The hemodynamic effects during sustained low-efficiency dialysis versus continuous veno-venous hemofiltration for uremic patients with brain hemorrhage: a crossover study

Clinical article

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Object. Hemodynamic instability occurs frequently during dialysis treatment and remains a significant cause of patient morbidity and mortality, especially in patients with brain hemorrhage. This study aims to compare the effects of hemodynamic parameters and intracranial pressure (ICP) between sustained low-efficiency dialysis (SLED) and continuous veno-venous hemofiltration (CVVH) in dialysis patients with brain hemorrhage.

Methods. End-stage renal disease (ESRD) patients with brain hemorrhage undergoing ICP monitoring were enrolled. Patients were randomized to receive CVVH or SLED on the 1st day and were changed to the other modality on the 2nd day. The ultrafiltration rate was set at between 1.0 kg/8 hrs and 1.5 kg/8 hrs according to the patient’s fluid status. The primary study end point was the change in hemodynamics and ICP during the dialytic periods. The secondary end point was the difference between cardiovascular peptides and oxidative and inflammatory assays.

Results. Ten patients (6 women; mean age 59.9 ± 3.6 years) were analyzed. The stroke volume variation was higher with SLED than CVVH (generalized estimating equations method, p = 0.031). The ICP level increased after both SLED and CVVH (time effect, p = 0.003) without significant difference between modalities. The dialysis dose quantification after 8-hour dialysis was higher in SLED than CVVH (equivalent urea clearance by convection, 62.7 ± 4.4 vs 50.2 ± 3.9 ml/min; p = 0.002). Additionally, the endothelin-1 level increased after CVVH treatment (p = 0.019) but not SLED therapy.

Conclusions. With this controlled crossover study, the authors provide the pilot evidence that both SLED and CVVH display identical acute hemodynamic effects and increased ICP after dialysis in brain hemorrhage patients. Clinical trial registration no.: NCT01781585 (ClinicalTrials.gov).

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Key Words • sustained low-efficiency dialysis • intracranial pressure • continuous veno-venous hemofiltration • hemodynamic stability

Patients with ESRD are at higher risk of brain hemorrhage. Hemodialysis per se is associated with a 10 times higher incidence of intracranial hemorrhage in these patients than in the general population. Furthermore, the occurrence of brain hemorrhage in ESRD patients carries a poor prognosis with high morbidity and mortality of up to 60%. Among all therapeutic strategies for brain hemorrhage, management of blood pressure and ICP are 2 important but not easily achieved tasks for ESRD patients due to the influence of RRT. Renal replacement therapy may also result in ICP instability, causing further structural and functional impairment by the deleterious effect on the compromised microcirculation19 and uremic...
metabolism. The modalities for critical dialysis can be categorized into intermittent and continuous RRT, with intermittent hemodialysis and CVVH as the main examples, respectively. The advantages of intermittent hemodialysis include rapid solute and fluid removal and a decreased need for anticoagulation, but there is a higher risk of causing systemic hypotension and cerebral edema with increased ICP compared with CVVH. On the other hand, CVVH can increase the patient tolerance to volume removal and preserved myocardial contractility and cause fewer changes in ICP and cerebral perfusion pressure than intermittent hemodialysis due to smaller changes in plasma osmolality and cardiovascular stability based on the convective transport. However, the necessary use of anticoagulation is a shortcoming of CVVH in critical patients with brain hemorrhage. Later on, a hybrid form of intermittent RRT termed SLED was developed. Sustained low-efficiency dialysis is noted not only for precise achievement of ultrafiltration and rapid normalization of uremic indicators, but also for better hemodynamic tolerance and lower risk of disequilibrium syndrome than intermittent hemodialysis. In the setting of critical care, the impacts of different RRT modalities on outcomes of critical patients were not revealed in the multicenter SHARF 4 (Stuivenberg Hospital Acute Renal Failure) study and a recently published meta-analysis of 19 randomized controlled trials.

To date, few studies have compared different RRT modalities with matched possible confounding factors, resulting in inclusive data for the hemodynamic change in RRT. To facilitate the potential neurological recovery in patients requiring RRT, it is important that dialysis per se does not cause further cerebral injury. Thus, we conducted a randomized crossover study to compare the effect of ICP, cardiac hemodynamic changes, and dialysis dose between SLED and CVVH in ESRD patients with intracranial hemorrhage.

