

# CRITICAL CARE ROUNDS™

November 2002  
Volume 3, Issue 9

AS PRESENTED IN THE GRAND ROUNDS OF  
PARTICIPATING HOSPITALS ACROSS CANADA

## Renal replacement therapy in the critically ill

By R. T. NOEL GIBNEY, MB, FRCPC

Acute renal failure (ARF) requiring renal replacement therapy (RRT) occurs in 4%-6% of patients admitted to critical care units. Despite major advances in overall supportive therapy and in techniques for RRT, mortality in patients with ARF – particularly when associated with multiple organ failure – remains high, with reported rates of up to 80%.<sup>1-6</sup> The development of ARF is an independent variable associated with a significantly higher mortality.<sup>6,7</sup> This issue of *Critical Care Rounds* will briefly review the indications for, and timing of, RRT in patients with ARF and will also discuss available RRT modalities and outcomes.

### Indications for RRT

The indications for RRT are listed in Table 1. There are now a number of safe and effective modalities for RRT. It is important, however, to understand that the lessons learned from chronic dialysis are not applicable to critically ill patients with ARF. There are a number of principles to be considered in the management of these critically ill patients.

- The degree of physiological disturbance in the first 24 hours of ICU care significantly determines eventual outcome. Rapid and effective correction of metabolic and physiologic derangement is an important therapeutic goal. RRT should be applied early to prevent electrolyte imbalance, uremia, acidosis, and pulmonary edema.
- Although not a traditional indication, oliguria (< 5 mls/kg/day) in the setting of shock or severe critical illness is an indication for RRT as these patients require large volumes of fluid for their antibiotics and vasopressors/inotropes. Critically ill patients with ARF as a component of multiple organ failure require the same high protein requirements as similar patients without renal failure. It is impossible to provide adequate nutrition to critically ill patients without early and effective RRT.
- The use of artificial organ system support should not delay the recovery of the organ system.
- The organ replacement system must be biocompatible and must not activate components of the immune or complement systems.

### Membranes

In order to remove potentially toxic solutes and water, the patient's blood is circulated over a semi-permeable membrane. Membranes may be classified as:

- cellulosic or synthetic
- low-flux or high-flux
- nonbiocompatible or biocompatible



### The Canadian Critical Care Society (CCCS) — Editorial Board

Graeme Rocker, MD  
*President, CCCS*  
Dalhousie University

Paul J. E. Boiteau, MD,  
*Past President, CCCS*  
University of Calgary

Deborah Cook, MD, *President, CCCTG*  
McMaster University

John Granton, MD, *Editor*  
University of Toronto

Mark Heule, MD  
University of Alberta

Daren Heyland, MD  
Queen's University

Jacques Lacroix, MD  
University of Montreal

Claudio Martin, MD  
University of Western Ontario

Cindy Hamielec, MD, *President,*  
*Canadian Intensive Care Foundation*  
McMaster University

Jamie Hutchison, MD  
University of Toronto

### The Canadian Critical Care Society

*Correspondence:*

John Granton, MD  
The Toronto General Hospital  
10 EN-220  
200 Elizabeth Street  
Toronto, ON. M5G 2C4  
Fax: 416-340-3359

The editorial content of  
*Critical Care Rounds* is determined  
solely by the Canadian Critical  
Care Society.

**Table 1: Indications for acute RRT in ARF<sup>8</sup>**

- Oliguria (urinary output <5 mL/kg/day)
- Anuria (no urinary output for > 12 hrs)
- Serum creatinine >600 µmol/L
- Plasma urea concentration >35 µmol/L
- Hyperkalemia (serum potassium concentration >6.5 mmol/l)
- Pulmonary edema unresponsive to diuretics
- Metabolic acidosis (pH <7.2)
- Uremic encephalopathy
- Uremic pericarditis
- Uremic neuropathy

Cellulosic membranes (cuprophane, hemophane, cellulose acetate) are manufactured from cotton fibres and are thin and hydrophilic with uniform porosity. Synthetic membranes include polysulphone, polymethylmethacrylate, polyacrylonitrile, polyamide and carbonate; these are thicker, but usually have larger pores. Low-flux dialysis membranes have smaller pores and are less efficient in solute removal, especially of larger molecules than high-flux membranes. Older unsubstituted cellulosic membranes activate the coagulation cascade, complement, and leukocytes, and have been implicated in the development of acute lung injury, delay in the recovery of renal function, and higher mortality.<sup>9,10</sup> Synthetic dialysis membranes and biocompatible cellulose triacetate membranes avoid these complications and only these biocompatible membranes should be used in RRT in ARF.<sup>11,12</sup>

### Modalities of RRT

Solutes can be removed from fluid by diffusion when molecules move across a semi-permeable membrane along a diffusion gradient or by ultrafiltration when solute molecules are carried convectively with water (solute drag) across a permeable membrane after hydrostatic pressure is applied. Smaller molecular weight substances are removed effectively by both techniques, while larger molecular weight substances are more effectively removed convectively. The available modalities for RRT are listed in Table 2.

