum of all anion charges of weak plasma acid (A_{TOT}) at T2 and T3 decreased from that at T1 in each group (**Figure 3B**). At T2 and T3, lactate

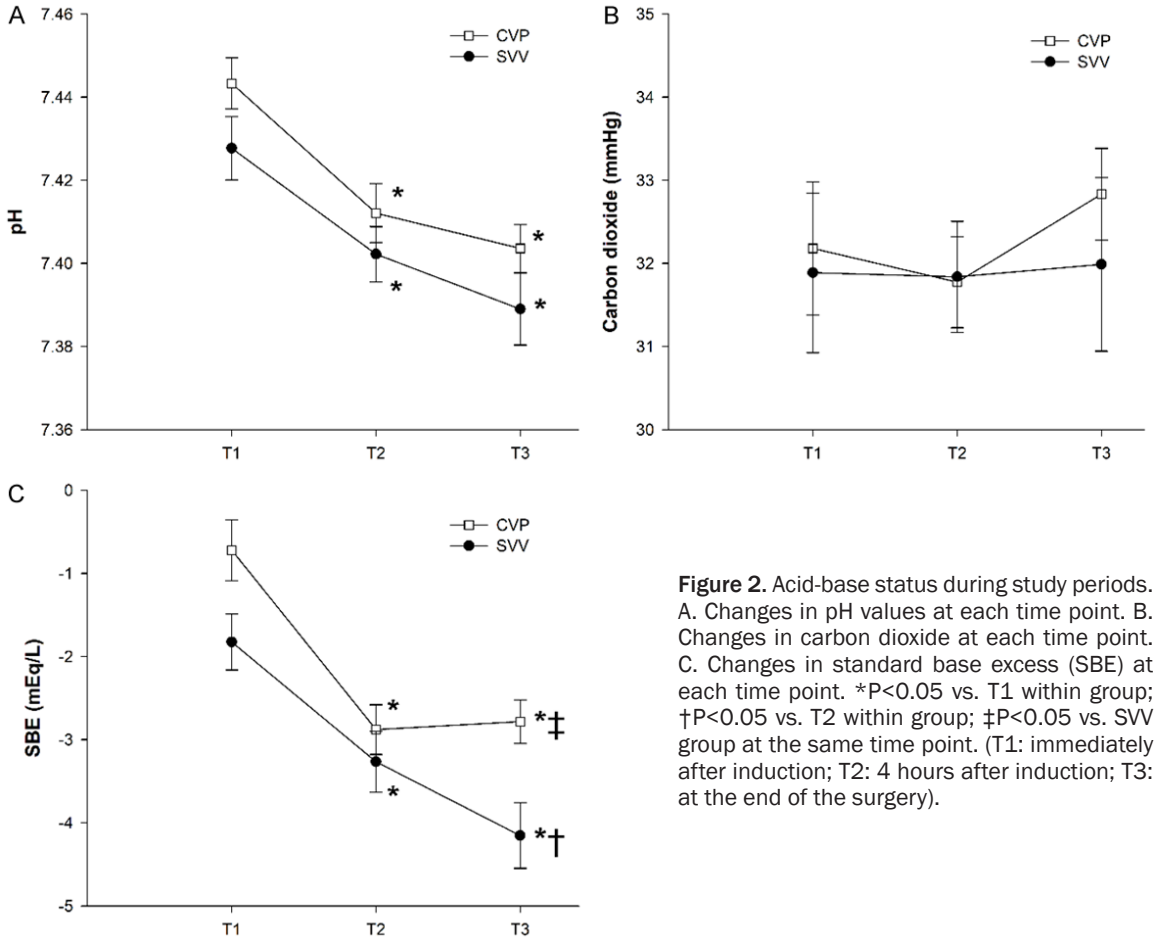

Figure 2. Acid-base status during study periods. A. Changes in pH values at each time point. B. Changes in carbon dioxide at each time point. C. Changes in standard base excess (SBE) at each time point. *P<0.05 vs. T1 within group; †P<0.05 vs. T2 within group; ‡P<0.05 vs. SVV group at the same time point. (T1: immediately after induction; T2: 4 hours after induction; T3: at the end of the surgery).

