In-Theater Peritoneal Dialysis for Combat-Related Renal Failure

Joseph S. Pina, MD, Soraya Moghadam, MD, Howard M. Cushner, MD, Greg J. Beilman, MD, and Vivian C. McAlister, MB

Background: Complications of renal failure may prevent timely evacuation of injured soldiers. Conventional renal replacement therapy is not available in forward surgical units.

Methods: Records of in-theater improvised peritoneal dialysis (IPD) in level III hospitals or forward surgical units in Iraq or Afghanistan were reviewed to determine the following: cause of renal failure and associated injuries; type of dialysate, peritoneal access, and exchange technique; and patient outcome. These data were used to propose method for IPD using commonly available materials.

Results: IPD is described in four patients. Abdominal or chest drains were used with either improvised dextrose–electrolyte solution or commercial dialysate. Exchanges were successful, despite fresh surgical wounds including full laparotomy, removed excess fluid and restored acid and electrolyte balance, but did not correct azotemia. Open abdominal packing prevented continuation of IPD after 48 hours. Two patients fully recovered, one died, and one patient with a poor prognosis was lost to follow-up.

Conclusion: IPD can be delivered effectively using readily available materials in forward surgical units and level III combat support hospitals.

Key Words: Combat-related renal failure, Renal replacement therapy, Peritoneal dialysis.

(*J Trauma.* 2010;68: 1253–1256)

There was an episode in the television serial M*A*S*H set in 1951 in which Forward Surgical Team (FST) members initially try to treat injured soldiers in renal failure by improvising a system of peritoneal dialysis (PD) before attempting hemodialysis (HD).[1] Historically, the United States Army fielded its first dialysis unit during the Korean War.[2] Because there was no commercial dialysis equipment available at that time, military clinicians used improvised equipment to perform HD. During the Vietnam War, the United States military provided dialysis support to wounded soldiers on a hospital ship and in a field dialysis unit.[3] Treatment of renal failure that occurred during Operation Iraqi Freedom usually consisted of HD or continuous renal replacement therapy (CRRT) and was supplied either on the USNS Comfort or in Landstuhl Regional Medical Center in Germany.[4] Despite the paucity of literature on the use of PD in a combat hospital, PD can be provided easily in a deployed setting since the supplies required to perform this procedure are readily available at combat support hospitals and probably available at FST facilities. Other types of renal replacement therapy, such as CRRT and HD require dialysis filters and blood pumps, which are not part of the field hospital inventory and are difficult to supply in a combat zone. Although treatment of renal failure has progressed considerably in the last 50 years, the problem of dealing with acute renal failure (ARF) in a forward surgical setting has not yet been solved. In this article, we report independent attempts to sustain patients with ARF in the Afghanistan and Iraq theaters of Operations Enduring Freedom, Iraqi Freedom, and the International Security Assistant Force.

Levels of care in the combat theater (also known as echelons of care) are generally aligned with the combat unit the healthcare element is intended to support, i.e. battalions and brigades, divisions, corps, and echelons above corps. There are five distinct levels and each successive one augments the treatment capacity of the previous level even if it possesses the same treatment capabilities. The evacuation route typically flows through each echelon. The primary health support elements at level I, which are focused on life-saving, resuscitative actions, are the self-aid/buddy aid, the combat lifesaver, and the battalion aid station. Level II care is commonly provided by the area support company and the FST in which further resuscitation and damage control surgery occur primarily. Featured by the combat support hospital, further resuscitation, damage control, and early repair work occur at level III. This level has a host of subspecialty support, but the focus is trauma surgery, intensive care, and air evacuation out of theater or return to duty. Level IV, the general hospital or medical center, is the first level at which definitive surgical repair and medical treatment occur. Level V centers provide highly subspecialized care and rehabilitative services and are typically located within the United States and Canada. Dialysis is routinely available only at levels IV and V.[5]

The first report of the use of peritoneal lavage to remove solute in patients with ARF was published in 1938 by Rhoads.[6] He reported on two patients with renal insufficiency treated by peritoneal lavage. He was able to demonstrate the removal of urea nitrogen in the effluent but the patients' blood urea nitrogen (BUN) remained unchanged. Rhoads treated several more patients but did not persist because of an inability to distinguish acute from chronic renal failure.[7] Rhoads's report influenced Wilhelm Kolff who more than anyone else introduced the

Submitted for publication August 28, 2009.
Accepted for publication February 17, 2010.