#### *Peritoneal dialysis*

Peritoneal dialysis uses the peritoneum as a natural semi-permeable membrane for the diffusive removal of solutes. It is a very effective modality in patients with chronic renal failure. It is preferable in patients with limited vascular access or in those who cannot tolerate hemodialysis because of severe hypotension due to limited cardiac reserve. Peritoneal dialysis is also valuable in pediatric critical care where vascular access is challenging and the peritoneal surface area is relatively larger than in adults.<sup>13</sup> In critically ill adult patients, peritoneal dialysis is

**Table 2: Modalities for RRT**

- peritoneal dialysis
- intermittent hemodialysis
- continuous renal replacement therapies
  - CVVH
  - CVVHD
  - CVVHDF
  - high volume ultrafiltration

of limited value because of low solute clearance in hypercatabolic patients and the development of pulmonary restriction in those with respiratory failure. It is also technically impossible when there are surgical drains and partially open surgical incisions.<sup>14</sup>

#### *Intermittent hemodialysis*

Hemodialysis is a process of solute clearance based on diffusion across the membrane that is driven by a concentration gradient between the blood and dialysate. The total amount of solute transported per unit of time (clearance), depends on the molecular weight of the molecule, the diffusibility of the membrane (dialysance), the dialysate flow, and the blood flow. In standard intermittent hemodialysis (IHD), the dialysate flow is 500 mL/minute and therefore requires that the dialysate be prepared on-line. This requires a supply of pyrogenic, electrolyte-free water.

Although the use of continuous renal replacement therapy (CRRT) is gaining more support in the critically ill, particularly in Australia and to some extent in Europe, IHD remains the primary mode of RRT in the management of ARF in many other countries and in North America. However, use of CRRT is increasing progressively.<sup>15,16</sup> While generally very effective in removing solutes, IHD may cause severe hypotension due to plasma capillary refill lagging behind fluid removal or by sudden shifts in tonicity, causing loss of intravascular fluid into the interstitial space. These episodes of hypotension and associated increases in vasopressor therapy may cause further renal damage on recovery from ARF.<sup>17,18</sup> Dialysis dysequilibrium syndrome caused by cerebral edema during IHD in patients with very elevated plasma urea levels is now very rare.<sup>19</sup> However, a similar situation occurs in patients with ARF associated with fulminant hepatic failure where the brain may already be edematous and the drop in urea levels during IHD may precipitate severe cerebral edema.<sup>20-23</sup>

#### *Continuous renal replacement therapy (CRRT)*

CRRT refers to a group of renal replacement therapies that are applied continuously to critically ill patients with brief interruptions for hemofilter replacement, trips to the operating room, or to diagnostic imaging. The most commonly applied modalities are continuous venovenous hemofiltration (CVVH), continuous venovenous hemodialysis

(CVVHD), and continuous venovenous hemodiafiltration (CVVHDF). During CVVH, solute is removed primarily by convective clearance, whereas during CVVHD, solute is cleared primarily by diffusion. CVVHDF combines both convective and diffusive clearance. CRRT provides slower solute clearance per unit time, but over 24 hours, may even exceed clearances with IHD. Because fluid is removed relatively slowly compared with IHD, plasma refilling can usually keep pace with this and there is generally more hemodynamic stability during CRRT, even in very critically ill patients.<sup>24,25</sup>

### Slow low efficiency daily dialysis (SLEDD)

These are variants of IHD where the duration of dialysis is extended to between 8 and 12 hours, blood flow is lowered to 100 mL/min, fluid removal is more gradual, and solute clearance slower. SLEDD is associated with less hemodynamic instability than IHD and has excellent solute control.<sup>26</sup>

### Timing of initiation and dose of RRT

The timing of the initiation of RRT in a critically ill patient with ARF cannot be based on recommendations for chronic renal failure. There is accumulating evidence that although urea is not directly toxic, it is a marker for other toxic substances that accumulate in ARF. There is also evidence that outcomes are improved when RRT is started when serum urea is at or below 35 mmol/L. It has been suggested that the provision of earlier RRT is associated with improved outcomes in critically ill patients.<sup>27,28</sup> It is rare to see patients with symptomatic uremia these days as RRT is usually initiated relatively early. On the other hand, it is important to remember that patients with ARF may develop symptomatic uremia at much lower urea levels because they do not have the time for adaptation seen in chronic renal failure.

