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Renal Replacement Therapy: Perioperative Implications

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This lecture will provide an overview of renal replacement therapies and the implications of the use of this technology on anesthetic management and perioperative care.

The perioperative management of the patient with renal failure presents a number of challenges to the anesthesiologist. Not only does the renal dysfunction complicate decision-making and management, but it is also associated with increased morbidity and mortality. At the same time, as a result of advances in anesthetic and surgical care, more patients with renal failure present for surgery and anesthesia. As the population ages, we can anticipate a larger number of patients with renal failure presenting for both simple and complex surgical care. To appropriately plan anesthetic and postoperative care for these patients, the anesthesiologist must have an understanding of renal physiology and therapeutic options, to manage fluid and electrolytes, as well as to minimize the risk of further compromising renal function.

For most patients with renal dysfunction, the intraoperative options are relatively limited. The primary goal is to maintain fluid and electrolyte balance, sometimes in the face of excessive blood loss or electrolyte abnormalities that occur during surgery. For some patients, these goals can be difficult to achieve. The initial management usually emphasizes fluid resuscitation, although for the patient with renal failure fluid management can be challenging; optimizing intravascular volume requires careful monitoring, often with the use of a central line to monitor central venous pressure or, in more complicated clinical situations, a pulmonary artery catheter or echocardiography. For the patient with reduced urine output or compromised renal blood flow during the surgical procedures, osmotic and loop diuretics are frequently administered (1). Although these drugs often improve urine flow, they can also cause significant fluid shifts, hypovolemia, and, in some cases, hypoperfusion of vital organs. Dopamine and fenoldopam have also been used to improve renal blood flow and urine output. Unfortunately, none of these therapies has been demonstrated to improve renal function or outcome associated with renal failure in the surgical patient population (2). In addition to the challenges associated with fluid management, patients with renal failure are at risk for significant electrolyte abnormalities, including hypokalemia or hyperkalemia, calcium and magnesium abnormalities, and metabolic acidosis, often on the basis of a renal tubular acidosis (1). Until recently, intraoperative management of fluid balance and electrolyte abnormalities has been restricted to diuretic therapy and careful administration of electrolyte replacement fluids. Dialytic therapy has been used preoperatively and immediately postoperatively, but in both cases the fluid and electrolyte shifts can cause disequilibrium syndrome as well as transient hypovolemia (3). Over the past few years additional renal replacement therapies have been used to provide supportive care preoperatively, postoperatively and, in selected situations, during surgery. This discussion will review the currently available renal replacement therapies with particular emphasis on the implications of and role for continuous renal replacement therapies on perioperative care.

What is Renal Replacement Therapy?

The general term renal replacement therapy (RRT) is used to describe all of the currently available approaches to "artificial" mechanical support of renal function (4,5). RRT includes traditional intermittent hemodialysis (IHD), peritoneal dialysis (PD) and a variety of other intermittent and continuous therapies. Most anesthesiologists are familiar with intermittent hemodialysis and peritoneal dialysis and the implications of both to perioperative care. For most surgical patients, intermittent hemodialysis will be the common method for dialysis for the patient with preexisting dialysis-dependent renal failure, although peritoneal dialysis may be used for the patient who does not have intraabdominal pathology that contraindicates its use. Although both of these therapeutic approaches influence anesthetic management, their primary implications for anesthetic management have to do with the timing of the therapy relative to the surgical procedure and the impact of the treatment on intravascular volume, fluid balance, and electrolytes. Although

IHD is used frequently for patients with renal failure—and as ongoing support in both the inpatient and outpatient settings, it has a number of shortcomings when used in the perioperative period. Even with a great deal of attention to fluid balance and hemodynamics, IHD is associated with significant blood pressure and intravascular volume changes. Hypotension is common, particularly with initiation of the therapy. In addition, because the therapy is used intermittently, it can cause transient electrolyte imbalance, disequilibrium, and complicate perioperative hemodynamics and myocardial function.

