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Renal Replacement Strategies in the ICU*

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Acute renal failure (ARF) with the concomitant need for renal replacement therapy (RRT) is a common complication of critical care medicine that is still associated with high mortality. Different RRT strategies, like intermittent hemodialysis, continuous venovenous hemofiltration, or hybrid forms that combine the advantages of both techniques, are available and will be discussed in this article. Since a general survival benefit has not been demonstrated for either method, it is the task of the nephrologist or intensivist to choose the RRT strategy that is most advantageous for each individual patient. The underlying disease, its severity and stage, the etiology of ARF, the clinical and hemodynamic status of the patient, the resources available, and the different costs of therapy may all influence the choice of the RRT strategy. ARF, with its risk of uremic complications, represents an independent risk factor for outcome in critically ill patients. In addition, the early initiation of RRT with adequate doses is associated with improved survival. Therefore, the "undertreatment" of ARF should be avoided, and higher RRT doses than those in patients with chronic renal insufficiency, independent of whether convective or diffusive methods are used, are indicated in critically ill patients. However, clear guidelines on the dose of RRT and the timing of initiation are still lacking. In particular, it remains unclear whether hemodynamically unstable patients with septic shock benefit from early RRT initiation and the use of increased RRT doses, and whether RRT can lead to a clinically relevant removal of inflammatory mediators. ***(CHEST 2007; 132:1379–1388)***

Key words: acute kidney injury; acute renal failure; continuous hemofiltration; dialysis dose; intermittent hemodialysis; renal replacement therapy; sepsis

Abbreviations: ARF = acute renal failure; CAVH = continuous arteriovenous hemofiltration; CRRT = continuous renal replacement therapy; CVVH = continuous venovenous hemofiltration; CVVHDF = continuous venovenous hemodiafiltration; EDD = extended daily dialysis; HVHF = high-volume hemofiltration; IHD = intermittent hemodialysis; Kt/V = clearance of the solute multiplied by time equals the volume of distribution of the solute; MODS = multiple organ dysfunction syndrome; RRT = renal replacement therapy; SLEDD = slow low efficient daily dialysis

The need for renal replacement therapy (RRT) in patients with acute renal failure (ARF) is a common and increasing problem in ICUs.[1–3] Sepsis represents the leading cause of ARF, which mostly develops as part of the multiple organ dysfunction syndrome (MODS).[4] Despite major advances in blood purification technology over the past few decades, the mortality rates associated with ARF remain high. The in-hospital mortality rate ranges from approximately 30% in patients with drug-induced ARF to up to 90% when ARF is accompanied with severe MODS.[5] Independent of the underlying illness, ARF increases the risk of death, and contributes to in-hospital mortality and morbidity.[6,7] Uremia and the need for RRT among critically ill patients frequently result in complications, such as bleeding, inadequate fluid removal or intravascular volume depletion, and enhanced susceptibility to infection, which can further aggravate the underlying condition. Therefore, the management of ARF in the ICU represents a significant ongoing challenge to nephrologists and intensivists.

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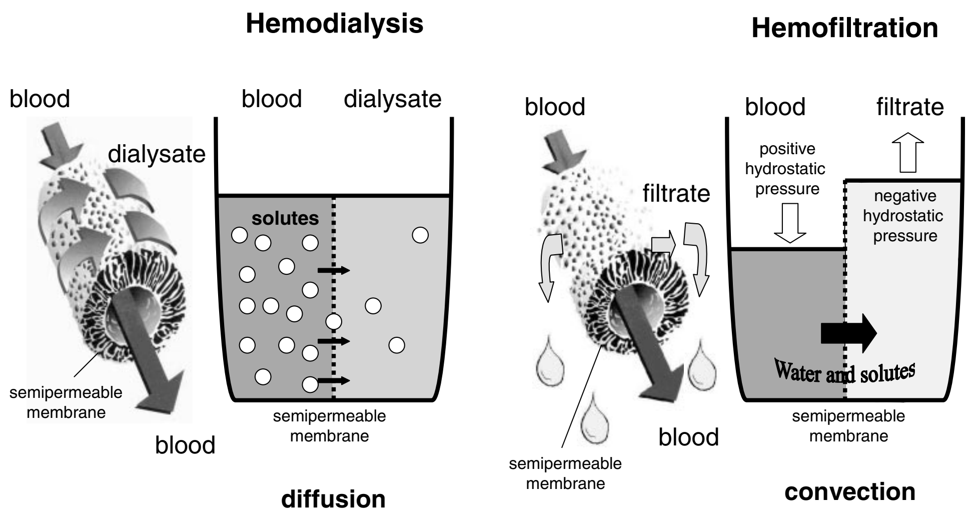

FIGURE 1. Principles of solute transport in hemodialysis and hemofiltration.

