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Original Article
Acute Kidney Injury

Predictors of post-hospitalization recovery of renal function among patients with acute kidney injury requiring dialysis

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Abstract
Introduction: Acute kidney injury (AKI) requiring dialysis complicates 1% of all hospital admissions, and up to 30% of survivors will still require dialysis at hospital discharge. There is a paucity of data to describe the postdischarge outcomes or to guide evidence-based dialysis management of this vulnerable population.

Methods: Single-center, retrospective analysis of 100 consecutive patients with AKI who survived to hospital discharge and required outpatient dialysis. Data collection included baseline characteristics, hospitalization characteristics, and outpatient dialysis treatment variables. Primary outcome was dialysis independence 90 days after discharge.

Findings: Overall, 43% of patients recovered adequate renal function to discontinue dialysis, with the majority recovering within 30 days post discharge. Worse baseline renal function was associated with lower likelihood of renal recovery. In the first week postdischarge, patients with subsequent nonrecovery of renal function had greater net fluid removal (5.3 vs. 4.1 L, $P = 0.037$), higher ultrafiltration rates (6.0 vs. 4.7 mL/kg/h, $P = 0.041$) and more frequent intradialytic hypotension (24.6% vs. 9.3% with 3 or more episodes, $P = 0.049$) compared to patients that later recovered.

Discussion: A significant proportion of AKI survivors will recover renal function following discharge. Outpatient intradialytic factors may influence subsequent renal function recovery.

Key words: Acute kidney injury, renal function recovery, outpatient dialysis

INTRODUCTION

Acute kidney injury requiring initiation of dialysis (AKI-D) occurs in approximately 1% to 2% of hospitalized patients and 5% to 7% of critically ill patients, and is associated with hospital mortality rates approaching 50%.[1–3] Among survivors, 10% to 30% of patients will remain dialysis-dependent at the time of hospital discharge.[3–5] Recent studies suggest that the incidence of AKI-D is rising but survival may be improving,[6,7] and therefore increasing numbers of AKI patients will require outpatient dialysis.

AKI patients requiring outpatient dialysis are a vulnerable population who remain at substantial risk for complications, yet few studies have focused on this group. However, it is clear that a significant proportion of AKI-D patients can recover renal function even after discharge, with rates of dialysis-independence ranging from 20% to 60%.[4] The reason for the variability in recovery rates is uncertain, and may in part be related to differences

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between study populations in nonmodifiable factors such as age and comorbidities, most notably preexisting chronic kidney disease (CKD).[8] However, the role of potentially modifiable factors, including dialysis prescription, has not been extensively explored. Most studies examining predictors of renal recovery have focused on either nonmodifiable factors or inpatient treatment factors.[1,9,10] As a result, there is a lack of evidence-basis and no guidelines for how to optimize outpatient management of AKI patients to best promote renal recovery and dialysis-independence.[4,11]

Recent studies have provided important insight into current care practices for the high-risk population of patients with AKI requiring dialysis at hospital discharge.[12,13] These studies have helped characterize recovery patterns and identified patient factors that may be predictive of renal recovery. At our medical center, it is routine practice for patients with AKI requiring dialysis at discharge to return to the hospital-based dialysis center for outpatient dialysis until either they experience renal function recovery or are deemed to have end-stage renal disease (ESRD). The objective of this study was to describe both patient and outpatient treatment factors associated with renal recovery in this vulnerable population.

MATERIALS AND METHODS

Design and setting

We performed a single-center, retrospective study of adult patients admitted to the University of Michigan Health System (UMHS) from January 1, 2013 through July 31, 2015, who developed AKI requiring dialysis initiation, and in whom dialysis was still required at discharge. Exclusion criteria were patients with preexisting diagnosis of ESRD, or those who had dialysis initiated at an outside hospital prior to transfer. This study was approved by the UMHS institutional review board with a waiver of informed consent.