Methods

This prospective, randomized crossover study was conducted by The National Taiwan University Study Group on Acute Renal Failure (NSARF) with the approval of the Institutional Review Board of the National Taiwan University Hospital. The enrollees received comprehensive written information and signed a consent form. The ClinicalTrials.gov identifier is NCT01781585.

Anuric patients undergoing dialysis who underwent ICP monitoring after brain hemorrhage were considered for enrollment. The inclusion criteria were anuric ESRD patients undergoing chronic dialysis for at least 3 months and who had increased ICP and underwent ICP monitoring after brain injury. Those with active brain hemorrhage, cardiac arrhythmia during dialysis, and an inotropic equivalent of more than 15 were excluded. Before patients were enrolled, they received CVVH, which is generally thought to be optimal to maintain brain hemodynamics. All patients were ventilated in controlled-volume mode in the supine position. After the patients recovered from acute brain hemorrhage presenting with stable hemodynamics with acceptable ICP of less than

20 mm Hg, they were randomized to receive CVVH or SLED on the 1st day and began the other modality on the 2nd day. Both RRT modalities were performed for 8 hours daily from 9:00 a.m. to 5:00 p.m. (Fig. 1).

During the data collection period, the supportive management, ventilatory settings, and vasopressor therapy remained consistent. The primary end point was the change in hemodynamics and ICP between the dialysis modalities. The secondary end point was the difference in cardiovascular peptides and oxidative and inflammatory mediators.

Cardiac Output and SVV Measurements

A high-fidelity dedicated pressure transducer (FloTrac sensor, Edwards Lifesciences LLC) was connected to the arterial line and was attached to the Vigileo monitor (software version 3.01, Edwards Lifesciences LLC). Pressure recording analytical methods obtain a beat-to-beat evaluation of the cardiac index, SVI, and SVV. Cardiac output was calculated on the basis of the real-time analysis of the arterial waveform every 20 seconds. This calculation was performed at a sample rate of 100 Hz without the need for prior calibration using a proprietary algorithm based on the principle that aortic pulse pressure is proportional to SV. The SV was measured as the standard deviation of the arterial pressure around mean arterial pressure and was inversely related to arterial compliance. The effects of arterial compliance and vascular resistance were estimated every minute on the basis of individual patient demographic data (age, sex, body weight, and height) and the arterial waveform shape analysis, respectively. The respective mean SVV was assessed every 20 seconds by the system. Cardiac output, SV, and SVV values were obtained and were averaged as the means of 180 consecutive measurements during 1 hour. All data were collected continuously in the data acquisition systems.

Intracranial Pressure and Hemodynamic Measurement

The ICP was measured either by EVD or an ICP monitoring system (Codman, Johnson & Johnson Co.) after ICP was stabilized. Average values per hour were used for analysis of the continuous data. Additionally, the patient’s hemodynamic status was monitored using the FloTrac/Vigileo hemodynamic monitoring system via a radial artery catheter. After zeroing the system against atmosphere, the arterial waveform signal fidelity was carefully checked using a fast flush test. A stable hemodynamic condition with no damping of the arterial pressure waveform was a prerequisite for hemodynamic measurements. During the recording period, no hypertonic agents such as mannitol were used.

Renal Replacement Therapy

For both RRT modalities, the ultrafiltration rate was set at 1.0–1.5 kg/8 hrs according to the patient’s fluid status, and the sodium concentration was fixed at 145 mmol/L during each session. In addition to ultrafiltration rate, the dialysis times were matched to eliminate possible confounding factors.
Continuous veno-venous hemofiltration was performed with high-flux filters (AV-600 1.4 m², Polysulfone hemofilter, Fresenius Medical Care AG & Co.). The hemofiltration rate was 35 ml/kg/hr, and the blood flow was 200 ml/min. The replacement fluid was bicarbonate buffered and was administered without dilution.

Sustained low-efficiency dialysis was performed by the same group of technicians, nephrologists, and intensive care physicians as CVVH with a standard protocol. It was delivered using the conventional hemodialysis machines (Fresenius 5008, Fresenius Medical Care AG) with a Fresenius FX60 dialyzer (Polysulfone, Fresenius Medical Care). The blood flow was 200 ml/min, and the dialysate flow was 300 ml/min as previously reported. The default dialysate composition was bicarbonate 33.3 mEq/L, potassium 2.0 mEq/L, and calcium 2.5 mEq/L. For patients with a high risk of postoperative bleeding, CVVH and SLED were performed without anticoagulant agents with a 100-ml saline flush every hour. The dialysate temperature was constant at 36°C during dialysis. Vascular access was obtained by percutaneous placement of a double-lumen catheter.