METHODS FOR RRT

For many years, intermittent hemodialysis (IHD) was the only treatment option for patients with ARF in the ICU. In numerous countries, it is still the most frequently used modality.[8] One problem with standard IHD was that it could not be used in patients with severe hemodynamic instability. This led to the development of continuous RRT (CRRT), which was first described by Kramer et al in 1977.[9] Continuous venovenous hemofiltration (CVVH) was subsequently proposed as an alternative to IHD in the critically ill, because it was better tolerated by hypotensive patients, and the continuous regulation of fluid and nutritional support avoided cycles of volume overload and depletion. This review will focus on IHD as the most often intermittent RRT and on CVVH as the most often used CRRT. With respect to the principle of solute transport, in this article IHD will stand for a "diffusive" modality and CVVH will stand for a "convective" modality. Figure 1 and Table 1 provides an overview of the major differences between IHD and CVVH, and these two transport principles. However, diffusive methods can also be used continuously (*eg*, continuous venovenous hemodiafiltration [CVVHDF] and extended daily dialysis [EDD]) or convective methods intermittently (*eg*, high-volume hemofiltration [HVHF]). In addition, both transport principles could be combined in one approach (*eg*, CVVHDF). An overview of the different methods is given in Table 5 and will be discussed in the "Hybrid Methods" section.

IHD

Hemodialysis is mainly based on diffusion, whereby solutes cross the membrane driven by the concentration gradient between blood and dialysate. In this process, the total amount of solute transported per unit of time (or "clearance") mainly depends on the molecular weight of the solute, the properties of the membrane, the dialysate flow, and the dialyzer blood flow. Because of the diffusive nature of hemodialysis and the high dialysate flow rates, hemodialysis is highly effective for the removal of small molecules, which allows intermittent therapy. In conventional hemodialysis, the dialysate flow rate is usually 500 mL/min, which makes on-line dialysate production necessary. The dialysis machine requires concentrated solutions of electrolytes and buffers in order to produce the dialysate. Therefore, hemodialysis is technically complex and needs to be performed by highly qualified and trained nursing staff.[10]

CVVH

Hemofiltration is based on convection, whereby plasma water is filtered, thus leading to the removal

Table 1—*Major Differences Between IHD and CVVH*

IHD	CVVH
Diffusive transport	Convective transport
High clearance for small molecules	Clearance for small and middle seized molecules
Dialysate production and high dialysate flow required 2–8 h/d, intermittently	Large amounts of substitution fluid in bags required 18–24 h/d, continuously
Technically demanding	Technically less difficult
Personnel with "renal" qualification required	ICU-trained personnel sufficient
Low work load	High work load for 24 h a day
Relatively cheap	Three to five times more expensive
Possible without anticoagulation	Usually continuous anticoagulation required

Table 2—*Indications for RRT in the ICU**

Indications	Description
Renal	
Uremia	Azotemia
	Neuropathy, myopathy
	Encephalopathy (unexplained decline in mental status)
	Pericarditis
Overload of fluids	Volume removal
	Pulmonary edema
	Oliguria with < 200 mL of urine output in 12 h
	Anuria with < 50 mL urine output in 12 h
Electrolytes	Hyperkalemia (K+ > 6.5 mmol/L)
	Sodium abnormalities
Acid-base	Metabolic acidosis (pH < 7.0)
Intoxications	With dialyzable toxin
Nonrenal	Allowing administration of fluids and nutrition
	Hyperthermia
	Severe hemodynamic instability in severe sepsis?
	Elimination of inflammatory mediators in sepsis?

