

Intraoperative Renal Replacement Therapy: A Narrative Review

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Abstract

Renal replacement therapy has been a long-established practice in medical settings outside of nephrology departments, including critical care and coronary cardiac units. Notwithstanding the advances in the medical and technological domains, the intraoperative application of renal replacement treatment modalities remains constrained to specific surgical procedures (predominantly cardiac surgeries, major vascular operations, and liver transplantations) and a select group of patients. The present paper explores the extant literature on the topic, synthesizing the current evidence in a valuable manner.

Keywords: Renal replacement therapy; Hemodialysis; Intraoperative care.

Introduction

Acute kidney injury (AKI) significantly impacts a substantial proportion of patients in intensive care units (ICUs), with prevalence rates reported between 40% and 66%, and 14% to 20% of these individuals necessitating further renal replacement therapy (RRT) according to the Kidney Disease Improving Global Outcomes (KDIGO)¹⁻². Consequently, this has led to heightened interest and accumulation of evidence in this domain. However, considerable heterogeneity exists regarding the types of selected RRT, and the associated mortality outcomes related to the appropriate application of these therapies, which range from 37% to 65%³⁻⁴.

In contrast, intraoperative renal replacement therapy (IORRT) remains less extensively recognized. Initially introduced in 1978 during cardiopulmonary bypass (CPB) for aortic valve replacement in a 58-year-old male patient⁵, IORRT is now applicable in a variety of surgical contexts, albeit in select cases. The prevailing literature predominantly discusses the application of intraoperative haemodialysis (IOHD) during CPB and orthotopic liver transplantation (OLT).

The current review seeks to provide a succinct update on the available literature concerning this topic, alongside clear and practical information regarding the intraoperative advantages and limitations of each modality. In contrast to existing literature, this manuscript aspires to encompass a wider range of surgical procedures, including cardiac, liver, and other interventions.

Literature search

A literature search was performed through PubMed® (National Library of Medicine U.S.A) database from 1974 to October 2025. Robust searches in EMBASE (Elsevier® Publ.) and Cochrane Library were also conducted, yet due to the duplication of the results, only PubMed results were selected. Search terms included 'intraoperative

dialysis' AND/OR 'renal replacement during surgery'. A total of 1486 articles were screened by three authors for eligibility, of which only 49 were included for further evaluation. Due to present heterogeneity of the articles such as different surgical procedures, different modalities, prevalence of case reports and case series), a narrative review approach was used to evaluate the remaining papers. SANRA tool was used during the process of writing for revision of the manuscript⁶. The focus of the current paper is IORRT, a separate note is also made about intraoperative use of other blood purification methods such as hemadsorption (HA) and plasmapheresis (Table 1)

Table 1: Extracorporeal blood purification techniques according to the 2024 Nomenclature standardisation conference⁷. Red: whole blood therapies, Green: albumin-based therapies, yellow: plasma exchange therapies, tan: plasma adsorption therapies. Terms to avoid: EDD, extended daily dialysis; IRRT, intermittent renal replacement therapy; LDL, low-density lipoprotein; SCUF, slow continuous ultrafiltration; SLED, sustained/slow low- efficiency daily dialysis.

Continuous veno-venous hemofiltration (CVVH)	Molecular adsorbent recirculating system (MARS)
Continuous veno-venous haemodialysis (CVVHD)	Single-pass albumin dialysis (SPAD)
Continuous veno-venous hemodiafiltration (CVVHDF)	Therapeutic plasma exchange (TPE)
Prolonged intermittent renal replacement therapy (PIRRT), older terms: SLED, EDD	Double filtration plasmapheresis (DFPP)
Isolated ultrafiltration, older term: SCUF	Plasma adsorption filtration (PAF)
Intermittent haemodialysis (IHD), older term: IRRT	Coupled plasma filtration and adsorption (CPFA)
Extracorporeal CO2 removal (ECCOR2)	Plasma filtration adsorption dialysis (PFAD)
Extracorporeal membrane oxygenation (ECMO)	Double plasma filtration molecular adsorption system (DPMAS)
Hemadsorption (HA), older term: hemoperfusion	Heparin-induced extracorporeal LDL precipitation (HELP)

The review does not include intraoperative use of extracorporeal membrane oxygenation (ECMO), extracorporeal ventricular assist device and other extracorporeal organ support devices indicated in the Table 2.

