
Continuous Renal Replacement Therapy Specialized Teams: A Challenge to Improve Quality Performance

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Abstract

Acute kidney injury is a common condition in critical care, and continuous extracorporeal therapies have become part of the requirement for multiorgan support in critically ill patients. Availability of continuous renal replacement therapy (CRRT) in a healthcare center can influence the therapy performance and patient's results, and it is challenging to attain high-quality standards in centers without previous experience in CRRT and with new therapy users. This chapter describes the experience of a highly specialized acute renal care service model with emphasis on timely interventions by an exclusive CRRT team, education and training, protocol development, quality performance improvement, and its impact on optimal clinical and pharmacoeconomic outcomes.

Keywords: renal replacement therapy, acute kidney injury, renal rapid response teams, interprofessional care, multidisciplinary care, patient safety, quality improvement, cost-effectiveness

1. Introduction

Acute kidney injury (AKI) is a clinical syndrome characterized by the abrupt decrease in the glomerular filtration rate (GFR), severe enough to compromise the elimination of waste products and uremic toxins. AKI is common in critically ill patients and has been documented in 30–60% of the hospitalized patients in intensive care unit (ICU) [1]. Its pathophysiology involves complex processes including hemodynamics and inflammation disarrangements, many of which are not entirely understood. AKI has multiple etiologies and clinical manifestations; patients may

present a wide spectrum of symptoms ranging from asymptomatic through anuria to multiple organ dysfunctions [2, 3].

Early recognition and timely interventions are important for the prognosis of AKI, as well as controlling associated hospital morbidity and preventing the development of long-term outcomes, such as chronic kidney disease and chronic cardiovascular conditions [4–6]. Approximately 13.3 million cases of AKI are estimated per year worldwide, with 1.7 million attributable deaths and a high health burden associated to the increase of the hospital and ICU length of stay (LOS), days of mechanical ventilation, and dialysis dependence [7].

International registries show that about 13% of ICU patients with AKI may require renal replacement therapies, and the mortality rate in this group could be up to 50% [8, 9]. The high mortality rate in this population reflects the critical state and the development of multiorgan failure. Several years ago, acute renal failure requiring dialysis was one of the most difficult conditions to treat in ICU, especially in patients with hemodynamic instability and risks of tissue hypoperfusion during extracorporeal interventions, due to lack of experience in therapy performing and the side effects related to circuit anticoagulation [10, 11].

The introduction of continuous renal replacement therapy (CRRT) allowed for the possibility of performing safely extracorporeal therapies in ICU, with less specific requirement for dialysis infrastructure and improved medical care in patients with access barriers to dialysis or hemodynamic tolerance concerns [11–13]. From the first continuous arteriovenous hemofiltration, CRRT evolves to veno-venous systems up to the modern integrated full-volume pump monitors, thus becoming a preferred, safe extracorporeal therapy in many critical care patients [14–16].

The success in the implementation of continuous renal replacement therapy (CRRT) in ICU does not depend only on its availability and technological advances, but on the development of excellent programs, where the intervention of specialized doctors and highly trained nurses complement one another. Specialized teams allow for a standardized care with the highest quality safety, facilitating the recognition of specific needs on the critical AKI population, improving decision-making and individualized management. In 1998, Ronco and Bellomo introduced the term “critical nephrology” to highlight the importance of a multidisciplinary approach in the critical patient with AKI, emphasizing the need for training, collaboration, and communication between various clinical teams [17, 18]. Currently, this approach is still valid and the role of the specialized renal care teams becomes relevant [19]. This chapter aims to explain, by means of the experience of a specialized network of critical nephrology teams, the most relevant guidelines in the construction of a rapid renal response team and its expected benefits.

2. Renal emergency team (RET) and a critical nephrology program (CNP): a rationale for critically ill patients

Delay in recognition of serious diseases or their associated complications has been identified in hospital care and ICU as one of the most important factors that could affect clinical outcomes

and the consumption of health resources. AKI is a disease with difficult early recognition, high health burden due to its important rate of complications in the short and long term, lack of knowledge of its pathophysiological processes and lack of a specific treatment.

Despite the progress in knowledge achieved in recent years, concerning biomarkers and their incorporation in therapeutic protocols [20, 21], incremental innovations in technology with an emphasis on multi-organ support [22, 23], patients outcomes continue to be suboptimal [24]. AKI is a complex phenomenon that rarely affects only the kidney, it encompasses multiple complex organ dysfunction and alterations in cross-talk between organs [25]; hence, an interdisciplinary approach allows for the knowledge leverage across different specialties. Participation of experts in each area, a specialist in critical nephrology and a highly trained group of CRRT/intermittent hemodialysis (IHD) nurses, potentially helps in priority establishment, implementation of standardized actions, and implementation of quality control processes [26, 27].

Specialized providers external to traditional intensive care staff, but with experience in critically ill patients, is not a recent practice. Areas such as respiratory care practitioners, a nutritional support team, clinical pharmacology, diagnostic and interventional radiology, cardiology, rehabilitation, and physiotherapy are examples of external groups involved in interprofessional care [28]. Requirements of complex patients, incorporation of IT systems and continuous improvement policies, together with advances in health care, are part of the institutional framework necessary to incorporate groups of excellence, facilitate cooperative work, and increase healthcare benefits.

Collaborative work experiences vary between nephrologists and intensivists. Nephrology has maintained leadership in the principles of extracorporeal techniques, while intensive care has deepened multisystemic management of AKI patients. However, at the moment, it is necessary to increase leadership in educational aspects, risk control, and vulnerability management in AKI patients. The critical nephrology team leader works as a medical director and also does clinical follow-up work; medical direction is essential to ensure compliance with the infrastructure, logistics, care staff, diagnostic tools, and treatment and technology standards required for patients. The RET leader manages to engage all the professionals under the same established strategy to overcome the complications associated with AKI and overcome institutional obstacles.