PD can also be used to facilitate perioperative care of the patient with chronic renal failure, although for most patients the contraindications to PD limit its value for the surgical patient. This form of therapy is contraindicated for the patient with peritonitis, other intraabdominal abnormalities, or patients who have recently undergone abdominal surgery. In addition, the fluid instilled into the peritoneal space can compromise ventilatory status and perioperative respiratory care. Its value, therefore in the management of the surgical patient with renal failure is limited.

A variety of other therapies are available that provide continuous therapy to support the patient with renal failure. The term CRRT refers to a number of continuous renal replacement therapies used to optimize fluid and solute management (4,6). In general these therapies provide better control of intravascular volume, electrolyte balance, and uremia depending in the characteristics of the renal replacement therapy.

What Are the Features of CRRT?

CRRT refers to any mechanical approach to providing continuous solute or fluid removal. Although the specific method of delivering the therapy varies, all forms of CRRT include an extracorporeal circuit with a hemofilter and semipermeable membrane connected to the patient via a catheter in either the arterial or venous circuit. Fluid removal is determined by the hydrostatic pressure gradient across the hemofilter. Large volumes of fluid can be removed using this approach. Fluid balance is controlled by providing replacement fluid through the system; electrolytes and acid base balance are controlled by the electrolyte and bicarbonate concentration in the replacement fluid. For most patients the replacement fluid is an isotonic, buffered electrolyte solution, with acetate, citrate, lactate or bicarbonate as the buffer. Dialysate can be added to the circuit in a countercurrent direction to provide dialysis for the uremic patient. In this case the dialysate creates a concentration gradient across the hemofilter membrane, allowing solute clearance by diffusion.

Each mode of continuous renal replacement is defined based on the source of blood flow to the system, the location of blood return to the patient, and the specific therapy used (hemofiltration, dialysis, or both). Continuous arteriovenous renal replacement therapy requires both arterial and venous access. Blood is removed through an arterial catheter and returned to the patient through a venous catheter. Flow through the hemofilter is dependent on the patient's arterial blood pressure. If the blood pressure falls, the amount of hemofiltration decreases. When used to remove ultrafiltrate and control fluid balance by adding replacement fluid alone, the therapy is termed continuous arteriovenous hemofiltration (CAVH). If the arteriovenous system is also used for dialysis by adding dialysate solution, the therapy is called continuous arteriovenous hemodialysis (CAVHD). If the patient undergoes both dialysis and fluid removal while receiving replacement fluids, the therapy is termed continuous arteriovenous hemodiafiltration (CAVHDF).

The more common mode for providing CRRT is through the use of a dual-lumen venous catheter for aspiration of blood from the patient to the filter with blood then reinfused through a separate port of the catheter. For this system, an external pump is required to provide the pressure gradient to facilitate hemofiltration. When ultrafiltrate volume is replaced, the method is termed continuous venovenous hemofiltration (CVVH). When the patient undergoes continuous dialysis alone without net fluid removal or the use of a replacement fluid, the method is termed continuous venovenous hemodialysis (CVVHD). When the patient is dialyzed with fluid removal and receives replacement fluid, the therapy is named continuous venovenous hemodiafiltration (CVVHDF).

One additional continuous renal replacement therapy is slow continuous ultrafiltration (SCUF). During SCUF therapy, the ultrafiltrate removal is controlled so that fluid removal is slow; fluid replacement is not required because the primary purpose of SCUF is to facilitate fluid removal (7).

What Are the Clinical Indications for CRRT?