**Quantification of Dialysis Adequacy**

The kinetic equivalence among patients treated with different RRT modalities was expressed as standard Kt/V (stdKt/V) and corrected EKRjc (ml/min), which was independent from the assumption of the urea steady state. The EKRjc is shown to provide a unifying expression of dialysis dose irrespective of dialysis modality.

**Vasoactive Peptides and Oxidative and Inflammatory Assays**

To determine the factors mediating hemodynamics, cardiovascular peptides and oxidative and inflammatory assays were also measured. Nitrite and nitrate ELISA kits (R&D Systems), ET-1 ELISA kits (R&D Systems), TBARS assay kit (Cayman Chemical), IL-6 (R&D Systems), and BNPs (USCN Life Science, Inc.) were used appropriately according to the manufacturers’ instructions.

**Statistical Analysis**

Individual delta values (change ratio from start to certain time points) in each RRT modality were calculated. The changes in the value of given variables from the baseline are presented as percentages. Statistical analyses were performed using SPSS for Windows (version 15.0, SPSS, Inc.). Continuous data are expressed as the mean ± SE. The mean results of each measurement were merged during the dialysis period. The Student t-test was used.
to analyze continuous data, whereas the chi-square test or Fisher exact test was used to analyze categorical data.

To examine the effect of dialysis modality on various time-dependent variables such as hemodynamics and ICP over the course of time, the marginal linear regression models were fitted to these repeatedly measured responses using the GEE method. Standardized regression coefficients and their 95% confidence intervals were calculated. The GEE is efficient in achieving a higher power with a smaller sample size or lower number of repeated measurements in both complete and missing data scenarios. A 2-sided p value ≤ 0.05 was considered statistically significant.

Power of the Study

The probability is 84% that the study will detect a treatment difference at a 2-sided 0.05 significance level if the true difference of ICP between the modalities is 3 mm Hg. This is based on the assumption that the within-patient standard deviation of the response variable is 2. A total of 10 patients will be necessary to enter this inequality 2-treatment crossover study performed using PASS software (version 2008, NCSS).

Results

Study Population

After the initial screening, 12 patients were enrolled in the first treatment protocol. One patient with brain rebleeding and another with atrial fibrillation during the study periods were excluded (Fig. 1). Therefore, 10 patients (6 women, mean age 59.9 ± 3.6 years) completed the study. The disease severities assessed by APACHE II (Acute Physiology and Chronic Health Evaluation II) and SOFA (Sepsis-related Organ Failure Assessment) scores at the initiation of the study were 29.4 ± 2.3 and 8.5 ± 0.8, respectively. Seven patients underwent craniotomy and ICP monitor insertion (Codman), 3 patients including 2 with thalamic hemorrhage underwent EVD, and 1 patient with aneurysm rupture underwent transarterial embolization and EVD.

At study enrollment, the mean blood urea nitrogen and creatinine levels were 45.4 ± 5.16 and 5.9 ± 0.7 mg/dl, respectively. The total ultrafiltration rate was comparable between SLED and CVVH (151.1 ± 10.1 vs 124.9 ± 12.1 ml/hr, p = 0.220). The demographic and clinical characteristics of the 10 patients are listed in Table 1.

Blood Pressure, Cardiac Output, and Cardiac Index

There was no significant difference in blood pressure between the SLED and CVVH patients. The mean blood pressure remained stable in patients undergoing SLED and CVVH (Fig. 2A). The cardiac output increased approximately 5.5% ± 1.5% in SLED and 4.2% ± 1% in CVVH during the dialysis period (Fig. 2B). The cardiac index also increased 3.0% ± 1.2% in SLED and 1.7% ± 1.0% in CVVH during the dialysis period (Fig. 2C). No differences were noticed in the cardiac output or cardiac index between the RRT modalities during the 8-hour dialysis period.

Stroke Volume, SVI, and SVV

There was no evidence of a difference between treatment modalities in the SV and SVI changes (Fig. 2D and E). However, the SVV was also significantly higher in patients receiving SLED shifted from CVVH (GEE, standardized regression coefficient for SLED 18.5 [95% CI 1.7–35.4], p = 0.031; Fig. 2F).