Table 2: Artificial liver systems.⁸

Molecular adsorbent recirculating system (MARS) with or without plasma exchange	Open Albumin Dialysis (OPAL)	Porcine hepatocytes in a membrane cartridge to perfuse patient plasma -HepatAssist® (Circe Biomedical, Lexington, MA)
Fractionated Plasma Separation and Adsorption (FPSA) – Prometheus® system (Fresenius Medical Care, Bad Homburg, Germany)	Single pass albumin dialysis (SPAD)	Sorbent-based dialytic therapy - Biologic-DT (detoxification) and DTPF (detoxification/purification)® (Hemocleanse, Lafayette, IN)
Extracorporeal human hepatic cell-based liver treatment (ELAD)	Advanced organ support system (ADVOS)	Liver Dialysis Device -DIALIVE®

Finally, the present paper does not include the newer artificial and man-made kidneys that have been developed to overcome the limitation of haemodialysis- portable or implantable-, such as the renal tubule assist device (RAD), the human nephron filter (HNF) and the bioartificial renal epithelial cell system (BRECS) as well as the automatic wearable artificial kidney (AWAK)⁹.

Intraoperative renal replacement therapy during open cardiac surgery

The incidence of acute kidney injury associated with cardiac surgery is reported in 20-50% of cases¹⁰. In open cardiac surgery IORRT is applied during CPB in patients with end stage renal disease to manage acute hyperkalaemia or fluid imbalance. Close communication among anaesthesiologists, nephrologists and surgeons is required. The time of IORRT application varies compared to the initiation of CPB¹¹⁻¹³. Preoperative and postoperative RRT also can be applied as a part of the management protocol¹⁴⁻¹⁷. Along with fluid management, removal of mediators has also been studied, yet the studies document controversial results. It has been found that IORRT has no effect on the postoperative levels of interleukin IL-6 and IL-10¹⁸. Nevertheless, during on-pump surgery in patients with renal impairment, removal of mediators displayed postoperative nephroprotective effect¹⁹. More detailed studies on the IORRT mode via measurement of renal PO₂ showed an advantage of combined ultrafiltration over other methods²⁰. A combination of postoperative continuous hemodiafiltration (CHDF) with IOHD provided a similar management protocol for dialysis patients compared to patients with normal renal function²¹. A later meta-analysis confirmed that ultrafiltration in cardiac surgery is not associated with AKI incidence and could be safely used in patients with chronic kidney disease²². Novel RRT modes, such as gravity drainage hemodiafiltration (GDHF) displayed even more promising results compared to conventional ultrafiltration (CUF). GHDF can be used intra- or postoperatively. GHDF employs a high-flux dialyzer to process blood where excess fluid is removed by convection and replacement fluid is returned directly into patient's bloodstream²³. Another approach, termed zero-balance ultrafiltration (ZBUF), is an intraoperative-only IORRT technique that utilizes an existing connection on the CPB circuit alongside a parallel-placed hemoconcentrator. In this method, replacement fluid is infused into the CPB circuit²⁴. While some studies debate the application of IORRT during open cardiac surgery in patients with non-dialysis-dependent CKD, others have observed reduced urine output when ZBUF is employed²⁵. This procedure works by removing plasma water while concurrently replacing it with crystalloid fluid. This can help maintain a stable intravascular volume, rather than inducing a net volume reduction that would typically trigger increased urination. As such, it functions as a substitution method, often contributing to lower urine production

Technically, when RRT is used during CPB, a special filter is connected to the bypass machine with its inlet after the arterial pump, before the oxygenator and its outlet connected to the venous recirculation. In addition, a special port located on the filter for a drainage bag should be also connected. Flow adjustments maintain patient perfusion, as the filtration process diverts 500 ml/min of flow: if target flow is 4.2 l/min, then the pump flow is increased to 4.7 l/min. Filtration rate is maintained at 30-50 mL/min and continues for the duration of reperfusion phase or beyond. Thus, if the filtration rate is about 40mL/min and the reperfusion lasts 22 minutes, multiplying these values results in removal of 900 mL of fluid, thereby increasing haematocrit and restoring fluid overload²⁶. Excessive fluid removal increases AKI risk. This is the reason why many centres prefer ZBUF: a study including 1,641 cardiac surgery patients suggested that CUF volume more than 32.9 mL/kg raised postoperative AKI risk by 60%²⁷. When crystalloid cardioplegia is used, the total extra volume exceeds 4l:2l of prime and 2l of cardioplegic solution, as well as fluids given during surgery^{25, 27}. This suggests that ultrafiltration is specially needed during these procedures. Table 3 describes the studies that applied IORRT during cardiac surgeries.