CRRT is used most commonly to manage the critically ill patient with acute renal failure. The therapy can be very helpful in addressing the uremia associated with renal failure but can also be helpful in managing hyperkalemia, controlling metabolic acidosis in the patient with either a renal tubular acidosis or lactic acidosis, and in optimizing fluid balance (8,9). CRRT also has a role in the management of patients with other clinical problems whether associated with renal failure or not. For example, it has been advocated as a therapy for the patient with pulmonary edema or

Table 1. Side Effects and Complications Associated with CRRT

Mechanical	Clinical
Clotting of the circuit and/or filter	Systemic bleeding
Circuit rupture	Vascular access complications
Catheter and circuit kinking	Hypothermia
Air embolism	Fluid balance errors
Insufficient blood flow	

congestive heart failure to facilitate acute fluid management in the septic patient and the patient with multi-system failure because of its ability to optimize cytokine clearance and in patients with severe respiratory failure for whom mechanical ventilatory support alone does not provide optimum gas exchange and control acid base balance. CRRT has also been used in patients with cerebral edema to optimize overall fluid balance without compromising cerebral blood flow.

One of the primary advantages of all forms of CRRT is the lack of hemodynamic changes associated with the therapy. Because CRRT is a slow, continuous form of therapy, normalization of renal function and control of fluid and electrolyte abnormalities can be accomplished without the hemodynamic changes that are commonly associated with diuretic therapy or intermittent hemodialysis.

Although patients can be managed more effectively with CRRT, there are no prospective, randomized studies that document that CRRT improves outcome in any clinical situation, particularly when compared with IHD. A number of multicenter studies are underway to evaluate outcomes associated with CRRT. Although they do not yet provide outcome data, preliminary analyses have validated the safety of the techniques and the ease of control of hemodynamics and volume status. For the anesthesiologist, these advantages might be sufficient to warrant broader use of the technology, even if long-term outcome is unaffected.

Although CRRT has a number of advantages when used in the perioperative period, it is also associated with a number of potential complications and side effects, as listed in Table 1 (8). The most significant complication associated with the circuit itself is the clotting or fibrin deposition that results in reduced blood flow. This complication is usually readily identified with changes in the circuit pressure. When the filter begins to clot, the filter and circuit must be replaced. During the circuit change, some blood is lost from the patient. The other most common complications associated with the use of CRRT include bleeding, hypothermia, and misunderstanding of the fluid and electrolyte changes related to the replacement fluid and the relationship between fluids administered through the circuit with those that are administered through other IV catheters. Although air emboli, if they occurred would have very serious consequences, the risk of emboli with venovenous circuits (CVVH), the more common method of administering the therapy is very low.

What Are the Implications of CRRT for the Anesthesiologist?

The anesthesiologist must be aware of the implications of CRRT on anesthetic and perioperative management (10). For the patient who is receiving CRRT preoperatively, the anesthetic plan will be affected by the therapy. When CRRT is contemplated for use in the operating room, resources must be available to ensure that the therapy is safely administered. Finally, the transition of the patient receiving CRRT to and from the operating room requires more attention to the logistics of the transfer than is usually required.

Preoperative Assessment

For the patient who is receiving CRRT, the preoperative assessment has some specific elements that must be ensured. First, the anesthesiologist should understand why the patient is receiving CRRT. Although the list of indications is lengthy, the primary concern for the anesthesiologist is the patient's fluid, electrolyte, and acid-base balance. Most, but not all, of the patients receiving CRRT will have multi-system failure. Many are receiving mechanical ventilatory support, are hemodynamically unstable, and many require vasopressor or inotropic therapy. In addition to the usual considerations for the management of the critically ill patient, the preoperative assessment of the patient receiving CRRT should clarify the indications for the therapy, the goals, and whether the goals have been met. For example, if the goal is to slowly remove fluid from the patient, the anesthesiologist must evaluate the current fluid balance, the amount of fluid being removed each hour, and, to the extent that the patient has a persistent positive fluid balance, the impact of the fluid status on intraoperative management. In addition, the patient may have underlying renal failure with all of its attendant anesthetic implications. One of the primary concerns of the anesthesiologist is whether the CRRT is being used to control the patient's acid-base status. If so, the amount of buffer that is being administered and its efficacy must be carefully assessed. For these patients the clinician will have to carefully consider the implications on discontinuing the therapy during transfer to and from the operating room and determine how best to manage the patient during those periods. In addition a careful review of the CRRT parameters and goals is essential to determine if the patient will require CRRT intraoperatively, and, if not, how the patient will be managed during the surgery.