Table 4. Measured parameters that affect metabolic acid-base status

	T1	T2	T3
Na^+ (mmol/L)			
CVP group	138.1 ± 3.7	138.8 ± 3.8	140.0 ± 3.5*
SVV group	137.9 ± 2.5	139.1 ± 2.7	140.3 ± 2.6*
Cl^- (mmol/L)			
CVP group	110.5 ± 3.5	113.3 ± 3.3*	114.8 ± 3.4*
SVV group	111.1 ± 3.2	113.2 ± 2.9*	115.1 ± 3.2*,†
Albumin (g/L)			
CVP group	35.7 ± 4.8	29.6 ± 3.3*	28.8 ± 2.9*
SVV group	34.6 ± 3.8	30.8 ± 4.9*	29.7 ± 4.4*

Values are expressed as a mean ± SD. *P<0.05 vs. T1 within group; †P<0.05 vs. T2 within group. T1: immediately after induction; T2: 4 hours after induction; T3: at the end of the surgery.

levels were significantly greater than those at T1, while levels were highest at T2 in each group (**Figure 3C**). There were no significant differences in strong iron gap (SIG) levels among the time points for either group (**Figure 3D**). There were also no significant differences between the two groups at each time point or in interactions between the groups.

Discussion

The primary outcome of this study was to evaluate whether goal-directed fluid management using SVV could alleviate the severity of metabolic acidosis after intraoperative 0.9% NS infusion in patients undergoing brain tumor surgeryies, compared with CVP-guided fluid management. The current study revealed that, compared to CVP, SVV-guided fluid management did not improve metabolic acidosis.

Conventionally, CVP is frequently used to make decisions regarding the administration of fluids or diuretics. In the past, internationally endorsed clinical guidelines [12] recommended using CVP as a reference of appropriate fluid resuscitation. Although there is controversy about its benefits regarding outcomes, one of the goals of early goal-directed therapy