While, in the past, there was the view that outcome was not determined by the intensity of dialysis, there is now extensive evidence that survival of critically ill patients with ARF is influenced by the intensity of RRT.<sup>29</sup> A meta-analysis by Kjellstrand suggests that mortality in ARF is reduced when plasma urea levels are maintained <35 mmol/L.<sup>30</sup> Effectiveness of RRT in IHD is measured as  $KT/V$ , where  $K$  = the dialysance of the dialyzer,  $T$  = time, and  $V$  = the volume of distribution. However, because the volume of distribution is so variable in critically ill patients, the practical use of this formula is clinically limited. For practical purposes, the duration of each dialysis session is the most important determinant of dialysis in IHD. In CRRT, the dialysis dose represents the volume of effluent fluid (replacement fluid and dialysate) delivered to the circuit.

Paganini and his group in Cleveland have established a clear link between dialysis dose and outcomes for critically ill patients with ARF.<sup>5</sup> This study showed that patients at the extremes of illness severity did not benefit

from more intensive RRT. However, in patients with mid-range severity of illness, a higher RRT dose (whether delivered by IHD or CRRT) was associated with significantly lower mortality. Schiffel also showed improved mortality in ICU patients with ARF treated with daily IHD compared to alternate day IHD.<sup>31</sup> RRT dose should be individualized, and in particular, take into account weight, as well as the degree of catabolism. Nomograms and computer programs have been created to estimate time and frequency of IHD, as well as dose of CRRT.<sup>32-35</sup> Heavier patients (> 100 kg) may require daily IHD for up to 6 hours to maintain acceptable urea levels. There is also evidence that CRRT dose influences outcome. Ronco et al showed that a moderately increased dose of CVVH of 35 mL/kg/hr was associated with improved survival in critically ill patients with ARF. However, increasing the dose to 45 mL/kg/hr did not improve outcomes.<sup>36</sup>

### High volume hemofiltration

Hemofiltration has the ability to remove significant amounts of middle molecular weight compounds, including various cytokines.<sup>37</sup> Two case series showed improvement in hemodynamic status and outcomes in patients with severe septic shock treated with high-volume hemofiltration at ultrafiltration rates of up to 9 L/hour for 4 hours, followed by CVVH at 1 L/hr.<sup>38,39</sup> However, these results were not supported in a more recent, prospective, randomized, controlled trial that found no significant differences in outcomes when compared to more conventional CVVH dosing.<sup>40</sup>

### Vascular access

Vascular access must be obtained using double lumen dialysis catheters. These may be inserted acutely in the internal jugular or femoral veins. If possible, the subclavian veins should not be cannulated to avoid subsequent venous stenosis, which may significantly complicate venous access if chronic hemodialysis is subsequently required.<sup>41-43</sup> Blood recirculation can reduce the effectiveness of RRT, particularly during IHD. Use of a short 13.5 cm catheter in the femoral vein may result in up to 23% blood flow recirculation and can be avoided by using longer catheters (19-25 cm) when using the femoral vein for vascular access.<sup>44</sup>

### Anticoagulation

Unfractionated heparin remains the mainstay of anticoagulation for IHD and CRRT.<sup>45</sup> Nonetheless, many critically ill patients are at high risk of hemorrhage because of trauma, major surgery, and/or coagulopathy. It is possible to perform regional anticoagulation with heparin neutralized with protamine; however, this is an extremely complex procedure and is often complicated by hemodynamic instability and rebound anticoagulation later when the heparin and protamine dissociate.<sup>46</sup> Because of the shorter duration and high blood flow used,

it is often possible to perform IHD without anticoagulation, particularly when the patient is coagulopathic. Low molecular weight heparin is excreted renally and should not be used without careful monitoring of factor Xa levels in patients with ARF.<sup>47</sup>