UMHS provides tertiary care to a geographic area including Michigan, northern Indiana and northern Ohio. For patients with AKI-D, the decision to prescribe renal replacement therapy is at the discretion of the nephrology consult team, and includes either standard intermittent hemodialysis (IHD; at least thrice weekly, with target urea reduction ratio of 70% per treatment) or continuous renal replacement therapy (CRRT; performed as continuous veno-venous hemodiafiltration with prescribed effluent dose of 25–30 mL/kg/h, using regional citrate anticoagulation[14]). Patients with AKI-D who survive to hospital discharge but who still require dialysis are referred back to dialyze in the hospital-based dialysis unit. Outpatient dialysis treatments are performed by the same team of nurses that provide inpatient dialysis care, and supervised by one primary nephrologist and a physician assistant. Patients are evaluated in-person at least weekly by the primary nephrologist, and weekly labs are collected to assess for trends in serum creatinine and electrolytes. Timed urine collections are obtained as indicated by clinical factors such as signs of recovery (e.g., decreasing predialysis creatinine, patient reported increasing urine output).

Data collection

Baseline patient characteristics, including comorbid conditions, were collected through review of the electronic medical record. Baseline renal function was defined as estimated glomerular filtration rate (eGFR) derived from the average of the 3 most recent outpatient creatinine values prior to admission, and calculated using the CKD-EPI equation.[15] Additional variables included cause of AKI (acute tubular necrosis [ATN]; hemodynamic, including hepatorenal and cardiorenal syndrome; glomerulonephritis; or other), initial dialysis modality, and hospital service. Laboratory parameters and patient weight were recorded at admission, dialysis initiation, and time of hospital discharge. Volume overload at dialysis initiation and hospital discharge were calculated as a percentage above/below hospital admission weight: ([dialysis initiation weight − admit weight]/admit weight) × 100%.[16] Urine output (UOP) in the 24 hours prior to discharge was recorded.

Outpatient treatment parameters were recorded for the first 3 outpatient dialysis sessions. These included dialysis treatment time, net fluid removal, ultrafiltration rate, and occurrence of intradialytic hypotension (defined as systolic blood pressure <90 mmHg[17]). Distance traveled for outpatient dialysis was also recorded.

Outcomes

The primary outcome was dialysis independence at 90 days postdischarge. We chose 90 days because this is typically the time beyond which a patient is designated as ESRD if still dialysis-dependent, at which time they are referred to an outpatient dialysis center. Secondary outcomes included eGFR at time of recovery among those achieving dialysis-independence.

Statistical analyses

T-tests were used to compare continuous variables between patients recovering renal function vs. those

Table 1 Patient characteristics at hospital admission, overall and by 90-day outcome

Variable[a]	Overall (n = 100)	90-Day outcome Off dialysis (n = 43)	ESRD or death (n = 57)	P value
Age in years	60.9 (14.6)	57.9 (15.9)	63.2 (13.2)	0.071
Race: White	76	36 (47.4%)	40 (52.6%)	0.029
Black	18	3 (16.7%)	15 (83.3%)	
Other	6	4 (66.7%)	2 (33.3%)	
Gender: Male	56	24 (42.9%)	32 (57.1%)	0.974
Female	44	19 (43.2%)	25 (56.8%)	
Charlson comorbidity index	2.75 (1.81)	2.32 (1.74)	3.07 (1.80)	0.041
Comorbidities:				
Diabetest mellitus	36	11 (30.6%)	25 (69.4%)	0.059
Hypertension	61	25 (41.0%)	36 (59.0%)	0.611
Congestive heart failure	35	11 (31.4%)	24 (68.6%)	0.086
Active cancer	11	4 (36.4%)	7 (63.6%)	0.638
Coronary artery disease	20	6 (30%)	14 (70%)	0.189
Peripheral vascular	18	8 (44.4%)	10 (55.6%)	0.891
Disease cirrhosis	14	6 (42.9%)	8 (57.1%)	0.991
Primary service:				0.007
Medicine	68	23 (36.8%)	45 (66.2%)	
Surgery	32	20 (62.5%)	12 (37.5%)	
Baseline eGFR (mL/min/1.73 m^2)	60.8 (30.5)	73.6 (28.8)	51.6 (28.6)	<0.001
Admission labs:				
Serum creatinine, mg/dL	3.57 (2.96)	3.20 (3.33)	3.85 (2.64)	0.285
BUN, mg/dL	58.1 (38.3)	49.7 (41.2)	64.3 (35.0)	0.060
Albumin, g/dL	3.15 (0.64)	3.2 (0.6)	3.1 (0.7)	0.310
Hemoglobin, g/dL	10.3 (2.3)	10.8 (2.6)	9.7 (2.0)	0.049