Intracranial Pressure

The mean ICP level increased after the 3rd hour of dialysis treatment, and the time effect on ICP level after dialysis was significant (Fig. 2G). Changes in time period contributed to change in ICP (GEE, standardized regression coefficient for time 2.7 [95% CI 1.1–4.3] in both modalities, p = 0.003 for first-order interaction). However, the ICP levels were not significantly different between modalities.

Delivery Doses and Changes in Vasoactive Peptides and Oxidative and Inflammatory Markers

The dialysis dose quantification was higher in SLED than CVVH after 8-hour dialysis (EKRjc, 62.7 ± 4.4 vs 50.2 ± 3.9 ml/min, p = 0.002). The serum ET-1 level increased after CVVH (p = 0.019) but not after SLED treatment. As for the other biochemistry markers including IL-6, TBARS, NOx, and pro-BNP, no statistical differences, whether before or after RRT, between RRT modalities were revealed (Fig. 3).

Discussion

The current prospective study is the first to compare the hemodynamic effect of SLED and CVVH in patients who recently suffered intracranial hemorrhage. As the prevalence of ESRD continues to increase, it is expected that neurologists, neurosurgeons, and nephrologists will encounter more dialysis patients suffering from brain hemorrhage. We raised the issue of dialysis after brain hemorrhage because it is far from being elucidated.

The dialysis strategies for patients in the ICU emphasized the high efficiency of uremic toxin elimination and gentle volume removal, especially for patients who have suffered acute brain injury. Since the initial phase of acute brain injury is of particular importance regarding the neurological outcome and is amenable to beneficial intervention, the exploration of dialysis modalities to improve the immediate management of patients who have suffered brain hemorrhage patients is important. The results of the study are noteworthy because the ICP increased in patients regardless of whether they received SLED or CVVH. We further propose that there was different cardiovascular optimization and toxic removal between SLED and CVVH in uremic patients with brain hemorrhage.

Hemodynamics

Kumar et al. previously reported that in patients treated with SLED the mean arterial pressure did not change significantly from predialysis, to midway, and to the end of treatment. Several studies reinforced the belief...
that procedures based on convective transport are superior to those based on diffusive transport in protecting the stability of blood pressure and heart rate. With comparable ultrafiltration volumes, the cardiovascular parameters assessed online via invasive monitoring were not significantly different between CVVH and SLED during treatment, although there was a trend toward higher systemic vascular resistance in patients using SLED. Similarly, the patients’ blood pressure, cardiac output, cardiac index, and ICP assessed during dialysis in our study were not significantly different between CVVH and SLED.

Previous studies have shown that convective methods result in better cardiovascular tolerance and blood pressure stability. Our serial hemodynamic studies showed that, for the rate of fluid removed, SLED elicited an appropriate increase in SVV, whereas CVVH failed to do so. Stroke volume variation reflects the dialysis-induced changes in the left ventricle stroke output and may serve as a variable continuously assessing the adequacy of fluid responsiveness as preload. As already indicated, SVV may reflect volume responsiveness, because the decrease in the venous return during SLED will greatly affect SV during hypovolemia (large SVV) but not during CVVH (small SVV). Because the relationship between the cardiac left ventricle output and preload in a defined contractility is not linear, the ability to predict whether the heart will augment its function after initializing dialysis is crucial. The ability of the SVV variable to predict the responsiveness to dialysis modality and the continuous measurement of SVV are of utmost clinical importance. Lopes et al. were the first to prospectively test the effects of minimizing pulse pressure variation (< 10%) during surgery, and they observed a significant reduction in postoperative complications and hospital length of stay. In agreement with our results, Altieri et al. noted a significant reduction in the frequency of hypotensive episodes during hemodialysis compared with hemodialysis.

One possibility is that CVVH effectively removed cytokines and myocardial depressants by ultrafiltration and membrane absorption. Our results showed that the ET-1 level increased after CVVH, while it was not changed after SLED. Endothelin-1 contributes to systemic vasoconstriction and plays a vital role in hemodynamic pathogenesis during dialysis. The faster response of ET-1 to therapy, with a plasma half-life of 1.4–3.6 minutes, make it a good vasoactive peptide, mediating hemodynamics during dialysis. Consistent with our report showing that free radicals and inflammatory cytokines were not increased during the SLED period, Lonneman et al. confirmed that daily SLED is at least as efficacious as continuous hemofiltration in modulating endotoxin-induced tumor necrosis factor–α production. Additionally, SLED offers advantages such as potential prolonged high-volume treatment to normalize indicators of uremic intoxication quickly. Acute vasospasm, cytotoxic edema, and a general metabolic stress response occur immediately after brain hemorrhage. The 8-hour dialysis efficiency of SLED was higher than CVVH with the same ultrafiltration rate according to the removal of small molecular toxins and could remove the metabolic stress quickly after acute brain injury.