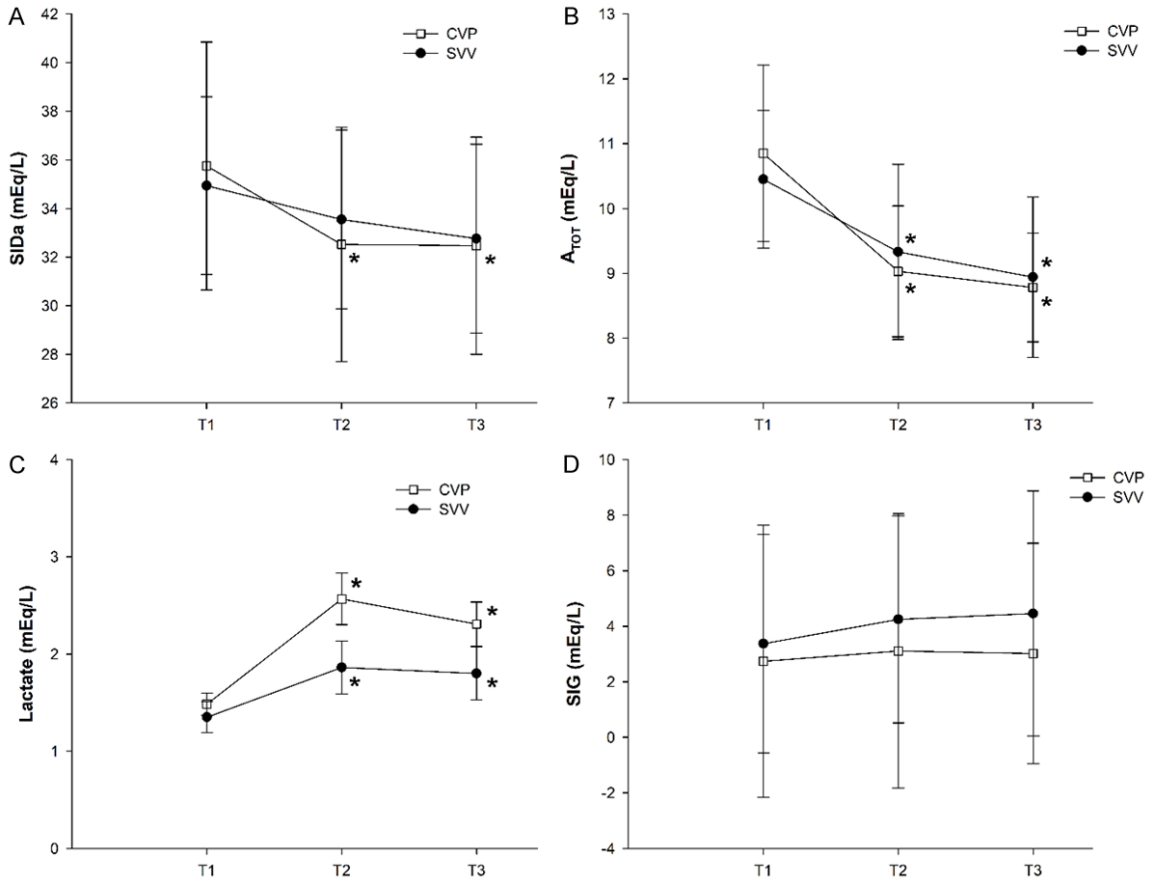

Figure 3. Measured and calculated values during study periods. A. Changes in apparent strong iron difference (SIDa) at each time point. B. Changes in the sum of all anion charges of weak plasma acid (A_{TOT}) at each time point. C. Changes in lactate at each time point. D. Changes in strong iron gap (SIG) at each time point. *P<0.05 vs. T1 within group. (T1: immediately after induction; T2: 4 hours after induction; T3: at the end of the surgery).

in patients with severe sepsis is aggressive volume resuscitation in the initial phase. CVP has been suggested as a method to achieve this goal [12, 13]. The basis for using CVP to guide fluid management comes from the dogma that CVP reflects intravascular volume. Specifically, it is widely believed that patients with a low CVP are volume depleted, while patients with a high CVP are volume overloaded [14]. However, CVP has been recognized as a less effective value for fluid management over recent decades because an individual's normal CVP values can vary with ventricular function and changes in CVP response do not necessarily reflect fluid responsiveness [2].

Many studies have reported positive outcomes of dynamic indices, based on heart-lung interactions during mechanical ventilation, assessing fluid responsiveness. Specifically, systolic pressure variation (SPV) and pulse pressure variation (PPV), derived from analysis of the arterial waveform, and stroke volume variation (SVV), derived from pulse contour analysis, have been shown to be predictive of fluid responsiveness [15]. These values correlate well with a patient's volume responsiveness, compared to CVP. In addition, fluid management based on these indices shows better postoperative outcomes [9, 16-18] and less perioperative complications [8]. In particular, SVV values obtained from the Vigileo-FloTrac™ system have been assessed and accepted as clinically useful and reliable indicators for fluid optimization in several types of operations [7, 19, 20].

Hyperchloremic metabolic acidosis also can result in poorer outcomes in patients undergoing brain surgery [21]. Hyperchloremia induced by 0.9% NS administration has been associated with gastrointestinal symptoms, ranging from nausea to abdominal pain, renal dysfunc-

tion, and coagulation abnormalities. Serum lactate elevation is an indicator of lower tissue hypoperfusion, indicating the presence of global tissue hypoxia and even shock status [22]. Lactic acidosis, a major source of metabolic acidosis, has been reported to be associated with higher mortality [23, 24]. Therefore, the aim of this study was to find a strategy that could be used to reduce metabolic acidosis that occurs after 0.9% NS use in patients undergoing brain surgery. Although study results did not indicate how intraoperative metabolic acidosis affected outcomes in patients undergoing brain surgery, it was expected that fluid management guided by SVV could be used to maintain normovolemia, thus preventing either hyperchloremic metabolic acidosis or lactic acidosis.

According to Stewart's approach, there are only three parameters that independently determine the hydrogen ion, $PaCO_2$, SIDa, and A_{TOT} [25]. Because $PaCO_2$ is regulated by respiration, metabolic acid-base disturbances are caused by changes in SIDa or A_{TOT}. Additional strong anions, such as lactate and SIG (unmeasured anions including formate, ketoacids, salicylate, sulfate, etc.), contribute to metabolic acidosis under pathologic conditions [25]. Present results indicate that SIDa decreased from T1 to T3 and that lactate increased from T1 to T3, resulting in a decrease in SBE. There were no significant changes in SIG between time points. The decrease in A_{TOT} from T1 to T3 may have been due to decreases in albumin during the same time period. The decrease in A_{TOT} reduced the magnitude of the SBE decrease. SIDa decreases are partially explained by an increase in chloride from T1 to T3, which may be induced by 0.9% NS administration. Because A_{TOT} changes largely result from a change in albumin levels [25], intraoperative loss or dilution of albumin may have caused the changes in A_{TOT}. However, no differences between the CVP and SVV groups in any of the parameters can affect metabolic acid-base disturbances. Although SBE in the CVP group was significantly higher than in the SVV group at T3, the SBE value for the CVP group started at a higher level than that of the SVV group, with no significant differences.