*Renal indications can be memorized by the vocals A, E, I, O, and U.

of small and middle-sized molecules that are dissolved in the plasma water. Transport is not size dependent as long as the molecular weight is lower than the cutoff of the membrane. The total amount of solute transported per unit of time is therefore only dependent on the amount of ultrafiltered plasma and the sieving coefficient of the membrane. The volume of the ultrafiltrate is continuously substituted by replacement fluids that can be delivered in ready-to-use bags. Hemofiltration is technically easier to perform than hemodialysis and can be performed by trained ICU nurses without a special renal qualification. Since in comparison to diffusive methods the clearance for small molecules per time unit is lower, hemofiltration usually has to be delivered continuously for 18 to 24 h per day, at least when ultrafiltration rates of 1 to 3 L/h are applied. However, hemofiltration can be used intermittently when higher ultrafiltration rates are applied (*ie*, HVHF).

Indications and Timing of RRT

The main indication for RRT in patients with ARF is to provide sufficient control of metabolic derangements, which are associated with kidney failure. Since the major functions of the kidney are to excrete uremic toxins and to control volume, electrolyte, and acid-base homeostasis, the failure of these functions can lead to urgent indications for RRT (Table 2).

A specific BUN or serum creatinine concentration at which RRT should be started in patients with ARF is difficult to define. Most cases of ICU-associated ARF occur under non-steady-state conditions in which the three determinants of serum creatinine concentration (*ie*, production, volume of distribution, and renal elimination) fluctuate. Therefore, daily changes in serum creatinine concentration poorly reflect the actual glomerular filtration rate.[11] For these reasons, even a uniform definition of ARF is still lacking, although there are ongoing attempts to achieve a consensus (Table 3).[12] In a recent questionnaire,[13] 560 contributors reported > 200 different definitions of ARF and about 90 different RRT initiation criteria.

Given the caveats in defining ARF, there is an ongoing debate as to whether RRT should be started "early" or "late." Since uremia exerts profound effects on different biological functions,[14,15] the early initiation of RRT and thus the avoidance of severe derangements in metabolic control should theoretically be able to mitigate the adverse effects of ARF.

In this context, nonrandomized or retrospective studies[16,17] have suggested that both the earlier

Table 3—*Risk, Injury, Failure, Loss, End-Stage Renal Disease (RIFLE) Classification for the Definition of ARF**

	GFR Criteria	Urine Output Criteria
Risk	Serum creatinine level increased 1.5 times or decrease in GFR of > 25%	< 0.5 mL/kg/h for 6 h
Injury	Serum creatinine level increased 2.0 times or GFR decreased by > 50%	< 0.5 mL/kg/h for 12 h
Failure	Serum creatinine level increased 3.0 times, GFR decreased by > 75%, or serum creatinine level decreased by > 4 mg/dL	< 0.3 mL/kg/h for 24 h or anuria for 12 h
Loss	Persistent acute renal failure, complete loss of kidney function for > 4 wk	
End-stage renal disease	End-stage renal disease for > 3 mo	

*From Bellomo et al.[12] GFR = glomerular filtration rate. The classification system includes separate criteria for creatinine and urine output. The criteria that lead to the worst possible classification should be used.

initiation of RRT and the use of higher ultrafiltration rates improve survival and the recovery of renal function. In addition, one study[18] examined the impact of the introduction of a new septic shock protocol based on early isovolemic hemofiltration in oliguric septic shock patients. For the initiation of CVVH, the only criterion for acute renal injury was persistent oliguria for 24 h that was independent of increases in BUN or serum creatinine levels. This change in the ICU policy for the treatment of patients with septic shock was associated with improved 28-day survival compared to a historical cohort in whom the conventional initiation of RRT had been applied. In accordance with these findings, higher doses of RRT, and therefore better uremic control, led to an improvement of survival in two high-quality prospective randomized studies.[19,20] The mean starting BUN concentration in patients who survived was lower than in the nonsurvivors in one of these studies.[19]

However, the idea of an early initiation of CVVH has only been investigated systematically in one trial so far. In this randomized study,[21] in mainly surgical patients with oliguric ARF but a low incidence of sepsis, no improvement in 28-day survival and recovery of renal function using high ultrafiltration rates or the early initiation of hemofiltration could be demonstrated.[21] It has been discussed whether the severity of disease was too low in this study to demonstrate a significant difference between the "early" vs the "late" approach.

"Prophylactic" hemofiltration in the absence of evidence for renal injury has been shown to be ineffective in studies in trauma patients[22] and in patients with septic shock without renal dysfunction.[23] Thus, the initiation of RRT as long as there is no elevation in the concentration of uremic solutes or oliguria seems not to be indicated.