Table 3: Studies including intraoperative renal replacement therapy during cardiac surgery. Pt, patient; AV, aortic valve; Ht, haematocrit, Cre, creatinine, HF, heart failure, avg, average, GHDF, gravity hemodiafiltration, UF, ultrafiltration, CKD, chronic kidney disease, HD, Hemodialysis, ZBUF, zero-balance ultrafiltration (ZBUF), CUF, conventional ultrafiltration, RBC, red blood cell, UO, urine output, AKI, acute kidney injury; CHDF, continuous hemodiafiltration, CRF, chronic renal failure; CVP, central venous pressure; CVVH, continuous veno-venous hemofiltration, UFH, unfractionated heparin, OHT, orthotopic heart transplantation; HF, hemofiltration.

Study	Population	Indication	Outcome
Soffer et al.⁵ 1979 Case report	55 y. o. female with CRF, hemodialysis- dependent, AV endocarditis, CHF	Intra-op hemodialysis: hyperkalemia and fluid balance, post-op anticoagulation regulation	K ⁺ 3.2–4.3 mEq/L, Ht 29–30%, stable post-op hemodynamics stable (BP 120/60 mm Hg, wedge pressure 11 mm Hg)

Kandil et al. ²³ (2021) Meta-analysis	8,005 Pts undergoing CPB: 2,165 UF vs. 5,840 non-UF groups	Intraoperative ultrafiltration (UF): regulate fluid balance, inflammatory mediators, Ht, hyperkalemia	Ultrafiltration did not increase AKI incidence between UF and non-UF groups: Risk Ratio (RR) = 0.90, 95% CI: 0.64–1.27, p = 0.55
Darup et al. ¹¹ (1979) Case series	N=10, cardiac surgery Pts with reduced renal function undergo CPB	Hemofiltration: fluid balance in Pts with renal insufficiency, regulation of hyperkalemia and hemodilution	10 cases: <ul style="list-style-type: none"> • UF average ~3.4 L; hemodilution correction Hct ~23% → 31%; total protein 5.8→5.4 g/dL • Case 1: Dialysis-dependent, (AVR): 11.5 L UF, ↓ in BUN and creatinine (21 vs 20 mg/dL; 4.3 vs. 3.6 mg/dL respectively), recovery w/o complications • Case 2, 3: Pre-op AKI (n=2): normalized renal function Pt 2 UF=9L, Pt 3 UF=1.5 L; Pt 2 died on the 29th day (cerebral damage); Pt 3 died on the 8th day (infection). <ul style="list-style-type: none"> • Case 4, 5, 6: Pre-op CRF w/ low output (n=3): Pt 4 UF=1.8L, Pt 5 UF=2.6L, Pt 6=1.5L regulation of intra-op fluid balance, post-op normalized renal function; recovery • Case 7, 8, 9, 10: Oliguria + intra-op hyperhydration (n=4): UF=1.8L, 2.5L, 1.1 L, 1.1 L respectively, fluid balance regulation; two discharged with normalized renal function, two deaths due to cardiac origin
Burra et al. ²¹ (2020) Prospective comparative study	16 Pts with Conventional and 16 Pts with Combined UF = conventional (CUF) + modified UF (MUF)	Regulation of fluid balance, hemodilution and removal of inflammatory mediators	CUF + MUF is superior in terms of renoprotection when compared to CUF only: better urinary PO ₂ in 30 min, 3h, 6 h => better renal medullary oxygenation; reduced post-op Cre rise 1.25 ± 0.14 vs 1.57 ± 0.16 (CUF), ↑ intra-op UO in combined UF group 2015.6 mL vs. 1319.1 mL (p = 0.005), fewer diuretics use, shorter ICU stay