The responsibilities of the critical nephrology team are identification of AKI etiology and severity assessment; AKI prevention strategy; drugs adjustment and identification of nephrotoxins; nutritional prescription adjustment; fluid balance planning and fluid overload monitoring; leadership in the planning, placement, use, and care of vascular access; timing for extracorporeal therapies; strict monitoring during the implementation of the different modalities to ensure compliance with clinical objectives; avoiding dialytrauma; and comprehensive clinical strategy after ICU discharge.

In recent years, there have been some before-after studies documenting the benefits of the interventions performed by a specialized and dedicated CRRT team (SCT) after the implementation of an educational and quality improvement program. Two observational studies in Asia showed that the SCT has a positive impact on outcomes such as improving CRRT filters

consumption (42 vs. 23 min, decrease of down time per day (4.8 vs. 3.3 h, $p < 0.001$), fewer days of stay in the ICU (27.5 vs. 21.1d, $p = 0.027$), decrease in red blood cell transfusions (70.7 vs. 63.5%, $p = 0.043$), and improving 90-day survival (29.3 vs. 40.7%, $p = 0.039$) [29, 30].

3. How to implement a CNP and a specialized team: the ARTIST model

After identifying an opportunity to implement a critical nephrology program and consolidate a specialized team, it is essential to develop an integrated care model to meet the fundamental aspects for success in a highly complex system. Below is a description of what we call the ARTIST model:

Alarm systems and risk prediction, Ready to evaluate and act, Timing Interventions, Systems for quality improvement, Transferring knowledge.

3.1. Alarm systems and risk prediction scores

Early AKI recognition begins with risk stratification in specific populations (cardiovascular surgery, surgery, exposure to contrast media), where easy-to-use risk assessment scales have been developed (Tables 1–3). IT systems facilitate the identification of high-risk patients in electronic medical records (EMRs) for the RET to evaluate preventive measures, previous to the exposure, and to plan the follow-up.

Risk factor	Score		
• Hypotension	5		
• Intra-aortic balloon counterpulsation (IABC)	5		
• Congestive heart failure (CHF)	5		
• Age > 75 years	4		
• Anemia	3		
• Diabetes mellitus (DM)	3		
• The volume of contrast media	1 per 100 mL		
Baseline GFR MDRD (mL/min/1.73 m ²)	Score		
40–60	2		
20–40	4		
<20	6		
Groups of risk	Total score	CIN risk (%)	Dialysis risk (%)
1	0–5	7.5	0.04
2	6–10	14	0.12
3	11–15	26.1	1.09
4	16 or higher	57.3	12.6

GFR, glomerular filtration rate; MDRD, modification of diet in renal disease equation.

Table 1. Contrast-induced nephropathy (CIN) risk scale [31].

Risk factor		Score
• Female		1
• CHF		1
• LVEF < 35%		1
• IABC		2
• Chronic obstructive pulmonary disease		1
• Diabetes mellitus on insulin		1
• Previous coronary artery bypass grafting (CABG)		1
• Emergent surgery		2
• Valve		1
• Valve + CABG		2
• Another type of surgery		2
• Preoperative creatinine		
1.2–2.1 mg/dL		2
>2.1 mg/dL		5
Risk group	Total score	CSA-AKI risk (%)
I	0–2	0.4
II	3–5	2
III	6–8	8
IV	9–13	21

CHF: congestive heart failure; LVEF: left ventricular ejection fraction; IABC: intra-aortic balloon counterpulsation.

Table 2. Cardiovascular surgery-associated AKI (CSA-AKI) risk scale [33].

Risk factor (RF)	Groups of risk (n)	P-AKI risk (%)	Hazard ratio (IC)
Age > 56 years			
Male	I (<2RF)	0.2	—
CHF	II (3 RF)	0.8	3.1 (1.9–5.3)
Ascites	III (4RF)	2.0	8.5 (5.3–13.7)
Hypertension	IV (5RF)	3.6	15.4 (9.4–25.2)
Urgent surgery	V (6RF)	9.5	46.2 (26.3–70.9)
Preoperative creatinine >1.2 mg/dL			
DM			

CHF: congestive heart failure.

Table 3. Perioperative-associated AKI risk (P-AKI) scale [37].

The primary prevention activities in AKI include the restriction of identified nephrotoxic agents, prescription of alternatives with lower renal impact, or active renal therapeutic interventions such as nephroprotection protocols for contrast medium or ischemic preconditioning in patients at high risk of CSA-AKI [32].

Sometimes, it is necessary to perform studies with contrast agents in critical patients. It is recommended, as far as possible, to defer exposure in patients with shock or heart failure until the hemodynamic state is restored. Repeated exposure to contrast medium should be avoided. Cases of contrast-induced nephropathy should be postponed for additional exposure to the contrast agent until the glomerular filtration rate (GFR) returns to the baseline.

Several studies have shown that the expansion of intravascular volume and the treatment of dehydration prevent AKI; however, the rate of infusion or the best type of fluid is still unknown [34]. Once the patient is exposed to a toxic agent, it is important to assess the renal injury severity. Controlling AKI-related complications is part of secondary prevention, one common example is fluid overload related to fluid resuscitation in patients with absence of diuresis response [35]. Research on novel AKI biomarkers opens up future possibilities to determine the moment of kidney injury before the GFR impairment. It will be possible to validate the effectiveness of timely medical interventions and potentially control the progression of the AKI in its early phases [36].

However, renal insult is not always possible to anticipate. In recent years, researchers have conducted studies to find scales that involve both preexisting conditions associated with AKI and clinical signs of daily monitoring, such as respiration rate and assessment of consciousness (**Table 4**). The prediction score of acute renal injury (APS) has been validated in the medical and surgical population, reaching a negative predictive value of 94%. Also, patients with APS greater than 5 have a significant increase in the risk of death, 1.9 (CI95 1.1–2.0, $p = 0.015$) [38, 39].