The current study had several limitations. First, the CVP value used for fluid management of the CVP group patients was measured using a catheter inserted at the femoral vein. This is routine practice for brain surgery at the institution. Placement of CVP at the femoral vein measures pressure from the common iliac vein or the inferior vena cava [26]. However, measurement of pressure at the inferior vena cava or common iliac vein is only partly reliable for measurement of right atrial pressure. Also, the 5 mmHg of cut-off value, which was referenced to guide normovolemia [27], may have caused different results compared to the typically used value of 8-12 mmHg. Second, SVV values that are not externally calibrated may not be accurate. The algorithms of SVV have been improved over four generations and accuracy has improved with every generation. However, the trending and inadequate cardiac output discriminating abilities with the fourth generation FloTrac for cardiac output monitoring are not statistically acceptable [28]. Even without surgical stress, application of the fourth generation FloTrac on an anesthetized critically ill patient is not ideal [28]. However, it is imperative to recall that this problem was also present in FloTrac before the fourth generation and postoperative outcomes of patients based on prior generation SVV measurements were superior to those based on CVP values for predicting fluid response. Finally, the sample size may have been insufficient to document differences in acid-base profiles between study groups.

In conclusion, compared to CVP-guided fluid therapy, intraoperative goal-directed fluid therapy with 0.9% NS based on SVV values from the Vigileo-FloTrac™ system did not alleviate the severity of metabolic acidosis in patients undergoing brain tumor resections.

Acknowledgements

This study was supported by departmental sources only.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Seung Ho Choi, Department of Anesthesiology and Pain Medicine, Yonsei University College of Medicine, (03722) 50-1 Yonsei-ro, Seodaemun-gu, Seoul, Korea. Tel: 02-2228-2415; Fax: 02-2227-7897; E-mail: csho99@yuhs.ac

References

[1] Tommasino C. Fluids and the neurosurgical patient. Anesthesiol Clin North Am 2002; 20: 329-46, vi.

[2] Grocott MP, Mythen MG and Gan TJ. Perioperative fluid management and clinical outcomes in adults. Anesth Analg 2005; 100: 1093-1106.

[3] Korosue K, Heros RC, Ogilvy CS, Hyodo A, Tu YK and Graichen R. Comparison of crystalloids and colloids for hemodilution in a model of focal cerebral ischemia. J Neurosurg 1990; 73: 576-584.

[4] Tommasino C, Moore S and Todd MM. Cerebral effects of isovolemic hemodilution with crystalloid or colloid solutions. Crit Care Med 1988; 16: 862-868.

[5] Hyodo A, Heros RC, Tu YK, Ogilvy C, Graichen R, Lagree K and Korosue K. Acute effects of isovolemic hemodilution with crystalloids in a canine model of focal cerebral ischemia. Stroke 1989; 20: 534-540.

[6] Kumar A, Anel R, Bunnell E, Habet K, Zanotti S, Marshall S, Neumann A, Ali A, Cheang M, Kavinsky C and Parrillo JE. Pulmonary artery occlusion pressure and central venous pressure fail to predict ventricular filling volume, cardiac performance, or the response to volume infusion in normal subjects. Crit Care Med 2004; 32: 691-699.

[7] Biais M, Nouette Gaulain K, Cottenceau V, Revel P and Sztark F. Uncalibrated pulse contour-derived stroke volume variation predicts fluid responsiveness in mechanically ventilated patients undergoing liver transplantation. Br J Anaesth 2008; 101: 761-768.

[8] Giglio MT, Marucci M, Testini M and Brienza N. Goal-directed haemodynamic therapy and gastrointestinal complications in major surgery: a meta-analysis of randomized controlled trials. Br J Anaesth 2009; 103: 637-646.

[9] Ramsingh DS, Sanghvi C, Gamboa J, Cannesson M and Applegate RL. Outcome impact of goal directed fluid therapy during high risk abdominal surgery in low to moderate risk patients: a randomized controlled trial. J Clin Monit Comput 2013; 27: 249-257.

[10] Emmett M and Narins RG. Clinical use of the anion gap. Medicine 1977; 56: 38-54.