Kamohara et al.²² (2007) Retrospective study	22 dialysis-dependent Pts undergoing CPB; 30 retrospective Pts in a control group with normal renal function undergoing CPB	Perioperative continuous hemodiafiltration (CHDF) combined with intraoperative hemodialysis (IHD) in dialysis-dependent Pts: fluid overload, electrolyte imbalance including hyperkalemia, metabolic acidosis, azotemia	No vascular access-related complications + good hemodynamic stability during CHDF were observed in dialysis-dependent who underwent IHD + CHDF. Better potassium control in dialysis patients compared ($p = 0.09$) to a significant increase in non-dialysis patients ($p = 0.004$). Good fluid balance in dialysis Pts groups, no difference in post-op bleeding. Longer ICU stay and 2 deaths compared to 0 deaths in control groups
Hakim et al.¹³ (1985) Prospective study	n = 26 Pts with impaired renal function and congestive HF	Intraoperative hemodialysis and hemofiltration in Pts with impaired renal function to regulate excessive fluid retention, hemodilution, electrolyte imbalance	For chronic renal failure (n=5) were applied intra-op HD/HF: <ul style="list-style-type: none"> • Post-op dialysis was delayed until day 3/4, normalized potassium level (mean ~4.5 mmol/L post-op), no immediate post-op fluid overload. ↓post-op Ureamean 24.3 (pre-op 31 mmol/L). For secondary renal impairment patients (n=16): <ul style="list-style-type: none"> • Haemodialysis (n=3): Fluidavg removed ~2.1 L; Haemofiltration (n=13): ultrafiltrateavg ~6.9 L; Potassium remained stable (mean ~4.4 mmol/L), Urea ↓ or stabilized post-op. 1 death - systemic sepsis/respiratory failure, another death due to cardiac origin For fluid overload in CHF patients (n=4): • Haemofiltration done at the end of CPB (10–20 min), Fluidavg removed: ~2.2 L
Ohtsubo et al.¹⁹ (2023) Retrospective study	41 dialysis-dependent patients undergoing cardiac surgery: 21 received GHDF, 20 received DUF	Effective removal of potassium and uremic toxins; postoperative outcomes improvement	Better removal of potassium, urea, and creatinine in GHDF vs. DUF. Higher P/F ratio, shorter mechanical ventilation time (8.7 vs 17.9 hours), lower inotrope use intraoperatively

**Malligigan¹⁴
(1985)**

Prospective
study

N = 72 cardiac
surgical Pts; 55 Pts
had UF at the
beginning of CPB.
17 Pts had UF
initiated during
CPB

Removal of excess
body water in Pts with
clinical evidence of excess
body water in preoperative
period, excessive CPB
reservoir volume, low
hematocrit (<18%),
prolonged bypass time
(>2h)

Intraoperative (start of CPB, 55
patients):

- Ultrafiltrate mean – 2,914 ± 1,662
mL
- Fluid mean balance: –219 ± 1,298
mL

Intraoperative (during CPB, 17
patients):

- Ultrafiltrate mean: 1,450 ± 898 mL
- Fluid mean balance: +1,296 ±
2,161 mL

**Inoue et
al.²⁵ (2023)**

Retrospective
cohort study

61 Pts with
stage G4/G5 non-
dialysis-dependent
CKD: IHD group
(n=28): Received
intra-op HD
Non-IHD group
(n=33): Did not
receive intra-op
HD

IHD was scheduled by
nephrologist-surgeon
consultation for patients at
high risk of post-op renal
complications to manage
fluid overload, electrolyte
imbalance, acidosis

90-day mortality:

- IHD – 7.1%, non-IHD – 0% ($p = 0.482$)

Postoperative initiation of RRT
within 30 days:

- IHD – 17.9%, non-IHD – 30.3%
($p = 0.373$)

- ↓ in CKD G4 patients with IHD
(0% vs. 25%, $p = 0.032$)

Secondary Outcomes

- No difference in hospital stay,
intubation time. Post-op Hb is ↑
in IHD group ($p = 0.005$)

Stammers et al.²⁶ (2021) Retrospective registry analysis	98,953 adult cardiac surgery Pts: • ZBUF group • non-ZBUF group	Zero-Balance Ultrafiltration is used for: ↓ circulating inflammatory mediators intra-op, correcting electrolyte imbalances, fluid balance management, improving post-op outcomes	ZBUF was associated with ↓ intraoperative urine output: • Median: 0.94 mL/kg/h in ZBUF group vs. 1.12 mL/kg/h in non-ZBUF group (p < .001) • ZBUF Pts received greater volumes of asanguineous fluids and more RBC transfusions • ZBUF Pts had association with ↑ use of CUF • Pts with higher BMI showed greater reductions in urine output ↑weight SD =>↓ in UO by 0.381 mL/kg/h Reduced UO during CPB may be a predictor of AKI
Nyui et al.¹⁶ (1990) Case report	64 y.o. male, dialysis-dependent	Management of fluid overload, hyperkalaemia	Intra-op HD + Extra-corporeal ultrafiltration method (ECUM) used during CPB, Postoperative: continuous ambulatory peritoneal dialysis (CAPD),
Kubota et al.¹⁷ (1997) Case series	43-year-old dependent on hemodialysis; 73-year-old man with CRF	CHDF during and after CPB for fluid, electrolyte, and metabolite management	Stable hemodynamics, serum potassium, urea, and creatinine were well controlled, no bleeding with nafamostat mesilate as anticoagulant; transferred to ICU successfully
Fukomoto et al.³² (2006) Retrospective study	33 hemodialysis-dependent Pts undergoing cardiac surgeries including off pump CABG (n=19)	Preservation of fluid and electrolyte balance, prevention of post-op bleeding in hemodialysis-dependent Pts, prevention of hemodilution	Lowered post-op incidence of morbidities and mortality in chronic dialysis Pts; Ht 30% - 35%, CVP 3 - 5 mmHg, serum potassium concentration 3.0 - 3.5 mEq/L.
Muslesh et al.¹⁸ (2009) Prospective randomized study	79 Pts undergoing CABG with CPB randomized into groups with and without HF	To evaluate the effect of hemofiltration during CPB on renal function and inflammation via IL6 and IL10 levels measurement	Hemofiltration did not reduce IL6 or IL10 and did not show renal protective effect post-op. Increased IL6 (>100 pg/ml) and IL10 (>30 pg/ml) 12 h after surgery were associated with AKI in post-op period