In the pediatric population, other predictive scales of severe AKI have been developed, such as the renal angina index. Recently validated in the adult population, it is a combination of risk conditions and signs of kidney injury; a score greater than 6 has an AUC of 0.76 for the development of severe AKI [40, 41].

Once it is clear how to perform the screening to identify high-risk populations, it is ideal to activate the RET either by healthcare professionals at the bedside, or by electronic alert systems. Several studies have shown that EMR designed to identify patients with AKI and to generate an electronic alert could affect the quality of hospital care, improve the control of this disease, its incidence and progression, and associated complications [42–44].

A critical factor, in keeping the high commitment of the RET in the priority assessment of high-risk patients, is to understand when to trigger the alert and initiate care to avoid phenomena such as habituation and fatigue due to the high workload in low-risk population [45].

3.2. Ready to evaluate and act

Once the alarm system has been defined and the setup criteria determined, a logistical structure must be established considering both human resources and required supplies to guarantee the

Risk factor (RF)	Score			
	0	1	2	3
Age	<60		60–79	≥80
Respiratory rate	<20	≥20		
AVPU (not alert)	Alert			Other
Chronic kidney disease stage 3–5	N	Y		
CHF	N	Y		
DM	N		Y	
Liver disease	N			Y
Total APS score	HA AKI risk (%)		Odds ratio (IC)	
0–3	4		0.4 (0.3–0.5)	
3–4	8		2.2 (1.6–2.9)	
5–6	14		2.3 (1.8–2.9)	
7	28		4.7 (3.1–7.2)	

AVPU: alert, voice, pain, unresponsive scale; CHF: chronic heart failure; DM: diabetes mellitus; Y: Yes; N: No.

Table 4. Acute prediction score (APS) for hospital-acquired (HA) AKI.

level of compliance and a sustainable care system. Rapid response teams should have autonomy and independence regarding budget, staff structure, implementation, and supply chain. Electronic health systems are essential to ensure the traceability of each process and further evaluation of the pharmacoeconomic results, clinical and operational efficiencies obtained by a highly specialized team.

The RET should have a portable module of supplies that could be taken to the bedside, including diagnosis (i.e., point-of-care), tubes for sampling, disposables, personal protection equipment, disinfectants, specific drugs, solutions, vascular assessment (i.e., ultrasound), catheters, and document formats. An additional portable module for patients in renal replacement therapies (RRTs) can include filters, circuits, solutions, quality tests, and the rest of dialysis supplies. The program should simplify the supply chain and inventory control, minimize unnecessary consumption, and optimize administrative processes. Nurses must be empowered in each of these processes [46].

Regarding healthcare staff, the RET must have team players with strong communication skills and a highly ethical commitment. Professionals must comply with training and certifications for AKI risk assessment, comprehensive assessment in intensive care and hospital care patients, monitoring and support in critical conditions, and training for acute extracorporeal renal support techniques [47]. In our institutions, we have managed to consolidate the RET with professionals with either experience in intensive care or trained nurses in dialysis. Training programs for new staff should guarantee a combination of nursing knowledge in both the expertise of primary-secondary-tertiary prevention activities and extracorporeal therapies (Table 5).

Clinical training	RRT training
Pathophysiology of acute kidney injury	Acute RRT basic principles and modalities
Risk scales for acute kidney injury and clinical assessment in high-risk patients	Monitors and risk management during acute RRT
How to measure and interpret fluid balance	Dialyzers and set up the circuit
Diagnostics on the AKI patient	Programming and navigation through screens
Primary, secondary and tertiary AKI prevention protocols	Pumps, flows and interpreting pressures during acute RRT
Monitoring systems in the critical patient	Troubleshooting alarms and hands-on skills
Hemodynamic and ventilatory support in the critical patient	Protocols for circuit preservation and identifying the coagulation of the circuit
Best clinical practices in vascular access use and care	Follow-up and EMR; roles and responsibilities; and guidelines and protocols of the program
Infection control	Ethics and compliance

Table 5. Specialized nursing training program.

A specialist in critical nephrology is essential to consolidate the RET. Models with the participation of general practitioners with specific training or residents in nephrology that can support some of the medical care processes may be reasonable depending on the volume and complexity of the care processes, and the academic nature of some institutions. It is essential to guarantee the scope and level of participation in these cases; for actions to be timely executed, the specialist should always participate in the decision-making processes.

The timely involvement of the nephrologist correlates with better outcomes in AKI patients. Soares et al. found in their meta-analysis that the delay in nephrology consultation significantly increases the risk of death with a log OR 0.79 (95CI 0.48–1.1, $p < 0.05$). The log OR controls the overall effect of the sample size, a result greater than 0 represents an increased risk of the measured outcome [48].

The specialist in critical nephrology must know in depth the fundamentals associated with the AKI patient. To understand the context of the critical patient, the specialist should perform a multisystemic approach to be able to align the ICU priorities with AKI interventions. As in the nursing group, the specialist must provide an environment of ongoing dialog and interaction with the ICU consultants, establishing agreements for joint interventions and periodic re-evaluation. Real teamwork between ICU healthcare professionals and the specialized team will enhance the collective learning resulting from the interdisciplinary interaction, improving patient health care [49].

3.3. Timing interventions

Preventive measures would impact the incidence and progression of AKI. The five standards of the AKI bundle are: (1) identify the etiology and try to control it, (2) maintain the best renal protection measures (i.e., mean arterial pressure, glucose control, and euvolemia), (3) avoid

new toxicity (contrast agents and daily evaluation for interruption or appropriate adjustment of drugs), (4) evaluate the progression of the injury and control of renal function, and (5) intensify the measures if there is progression. The intensity of invasive monitoring and intervention should be adjusted to multi-organ dysfunction and AKI severity.

The emergence of early AKI biomarkers and the development of AKI care bundles have allowed assessing indirectly feasible interventions that could be done by a specialized team in AKI treatment or prevention. Recently, Kolhe et al. published an analysis of a large match cohort of 3717 patients and found a decreased rate of inhospital death (OR 0.76) and less progression to more severe AKI stage (4.2 vs. 6.7%, $p = 0.02$) in 936 patients (25.6%) who completed the KDIGO care bundle within 24 h of follow-up [50].