Continuous anticoagulation is usually required to maintain CRRT circuits and may result in significant hemorrhage over time.<sup>47</sup> While unfractionated heparin is still used in most centres, regional citrate anticoagulation with either 4% trisodium citrate or ACD-A is increasingly used for CRRT. Regional citrate anticoagulation gives a longer hemofilter life and eliminates any extra risk of bleeding.<sup>49-52</sup> Regional citrate anticoagulation may also be used with IHD in patients at high risk for hemorrhage.<sup>53</sup> Prostacyclin has been used in patients at high risk of bleeding, particularly those with combined ARF and hepatic failure. It is associated with hypotension and a need for increased vasopressor requirements in most patients. Lower doses of prostacyclin may be used with low doses of unfractionated or low molecular weight heparin.<sup>54</sup>

In patients with heparin-induced thrombocytopenia (HITT), direct thrombin inhibitors should be used for systemic and extracorporeal circuit anticoagulation.<sup>55,56</sup> Options include danaparoid, lepirudin and argatroban. Danaparoid may interact with anti-heparin antibodies in 20%-40% of patients with HITT.<sup>57</sup> Lepirudin, a recombinant form of hirudin, is a potent thrombin inhibitor, but is renally excreted and standard tests of coagulation are poor monitors of the degree of anticoagulation.<sup>58,59</sup> Argatroban, another potent direct thrombin inhibitor, has recently become available for clinical use and offers significant advantages in patients with renal failure since it is metabolized in the liver and the dosage may be accurately monitored using PTT.<sup>60,61</sup>

### Nutrition during RRT

The once favoured concept of protein restriction in ARF should no longer be applied. Critically ill patients with ARF are hypercatabolic and require the same protein and caloric intake as critically ill patients who do not have ARF.<sup>62-64</sup> The dose of RRT, whether IHD or CRRT, should be tailored to avoid azotemia. Effective RRT dosing results in significant removal of amino acids. Higher doses of CRRT remove up to 12% of administered amino acids and administered protein should be proportionately increased to compensate for these losses.<sup>65</sup>

### IHD or CRRT?

CRRT allows for the provision of effective RRT in critically ill, hemodynamically unstable patients

who would not tolerate IHD. Although many studies have attempted to investigate which modality of RRT is superior, these have been underpowered, have excluded unstable patients from IHD, or have had high crossover rates from IHD to CRRT.<sup>66-69</sup> Consequently, there is no definitive answer about whether one modality is superior in all clinical settings of ARF. A recent meta-analysis by Kellum et al suggests that CRRT may offer survival advantages over IHD in critically ill patients. CRRT is considerably more expensive than IHD (costing CDN \$200-\$500 per day), depending on the dose and numbers of hemofilters used. It also requires that the patient remain immobilized, even when beginning to stabilize. Consequently, it would seem prudent to use CRRT initially in unstable patients with ARF, subsequently converting to IHD once hemodynamic stability has been achieved.

### Who should prescribe and monitor RRT?

Unfortunately, issues of “turf” have tended to cloud institutional decisions over the provision of IHD versus CRRT. While local politics and medical expertise are important to consider, patient-care issues should be paramount in deciding who should prescribe and monitor RRT in the ICU. Critically ill patients with ARF are the most unstable patients in the hospital and require moment-to-moment titration of therapy. This is particularly an issue in fluid and vasopressor management. Consequently, it is preferable that RRT should be prescribed and monitored by the team managing other organ system support therapies.<sup>71-73</sup> It is also important to maintain close nephrological observation when managing critically ill patients with ARF to rule-out the possibility of reversible intrinsic renal disease and to follow those who may require ongoing IHD following their transfer from the ICU.<sup>74,75</sup> The clinical “bottom lines” for the administration of renal replacement therapy are shown in Table 3.

**Table 3: Clinical bottom lines for RRT**

- Provide adequate nutrition
- Initiate early, effective, gentle RRT for critically ill patients with ARF
- Use biocompatible membranes
- Use access catheters appropriate for insertion site
- Avoid IHD if risk of cerebral edema
- Use CRRT if hemodynamically unstable

## The future of RRT in the ICU

The expense of the fluids required for CRRT has limited their use and kept dosing typically below recommended levels. However, it is certain that on-line proportioning devices to produce ultrapure fluids will be incorporated into future CRRT machines.<sup>76,77</sup> There is increasing interest in albumin dialysis to remove toxins accumulating in hepatic failure. This modality is currently undergoing clinical evaluation and may be clinically available in the near future.<sup>78</sup> The use of other adsorbent mechanisms such as coupled plasma-filtration adsorption for the selective removal of cytokines has had encouraging preliminary results in severe sepsis and more clinical studies are currently underway.<sup>79,80</sup>