Roscitano et al.²⁰ (2009) Prospective study	124 Pts with moderate renal dysfunction (GFR 30–60 mL/min) undergoing CABG	Assessment of renoprotective effect of continuous veno-venous hemofiltration (CVVH) on postoperative acute renal failure (ARF)	Intraoperative CVVH and off-pump CABG were protective against ARF compared to non-CVVH on-pump CABG group
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Peritoneal dialysis (PD) is not used intraoperatively due to possible pleuro-peritoneal leaks, decreased splanchnic perfusion, increased transdiaphragmatic pressures and coordination problems between PD and operating room teams. PD has been used postoperatively, but most centres do not rely on this method for at least 2-4 weeks postoperatively. However, the approach of switching from PD to HD and then back to PD is currently under debate²⁸⁻²⁹. Considering off-pump procedures, vascular access is achieved with insertion of large (12-French) double lumen catheter in femoral vein³⁰⁻³¹.

Finally, a note regarding hemadsorption (HA), another method of blood purification, that has shown significant cytokine reduction intraoperatively and improved outcomes, highlighting difference between renal replacement and adsorption-based extracorporeal therapies. HA employs separate filters that can be integrated into other extracorporeal circuits such as CPB, CRRT, ECMO, and used as an add-on therapy to haemodialysis to increase the removal of specific toxins. Available literature documents application of intraoperative HA in surgeries regarding infective endocarditis, complex elective cardiothoracic surgeries with prolonged CPB time, aortic surgeries, left ventricular assist device implantation (LVAD) and heart transplantation³². Recently, intraoperative HA has been shown to mitigate renal function and inflammation in coronary artery bypass grafting (CABG) patients with CKD and reduce severe perioperative bleeding complications³³⁻³⁴.

Intraoperative renal replacement therapy during liver transplantation (LTx)

Although IORRT application during LTx and retransplantation (LRTx) started relatively soon after its use in cardiac surgery (in the early 90s)³⁵⁻³⁶, its further application is limited to selected cases. Back then, surgical techniques varied from clamping inferior vena cava with or without external veno-venous bypass (VvB) to the “piggy-pack” technique, yet haemodialysis whether conventional or high volume, showed favourable results in LTx, LRTx or combined kidney-liver transplantations (CKLTx)³⁷. In CKLTx, selection of ultrafiltration or haemodialysis or a combination of both, was also depended on the surgical technique used³⁸. Generally, continuous arterio-venous haemodialysis (CAVHD) was preferred. Vascular access was obtained via femoral artery and internal jugular vein, which allowed a maximum ultrafiltrate volume of 2 L/h depending on patient’s haemodynamics³⁹⁻⁴⁰. Later, continuous veno-venous hemofiltration (CVVHF) was also applied: in cases with VvB, axillary and femoral veins were cannulated. It was also possible to perform intraoperative plasmapheresis when prothrombin time was greater than 20 seconds in the presence of volume overload⁴¹. In a large series of 41 cases considering LTx without VvB, continuous veno-venous hemodiafiltration (CVVHDF) was selected. A standard double lumen catheter for RRT was inserted (neck vein were preferred) and settings included Qb equal to 120-150 mL/min, and dialysate and replacement ranging 1-1.5 L/h. Coagulation approach was not generally applied: regional citrate coagulation was preferred in 5 cases, while in 4 other scenarios prostacyclin infusion of 4 ng/kg/min was implemented. Citrate coagulation can be used safely, yet close monitoring of calcium level is needed, especially during anhepatic phase⁴³⁻⁴⁴. In the absence of anticoagulation, clotting of the extracorporeal system may occur, which can be resolved by the circuit replacement. Replacement of dialysate could be also needed: starting with a “3K/3Ca” (i.e. 3mEq/L potassium and 3 mEq/L calcium) dialysate and close potassium monitoring, replacement to 1K dialysate during cross clamping release and then back substitution to 3K could be required. CVVHDF without fluid removal has been successfully applied for management of severe lactic acidosis during orthotopic LTx (OLTx) even in a patient with normal preoperative renal function⁴⁵. Combination of pre- and postoperative HD performed in close proximity (within 90 min) to the procedure, together with intraoperative CVVHDF, have been successfully applied in cases with primary hyperoxaluria type 1⁴⁶. Nevertheless, careful planning is essential: in a large = retrospective evaluation of 500 OLTx, recipients of emergent IORRT had more intraoperative complications, such as arrhythmias, coagulopathy, postreperfusion syndrome), higher postoperative mortality and morbidity⁴⁷. Thus, a model was proposed to identify patients who may benefit from IORRT. The model scores various parameters – bilirubin, cold ischemia time, BMI, pretransplant blood K⁺ level, pretransplant vasopressors administration and CRRT, re-transplantation and donor type - both for End stage renal disease (ESRD) and acute liver failure (ALF). An ESLD score greater than 42 and an ALF score greater than 38 identify a recipient at high risk of requiring intraoperative RRT (IORRT), and should trigger the IORRT utilization at the start of OLTx⁴⁸.