Early detection of acute kidney injury by introducing biomarkers with better receiver operating characteristics (ROCs) has begun to change the natural history of the disease. A prospective randomized trial of 121 surgical patients, at high risk of AKI with positive TIMP2-IGBP7, tests the KDIGO care bundle vs. standard care to reduce the incidence of primary AKI. Although they did not reach the primary outcome in the entire population, the subanalysis of the low positive biomarker population (TIMP2-IGBP7: 0.3–2) showed a significant reduction in the incidence of AKI (27 vs. 48%, $p = 0.03$), decrease in moderate and severe AKI (6.7 vs. 19.7%, $p = 0.04$) and shorter duration of hospitalization (16 vs. 21, $p = 0.04$). Furthermore, responders showed a greater reduction in biomarker control levels [21].

In another randomized controlled trial (RCT) in postcardiovascular surgery with a high risk of AKI, 276 patients with positive TIMP2-IGFBP7 were randomized to the KDIGO care bundle vs. standard care. Patients in the intervention group most frequently received inotropic drugs and a vasopressor, tight glucose control, and more often withdrawal of ACEi/ARB. The primary outcome showed a general decrease in the incidence of AKI (55.1 vs. 71%, $p = 0.004$) and less moderate and severe AKI (44.9 vs. 21%, $p = 0.009$) in the intervention group. They did not find differences in the requirement of renal replacement therapies or major adverse kidney events (MAKE) [20].

When medical interventions do not control the progression of the disease or when multisystem involvement is severe, it may be necessary to evaluate the need for extracorporeal renal support. If in doubt, the furosemide stress test can help [51]. At present, the early approach to renal support is widely accepted within the scientific intensive care community, before the deleterious consequences of severe AKI appear [52].

3.4. Systems for quality improvement

During medical interventions, safety and quality have been professional and ethical responsibilities. However, the varied experiences at centers performing CRRT, the lack of evidence proving a protocol better than the others, and the variable needs of critical patients, have resulted in great heterogeneity in practices at the bedside, facilitating the gap between therapeutic intentions and what is achieved. The fragility of the patient in intensive care increases the risk of medical errors, and logistical changes or staff shift in the institutions generates different risk moments during the process of care.

International initiatives have raised the awareness for standardized quality measurements in the care of CRRT in ICU. Identify moments or processes where there are potential interventions, with adequate follow-up is essential to strengthen CRRT programs and evolve towards the practices of centers of excellence. Some examples of activities within a quality improvement program are the continuous evaluation of training and education standards, evaluation of clinical practice guidelines and adherence to protocols, unplanned infield auditing, and team discussion of quality indicators and in-depth analysis of adverse events under different perspectives.

Several quality improvement models have been described and they have in common the identification of an improvement opportunity, the implementation of an action plan, the analysis of the results obtained, and the redefinition of the processes. To do so, it is necessary to have a culture of monitoring and reporting within the work team, i.e., constructive and continuous internal audits in which teams participate proactively and without coercion to achieve professional development and evolution in care processes.

For any center of excellence in CRRT, one must be able to answer correctly three questions: do all patients who benefit from the therapy have access as long as they need it? Is the maintenance of the therapy what we expected? And does the patient receive treatment as medically proposed?

The daily monitoring of CRRTs should include the above questions not only from an opportunity perspective but also from the perspective of team empowerment needed to overcome the obstacles and difficulties. Nursing checklists and internal nursing audits should include CRRT configuration; priming; catheter assessment and care; circuit monitoring; exchange of bags and supplies; troubleshooting and alarm resolution; connection, disconnection, and recirculation; evaluation and early recognition of circuit coagulation; and termination of therapy.

Improving documentation of medical records (EMR) is essential for controlling clinical outcomes, especially if there are special forms in place to monitor treatment. Fluid registration is usually a challenge, but after the personnel overcomes the learning curve, they value the importance of accurate information and optimal fluid management. An excellence center should minimize the risks associated with therapy performance (dialytrauma); the application of checklists (**Table 6**) by nursing coordinators or general practitioners during clinical rounds would allow early interventions and will help to start quality improvement plans in cases of inadequate recognition.

The quality indicators, the results of the internal audits, and the events presented must be analyzed with adequate frequency to achieve compliance with improvement plans. The duration of the circuit, the therapy dose administered, the time of inactivity, and the episodes of bleeding are parameters accepted internationally as quality indicators [53].

3.5. Transferring knowledge

The last part of the care model, and not the least important, is all the activities generated within the team to increase the collective knowledge about managing patients with severe AKI and the activities with the intensive care group to close the interdisciplinary knowledge gaps.

CRRT Patient safety chart																																		
NAME					ID					AGE					APACHE					INITIAL SOFA					ROOM									
DIAGNOSIS					RESPONSIBLE					TIME OF CRRT INITIATION					INITIAL FLUID BALANCE																			
YEAR:	MONTH:	DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	UTD
1. INFECTION AND ADVERSE EVENTS CONTROL																																TOTAL		
Proper cleaning and proper changing of dressing																																		
Insertion site without evidence of infection																																		
Follow the facility Cleaning & Disinfection protocol																																		
Follow the isolation precautions																																		
Good vascular access function																																		
No ischemic complication associated with access																																		
KPI (>80%)																																		
2. Adjustment of drugs and toxicity prevention																																		
Antibiotics																																		
Nephrotoxic have been suspended																																		
Vasopressor have been adjusted to the PAM goal																																		
Fluid infusion rate meets the goal																																		
Phosphate guidelines adopted																																		
Potassium guidelines adopted																																		
Nutrition guidelines adopted																																		
Contrast agent control																																		
Best renal protection measures (e.g. glucose control)																																		
KPI (>90%)																																		
4. CRRT MANAGEMENT																																		
Timing intervention																																		
Downtime Target < 15%																																		
CRRT Deliver dose Target > 25ml/kg/h																																		
Filter life time expected																																		
Reach ultrafiltration Target > 80%																																		
KPI (>80%)																																		
5. COMPREHENSIVE INTERVENTIONS																																		
Complete EMR																																		
Labs test as protocol																																		
Measured and control bleeding risk																																		
Critically ill rehab guidelines adopted																																		
Stress ulcer prophylaxis guidelines adopted																																		
DVT prophylaxis guidelines adopted																																		
Sedation and analgesia guidelines adopted																																		
KPI (>80%)																																		
Auditor																																		
<div>1 YES</div> <div>0 NO</div>																																		

Table 6. Patient safety chart.