---

**R. T. Noel Gibney, MB, FRCPC, is a Professor in the Division of Critical Care Medicine, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta**

---

### References

- Schaefer JH, Jochimsen F, Keller F, Wegscheider K, et al. Outcome prediction of acute renal failure in medical intensive care. *Intensive Care Med* 1991;17:19-24.
- Chertow GM, Christiansen CL, Cleary PD, Munro C, et al. Prognostic stratification in critically ill patients with acute renal failure requiring dialysis. *Arch Intern Med* 1995;55:1505-1511.
- Brivet FG, Kleinknecht DJ, Philippe L, et al. Acute renal failure in intensive care units – Causes, outcome, and prognostic factors of hospital mortality: A prospective, multicenter study. *Crit Care Med* 1996;24:192-198.
- Liano F, Pascual J, and the Madrid Acute Renal Failure Study Cluster. Epidemiology of acute renal failure: A prospective, multicenter, community-based study. *Kidney Int* 1996;50:811-818.
- Paganini EP, Tapolyai M, Goormastic M, et al. Establishing a dialysis therapy/patient outcome link in intensive care unit acute dialysis for patients with acute renal failure. *Am J Kidney Dis* 1996;28:S81-S89.
- Metnitz PG, Krenn CG, Steltzer H, et al. Effect of acute renal failure requiring renal replacement therapy on outcome in critically ill patients. *Crit Care Med* 2002;30:2051-2058.
- Levy EM, Visconti CM, Horwitz RI. The effect of renal failure on mortality: a cohort analysis. *JAMA* 1996;275(19):1489-1494.
- Bellomo R, Ronco C. Acute renal failure in the intensive care unit: adequacy of dialysis and the case for continuous therapies. *Nephrol Dial Transplant* 1996;11:424-428.
- Craddock PR, Fehr J, Brigham KL, et al. Complement and leukocyte-mediated pulmonary dysfunction in hemodialysis. *N Engl J Med* 1977; 296:769.
- Hakim RM, Wingard RL, Parker RA. Effect of the dialysis membrane in the treatment of patients with acute renal failure. *N Engl J Med* 1994;331:1338-42.
- Hakim RM. Clinical implications of hemodialysis membrane incompatibility. *Kidney Int* 1993;44:484-494.
- Subramanian S, Venkataraman R, Kellum JA. Influence of dialysis membranes on outcomes in acute renal failure: a meta-analysis. *Kidney Int* 2002;62:1819-23.
- Williams DM, Sreedhar SS, Mickell JJ, Chan JC. Acute kidney failure: a pediatric experience over 20 years. *Arch Pediatr Adolesc Med* 2002;156:893-900.
- Phu NH, Hien TT, Mai NT, et al. Hemofiltration and peritoneal dialysis in infection-associated acute renal failure in Vietnam. *N Engl J Med* 2002;347:895-902.
- Silvester W, Bellomo R, Cole L. Epidemiology, management, and outcome of severe acute renal failure of critical illness in Australia. *Crit Care Med* 2001;29:1910-5.
- Mendelssohn DC, Hyman A. Current Canadian approaches to dialysis for acute renal failure in the ICU. *Am J Nephrol* 2002;22:29-34.
- Conger J. Hemodynamic factors in acute renal failure. *Adv Renal Replac Ther* 1997;4(Suppl):25-37.
- Kelleher SP, Robinette JB, Miller F, et al. Effect of hemorrhagic arterial pressure reduction in different ischemic renal failure models. *Kidney Int* 1994;46:318-326.
- Arieff AI. Dialysis disequilibrium syndrome: current concepts on pathogenesis and prevention. *Kidney Int* 1994;45:629-635.
- Davenport A, Will EJ, Losowsky MS, et al. Continuous arteriovenous hemofiltration in patients with hepatic encephalopathy and renal failure. *Br Med J* 1987;295:1028.
- Davenport A, Will EJ, Davison AM, et al. Changes in intracranial pressure during haemofiltration in oliguric patients with grade IV hepatic encephalopathy. *Nephron* 1989;53:142-146.
- Davenport A, Will EJ, Davison AM, et al. Changes in intracranial pressure during machine and continuous haemofiltration. *Int J Artif Organs* 1989;12: 439-444.
- Davenport A. Is there a role for continuous renal replacement therapies in patients with liver and renal failure? *Kidney Int* 1999;56 (Suppl):S62-S66.