In summary, no clear guidance on the timing of the initiation of RRT can currently be given, and decisions have to be made on an individual basis for each single patient. However, since ARF and its associated metabolic alterations appear to increase the risk of severe extrarenal complications, the initiation of an RRT should not be retarded in patients with severe, rapidly developing, and oliguric forms of ARF.

Dose of RRT

In long-term dialysis patients, the delivered dose of RRT is considered to have an important impact on long-term morbidity and mortality. The dose of RRT is also thought to play a role for outcomes in patients with ARF.[24]

Despite some limitations in the exact measurements of the applied dose of RRT in the ICU setting, Kt/V values (*ie*, the clearance of the solute [K] multiplied by time [t] equals the volume of distribution of the solute [V]) as an index of dialysis efficacy (Fig 2) in various continuous methods have been established.[25] In hemofiltration, the applied dose is equal to the rate of ultrafiltration. Patients treated with continuous arteriovenous hemofiltration (CAVH) showed a higher mortality rate in comparison to those treated with CVVH, which was attributed to the "inadequate" dose of only 12 to 15 L per ultrafiltration per day provided by CAVH.[26] A filtration rate of at least 1.5 L/h seems to be required for CVVH to control the concentrations of BUN and creatinine, and metabolic acidosis sufficiently.[27] The corresponding Kt/V was calculated to be 0.8. A large retrospective analysis[28] suggested that patients with ARF who survived had received a higher dose of intermittent RRT and CRRT than those who had died.

In a prospective study, Schiffl et al[20] demonstrated that daily IHD resulted in better control of uremia and more rapid resolution of ARF than did alternate-day IHD. Less frequent hemodialysis was an independent risk factor for death in this study. A landmark single-center randomized trial by Ronco et al[19] found that an ultrafiltration rate of 35 mL/kg/h (Kt/V, about 1.4) was associated with a significantly higher survival rate compared to an ultrafiltration rate of only 20 mL/kg/h (Kt/V, about 0.8). In a very recent single-center study,[29] this survival benefit could be confirmed not by increasing the ultrafiltration rate (25 mL/kg/h), but by adding a dialysis dose of 18 mL/kg/h using CVVHDF.

It can be concluded from these studies that increasing the delivered dose of RRT may reduce the rate of uremic complications and improve outcome in ARF patients. However, since there have also been negative results on increasing RRT dose,[21] the optimal dose of RRT in ARF patients remains to be determined in larger multicenter studies. The results of two such studies, the Acute Renal Failure Trial Network study and the Randomized Evaluation of Normal vs Augmented Level of RRT study, should be available in approximately 2008.[30] At the moment, IHD should be prescribed on a daily basis 3 to 4 h a day, and CVVH should be prescribed with ultrafiltration rates of 35 mL/kg/h for 24 h a day. The undertreatment of ARF should be avoided.

In this context, one has to realize that continuous therapies are rarely operative for the full 24 h per day because of filter clotting or transport of the patient for interventions.[31] This filter downtime has to be taken into account when prescribing the RRT dose that should be delivered.