Discussions of difficult cases, presentations of new scientific literature, and updates of clinical practice guidelines among services are some examples of knowledge transfer activities. Similarly, in the nursing environment, the analysis of quality indicators and opportunities for improvement in patient care constitute feedback and learning activities between the ICU and nephrology nurses.

4. Experience and outcomes of a critical nephrology program and two CRRT specialized teams in a net of an acute service provider in Colombia

The following results are part of an internal audit analyzed by our team from the CNP database in two academic centers in Bogota from 2013 to 2016, where a RET operates CRRT. Renal Therapy Services (RTS) is an external provider of specialized renal care services offering IRRT and CRRT as an ARTIST model to hospitals in Colombia.

4.1. The RTS model

RTS is part of Baxter’s renal care division, which provides healthcare services for acute and chronic kidney disease. RTS clinics are located in Latin America, Europe, and Asia, equipped with Baxter technology; RTS is responsible for the supply chain and has the nephrology

experts for the management of kidney diseases. Some clinics provide hospital services with specialized clinical staff and critical nephrology training: nephrologists, general practitioners, nurses, and pharmacists. Besides, RTS has centralized management support for the clinical operation, quality assurance and information management, a training-education area, and an IT department. RTS has permanent technical support to guarantee continuous therapy.

RTS together with the hospital clinical staff develops the guidelines for the RET, the triggering process of the RET, and the quality indicators for all the processes involved. RTS is responsible for the specialized team, the timely response, the technology and supplies for the renal intervention.

A key factor identified to enhance opportunity is the close interaction between the hospital staff and the RET. In highly complex institutions with high-risk patients and an important demand for services, it is imperative that the hospital team guarantee cost-effectiveness. The RET leader is the nephrologist, assisted by a nurse who directs and organizes the staff according to the daily requirements of the institution, monitors compliance with the protocols, initiates therapies, evaluates patient safety, and provides continuing education to the staff. When the RET receives an alert, it evaluates the patient and decides whether an intervention is necessary or not. If a patient requires extracorporeal therapy, the nephrologist will choose a modality according to national guidelines. The preferred modality for hemodynamically unstable patients (cardiovascular SOFA 3–4) is CRRT. In these cases, the rest of the RET will join in to generate attention to the patient and prepare all requirements for the vascular access placement and the initialization of the therapy. Catheter insertion is performed by the nephrologist and guided by ultrasound. The nursing staff is responsible for setting up of the circuit and the filter, and for programming the monitor according to the nephrologist prescription.

Modern CRRT platforms, such as Primaflex monitors, allow for a friendly, safe and easy-to-use configuration and programming. Also, high-precision fluid monitoring and its easy interpretation on the screen with updated information allow for optimal therapy monitoring and to achieve personalized treatment to reach dosage targets and fluid balance. RTS uses bicarbonate replacement fluids and filters with high permeability and adsorptive properties; dosage and modality are clearly defined in the RTS CRRT protocols.

The specialized RTS CRRT team has established parameters for optimal care and quality goals (Table 7).

CRRT initiation	CRRT delivery dose	Reach ultrafiltration
Target < 3 hours	Target > 25 ml/kg/h	Target > 80%
KPI > 90%	KPI 80%	KPI > 90%
Downtime	Filter life time	Access alarms
Target < 15%	Target > 30 h	Target < 5 in 24 h
KPI 90%	KPI > 90%	KPI > 90%

KPI: key performance indicator.

Table 7. CRRT quality indicators.

RTS has a policy of no anticoagulation in patients with high and medium risk of hemorrhage. Over the years, the nursing staff has gained experience in circuit maintenance. In highly experienced groups in RTS, the average survival time of the CRRT filter is up to 36 hours; 60% of the filters do not require anticoagulation in addition to the usual prophylaxis used for ICU patients. The heparin protocol is used for filters with less than 24 hours of lifespan; the dose is adjusted to maintain aTTP of 45 s and vTTP 65 s, the nursing team is responsible for sampling the circuit and reporting results to the specialist. The performance of the filter is evaluated daily, determined by the ratio between nitrogen loss in the ultrafiltrate and the blood urea nitrogen, to anticipate any circuit change when the result is less than 80%.

The nephrologist visits patients with CRRT two or three times a day, assesses changes in the general health of the patient, organic dysfunction, fluid balance, analysis of laboratory tests, organ supports and clinical concerns of the consultant of the UCI. The adjustment to the CRRT prescription is discussed with the ICU staff to maintain consistency in the patient treatment and to understand, in concert, planned clinical targets. Hemodynamic, ventilatory, and fluid monitoring should be guaranteed during the CRRT. The decision to wean off the renal support is evaluated at least daily, considering diuresis, markers of clearance and improvement of multi-organ failure. Close monitoring during the next 6 hours after the suspension of CRRT is a regular practice; some patients need control laboratories to maintain a safe weaning. All patients are followed up according to the nephrologist's clinical criteria.

The RET nursing staff is responsible for therapy maintenance and care for the circuit and the filter lifespan. They keep hourly records of circuit parameters such as pressures, flows, air detection in the circuits; and changes out of the expected parameters are reported to the nephrologist. The nursing staff is trained to solve regular alerts and to follow simple algorithms prior to the nephrologist intervention. A continuing education program and a periodic evaluation of protocols adherence are given to the nursing staff to guarantee homogeneous experience levels. Records are analyzed, and coagulation cases are discussed on a daily basis.