### Intracranial Pressure

We showed no advantage of CVVH over SLED in regard to the stability of ICP. The resultant cerebral ischemia and hypoxia during the dialysis period would be expected to increase ICP. Hemodynamic stability and maintenance of cerebral perfusion pressure are crucial to the treatment of patients with intracranial pathology. The postdialysis hyper-ICP was noted to increase after 3 hours in both modalities. These changes occur after starting dialysis, although the pathophysiology is unclear. Alterations of cardiovascular and hemodynamic functions that can occur during dialysis would be expected to impair cerebral perfusion pressure and cerebral oxygen delivery.

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**TABLE 1: Comparisons of the demographic and clinical characteristics of the postoperative acute renal failure patients receiving CVVH or SLED**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Comorbidity</th>
<th>BUN (mg/dl)</th>
<th>Creatinine (mg/dl)</th>
<th>PaO2 (mm Hg)</th>
<th>FiO2 (%)</th>
<th>SOFA</th>
<th>APACHE II</th>
<th>Died</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57.9, F</td>
<td>DM, HTN, polymyalgia rheumatica</td>
<td>42.7</td>
<td>5.1</td>
<td>106.2</td>
<td>0.4</td>
<td>9</td>
<td>21</td>
<td>yes</td>
<td>traumatic SDH, ICH</td>
</tr>
<tr>
<td>2</td>
<td>69.5, F</td>
<td>HTN</td>
<td>64.1</td>
<td>8.8</td>
<td>237.1</td>
<td>0.6</td>
<td>13</td>
<td>41</td>
<td>no</td>
<td>ACA rupture</td>
</tr>
<tr>
<td>3</td>
<td>61.9, M</td>
<td>DM, HTN, PAOD, CAD</td>
<td>25</td>
<td>5.1</td>
<td>187.2</td>
<td>0.4</td>
<td>4</td>
<td>19</td>
<td>no</td>
<td>ACA rupture</td>
</tr>
<tr>
<td>4</td>
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<td>HTN</td>
<td>55.6</td>
<td>5.9</td>
<td>185.2</td>
<td>0.4</td>
<td>7</td>
<td>22</td>
<td>no</td>
<td>Lt ACA aneurysm rupture</td>
</tr>
<tr>
<td>5</td>
<td>80.8, M</td>
<td>DM, HTN, CAD</td>
<td>74</td>
<td>5.1</td>
<td>115.4</td>
<td>0.4</td>
<td>11</td>
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<td>traumatic SDH</td>
</tr>
<tr>
<td>6</td>
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<td>HTN</td>
<td>22.8</td>
<td>2.3</td>
<td>123.7</td>
<td>0.35</td>
<td>7</td>
<td>29</td>
<td>yes</td>
<td>rt putaminal hemorrhage</td>
</tr>
<tr>
<td>7</td>
<td>58.9, F</td>
<td>DM, HTN, CAD</td>
<td>52</td>
<td>9.83</td>
<td>126.1</td>
<td>0.5</td>
<td>9</td>
<td>30</td>
<td>no</td>
<td>Lt thalamic hemorrhage w/ IVH</td>
</tr>
<tr>
<td>8</td>
<td>58.8, M</td>
<td>DM</td>
<td>44</td>
<td>6.57</td>
<td>122</td>
<td>0.4</td>
<td>8</td>
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<td>yes</td>
<td>Lt thalamic hemorrhage w/ IVH</td>
</tr>
<tr>
<td>9</td>
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<td>39</td>
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<td>250.1</td>
<td>0.6</td>
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<td>35</td>
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<td>Lt putaminal hemorrhage</td>
</tr>
<tr>
<td>10</td>
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<td>35</td>
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<td>105.9</td>
<td>0.5</td>
<td>8</td>
<td>29</td>
<td>no</td>
<td>Lt putaminal hemorrhage</td>
</tr>
</tbody>
</table>

