Successful CAVH in an austere environment using readily available disposable hospital supplies*

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given its simplicity, low cost and ready availability, the circuit herein described may be useful for disaster management teams planning for the care of multiple renal patients in austere locations if standard systems fail or become dysfunctional.

Case

The patient was a 26-year-old male who was transferred from an outlying military medical clinic, where he was noted to have blood urea nitrogen (BUN) and plasma creatinine levels of 226 and 22 mg/dl, respectively. His plasma potassium was 5.6 mmol/l. He was transferred to our hospital for further evaluation and management.

He reported a history of beating by local youths, ~10 days prior to our evaluation. Since his trauma, he had noted a decrease in his urine output, the recent onset of anorexia and occasional emesis over the prior several days. He denied the use of any prescribed medications or supplements, and any personal or family history of renal disease. On exam, his blood pressure was 132/78, heart rate was 110 and respiratory rate was 22. Pulse oximetry on room air was 90%. This improved to 98% with low-flow supplemental oxygen, via nasal canula. Bruising was noted across his flanks, abdomen and right upper thigh. Jugular venous pressure was estimated at 10 cm water. Pulmonary basilar crackles and a pericardial friction rub were noted on exam. He had 1+ oedema in his lower extremities. His elevated BUN and plasma creatinine were confirmed on repeat analysis. His potassium level had increased to 6.2 mmol/l. A plasma creatine kinase level was mildly elevated at 1046 U/l, and a plasma myoglobin level was noted to be above the upper limit of the lab’s assay range (500 ng/ml). On urinalysis, the dipstick was positive for haeme pigment; no red blood cells were noted on microscopic examination of the sediment; and the urine supernatant was also positive for haeme. The hospital laboratory was not able to test
for urine myoglobin. As the patient was oliguric over the initial hours of his hospitalization, a decision was made to initiate renal replacement therapy for uraemia, hyperkalaemia and volume overload.

Because the facility was not equipped with the appropriate resources for pump-driven renal replacement therapy, the patient was initiated on CAVH, using a circuit adapted from that of Kramer et al. [4]. Eight Fr arterial and venous catheters (MedComp, Harleysville, PA, USA) were placed in the right femoral artery and vein and packed with 5000 units/ml heparin (1.8 ml priming volume per catheter). Table 1 lists the equipment used for CAVH in this patient, with specific modifications. Figure 1 shows the completed CAVH circuit (without the CAVH catheters attached).

The CAVH circuit was assembled under sterile conditions at the bedside. The CAPD transfer set tubing was connected directly to the arterial and venous catheters without modification. At the arterial limb, the spiked distal end of the transfer set tubing was connected to the modified haemodialysis blood tubing line, which in turn was connected to the arterial side of the dialyser. The arterial side of the haemodialysis blood tubing line was cut down proximal to the drip chamber, while the proximal (venous) port was open to the Foley bag for collection of ultrafiltrate. The Foley catheter itself was cut down at the 16 Fr rubber connector, reversed in direction, and attached to the Hansen port via the rubber connector. The connection was sealed with surgical tape.

The venous haemodialysis blood tubing line was cut down and attached to the CAPD transfer set tubing and to the dialyser, in the same fashion as the arterial blood tubing line. A 4-way stopcock was placed between the haemodialysis blood tubing line and the CAPD transfer set tubing, along the venous limb of the circuit. Replacement fluid was infused through a port on this stopcock.

CAVH was continued for 75 consecutive hours. Figures 2 and 3 outline the metabolic impact during and after CAVH therapy. Post-filter replacement fluid was provided using various combinations of standard, manufactured, sterile solutions of 1/4 normal saline, 1/2 normal saline and normal saline. Bicarbonate (50–100 meq/l as sodium bicarbonate) was added to the hypotonic fluids as needed, to maintain a plasma bicarbonate of >20 mmol/l. Potassium (1–4 meq/l potassium as potassium chloride) was also added once the plasma potassium level fell <4.5 mmol/l. Calcium and magnesium replacement was given intermittently through a non-circuit central venous catheter as needed. Labs (aPTT, PT, CBC and basic chemistry) were initially monitored every 2 h, then every 4 h after the first 18 h of therapy.

The patient was anticoagulated with continuous heparin infusion throughout course of therapy, and given peripherally. An IV infusion pump for replacement fluid rate control is necessary.