Additional clinical parameters are recorded on the CRRT flowsheet and in the CRRT EMR as well (**Figure 1**).

Monthly, the results of the program are discussed in the CNP committee, consisting of the nephrology director, the nursing leader, the medical team and the clinical operations manager. The Prismaflex CRRT management report is obtained directly from the Prismaflex monitors through the Sharesource connect platform. It collects and analyzes all the therapy parameters at each center (**Figure 2**). The results obtained are contrasted with the established CRRT quality indicators, targets and KPI. The CNP committee also analyzes survival, renal recovery, adverse events as well as the cost-effectiveness of the evaluated period. This is how quality improvement plans for the teams are defined.

4.2. Audit results

Patients older than 18 years who underwent CRRT for renal indication, during ICU stay were included in the analysis of audit results. Therapy less than 24 hours, mortality within the first 24 hours of treatment and patients with missing information were excluded from the analysis. Only data from the first intervention period were included. The population was characterized

[illegible]

Figure 1. CRRT flowsheet. PEEP: positive end expiratory pressure. FiO₂: fraction of inspired oxygen. IABC: intra-aortic balloon counterpulsation. ECMO: extracorporeal membrane oxygenation. VAD: ventricular assist device. HR: heart rate. AP: arterial pressure. MAP: mean arterial pressure. RR: respiratory rate. T: temperature. CVP: central venous pressure. UF: ultrafiltration. Qb: blood flow. TMP: transmembrane pressure. OP: circuit outlet pressure. IP: circuit inlet pressure.

by age, sex, indication of CRRT, AKI etiology, and length of hospital stay. Some clinical characteristics were recorded at the therapy start, including serum creatinine, ureic nitrogen, pH, lactic acid, cardiovascular SOFA, vasopressor, mechanical ventilator, and fluid balance. CRRT technique such as modality, dose, and net UF within the first 24 hours were recorded. Inhospital mortality and renal function recovery, defined as dialysis independency at of hospital discharge, were analyzed.

In both of the centers participating in the audit, 265 patients underwent CRRT during the period described. **Table 8** shows the clinical characteristics of the patient. Sepsis, cardiovascular disease, and postoperative abdominal states were the main causes of acute kidney injury. The most frequent CRRT indications were metabolic acidosis, hyper-azotemia and fluid overload in 46, 34.7, and 10.9% of patients, respectively (**Figure 3**). The majority of patients

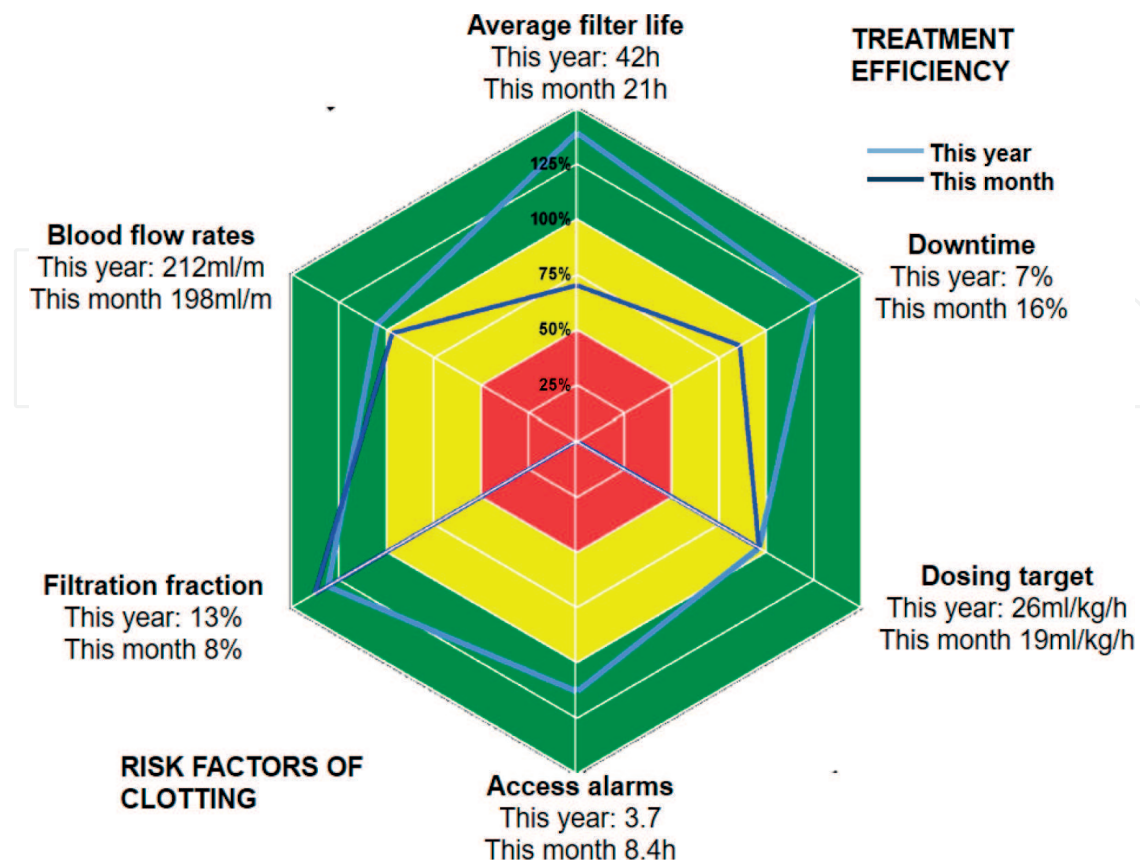


Figure 2. Prismaflex CRRT management report.

(74.7%) had 3 and 4 points of cardiovascular SOFA at CRRT beginning. The mean total SOFA was 10.3, with almost half of the patients (43.4%) with a score equal to or greater than 11.