In addition to assessing the metabolic implications of the CRRT, the evaluation should include an evaluation of the coagulation status of the patient, in part because of the implications of renal failure on coagulation (e.g., platelet function) and whether the patient is receiving anticoagulants through the CRRT circuit to prevent filter and circuit clotting (11,12). Although, when heparin is used as an anticoagulant, it is generally administered before the filter to minimize the systemic effects, the impact on clotting can be unpredictable. For some patients, alternative anticoagulants are used, including citrate (13). For every patient receiving CRRT, coagulation parameters must be carefully monitored.

Finally, the patient's temperature trend must be interpreted with caution. Considerable heat is lost through the extensive extracorporeal circuit. As a result, most patients receiving CRRT are hypothermic; some require rewarming with a warming blanket. It is rare that a patient receiving CRRT has a fever, so if the temperature is normal (or elevated), the likelihood of infection is high and may require evaluation before elective surgery.

Intraoperative Management

Although CRRT has become a common mode of therapy for critically ill patients, the therapy will be discontinued before transfer to the operating room for most of these patients who require surgery. To facilitate the transition from CRRT requires an understanding of the process and careful planning regarding the management of the patient once the therapy has been stopped. The actual discontinuation of CRRT is straightforward. The CRRT pump and filter are separated from the access catheter and the circuit discarded. Once the system is disconnected, the catheter should be flushed with heparinized solution before capping it to ensure that it remains patent unless heparin is contraindicated. Before using the catheter again, the heparin should be aspirated from it.

When CRRT is discontinued, either for transport or for the duration of the surgical procedures, the anesthesiologist must have a plan for managing both fluid balance and electrolytes. To determine how best to manage the patient, the anesthesiologist should review the CRRT orders to clarify the fluid goals for the therapy, the amount of replacement fluid provided each hour and to clarify the electrolytes and bicarbonate that has been included in the replacement fluid. Based on the review, a plan for managing fluids, electrolytes and acid-base balance can be developed for the intraoperative period.

For selected patients, the anesthesiologist may elect to continue the CRRT intraoperatively. In this case, the system will still have to be discontinued for the transport of the patient and reinstituted after the patient is transferred to the operating room. The transition requires an entirely new set-up, including the filter and circuit.

Although CRRT systems have become much easier to use, the technology is not familiar to most anesthesiologists. If the CRRT is to be initiated or continued intraoperatively, therefore, the anesthesiologist either must be familiar with the equipment and have the ability to "troubleshoot" any problems that arise or must have resources available to support the system. In some institutions CRRT will be managed by an intensive care or dialysis nurse who is physically present in the OR for the duration of the procedure. In other cases someone familiar with the equipment and therapy will be available on call to provide advice and assistance to the anesthesiologist.

Whenever CRRT is used intraoperatively, the anesthesiologist must pay even closer attention than usual to total fluid administration both in terms of quantity and specific replacement fluids because the CRRT circuit provides an additional (and unfamiliar) method for managing fluid balance. In addition the patient who has been receiving CRRT may need significant adjustment in the fluid and buffer administration as part of the replacement fluid as a result of intraoperative events. Careful monitoring of arterial blood gases and electrolytes is therefore essential during CRRT to ensure that the specific acid base goals are achieved. For example, the composition of the replacement fluid may have to be modified during the procedure if a patient develops a severe metabolic acidosis or if the cause for the acidosis is addressed, as may occur with resection of ischemic bowel. Similarly, because the replacement fluid contains a buffer that must be metabolized by the liver to bicarbonate (e.g., citrate, acetate, or lactate), any intraoperative events that compromise hepatic blood flow might cause a paradoxical acidemia. As a result, if CRRT is being used for a patient for whom liver function may be compromised, bicarbonate, rather than citrate or acetate, should be used as the buffer.