From the United States Army Pacific (J.S.P.), Canadian Forces Medical Service (S.M., V.C.M.A.), Nephrology Service (H.M.C.), Madigan Army Medical Center, Tacoma, Washington; and Division of Surgical Critical Care (G.J.B.), Department of Surgery, University of Minnesota Medical School, Minneapolis, Minnesota.
The opinions expressed here are those of the authors and do not necessarily reflect those of the Canadian Forces Medical Service or the US Department of Defense.
Address for reprints: Dr. Vivian McAlister, C4-212 University Hospital, London, ON N6A5A5; email: vmcalist@uwo.ca.

DOI: 10.1097/TA.0b013e3181d99089

modern era of renal replacement therapy.[7] There are only a few modern reports of improvised PD (IPD) usually involving adaptation of supplies in developing countries.[8] Currently in Afghanistan and Iraq, injured coalition soldiers with renal failure have to be evacuated to Landstuhl Regional Medical Center, a level IV hospital in Germany, for HD.[4] A mobile level IV hospital with HD is also available on USNS Comfort.[4] The patients described in the current report were either too unstable or otherwise ineligible for transfer to these units.

METHOD

The hospital records of patients who underwent in-theater IPD in level III hospitals or forward surgical units in Iraq or Afghanistan were reviewed. The following data were recorded: patient details, cause of renal failure and associated injuries, type of dialysate or method for making dialysate, technique of improvising PD (peritoneal access and exchange), and patient outcome. These data were used to determine whether IPD should be attempted in situations at which conventional renal replacement therapies are not possible and to propose a method for IPD using commonly available materials.

RESULTS

The injuries and clinical status of patients requiring IPD are summarized in Table 1. The methods used to institute IPD and their impact on patient care and outcomes are summarized in Table 2. We are not aware of other attempts at IPD but we were unable to do a comprehensive search.

Patient 1 was a 9-year-old boy (weight, 28 kg) who was shot through the right side of the pelvis by a negligent discharge of an AK47. His initial care was provided by a local hospital at which a laparotomy was performed and the right femoral artery was ligated through a groin incision to control hemorrhage. Three days later he seemed to be dying. His family brought him a hundred miles to our forward surgical unit at a level III hospital. The level of gangrene extended above the inguinal ligament anteriorly. It was necessary to disarticulate the hip to debride all the necrotic tissue. The patient had been anuric since admission with a massive positive fluid balance, creatinine of 7.1 mg/dL, pH of 7.05, and serum potassium of 6.9 mEq/L. One day after amputation, the laparotomy incision was opened and two Jackson-Pratt abdominal drains were inserted in two areas of the abdomen and pelvis. Stoma appliances were applied to

TABLE 1. Injuries and Clinical Status of Patients Requiring Improvised Peritoneal Dialysis

Patient	Injury	Surgery	Cause of Renal Failure	Indication for Dialysis
1: Male, age 9 yr, local civilian	Gunshot wound right iliac fossa and thigh, gangrene right leg	Laparotomy, hip disarticulation–amputation	Septic shock	Acidosis, hyperkalemia, fluid overload
2: Male, age 23 yr, local security force	Gunshot wound right arm and leg, fractured pelvis, bilateral renal contusion	Arm amputation, fasciotomy and external fixation leg	Renal contusion, hypovolemic shock	Acidosis, hyperkalemia, fluid overload
3: Male, age 32 yr, contract worker from third-party country	Cardiopulmonary arrest secondary to pneumonia	None	Anoxic injury	Acidosis, fluid overload, possible uremic coma
4: Male, age 19 yr, local security force	Massive soft tissue injury, fractured liver, spleen, abdominal compartment syndrome	Laparotomy, splenectomy, liver repair, debridement	Hypovolemic shock	Fluid overload