Continuous veno-venous hemofiltration (CVVH) was the preferred CRRT modality predominantly in the predilution mode. The average of fluid balance at therapy start was 9.5 L (range −2.3 to 69 L) and the net ultrafiltration in the first 24 hours of CRRT was 1387 mL. Hospital mortality rate was similar to worldwide reports (63%), but we found a higher rate of renal recovery in the patients who survived (82%) (**Figure 4**). The average time on mechanical ventilation was 7 days with 31 days of hospital length of stay.

4.3. Economic analysis of the audit

The cost-effectiveness of continuous renal replacement therapies has been questioned in different health systems. Information on the economic impact of a service model by an external provider has not been well studied. Audit results in the renal recovery have motivated the development of an analytical model of Markov that adapts a previously validated model to our reality, in a time horizon of 5–10 years and subsequent simulation of a hypothetical cohort of 1000 patients. Health costs (COP) and adjusted life quality (QALY) were compared between intermittent hemodialysis and CRRT provided by a renal emergency team (**Table 9**) [54].

Characteristic	Number (%)
<i>Gender—number (%)</i>	
Male	172 (64.9)
Female	93 (35.1)
<i>Age—years</i>	
	64.7 (18–92)
<i>Acute kidney injury etiology</i>	
Sepsis	148 (55.8)
Cardiovascular disease	58 (21.9)
Abdominal postoperative state	31 (11.7)
Coronary artery bypass grafting	17 (6.4)
Autoimmune disease	5 (1.9)
Trauma	4 (1.5)
Nephrotoxicity	2 (0.8)
Vasopressor therapy at CRRT initiation	213 (80.4)
<i>Cardiovascular SOFA score—number (%)</i>	
0	53 (20)
1	5 (1.9)
2	9 (3.4)
3	77 (29.1)
4	121 (45.7)
Characteristic	Mean (SD)
Total SOFA score	10.3 (3.89)
pH	7.24 (0.12)
Bicarbonate (HCO ₃)—mmol/L	16.4 (4.98)
Base excess (BE)	−9.09 (6.89)
Lactate (mmol/L)	3.3 (3.59)
Serum creatinine (mg/dL)	3.8 (4.14)
BUN (mg/dL)	63.9 (31.75)
Delivered dose (mL/kg/h)	26.9 (7.02)
Fluid balance at CRRT initiation (L)	9.5 (11.78)
Net ultrafiltration within the first 24 hours (L)	1.3 (1.87)

Table 8. CRRT patient characteristics (265 patients).

The results of the economic analysis showed that CRRT performed by a highly specialized external provider with optimal renal recovery results was a dominant alternative when compared with IHD (**Figure 5**). The results were maintained after a sensitivity analysis varying

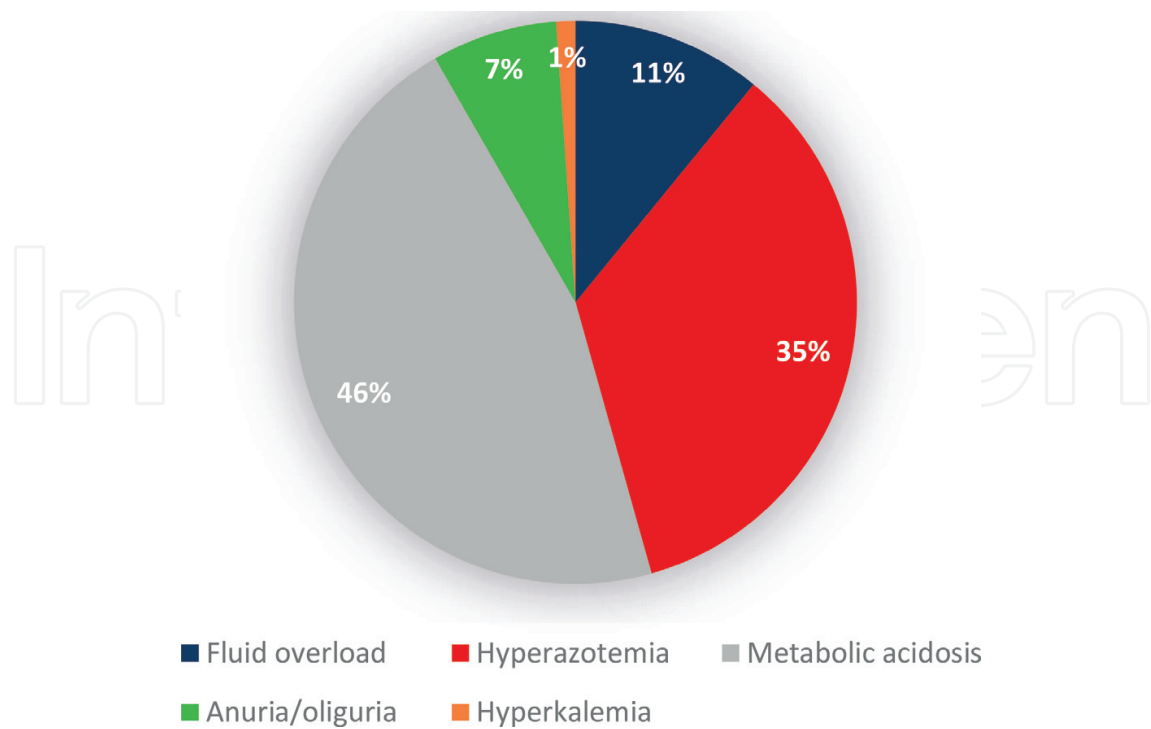


Figure 3. CRRT indications.