Later, a pilot open-labelled randomised trial (INCEPTION) found no difference in one-year survival in patients, with MELD (Model for End-Stage Liver Disease) score greater than 25 and estimated creatinine clearance less than 60 mL/min/1.76 m² receiving IORRT compared to standard of care⁴⁹. Even in series with high MELD score (>31), IORTT was shown to be safe with low post reperfusion syndrome (13.9%) and dialysis circuit clotting (9.1%)⁵⁰. However, in cases of CKLTx, the same team reported a high incidence of circuit clotting (50%)⁵¹. Portable dialysis systems have also been utilized successfully during LTx⁵². In cases of CKLTx, multiple vascular catheters may be needed: there are reports applying a “double-stick” in the left jugular vein (placing a 3 or 4~ lumen central venous catheter (CVC) and a pulmonary artery catheter), a CVC for IORRT in the right subclavian vein, along with the access to the left femoral and the left radial arteries for monitoring and blood sampling. The use of IORRT may start at the beginning of liver transplantation and then continue or stop during renal transplantation⁵³. Recently, the use of supra- and infradiaphragmatic catheters (two dialysis catheters: one in the femoral vein and one in the subclavian vein) was applied as a method of limited veno-venous bypass (the femoral vein to a dialysis machine and then to the subclavian vein). -This allows right ventricular offloading and haemodialysis application throughout the procedure for a patient with a concomitant anuric hepatorenal syndrome and pulmonary hypertension with right ventricular dysfunction⁵². (Table 4)

Table 4: Studies including intraoperative renal replacement therapy during liver surgery Pts, patients; POD, post-operative day; LTx, liver transplantation; CAVHD, continuous arteriovenous hemodialysis; CVVHF, continuous veno-venous hemofiltration; CVVH, continuous veno-venous hemofiltration, CAVH, arterial-venous hemofiltration; AKI, acute kidney injury, HD, hemodialysis; UF, ultrafiltration; HDF, hemodiafiltration; CVP, central venous pressure; CRRT, continuous renal replacement therapy; ESLD, end-stage liver disease.

Study	Population	Indication	Outcome
Salord et al.³⁶ (1991) Case series	Pt 1, 37 y.o. male, on the POD 6 and Pt 2, 47 y.o. male, on POD 2 after LTx => hepatic failure	Emergent hepatic LRTx => CAVHD: before and during hepatic LRTx for lactic acidosis, hyperkalemia, uremia, fluid management	Intra-op duration: 11–12 hours (maintenance of pH, potassium, and lactate, no clotting, no neurological complications: Pt 1: IRRT = 11 hours, UF = 855 ml/h, awoke in 6 hours post-op Pt 2: IRRT = 12 h, UF = 740ml/h, awoke in 8 hours post-op
Bellomo et al.³⁷ (1993) Case report	51 y.o. male, with pulmonary edema and AKI undergoing LTx	CVVHF for fluid removal, replacement for renal function	no paper to extract results, only first page w/o outcomes
Sevillano et al.³⁸ (1997) Retrospective study	22 Pts with advanced liver disease: 6 LTx /5 LRTx/11 CKLTx	11 Pts: Acute renal failure 11 Pts: Chronic Kidney disease	7 Pts: HD 4 Pts: UF 7 Pts : HD and UF. 8 Pts partial IVC clamping, 8 Pts no clamping, 6 Pts with total IVC clamping