TABLE 2. In-Theater Improvised Peritoneal Dialysis

Patient	Catheter/Abdominal Surgery	Dialysate	Volume/Dwell Time	Duration of Dialysis and Total Number of Exchanges	Effect of Dialysis	Outcome
1	Two abdominal drains, midline laparotomy with closure	Improvised 4.5% dextrose solution	500 mL/2–4 h	10 d/27 exchanges	Fluid, acid, and electrolyte balance normalized	Full recovery, discharged home
2	Abdominal drain placed into pelvis	1.5% Dianeal (Baxter)	2 L/4 h	3 d/6 exchanges	Fluid removed, worsening azotemia	Transferred to local hospital for ongoing care
3	Pediatric chest drain placed into pelvis	Improvised 1.5% and 2.5% dextrose solutions	1.5–2 h	7 d/42 exchanges	Stabilization of fluid, electrolyte, acid balance; possible improved mental status, despite persistent azotemia	Transferred to home hospital on ventilator; full recovery after prolonged ICU stay and hemodialysis
4	Two abdominal drains, midline laparotomy with abdominal packing	4.25% Dianeal (Baxter)	Initial: 500 mL Later: continuous	4 d/11 exchanges	Fluid removed, azotemia, acidosis unaltered	Death with multiple organ failure

TABLE 3. Procedure to Make 500 mL of Improvised Peritoneal Dialysate

	1.25% Dextrose	2.5% Dextrose	4.5% Dextrose
5% Dextrose water (mL)	125	250	449.75
10% $CaCl_2$ (mL)	0.25	0.25	0.25
5% $NaHCO_3$ (mL)	50	50	50
0.9% saline (mL)	324.75	199.75	0
Instructions	Remove appropriate volume from a 500-mL bag of 5% dextrose, add the other ingredients and fill back to a total volume of 500 mL with 0.9% saline		

the skin around the drain sites. The drains were brought through the front of the bag which was placed to catch fluid leakage. These tube drains were used to deliver and remove dialysate that had been prepared according to a recipe summarized in Table 3. Exchanges were tested with 100 mL volumes several hours after surgery and increased to 200 to 500 mL with dwell times of 1 to 4 hours. The patient's creatinine level remained at approximately 7 mg/dL, but fluid balance, pH (7.05–7.45), and serum potassium (6.9–5.0 mEq/L) normalized over the first week. PD was continued for 10 days with a total of 27 exchanges. Urine output returned after 8 days. The patient was weaned from the ventilator 4 days after admission. The patient was mobile with crutches and his creatinine had dropped to 1.28 at the time of discharge.

Patient 2 was a 23-year-old man (weight, 65 kg) who received multiple gunshot injuries to the right side. He was treated in a local hospital before transfer to the level III forward surgical hospital. One bullet had caused extensive neurovascular and soft tissue injury in the axilla as the bullet tracked through the scapula and shoulder. Another had fractured the right pubic ramus and there was an evidence of bilateral renal contusion. A third bullet had fractured the right tibia and fibula. Despite resuscitation, including fluid, blood products, and mechanical ventilation, the patient remained in ARF. Surgery included a right arm amputation, laparotomy, and external fixation of the right leg. The patient remained hemodynamically stable but anuric. Five days after admission, 1 week after the injury, management became difficult because of fluid overload. Serum creatinine was 8.65 mg/dL, pH 7.28, and potassium 2.9 mEq/L. An abdominal drain (Jackson-Pratt catheter) was placed through the lower part of the laparotomy incision into the pelvis. Exchanges were started immediately and were initially performed with commercial 4.25% dextrose (Dianeal, Baxter) and then with 1.5% dextrose (Dianeal, Baxter). A total of 19 L was exchanged to remove an additional 3 L. Despite an ongoing increase in serum creatinine, the patient stabilized. The patient was transferred to a local hospital for ongoing care. Long-term outcome is not known.