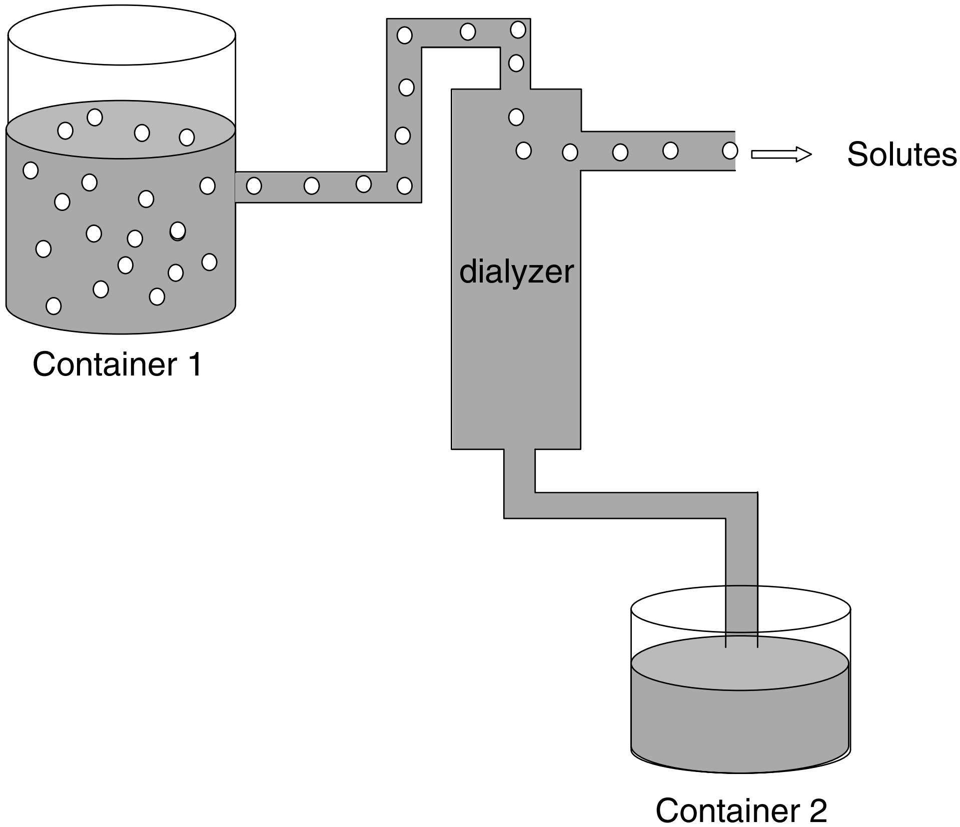

FIGURE 2. The concept of Kt/V for the assessment of RRT dose. The solute (white) in the total body water (Container 1) is entirely removed as all of the fluid passes through the dialyzer during time (t) to Container 2. The clearance of the solute (K) multiplied by t equals the volume of Container 1, which is the volume of the distribution of the solute (V). Thus, Kt = V, or Kt/V = 1. This simple model assumes that total body water is distributed in one compartment, which is not the case in nature.

Hemodynamic Tolerance of RRT in the Critically Ill

An important potential benefit of CRRT over IHD is thought to be better hemodynamic stability, due to a more gradual fluid and solute removal. Since improved systemic hemodynamics might be associated with fewer episodes of renal and GI ischemia,[32] CRRT might reduce the time of recovery of renal function and even result in increased survival. However, whether or not CRRT improves hemodynamic stability or even outcome is controversial.

Whereas retrospective studies[33] have reported a lower rate of hypotension with CRRT than with IHD, prospective studies[34,35] have provided inconsistent results. One study[36] in septic shock patients found no differences in splanchnic perfusion parameters despite differences between CVVH and IHD in systemic hemodynamics. The trend toward a less hyperdynamic "septic" circulation in septic patients receiving CVVH seems to be strongly related to a significant fall in body core temperature during CVVH.[36,37] The heat loss that occurs during CRRT may result in mild hypothermia with an increase in systemic vascular resistance and venous tone,[38,39] thus providing an alternative explanation for the reported hemodynamic benefits of CRRT. In this context, the hemodynamic tolerance of IHD in critically ill patients was also substantially improved after the implementation of guidelines derived from long-term hemodialysis,[40] including cooling of dialysate, daily dialysis, and the introduction of longer dialysis times.[20,41–44] A recent multicenter randomized study[45] that compared CCVH and IHD in critically ill patients using specific guidelines to achieve optimum hemodynamic tolerance did not record any significant difference in the incidence of severe arterial hypotension between both groups.

Whether possible improvements in hemodynamics during CRRT in septic patients are also induced by the effective removal of inflammatory mediators during hemofiltration remains a matter of debate. To remove sufficient amounts of mediators, HVHF, an adaptation of CVVH, was developed using ultrafiltration rates of > 35 mL/kg/h. Improved hemody-

Table 4—*Potential Advantages and Disadvantages of the Two Major RRT Modalities To Guide a Differentiated RRT for the Individual Patients Needs, Underlying Disease, Time Course of Illness, and Available Resources**

Variables	IHD	CVVH
No osmotic cellular shift/cerebral edema	−	++
Hemodynamic tolerance	−	++
24-h volume and electrolyte balance	−	++
Nutritional support	−	+
Removal of cytokines	−	?
Acute hyperkalemia	++	−
RRT dose/adequate uremia control	++ daily treatment necessary	+ 35 mL/kg/h UF volume necessary
Anticoagulation/bleeding disorders	++	−−
Filter clotting	++	−−
Patient's mobility, time for interventions	++	−−
Loss of nutrients, vitamins, trace elements	+	−
Drug/antibiotic dosage	++	— (no clear data on many drugs, different UF rates, and filter downtimes)
Cost	++	−−
Outcome/mortality	?	?