<table>
<thead>
<tr>
<th>Item</th>
<th>Manufacturer</th>
<th>Model #</th>
<th>Description</th>
<th>Modifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAVH catheters</td>
<td>MedComp</td>
<td>MC8CAVH6</td>
<td>8 Fr X 15 cm straight CAVH catheter set</td>
<td>None</td>
</tr>
<tr>
<td>CAPD transfer set tubing</td>
<td>Baxter</td>
<td>5C-41-60</td>
<td>CAPD Transfer Set Tubing (1.2 M, 48&quot;)</td>
<td>None</td>
</tr>
<tr>
<td>Haemodialysis blood tubing set</td>
<td>Fresenius</td>
<td>5KR279 03-2622-3</td>
<td>‘Combsiet’ blood tubing set</td>
<td>Tubing was cut proximal to drip chamber; connects to CAPD transfer set via spike connector on transfer set tubing</td>
</tr>
<tr>
<td>High flux, polysulfone dialyser</td>
<td>Fresenius</td>
<td>Optiflux 160NR</td>
<td>Haemofilter</td>
<td>Proximal (arterial) Hansen port capped</td>
</tr>
<tr>
<td>Foley catheter and collection bag</td>
<td>Kendall</td>
<td>Precision 400</td>
<td>Foley catheter, collection bag with urometer</td>
<td>Foley tube was cut down at 16 Fr rubber connector and attached to the Hansen port at the venous end of the dialyser</td>
</tr>
<tr>
<td>4-way stopcock</td>
<td>B. Braun</td>
<td>DS00 456020</td>
<td>4-way stopcock</td>
<td>None</td>
</tr>
<tr>
<td>Replacement fluid</td>
<td>Multiple</td>
<td>NA</td>
<td>Standard pre-mixed, sterile normal saline, 1/2 normal saline or 1/4 normal saline</td>
<td>Additives: 1. Na Bicarbonate (50–100 meq/l)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2. Potassium chloride (1–4 meq/l)</td>
</tr>
</tbody>
</table>

Ca++, Mg++ replacement is required intermittently via another central access.
Continuous heparin infusion throughout course of therapy is required, and given peripherally.
An IV infusion pump for replacement fluid rate control is necessary.

Table 1. Required equipment for CAVH circuit
Fig. 1. CAVH circuit (without arterial or venous catheters).

Fig. 2. Trends in plasma electrolyes, BUN and creatinine during and after CAVH.
The ultrafiltrate collection bag was maintained at 90–100 cm below the bed level throughout the course of the therapy. Daily ultrafiltration volumes ranged from 17.9 to 23.8 l, while hourly urine output ranged from 15 to 65 cc/h. Initially, fluid was replaced at 1/2 the ultrafiltrate rate until jugular venous pressure normalized, basilar lung crackles resolved, and the patient no longer had an oxygen requirement. Hypotension did not develop during the course of therapy; mean arterial pressures were consistently greater than 80 mmHg.

The circuit was changed once at 60 h, due to circuit clotting and reduced ultrafiltration. Because of improving urine output, CAVH was stopped after 75 h. At that time the BUN was 73 mg/dl, plasma creatinine was 9.2 mg/dl, plasma potassium was 4.1 mmol/l and plasma bicarbonate was 21 mmol/l. At first, the patient's BUN, creatinine and potassium all rose over several days, despite excellent urine output, after which steady improvements in these parameters were observed. He was transferred to an outlying military hospital on hospital day 10. At the time of last follow-up, 16 days after presentation, and 11 days since CAVH was stopped, his BUN and serum creatinine were 13 and 1.8 mg/dl, respectively.

**Discussion**

We have demonstrated the successful use of an inexpensive, easy-to-assemble CAVH circuit, comprised of readily available hospital and chronic dialysis supplies, which functions independently of local water and electrical systems in a patient with presumed myoglobinuric acute renal failure. Control of azotemia and metabolic and volume homeostasis were achieved with this system, over several days.

We calculate the cost of a single circuit set-up (not including replacement fluid) at $128.80 (USD).

The cornerstone of management of rhabdomyolysis consists of early aggressive saline resuscitation to achieve a urine output of 200–300 ml/h [5]. Mannitol to promote a diuresis and alkalinization of the urine to limit myoglobin tubular toxicity are commonly employed interventions, though their use is not without controversy [6,7]. Despite these interventions, a substantial subset of patients may require renal replacement therapy. Intermittent or continuous therapies (convective or diffusive in nature) employing venovenous access (CVVH or CVVHD) have become standard blood purification methods in these cases.