Perez-Cerda et al.³⁹ (1998) Retrospective study	11 Pts with end-stage hepatic disease and chronic kidney failure.	CKLTx: 4 Pts: HD 1 Pt: UF 3Pt: HDF	<ul style="list-style-type: none"> - Survival: 72.7% = 8/11 Pts - HD and/or UF possible and beneficial during combined liver-kidney Tx. - Partial IVC clamping reduced ultrafiltration needs. - 1 death in the 1st month, 2 deaths during follow-up. - No ↑ in perioperative mortality with preserved renal function during liver Tx
Acosta et al.⁴⁰ (2002) Retrospective study	9 cirrhotic Pts undergoing emergency LRTx within 48 hours	CAVHD for anuric patients to control hemodynamics and metabolic parameters	CAVHD application led to mean fluid removal of 5.8 ± 2.2 L without hemodynamic disturbances. Better MAP, K, Na, HCO ₃ ⁻ ; cardiac index, systemic vascular resistance, P/F were achieved compared to preoperative values.
Blackwell et al.⁴¹ (2003) Retrospective study	21 patients with renal insufficiency undergoing LTx had IRRT	K \geq 5 mEq, ↑CVP in the setting of renal insufficiency/ or ↓ renal function, ↑ O ₂ demand, or pulmonary edema: intra-op plasmapheresis (n=3), CVVH (n=7), dialysis (n=8), and intraoperative dialysis with fluid removal (n=3)	Effective reduction of K level, significant decrease in CVP; improvement in Prothrombin time in patients undergoing plasmapheresis (n=3)
Townsend et al.⁴² (2009) Retrospective study	41 Pts with pre-op AKI undergoing LTx	intra-op CRRT: fluid management and electrolyte balance	Even/negative fluid balance by the end of the surgery; intra-op circuit thrombosis – 40%; one month survival – 97.6%, one year survival – 75.6%, Renal recovery – 100%by year one; median GFR - 54.7 mL/minute/m ² with 62.1% having CKD (eGFR <60).
El Kouny et al.⁵² (2016) case series	3 Pts undergoing CKLTx	CVVHD for intravascular volume maintenance: including venous outflow of the hepatic allograft and diuresis of the renal allograft; management of coagulopathy	Stable intraoperative and post-operative courses for all 3 patients; two Pts had a good graft function, while one Pt required continued dialysis, but was successfully discharged and continued outpatient dialysis

Winrow et al⁴³ (2009) Case report	a 40 y.o. female with fulminant liver failure and AKI	Intraoperative sustained low-efficiency dialysis with citrate dialysate for management of fluid excess, metabolic acidosis, and electrolyte abnormalities	Stable intra-op hemodynamics, ABGs parameters, absent citrate toxicity, on POD 17 dialysis was terminated, at 21 st month of follow-up transplanted allograft functioned normally
Vitin et al⁴⁵ (2010) Case report	A 53 y.o. male, ESLD, with normal kidney function	CVVHD for severe uncompensated lactic acidosis during pre-anhepatic stage of LTx	Effective removal of lactate and hemodynamic stability during liver Tx; lactate returned to normal intra-op; improving post-op course, POD 4 the patient was extubated
Sedra et al.⁴⁴ (2011) Narrative review	140 Pts undergoing LTx with impaired kidney function	Intra-op hemodialysis (≥ 200 ml/h) to solve metabolic acidosis, hyperkalemia; fluid management particularly anuric Pts; warm-up of introduced fluids	- Zero intraoperative mortality and zero 48-hour postoperative mortality reported in preliminary data. - IHD improved management of acidosis, hyperkalemia, and volume overload, enhancing intraoperative stability.
Karvellas et al.⁴⁸ (2019) Pilot randomized study	15 Pts undergoing LTx were allocated to intra-op CRRT, while other 17 Pts were randomized to the standard of care group	Preoperatively, Pts were randomized to receive either intra-op CRRT or standard of care. Later 7 patients from standard of care group were transferred to CRRT group due to 1) high CVP (n = 4); 2) abdominal distension (n = 1); 3) massive transfusion (n = 1); 4) hyperkalemia (n = 1).	No adverse events related to catheter or clotting during intra-op CRRT; survival at the 1 st year in Pts receiving intra-op CRRT was n = 10/14, while for the group not receiving CRRT n = 14/15 (RR 0.77; 95% CI, 0.54 to 1.1). No differences were observed in the medians of serum creatinine levels between the groups at the 1 st year follow-up. The trial was executable and safe, inferring the need for a larger trial.
Kościelska et al.⁵⁰ (2020) Retrospective study	88 Pts undergoing CKLTx	Extent of renal insufficiency, creatinine ≥ 2 mg/dL, dependance on RRT before liver Tx; emergent intra-op RRT due to: \downarrow urine output, refractory metabolic acidosis, hyperkalemia	Decrease in CVP, mean arterial pH 7.2 ± 0.12 , potassium 4.04 ± 0.95 mmol/L. Postreperfusion syndrome occurred in 11 Pts, which is lower than expected rate; clotting of the circuit – 9.1% of cases, no other adverse effects => intra-op HD inferred to be safe and executable.
Kościelska et al.⁵¹ (2022)	10 Pts with End-Stage Kidney	HD dependent and with metabolic disturbances – risk	6 Pts, receiving intra-op HD had better lactate and HCO ₃ ⁻ level compared to 4 Pts with no intra-op
Retrospective study	Disease undergoing CKLTx	due to prolonged surgery time	HD. Hyperkalemia and postperfusion syndrome were not observed in both groups. 1 death in the group with intra-op HD, 2 deaths in the group without intra-op HD within year 1. 50% incidence of circuit clotting in the groups with intra-op HD. Upon discharge all patients were weaned from HD.