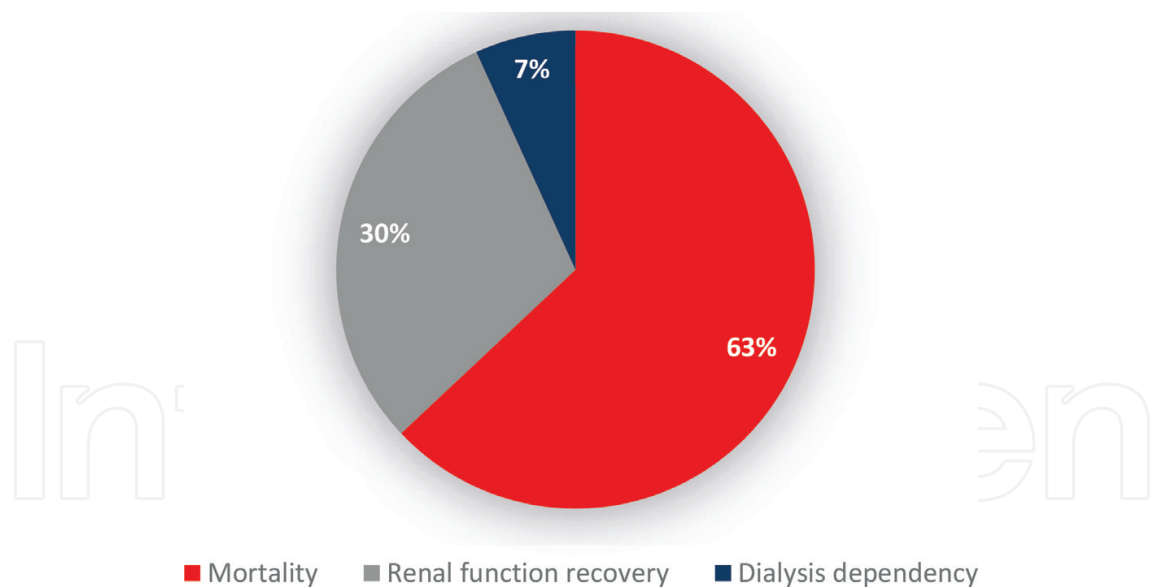


Figure 4. Inhospital outcomes.

costs, time on therapy, and mortality. The experience of a specialized CRRT service model such as RTS increases the net monetary benefit in emerging countries and invites other healthcare systems to challenge the adoption of high-quality service models.

5% discount			
	Intermittent	Continuous therapy	Difference
Total cost (COP)	IRRT	CRRT	
1 year	10,442,981,398	7,646,696,331	−2,796,285,067
5 years	26,847,707,264	15,079,774,140	−11,767,933,123
10 years	38,715,397,630	20,959,366,355	−17,756,031,275
Total QALY			
1 year	210	231	21.3
5 years	670	745	75.1
10 years	992	1103	111.0

Table 9. Base case results (Cohort 1.000).

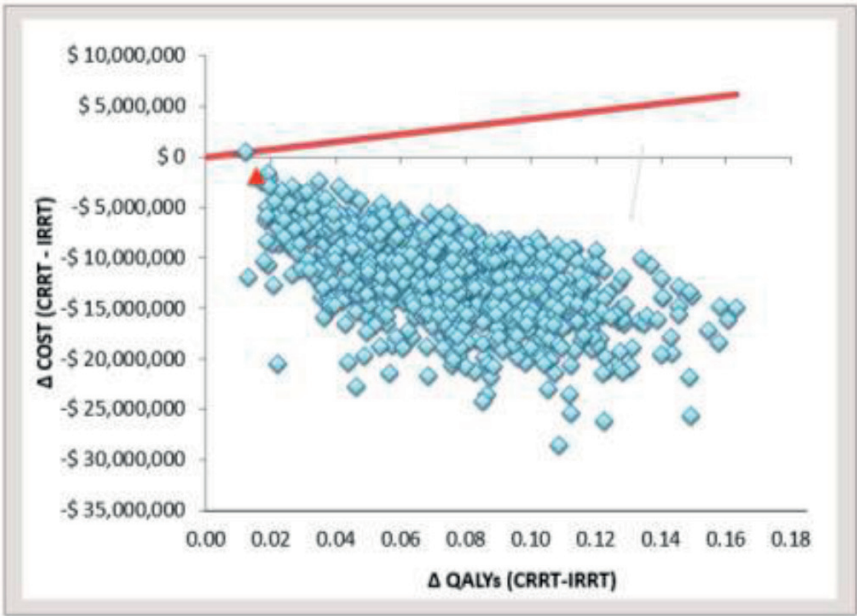


Figure 5. Probabilistic analysis.

5. Conclusion

In this chapter, we described the characteristics of our renal emergency team model and the rationale of a CRRT specialized team. Understanding how the alarm system works, being ready to act, carrying out timely interventions, developing a quality improvement program, and being able to have two-way learning between ICU and the nephrology team are part of the key aspects for success. From our experience, we showed the results of two centers of excellence where our model operates in Colombia, obtaining high clinical results, high-quality standards, and improvement in renal recovery. The population analyzed was critically ill, with high rates of multi-organ dysfunction and hemodynamic instability. The protocols used

allowed a good filter life and an optimal delivered therapy dose as per international recommendations.

Sepsis is still the disease most associated with acute kidney injury as well as postoperative conditions and cardiovascular failure. Severe metabolic acidosis, positive fluid balances, and the requirement for vasoactive support continue to be frequent conditions during the initiation of CRRT. Although azotemia is the second most frequent indication in our registry, it is moderate and usually involves some of the formerly mentioned factors. Absolute indications for starting dialysis are rare in our registry. The burden of severe acute kidney injury remains important, not only because of the consumption of hospital resources but also because of the long-term prognosis and the consequent dependence on dialysis. Providing an adequate renal care system in the hospital aligned with the renal recovery policies should be part of the interest and approach of all the stakeholders in the healthcare system. Decisions in health economics and care models in extracorporeal therapies should integrate these elements.

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Conflict of interest

Dr. Jorge Echeverri wrote this chapter while being the nephrology director of RTS Central Military Hospital. He is currently the global medical director for Acute Therapies at Baxter Healthcare Corporation.

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