- Bellomo R, Ronco C, Mehta RL. Nomenclature for continuous renal replacement therapies. *Am J Kidney Dis* 1996;28 (Suppl):S2-S7.
- Kellum JA, Mehta RL, Angus DC, et al. The first international consensus conference on continuous renal replacement therapy. *Kidney Int* 2002;62:1855-1863.
- Kihara M, Ikeda Y, Shibata K, et al. Slow hemodialysis performed during the day in managing renal failure in critically ill patients. *Nephron* 1994;67:36-41.
- Gettings LG, Reynolds HN, Scales T. Outcome in post-traumatic acute renal failure when continuous renal replacement therapy is applied early vs. late. *Int Care Med* 1999;25:805-813.
- Guerin C, Girard R, Selli JM, et al. Initial versus delayed acute renal failure in the intensive care unit. *Am J Respir Crit Care Med* 2000; 161:872-879.
- Gillum DM, Dixon BS, Yanover MJ, et al. The role of intensive dialysis in acute renal failure. *Clin Nephrol* 1986;25(5):249-55.
- Kjellstrand C, Jacobson S, Lins L. Acute renal failure. In: Maher J (ed), *Replacement of renal function by dialysis* 3<sup>rd</sup> edition. Dordrecht, The Netherlands: Kluwer Academic 1989;616-649.
- Schiff H, Lang SM, Fischer R. Daily hemodialysis and the outcome of acute renal failure. *N Engl J Med* 2002;346:305-310.
- Clark WR, Mueller BA, Kraus MA, Macias WL. Extracorporeal therapy requirements for patients with acute renal failure. *J Am Soc Nephrol* 1997;8(5):804-812.
- Frankenfield DC, Reynolds HN, Wiles CE, et al. Urea removal during continuous hemodiafiltration. *Crit Care Med* 1994;22(3):407-12.
- Garred LJ. Dialysate-based kinetic modeling. *Adv Renal Replacement Ther* 1995;2: 305-318.
- Garred L, Leblanc M, Canaud B. Urea kinetic modeling for CRRT. *Am J Kidney Dis* 1997;30:S2-S9.
- Ronco C, Bellomo R, Homel P, et al. Effects of different doses in continuous veno-venous haemofiltration on outcomes of acute renal failure: a prospective randomized trial. *Lancet* 2000; 356:26-30.
- Uchino S, Bellomo R, Goldsmith D, et al. Super high flux hemofiltration: a new technique for cytokine removal. *Int Care Med* 2002; 28:651-655.
- Oudemans-van Straaten HM, Bosman RJ, van der Spoel JL. Outcome of critically ill patients treated with intermittent high-volume haemofiltration: a prospective cohort analysis. *Intens Care Med* 1999; 25(8):814-21.
- Honore PM, Jamez J, Wauthier M. Prospective evaluation of short-term, high-volume isovolemic hemofiltration on the hemodynamic course and outcome in patients with intractable circulatory failure resulting from septic shock. *Crit Care Med* 2000;28:3581-3587.
- Bouman CS, Oudemans-Van Straaten HM. Effects of early high-volume continuous venovenous hemofiltration on survival and recovery of renal function in intensive care patients with acute renal failure: a prospective, randomized trial. *Crit Care Med* 2002;30:2205-2211.
- Cimochowski GE, Worley E, Rutherford WE, et al. Superiority of the internal jugular over the subclavian access for temporary dialysis. *Nephron* 1990;54:154-161.
- Stalter KA, Stevens GF, Sterling WA, Jr. Late stenosis of the subclavian vein after hemodialysis catheter injury. *Surgery* 1986;100:924-927.
- Bambauer R, Inniger R, Pirrung KJ, et al. Complications and side effects associated with large-bore catheters in the subclavian and internal jugular veins. *Artif Organs* 1994;18:318-321.
- Kelber J, Delmez JA, Windus DW. Factors affecting delivery of high-efficiency dialysis using temporary vascular access. *Am J Kidney Dis* 1993;22:24-29.
- Favre H, Martin PY, Stoermann C. Anticoagulation in continuous extracorporeal renal replacement therapy. *Semin Dial* 1996;9:112-118.
- Lindholm DD, Murray JS. A simplified method of regional heparinization during hemodialysis according to a predetermined dosage formula. *Trans Am Soc Artif Intern Organs* 1964;10:92-97.