* ACA = anterior cerebral artery; ACoA = anterior communicating artery; APACHE II = Acute Physiology And Chronic Health Evaluation II; BUN = blood urea nitrogen; CAD = coronary artery disease; DM = diabetes mellitus; FiO2 = fraction of inspired oxygen; HTN = hypertension; ICH = intracerebral hemorrhage; IVH = intraventricular hemorrhage; PaO2 = partial pressure of oxygen; PAOD = peripheral arterial occlusive disease; SDH = subdural hematoma; SOFA = Sepsis-related Organ Failure Assessment score.
SLED versus CVVH in patients with brain hemorrhage

Fig. 2. Comparisons of the clinical parameters between the uremic patients with recent brain hemorrhage receiving CVVH and SLED by GEE method; all values are reported as the mean ± SEM. 

- A: Mean blood pressure (MBP), between modality comparison, \( p = 0.591 \).
- B: The cardiac output (CO) between modality comparison, \( p = 0.750 \).
- C: The cardiac index (CI) between modality comparison, \( p = 0.550 \).
- D: The SV between modality comparison, \( p = 0.185 \).
- E: The SVI between modality comparison, \( p = 0.129 \).
- F: The SVV between modality comparison, \( p = 0.031 \) (GEE, standardized regression coefficient for SLED 18.5 [95% CI 1.7–35.4], \( p = 0.031 \)).
- G: The ICP between modality comparison, \( p = 0.460 \). Changes in time period contributed to changes in ICP after 3 hours (GEE, standardized regression coefficient for time 2.7 [95% CI 1.1–4.3] in both modalities, \( p = 0.003 \) for first-order interaction).

Fig. 3. Mean and individual values of ET-1 (A), IL-6 (B), TBARS (C), NOx (D), and pro-BNP (E) in CVVH and SLED at the start and the end of dialysis. \( *p < 0.05 \).
need further study. The disequilibrium syndrome caused by acute changes in urea or bicarbonate plasma concentration may contribute to the impairment of cerebral perfusion pressure.32

The primary mechanism for increased ICP is likely related to cardiovascular instability and fluctuating cerebral perfusion pressure in the setting of disrupted cerebral autoregulation because of osmotic or fluid shifts and rapid exchange of bicarbonate.3 Given the high mortality rate and poor neurological outcome associated with acute brain injury, further research may be warranted.

Our findings do not support the cerebrovascular stabilizing effect of convective techniques over diffusive. Until now, randomized controlled trials failed to demonstrate a survival benefit for CRRT over other mortality for critical patients. Further large, prospective studies are needed to compare the outcomes between SLED and CVVH in dialysis patients with brain hemorrhage.

There are some limitations in our study. First, because of the difficulty of enrolling anuric dialysis patients in the ICU, only 10 patients completed the current randomized controlled study. To overcome the shortcoming of participant size, we used the crossover design, which requires a smaller sample size than parallel-group trials of participant size, we used the crossover design, which in the ICU, only 10 patients completed the current randomized controlled study. To overcome the shortcoming of participant size, we used the crossover design, which requires a smaller sample size than parallel-group trials to meet the same criteria in terms of Type I and Type II errors and to confirm the existence of a treatment effect.38 Second, our patients were actually heterogeneous with the various hemorrhage causes. However, the crossover design could avoid the heterogeneity of different groups when doing outcome comparison.87 Third, the crossover design of study could not provide the results of relevant patient outcomes. In the preliminary data, we showed the novel differences of hemodynamics, ICP, cardiovascular peptides, and oxidative and inflammatory responses between dialysis modalities. All of these may lead to further randomized controlled study regarding more solid patient outcomes.

Conclusions

We provide pilot evidence that under controlled conditions, SLED and CVVH display an identical acute hemodynamic profile for patients with brain hemorrhage. Although with compatible blood pressure, CVVH showed increased vasoactive peptide and lower fluid responsiveness than SLED. However, SLED offers the advantage of clearance of low-molecular-weight substance. Both modalities need to be considered as complementary in cases of acute brain hemorrhage.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following: Conception and design: VC Wu, TM Huang, Tsai, WJ Wang, KD Wu. Acquisition of data: VC Wu, TM Huang. Analysis and interpretation of data: VC Wu, Ko. Drafting the article: KC Wang, VC Wu, Tsai, WJ Wang, Ko. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Statistical analysis: Lai, WJ Wang. Administrative/technical/material support: Shiao, HY Huang. Study supervision: HY Huang, Ko.

References

SLED versus CVVH in patients with brain hemorrhage