One of the primary advantages of using CRRT during surgery is related to overall fluid management. Although the long-term benefits have not been objectively demonstrated, CRRT does minimize extravascular fluid accumulation and edema. Most patients who receive CRRT during surgery are less edematous and have smaller fluid shifts after major surgical procedures than do patients who receive conventional fluid management.

One additional feature of the system warrants additional comment. If CRRT is used during the surgical procedure, the cannula used for the therapy must be easily accessible to the anesthesiologist. Although femoral catheters are occasionally used for CRRT, it is more common to use internal jugular catheters because they provide good flow characteristics and are on site in the operating room. Jugular catheters are easily monitored for evidence of kinking and malpositioning, so the risk of circuit clotting can be minimized.

Other complications of CRRT must be considered when it is used in the operating room. Clotting or fibrin deposition on the CRRT filter is common whenever CRRT is in use. The clotting will reduce the effectiveness of the CRRT and may require setup of a new filter and circuit. As noted above, temperature regulation is also affected by the CRRT circuit. Hypothermia is a common side effect. The cooling is the result of high flow through a large volume extracorporeal system. Some of the newer circuits include in-line blood warmers to prevent heat loss; if they are not included, the temperature must be closely monitored and a warming blanket used, if necessary to maintain body temperature.

An additional consideration when using CRRT for a patient undergoing anesthesia is the affect of the circuit and filter on drug pharmacodynamics (14,15). Although for the anesthesiologist, the administration of most drugs is based on the clinical effect, it is important to understand the effect the CRRT circuit will have on drug levels. The first consideration is the extent to which the drug is eliminated by the kidney. Drugs eliminated primarily by nonrenal pathways are unlikely to be removed during CRRT and will not require adjustment of drug dosing. The continuous dosing of fentanyl, for example, which undergoes <10% renal elimination, is not altered by the presence of CRRT. Other drug characteristics that affect clearance by CRRT include protein binding, volume of distribution, and, to a lesser extent, molecular weight, drug charge, water or lipid solubility, and membrane binding. The specific components and characteristics of the CRRT system also have an impact on drug administration. The greater the permeability of the filter, the greater is the drug clearance. Similarly, the greater the surface area of the filter, the greater is the drug clearance by both membrane adsorption and filtration.

At the present time, the most common clinical situations for which intraoperative CRRT is used include orthotopic liver transplantation and patients with renal failure who are undergoing surgical procedures using cardiopulmonary bypass. When used for these procedures, there is clinical evidence that fluid and hemodynamic management are optimized, although overall outcome is not necessarily improved. Based on the experience in these patients, it is anticipated that CRRT will gain more widespread use in the operating room as more anesthesiologists become familiar with the technology and its potential value.

Postoperative Use

When CRRT is used in the postoperative period, the clinicians managing the therapy in the postoperative period must be cognizant of the intraoperative course (10). The flows and replacement fluid composition must be carefully titrated to account for intraoperative fluid shifts or blood loss and changes in intravascular volume. The patient must be closely monitored for evidence of postoperative coagulopathy or electrolyte abnormalities.

CRRT should also be considered as a therapeutic option in the postoperative period for the patient with progressive renal dysfunction or fluid overload that compromises gas exchange or pulmonary function. Based on the experience with the use of CRRT in the management of other critically ill patients, it is likely that the therapy can facilitate the management of these patients as well.

Conclusion

Renal replacement therapies include a number of treatments to support the patient with renal failure or fluid and electrolyte abnormalities. Although most anesthesiologists are familiar with intermittent renal replacement therapies, such as intermittent hemodialysis and peritoneal dialysis, the availability of CRRT now offers another approach to perioperative management that has significant potential clinical value. As a result, although CRRT is now most commonly used in the management of the unstable patient in the ICU, anesthesiologists should understand the clinical indications for CRRT, the approaches that are available, and the potential value of the technique in optimizing perioperative care.

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