47. Schrader J, Stibbe W, Kandt M, et al. Low molecular weight heparin versus standard heparin. A long-term study in hemodialysis and hemofiltration patients. *ASAIO Trans* 1990;36:28-32.
48. Bellomo R, Teede H, Boyce N. Anticoagulant regimens in acute continuous hemodiafiltration: a comparative study. *Int Care Med* 1993;19:329-332.
49. Mehta RL, McDonald BR, Aguilar MM, Ward DM. Regional citrate anticoagulation for continuous arteriovenous hemodialysis in critically ill patients. *Kidney Int* 1990;38:976-981.
50. Hofbauer R, Moser D, Frass M, et al. Effect of anticoagulation on blood membrane interactions during hemodialysis. *Kidney Int* 1999;56:1578-1583.
51. Kutsogiannis DJ, Mayers I, Chin WD, Gibney RT. Regional citrate anticoagulation in continuous venovenous hemodiafiltration. *Am J Kidney Dis* 2000;35:802-11.
52. Palsom R, Niles JL. Regional citrate anticoagulation in continuous venovenous hemofiltration in critically ill patients with a high risk of bleeding. *Kidney Int* 1999;55:1991-1997.
53. Pinnick RV, Wiegmann TB, Diederich DA. Regional citrate anticoagulation for hemodialysis in the patient at high risk for bleeding. *N Engl J Med* 1983;308:258-61.
54. Camici M, Giordani R, Morelli E, et al. Safety and efficacy of anticoagulation in extracorporeal hemodialysis by simultaneous administration of low-dose prostacyclin and low molecular weight heparin. *Minerva Med* 1998;89:405-409.
55. Warkentin TE. Heparin-induced thrombocytopenia: IgG-mediated platelet activation, platelet microparticle generation, and altered procoagulant/anticoagulant balance in the pathogenesis of thrombosis and venous limb gangrene complicating heparin-induced thrombocytopenia. *Transfus Med Rev* 1996;10:249-258.
56. Chong BH. Heparin-induced thrombocytopenia. *Aust N Z J Med* 1992;22:145-152.
57. Chong BH, Magnani HN. Organ in heparin-induced thrombocytopenia. *Haemostasis* 1992;22(2):85-91.
58. Greinacher A, Janssens U, Berg G, et al. Lepirudin (recombinant hirudin) for parenteral anticoagulation in patients with heparin-induced thrombocytopenia. Heparin-Associated Thrombocytopenia Study (HAT) investigators. *Circulation* 1999;100:587-593.
59. Fischer KG. Hirudin in renal insufficiency. *Semin Thromb Hemost* 2002;28:467-482.
60. Kathiresan S, Shiomura J, Jang IK. Argatroban. *J Thromb Thrombolysis* 2002;13:41-47.
61. Lewis BE, Wallis DE, Berkowitz SD, et al. Argatroban anticoagulant therapy in patients with heparin-induced thrombocytopenia. *Circulation* 2001;103:1838-1843.
62. Bellomo R, Seacombe J, Daksalis M, et al. A prospective comparative study of moderate versus high protein intake for critically ill patients with acute renal failure. *Renal Failure* 1997;19:111-120.
63. Kierdorf HP. The nutritional management of acute renal failure in the intensive care unit. *New Horizons* 1995;3:699-707.
64. Bellomo R, Ronco C. The nutritional management of acute renal failure in the intensive care unit. *Am J Kidney Dis* 1996;28 (Suppl):S58-S61.
65. Maxvold NJ, Smoyer WE, Custer JR, et al. Amino acid loss and nitrogen balance in critically ill children with acute renal failure: a prospective comparison between classic hemofiltration and hemofiltration with dialysis. *Crit Care Med*. 2000;28:1161-1165.
66. Kierdorf H. Continuous versus intermittent treatment: clinical results in acute renal failure. *Contrib Nephrol* 1993;12:1-12.
67. Bellomo R, Boyce N. Continuous venovenous hemodiafiltration compared with conventional dialysis in critically ill patients with acute renal failure. *ASAIO J* 1994;42:M794-M797.
68. van Bommel E, Bouvy ND, So KL, et al. Acute dialytic support for the critically ill: intermittent hemodialysis versus continuous arteriovenous hemodiafiltration. *Am J Nephrol* 1995;15:192-200.
69. Mehta RL, McDonald B, Gabbai FB, et al. A randomized clinical trial of continuous versus intermittent dialysis for acute renal failure. *Kidney Int* 2001;60:1154-1163.
70. Kellum JA, Angus DC, Johnson JP, et al. Continuous versus intermittent renal replacement therapy: a meta-analysis. *Intensive Care Med* 2002;28:29-37.
71. Bellomo R, Cole L, Reeves J, Silvester W. Who should manage CRRT in the ICU? The intensivists' view point. *Am J Kidney Dis* 1997;30 (5 Supp 4):S109-111.
72. Cole L, Bellomo R, Silvester W, et al. A prospective, multicenter study of the epidemiology, management, and outcome of severe acute renal failure in a "closed" ICU system. *Am J Respir Crit Care Med* 2000;162:191-196.
73. Silvester W, Bellomo R, Cole L. Epidemiology, management, and outcome of severe acute renal failure of critical illness in Australia. *Crit Care Med* 2001;29:1910-1915.
74. Suki WN. Role of the nephrologist in the intensive care unit. *Intensive Care Med* 1995;10:101-103.
75. Chanard J, Wynckel A. The role of the nephrologist in the intensive care unit. *Nephrol Dial Transplant* 1998;13:268-270.
76. Pizzarelli F, Cerrai T, Dattolo R, et al. Convective treatments with on-line production of replacement fluid; a clinical experience lasting 6 years. *Nephrol Dial Transplant* 1998;13:363-369.
77. Pizzarelli F, Maggiore Q. Clinical perspectives of on-line haemodiafiltration. *Nephrol Dial Transplant* 1998;13 (Suppl):34-37.
78. Klammt S, Stange J, Mitzner SR, et al. Extracorporeal liver support by recirculation albumin dialysis: analysing the effect of the first clinically used generation of the MAR System. *Liver* 2002;22 (Suppl 2):30-34.
79. Tetta C, Bellomo R, Brendolan A. Use of absorptive mechanisms in continuous renal replacement therapies in the critically ill: A pilot study of coupled plasma filtration with adsorption in septic shock. *Kidney Int* 1999;72:S15-S19.
80. Ronco C, Brendolan A, Lonnemann G, et al. A pilot study of coupled plasma filtration with adsorption in septic shock. *Crit Care Med* 2002;30:1250-1255.