[11] Kim JY, Lee D, Lee KC, Choi JJ and Kwak HJ. Stewart's physicochemical approach in neurosurgical patients with hyperchloremic metabolic acidosis during propofol anesthesia. J Neurosurg Anesthesiol 2008; 20: 1-7.

[12] Dellinger RP, Carlet JM, Masur H, Gerlach H, Calandra T, Cohen J, Gea-Banacloche J, Keh D, Marshall JC, Parker MM, Ramsay G, Zimmerman JL, Vincent JL, Levy MM; Surviving Sepsis Campaign Management Guidelines Committee. Surviving sepsis campaign guidelines for management of severe sepsis and septic shock. Crit Care Med 2004; 32: 858-873.

[13] Hollenberg SM, Ahrens TS, Annane D, Astiz ME, Chalfin DB, Dasta JF, Heard SO, Martin C, Napolitano LM, Susla GM, Totaro R, Vincent JL and Zanotti-Cavazzoni S. Practice parameters for hemodynamic support of sepsis in adult patients: 2004 update. Crit Care Med 2004; 32: 1928-1948.

[14] Marik PE, Baram M and Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. Chest 2008; 134: 172-178.

[15] Michard F and Teboul JL. Predicting fluid responsiveness in ICU patients: a critical analysis of the evidence. Chest 2002; 121: 2000-2008.

[16] Mayer J, Boldt J, Mengistu AM, Rohm KD and Suttner S. Goal-directed intraoperative therapy based on autocalibrated arterial pressure waveform analysis reduces hospital stay in high-risk surgical patients: a randomized, controlled trial. Crit Care 2010; 14: R18.

[17] Hamilton MA, Cecconi M and Rhodes A. A systematic review and meta-analysis on the use of preemptive hemodynamic intervention to improve postoperative outcomes in moderate and high-risk surgical patients. Anesth Analg 2011; 112: 1392-1402.

[18] Giglio M, Dalfino L, Puntillo F, Rubino G, Marucci M and Brienza N. Haemodynamic goal-directed therapy in cardiac and vascular surgery. A systematic review and meta-analysis. Interact Cardiovasc Thorac Surg 2012; 15: 878-887.

[19] Biais M, Bernard O, Ha JC, Degryse C and Sztark F. Abilities of pulse pressure variations and stroke volume variations to predict fluid responsiveness in prone position during scoliosis surgery. Br J Anaesth 2010; 104: 407-413.

[20] Suehiro K and Okutani R. Stroke volume variation as a predictor of fluid responsiveness in patients undergoing one-lung ventilation. J Cardiothorac Vasc Anesth 2010; 24: 772-775.

[21] Handy JM and Soni N. Physiological effects of hyperchloraemia and acidosis. Br J Anaesth 2008; 101: 141-150.

[22] Englehart MS and Schreiber MA. Measurement of acid-base resuscitation endpoints: lactate, base deficit, bicarbonate or what? Curr Opin Crit Care 2006; 12: 569-574.

[23] Stacpoole PW, Wright EC, Baumgartner TG, Bersin RM, Buchalter S, Curry SH, Duncan C, Harman EM, Henderson GN and Jenkinson S. Natural history and course of acquired lactic

acidosis in adults. DCA-lactic acidosis study group. Am J Med 1994; 97: 47-54.
[24] Gunnerson KJ, Saul M, He S and Kellum JA. Lactate versus non-lactate metabolic acidosis: a retrospective outcome evaluation of critically ill patients. Crit Care 2006; 10: R22-R22.
[25] Fidkowski C and Helstrom J. Diagnosing metabolic acidosis in the critically ill: bridging the anion gap, Stewart, and base excess methods. Can J Anaesth 2009; 56: 247-256.
[26] Desmond J and Megahed M. Is the central venous pressure reading equally reliable if the central line is inserted via the femoral vein. Emerg Med J 2003; 20: 467-469.
[27] Lennihan L, Mayer SA, Fink ME, Beckford A, Paik MC, Zhang H, Wu YC, Klebanoff LM, Raps EC and Solomon RA. Effect of hypervolemic therapy on cerebral blood flow after subarachnoid hemorrhage: a randomized controlled trial. Stroke 2000; 31: 383-391.
[28] Lin SY, Chou AH, Tsai YF, Chang SW, Yang MW, Ting PC and Chen CY. Evaluation of the use of the fourth version FloTrac system in cardiac output measurement before and after cardiopulmonary bypass. J Clin Monit Comput 2018; 32: 807-815.