The CAVH circuit we have employed may prove useful for the short-term management of patients requiring renal replacement therapy after mass casualties and natural disasters. However, given that this circuit has not been systematically evaluated and tested, we do not recommend its wholesale implementation. Instead, we describe its use here as an ‘option of last resort’, when no other viable form of renal replacement therapy is available. Others may find themselves in similar situations after a natural disaster. In these and similar situations, large numbers of patients with acute renal failure, in some cases superimposed upon a chronic dialysis population, may overwhelm local medical resources already challenged by impure or inadequate water supplies and impaired electrical sources. Except for the CAVH catheters, the components of the system are not specifically intended for use in CAVH. However, they are readily available, abundant and, in the case of the dialyser and blood tubing, used widely in the management of patients on chronic haemo- and peritoneal dialysis. They could be pre-assembled and stored in bulk, in order to assist disaster management teams in their planning, or obtained readily at the time of need, perhaps even locally after the disaster, especially in areas where there are large populations of chronic haemo- and peritoneal dialysis patients.

CAVH, although the first form of continuous renal replacement therapy described, has been largely replaced clinically by veno-venous (CVVH), pump-driven methods. Although CAVH catheters may be readily purchased, it is difficult to obtain ‘CAVH-dedicated’ blood line and haemofilter kits at short notice and in bulk, at least in the US. In fact, our inability to locate an in-stock CAVH blood-line and haemofilter kit when we foresaw the need for the modality, was the impetus for the development of this system. Many CVVH line and filter kits are available, but these are designed to fit ‘as a piece’ into a proprietary CVVH machine, and are not adaptable to CAVH. Dedicated CAVH kits are still readily available in Europe, however.

Others have previously suggested the use of CAVH for mass casualty victims. Omert et al. [8] described the hypothetical use of pumped continuous arteriovenous haemodiafiltration (CAVHD) in the mass casualty situation. In addition to the convective clearance
provided by CAVH, they suggested the addition of countercurrent dialysate flow through the filter, via a standard medication infusion pump, to enhance diffusive clearance of small molecular weight substances. This circuit would require electricity for use of the infusion pump. In addition, the authors had not yet tested their circuit clinically, and so conclusions regarding efficacy and feasibility are limited [8].

Better, in a brief review of the management of crush victims with myoglobinuric acute renal failure in the setting of natural disasters, recommends the use of CAVH when haemodialysis is unavailable. Though no cases are described in this report, the advantages of a non-pumped modality (the need for minimal equipment, lack of reliance upon local water and electrical resources, and improved haemodynamic stability) are described [9].

It is unknown whether the system we describe would be effective for all types of renal failure, or feasible in non-hospital settings, given the continuous electrolyte and haemodynamic monitoring involved. Myoglobinuric renal failure, as in our patient, may be particularly amenable to haemofiltration, given the relatively large size of myoglobin (molecular weight 17 000 Da). This has been clinically described in a number of reports [10–12]. However, not all authors concur on this point. The rate of myoglobin turnover in active rhabdomyolysis may overwhelm the clearance capacities of standard diffusive and convective modalities [13]. In addition, the clearance of myoglobin once renal failure is established may be unaffected by any blood purification modality [14].

The CAVH circuit described here was effective in controlling the acidosis, hyperkalaemia and hyperkalaemia that would be the most common life-threatening abnormalities in all patients with acute and chronic renal failure, regardless of cause. However, this circuit’s capacity to control more severe cases of hyperkalaemia, as seen in many cases of rhabdomyolysis, remains unknown. In addition, subsequent to the case described, we were successful in using the same system with a post-surgical trauma patient suffering from oliguric acute tubular necrosis, for a period of 12 h prior to transfer to a facility with dialytic capabilities.

Our system requires anticoagulation, with an attendant risk of bleeding in trauma patients, especially those with head trauma. This may limit this system’s use in some populations, as has been previously reported [15]. Our patient had evidence of uraemic pericarditis at presentation; given the inability to provide alternate forms of acute renal replacement therapy which would not require anticoagulation, we anticoagulated this patient in order to perform CAVH. The use of regional citrate anticoagulation or alternate forms of renal replacement therapy, such as peritoneal dialysis, would be optimal for patients at high-risk for bleeding complications. In addition, as with any CAVH system, the patient requires large volumes of sterile replacement fluid (up to 241/day under the conditions described herein) which may present a transport challenge for disaster planning teams. Whether or not such a circuit would be effective in anuric patients remains unknown.

Nephrological care of trauma victims can be greatly complicated by the loss of local infrastructure and resources due to natural or man-made disasters, and ideally involves substantial advance planning [16]. The management of complex medical patients in suboptimal conditions may require creative solutions utilizing immediately available resources. We have described the successful use in an austere environment of a simple disposable non-pumped arteriovenous haemofiltration system that is easily assembled, functions independently of local water and electrical sources, is made from readily available sterile components, can be bulk-stored in advance and is easily transported. While we do not recommend implementation of this system when standard renal replacement modalities are available, the circuit we describe may prove useful in austere situations, if these standard modalities are unavailable or dysfunctional. Further testing of this system is warranted.

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Conflict of interest statement. None declared.

References

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