*+ = advantage; ++ = major advantage; − = disadvantage; −− = major disadvantage; UF = ultrafiltration; ? = no clear evidence. Hybrid methods (*eg*, EDD and slow continuous ultrafiltration) are not specified in the table but advantages and disadvantages are often between those of IHD and CVVH.

namics, decreased vasopressor requirements,[46–48] and a trend toward improved survival[49] suggest that HVHF may be efficacious. However, further confirmation is required in large, randomized clinical trials.

With regard to hemodynamic tolerance, CRRT may be advantageous to IHD in patients with severe cardiovascular instability or severe fluid overload. Therefore, continuous therapies are often chosen to treat these patients, although the evidence base is limited. Intermittent therapies seem to be much more comparable in terms of hemodynamic stability if applied with longer dialysis times, daily dialysis, sodium profiling, and cooling of the dialysate.

Intermittent vs CRRT: Advantages and Disadvantages

Table 4 summarizes the potential advantages and disadvantages of IHD and CRRT. Because CRRT is a continuous modality, there is less fluctuation of volume status, solute concentrations, and acid-base status over time. It represents the superior method in patients with cerebral edema because of the avoidance of osmotic cellular shifts. In contrast, IHD is highly effective in removing small solutes from the circulation. Although clearance rates for small solutes with CVVH are lower than those with IHD per hour, the overall clearance rate per 24 h with CVVH may be even better than with IHD, depending on the ultrafiltration rate applied.

Although sometimes CRRT can be performed without anticoagulation, especially when blood flow can be kept to > 200 mL/min, the main disadvantages of CRRT include access and filter clotting and the consequent need for anticoagulation in the ICU setting. Unfractionated heparin has been the mainstay of anticoagulation. The use of fractionated heparins is problematic, because of their long half-life, their accumulation in renal failure, and the problem of monitoring the anticoagulant effect.[50]

Table 5—*Different RRT Modes in the Critical Care Setting**

RRT Modality	Transport Principle	Comment
IRRT		All intermittent therapies
IHD	Diffusion	"Classic" hemodialysis
EDD	Diffusion	Longer dialysis times, slower blood and dialysate flows
SLEDD	Diffusion	Longer dialysis times, slower blood and dialysate flows
SCUF	Mainly convection	Only UF with conventional dialysis machines
CVVHDF	Convection and diffusion	Hemofiltration combined with dialysis (low dialysate flow)
EIHF	Convection	Early hemofiltration in septic shock with high UF rates (like HVHF) but without volume loss
HVHF	Convection	Hemofiltration with high UF rates (equal to high RRT dose; allows intermittent therapy)
CAVH	Convection	Without pumps, allows UF rates of only 10–15 L/d
CVVH	Convection	"Classic" hemofiltration
CRRT		All continuous therapies

*IRRT = intermittent renal replacement therapy; SCUF = slow continuous ultrafiltration; EIHF = early isovolemic hemofiltration. See Table 4 for abbreviation not used in the text.

The regional application of citrate, with equimolar calcium/magnesium infusion at the dialyzer outlet to neutralize the anticoagulant effects of citrate is gaining more acceptance.[51] The use of citrate anticoagulation, however, increases the complexity of CRRT. IHD can even be performed without anticoagulation for a restricted period of time and is therefore considered to be the method of choice in patients with bleeding complications.

The interruption of the treatment for diagnostic and therapeutic procedures prolongs filter downtime and decreases the efficacy of CRRT. This is less problematic with intermittent therapies.

No clear data exist on the dosing of many drugs during CRRT, especially for antibiotics. The underdosage of drugs is a real danger, especially when high ultrafiltration rates are used. In contrast, for IHD valuable pharmacodynamic data exist for most drugs.

Finally, CRRT is more expensive than IHD in many countries because of the need for specific substitution fluids manufactured and stored in bags. One study[52] has demonstrated immediate cost savings by increasing the use of IHD rather than CRRT for patients with ARF in the ICU. Since higher doses, and therefore ultrafiltration rates, in CRRT are now requested than in the past,[19] the cost for CRRT may increase even further.