Patient 3 was a 32-year-old Ugandan man with pneumonia, transaminitis, anemia, thrombocytopenia, normal renal function with normal urinalysis, and a normal total white blood cell count with lymphopenia at admission. Malaria studies, Q fever titers, stool culture and microscopic examination, and blood cultures were all negative. Despite broad-spectrum antibiotics, the patient required mechanical ventilation. Bronchoscopy failed to reveal an etiology. There was no evidence of pulmonary hemorrhage. On hospital day 8, the patient went into cardiopulmonary arrest caused by an obstructed endotracheal tube. After 8 minutes of cardiopulmonary recuscitation with reintubation, reoxygenation, and Advanced Cardiac Life Support protocol, he regained a pulse and blood pressure. Since the arrest, the patient's neurologic examination was consistent with anoxic brain injury. Sedation and control of agitation was accomplished with midazolam and fentanyl. The patient developed classic acute tubular necrosis with typical dark brown muddy casts in the urine sediment. Five days after the cardiac arrest, the serum BUN and creatinine increased to 132 mg/dL and 5.9 mg/dL respectively, and he maintained a non-gap metabolic acidosis, yet he was not oliguric or hyperkalemic. Uremic mental status changes could not be adequately assessed while he was on intravenous sedatives. Because HD or CRRT filters were not available at this level III hospital, the critical care team started PD. A pediatric chest tube was used as the infusion/effluent catheter since the facility does not stock conventional PD catheters. The team started 1-L exchanges of a 2.5% dextrose-based solution (with added sodium lactate) with 1.5-hour dwell times, which were tolerated well. Initially when 2-L exchanges were attempted, the patient became hypoxemic, possibly because of compromised venous return and mechanical effects on the thorax. The patient received a total of 42 exchanges over 7 days. Eventually, 2-L (1.5% to 2.5%) dextrose solution-based exchanges with 2-hour dwell times were the average treatment. We observed downtrending of the serum creatinine from a high level of 7.7 mg/dL to 6.4 mg/dL, although the BUN continued to peak at a high level of 199 mg/dL. The patient never developed hyperkalemia, oliguria, or fluid overload, and the metabolic acidosis improved. When the patient's sedation was lightened, the patient began to respond to voice and commands, despite his extreme uremic state. The patient stabilized from a pulmonary and renal point of view such that he could be air evacuated to Johannesburg, South Africa, for follow-on care. He completely recovered his neurologic, pulmonary, and renal function and is home with his family in Uganda today.

Patient 4, a 19-year-old man (weight, 68 kg) was brought to the level III forward surgical unit in shock having been thrown out of a moving truck. He suffered multiple fractures of vertebrae and ribs. There was massive soft tissue injury on his back and buttocks from shear stress. He required an urgent laparotomy and splenectomy to control hemorrhage from a fractured liver and spleen. He was anuric and he developed abdominal compartment syndrome. A second laparotomy was performed and the abdomen was left open with a gauze and op-site dressing. An abdominal drain (Jackson-Pratt catheter) was placed in the gauze to drain effluent. A second drain had been placed in the pelvis. PD was instituted by instilling 4.25%

commercial dextrose solution (Dianeal, Baxter) in the pelvis. Volumes of 0.5 L to 1 L were dwelled for 2 hours to 4 hours for the first 2 days. After this, fluid leaked via the abdominal packing soon after instillation. Continuous exchange was attempted for another 48 hours with less effect. Eleven exchanges were performed using a total volume of approximately 20 L of dialysate, removing about 3 L of additional fluid. However, the patient deteriorated after exchanges became less effective. As the serum creatinine level increased to 14.4 mEq/dL, the patient developed acidosis and hyperkalemia before he suffered cardiac arrest and death, 8 days after admission.

DISCUSSION

Military clinicians often face ARF in the severely injured patient. Modern developments such as damage control resuscitation and rapid evacuation reduce the requirement for in-theater renal replacement therapy. For this reason, dedicated expert teams capable of supporting patients with renal failure have not been deployed in Afghanistan or Iraq.[3] However, evacuation to level IV hospitals is not available to patients who are too unstable for air transport or to local victims of conflict. All the patients in this series were local nationals or citizens of a third-party country. When considering dialysis for local patients, providers should expect rapid recovery of native renal function, because chronic dialysis cannot be supported by level III hospitals and it may not be available in the host country. In the case of foreign nationals, dialysis can be performed until the patient is stable enough for transport to a higher level of care. The depletion of resources by a single patient with chronic renal failure is the same dilemma that Rhoads faced in 1938.[6,7]

In some situations, US Military and Coalition Forces members with ARF may be too unstable for transfer. Survival of these wounded soldiers may require the initiation of renal replacement therapy to stabilize them for evacuation to a level IV healthcare facility. Although this group is more likely to require renal replacement therapy, air evacuation of injured coalition soldiers may not be possible because of the complications of ARF such as fluid overload, acidosis, and hyperkalemia. Experience with acute renal replacement used in the care of carefully selected local patients may be extremely beneficial if the procedure is applied in preparing soldiers for evacuation.