## Upcoming meetings

28 January- 02 February 2003

### 32<sup>nd</sup> Critical Care Congress – Society of Critical Care Medicine

San Antonio, Texas

CONTACT: Society of Critical Care Medicine

Tel. 847-827-6888

Fax: 847-827-6886

Email:info@sccm.org

18-21 March 2003

### 23<sup>rd</sup> International Symposium on Intensive Care and Emergency Medicine

Brussels, Belgium

CONTACT: <http://www.intensive.org>

16-21 May 2003

### The American Thoracic Society Meeting

Seattle, Washington

CONTACT: <http://www.thoracic.org/ic/ic2003/default.asp>

## Websites of interest

Canadian Critical Care Society  
[www.canadiancriticalcare.org](http://www.canadiancriticalcare.org)

Canadian Association of Critical Care Nurses  
[www.caccn.ca](http://www.caccn.ca)

Society of Critical Care Medicine  
[sccm.org](http://sccm.org)

Change of address notices and requests for subscriptions to *Critical Care Rounds* are to be sent by mail to P.O. Box 310, Station H, Montreal, Quebec H3G 2K8 or by fax to (514) 932-5114 or by e-mail to [info@snellmedical.com](mailto:info@snellmedical.com). Please reference *Critical Care Rounds* in your correspondence. Undeliverable copies are to be sent to the address above.

This publication is made possible by an educational grant from

# Eli Lilly Canada Inc.

©2002 Canadian Critical Care Society, which is solely responsible for the contents. The opinions expressed in this publication do not necessarily reflect those of the publisher or sponsor, but rather are those of the authoring institution based on the available scientific literature. Publisher: **SNELL Medical Communication Inc.** in cooperation with the Canadian Critical Care Society. <sup>TM</sup>*Critical Care Rounds* is a Trade Mark of **SNELL Medical Communication Inc.** All rights reserved. The administration of any therapies discussed or referred to in *Critical Care Rounds* should always be consistent with the recognized prescribing information in Canada. **SNELL Medical Communication Inc.** is committed to the development of superior Continuing Medical Education.