Intermittent vs CRRT: Outcome

Several studies have attempted to address the question of whether the choice of RRT modality affects patient outcome. However, observational studies[53,54] and prospective studies[55–58] comparing IHD with CRRT could not demonstrate an impact of RRT modality on all-cause mortality or the recovery of renal function. A metaanalysis[59] found no overall difference in mortality; however, after adjustment for study quality and severity of illness, mortality was lower in patients treated with CRRT. Very recently, a large prospective, randomized, multicenter study[45] compared the effects of IHD and CVVHDF on survival rates in critically ill patients with ARF as part of MODS. The rate of survival did not differ between the groups (IHD group, 32%; CRRT group, 33%). Of note, strict guidelines to achieve optimum metabolic control and hemodynamic tolerance in both groups were applied. However, randomizing patients to receive only one therapy or only the other regardless of the clinical condition does not answer the practical question of whether a single patient will do better with one or the other therapy or when it is most appropriate to switch from one method to the other.[60]

Hybrid Methods

The following two modifications of the standard dialysis techniques deserve further attention: EDD; and slow low efficient daily dialysis (SLEDD). Both are hybrid techniques that are designed to combine the theoretical advantages of both IHD and CRRT.[41–43] They are slower dialytic modalities that run for prolonged periods using conventional dialysis machines (*ie*, SLEDD) or even a technically simple, single-pass, batch dialysis system (*ie*, EDD). Typically, low blood-pump speeds of 200 mL/min and low dialysate flow rates of 100 to 300 mL/min for 6 to 12 h daily are used. EDD allows for improved hemodynamic stability through gradual solute and volume removal, as in CRRT.[44] On the other hand EDD is able to provide solute clearances similar to those of IHD. However, there have been no outcome studies performed on these techniques to date.

Nonrenal Indications of RRT: Extracorporeal Inflammatory Mediator Removal

In many cases, MODS develops as a complication of severe infection and septic shock.[61] The host response to infection in patients with septic shock involves the generation of proinflammatory but also antiinflammatory molecules.[62] This response may be responsible, at least in part, for the development of organ dysfunction in patients with sepsis. It has been hypothesized that CRRT, apart from representing a valuable renal replacement modality, may modulate the inflammatory response by nonspecific extracorporeal removal of cytokines and other mediators from the circulation.[63,64] This hypothesis is based on the following two assumptions: (1) cytokines can be effectively removed by extracorporeal techniques; and (2) the nonselective removal of mediators from the systemic circulation is beneficial for septic patients. Despite numerous studies, neither assumption has been supported by convincing evidence.

Although several studies[65] have reported the elimination of various inflammatory mediators with CRRT, a detailed quantitative analysis revealed that, due to the molecular size and structure of these mediators, only a small portion of the circulating pool can be eliminated.[66] This elimination occurs mainly by adsorption to the filter membrane.[67,68] Despite efforts to increase convective transport and/or adsorptive capacity of the membrane, most controlled studies failed to demonstrate a significant and sustained effect on cytokine plasma concentrations with CRRT.[64,65,68–71] In addition, equivalent removal rates of proinflammatory and antiinflammatory cytokines have been reported.[65] It remains to be elucidated whether the removal of antiinflammatory cytokines abrogates the proinflammatory cytokine removal and *vice versa*.

Several new strategies to increase mediator removal, termed *extracorporeal blood treatment*,[72] have been proposed and are currently being evaluated. HVHF,[46,47,73,74] pulse HVHF,[48] plasma filtration, plasma adsorption, coupled plasma filtration adsorption,[75,76] and high-permeability hemofiltration with high cutoff hemofilters[77] are all new extracorporeal blood treatment modalities that combine different principles of blood purification in order to increase mediator removal and/or to improve hemodynamics and organ perfusion. However, up to now, well-designed randomized controlled trials of these techniques have not been available.

Conclusion

The epidemiology of severe ARF in the ICU has significantly changed over the past decade to sepsis and septic shock (mostly as part of a MODS). This has been accompanied by an ongoing evolution in blood purification technology for renal support. Intermittent RRTs and CRRTs are available, and have both advantages and disadvantages depending on the individual clinical situation. Since a survival benefit has not been demonstrated for either method, it is the task of the nephrologist/intensivist to develop an RRT strategy for each individual patient. From this standpoint, it seems prudent to have different RRT modalities available.[78]

Although we have learned that adequate RRT doses result in improved survival in patients with ARF, clear guidelines on the dose of RRT and the timing of the initiation of RRT are still lacking. It remains a matter of debate whether patients with sepsis and septic shock benefit from early RRT initiation, the use of increased RRT doses, and/or increased removal of mediators.

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