None of our patients had any evidence of premorbid renal insufficiency. Patients 1 and 3 clearly fall into the group in which short-term renal replacement therapy permits recovery from otherwise fatal injuries because definitive surgical or medical treatment can be completed quickly, whereas patients 2 and 4 have less certain outcomes because multiple complex surgeries are required to achieve stability. The dilemma facing healthcare providers in the forward surgical setting is not so much distinguishing patients with ARF from those with chronic renal failure but predicting how long a patient may require IPD.

The procedure given in Table 3 for improvised dialysate uses materials commonly available in critical care. The method of adding the correct amount of each ingredient to approximate conventional dialysate has been simplified to avoid hazardous calculations during a period of stress. The availability of an onsite pharmacist or of commercial dialysate would make this process easier. However, the measuring techniques and solutions used are familiar to critical care staff who should be capable of making improvised dialysate at the point of care as long as the formula is available to them.

In all the patients in this series, PD had to be instituted before healing of the abdominal incision, and the size of the laparotomy incision limited the efficiency of IPD. This was particularly so in patient 4 who required open abdominal packing for abdominal compartment syndrome. Patients 1 and 3 are examples of how one can fully improvise PD by creating a dialysate from scratch and using a thoracostomy tube or an abdominal surgical drain in lieu of a commercial PD catheter. Although azotemia and uremia were not reversed by IPD, it is believed that fluid overload, hyperkalemia, and acidosis were prevented to allow for recovery or safe transfer to a higher level of care that could provide HD.

In the episode of M*A*S*H, BJ, and Hawkeye were unsuccessful with PD and so resorted to improvised HD with materials ordered from the Sears catalogue and sausage casing from Packo's Café in Toledo.[1] In developed countries, trauma-related ARF is usually treated with conventional HD or by CRRT. PD is usually reserved for stable patients with chronic renal failure and then instituted only after the mini-laparotomy incision has healed. Trauma patients often have larger abdominal incisions and cannot wait for healing before the exchanges are to begin. Leakage of fluid interferes with adequate dialysis but does not prevent it. The problem of leakage is considerably worse if the abdomen has to be packed open. The efficacy of exchanges may deteriorate after a few days because the direct flow or communication between infusion and effluent tubes limits dialysate exposure time to an adequate amount of peritoneal surface area.

The fictionalized care given in the drama M*A*S*H is remarkably accurate because of advice given to the writers by physician veterans of the Korean War. Both the physicians and the writers believed that improvised HD would be feasible in a forward surgical hospital. This has proved not to be the case. A low-technology renal replacement therapy such as IPD is possible and could be a valuable adjunct to soldier care.

ACKNOWLEDGMENTS

We are grateful to Canadian Forces pharmacist Lt (N) Cory Ryan for advice regarding the composition of improvised dialysate.

REFERENCES

1. Wilcox D, Mumford T. A War for all Seasons (M*A*S*H, Season 9, 29 December) 1980. 20th Century Fox Film Corporation, Los Angeles, CA.
2. Teschan PE. Acute renal failure in the Korean War. *Ren Fail.* 1992;14:237–239.
3. Chung KK, Perkins RM, Oliver JD III. Renal replacement therapy in support of combat operations. *Crit Care Med.* 2008;36(7 suppl):S365–S369.
4. Perkins R, Simon J, Jayakumar A, et al. Renal replacement therapy in support of Operation Iraqi Freedom: a tri-service perspective. *Mil Med.* 2008;173:1115–1121.
5. *Army Field Manual 8–10*, Chapter 3, Section II, paragraphs 3.5 and 3.6.
6. Rhoads JE. Peritoneal lavage in the treatment of renal insufficiency. *Am J Med Sci* 1938;196:642–647.
7. Barker CF. Jonathan Rhoads MD 1907–2002. *Ann Surg.* 2002;235:740–744.
8. Onwubalili JK. Successful peritoneal dialysis using 0.9% sodium chloride with modified M/6 sodium lactate solution and recycled catheters. *Nephron.* 1989;53:24–26.