McGinn et al⁵³ (2024) Case report	54 y.o. female undergoing LTx with acute renal insufficiency, dialysis dependent, with right ventricular dysfunction	Fluid management during anuric state, maintain electrolyte and acid-base balance	Successful LTx, fluid removal (4.5 L), absent electrolytes derangements, length of stay in ICU – 33 days, dialysis independent in 3 months post-op
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Intraoperative renal replacement therapy during other procedure.

IORRT has also been used during various other surgeries, yet the literature available to date (till October,2025) includes only case reports in selected patients. Vascular surgeries is an example: haemodialysis in an extraanatomical bypass is successfully used during the acute occlusion of the descending thoracic aorta and acute abdominal aortic obstruction⁵³⁻⁵⁴. High volume CVVHD has also been applied in a patient with Leriche's syndrome (an acute aortoiliac occlusion) for management of hyperkalaemia and metabolic acidosis⁵⁵. In cases of myoneuropathic metabolic syndrome due to acute limb ischemia, CVVHDF with selective drainage from the clamped femoral vein of ischemic limb and return of the processed blood into the contralateral femoral vein, has been utilised to optimise the removal of myolysis metabolites intraoperatively⁵⁶.

There is also a documentation regarding a patient diagnosed with multiple comorbidities (peripheral arterial disease stage IV, type III Leriche syndrome, abdominal aorta thrombosis, superior and inferior mesenteric artery occlusion, celiac trunk occlusion, left lower limb critical ischemia and right lower limb chronic ischemia, arterial ulcer on the left anterior calf, coronary heart disease, non-insulin dependent type 2 diabetes mellitus and renal impairment) in whom combined general-epidural anaesthesia and simultaneous CVVH (Qb-180ml/min, filtration rate 25ml/kg/h, ultrafiltration 50ml/h, dialysis 800ml/h, replacement pre-filter 160ml/h, post-filter 640ml, coagulation heparin targeting aPTT 50-70 sec) were effectively used⁵⁷. Use of IORRT has also been applied to a simultaneous revascularization for acute myocardial infarction and acute limb ischemia (external iliac artery occlusion) in a case-customised operation room⁵⁸. Recently, CRRT with cytokine-absorbing haemofilter was evaluated in mitigation of REBOA (resuscitative endovascular balloon occlusion of the aorta)- related ischemia-reperfusion injury in animals models⁵⁹.

IORRT has also been successfully applied in cases of gastroenterological surgeries and even in emergent laparotomy in patients with preexisting ESRD⁶⁰⁻⁶¹. In such cases, the use of existing arteriovenous fistula is also a feasible option⁶¹.

Finally, there are reports of IORRT application during selective and emergent neurosurgeries. In a case with a brain tumour resection, CVVHDF without coagulation was performed during the procedure which was carried out in the lateral position⁶². Another example documents IORRT application during intracerebral hematoma evacuation in order to manage severe hyperkalemia⁶³.

Conclusion

At present, there is no conclusive evidence to support the routine use of IORRT, nor are there established guidelines for its implementation. Its application is further complicated by various technical, economic, and logistical challenges. However, IORRT remains a viable option in specific cases that demand precise metabolic and fluid management. Existing studies highlight its frequent significance in achieving successful patient outcomes. Even so, it is imperative to carefully select cases and conduct a thorough cost-benefit analysis before proceeding. Most contraindications to IORRT are relative and typically linked to patients' comorbidities. Therefore, a multidisciplinary approach, meticulous planning, and seamless communication among team members are vital to ensuring success. As global data on IORRT continues to grow, future research will likely provide greater clarity on its role in perioperative care.

Disclosure

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