[a]Values for continuous variables are presented as means (SD). Values for categorical variables are presented as counts (% of total).
ESRD = end-stage renal disease; eGFR = estimated glomerular filtration rate; BUN = blood urea nitrogen.

remaining on dialysis, while categorical variables were assessed using chi-square tests. Multivariate logistic regression models were developed to predict the primary outcome of dialysis-independence at 90 days, using forward selection and including variables with $P < 0.10$ significance in univariate analysis. Statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Patient characteristics

During the study period 100 patients met inclusion criteria. Baseline characteristics are shown in Table 1. Mean age was 60.9 years, with 56% male; 76% were white, and 18% were black. Comorbidities were common and 36% had diabetes mellitus (DM) while 35% had congestive heart failure (CHF). The mean baseline eGFR was 60.8 mL/min/1.73 m^2. Most (53%) patients had some degree of CKD at baseline: 38 with stage 3 CKD, 13 with stage 4 CKD, and 2 with stage 5 CKD. Overall, 68 patients were admitted to a medicine service and 32 patients to a surgery service.

Inpatient treatment characteristics are listed in Table 2. For AKI etiology, 68% of cases were attributed to ATN, 11% to hemodynamic causes, 11% to glomerulonephritis, and 10% to other causes. CRRT was the initiating modality in 30 patients and IHD in the remaining 70 patients.

Renal function recovery

Overall, 43 patients recovered adequate renal function to be independent of dialysis by 90 days postdischarge; 16 experienced full recovery to baseline renal function while 27 had new or worsened CKD. Among the remaining 57 patients, 45 were declared ESRD and 9 were deceased. The majority (31 of 43, 72%) of recovering patients were dialysis independent by 30 days postdischarge. Among patients recovering renal function, the mean duration of

Table 2 Inpatient treatment characteristics, overall and by 90-day outcome

Variable[a]	Overall (n = 100)	90-Day outcome: Off dialysis (n = 43)	ESRD or death (n = 57)	P value
Cause of AKI				0.002
ATN	68	38 (55.9%)	30 (44.1%)	
Hemodynamic (hepatorenal syndrome, cardiorenal syndrome)	11	1 (9.1%)	10 (90.9%)	
Glomerulonephritis	11	2 (18.2%)	9 (81.8%)	
Other	10	2 (20.0%)	8 (80.0%)	
Initial RRT modality:				<0.001
CRRT	30	21 (70%)	9 (30%)	
IHD	70	22 (31.4%)	48 (68.6%)	
Mechanical ventilation	42	25 (59.5%)	17 (40.5%)	0.005
Vasopressor use	27	20 (74.1%)	7 (25.9%)	<0.001
RRT initiation labs:				
Serum creatinine, mg/dL	5.72 (2.64)	5.63 (2.96)	5.79 (2.39)	0.770
BUN, mg/dL	84.9 (38.0)	78.2 (42.1)	89.9 (34.1)	0.128
Albumin, g/dL	2.94 (0.55)	3.0 (0.5)	2.9 (0.6)	0.555
Hemoglobin, g/dL	9.1 (1.6)	9.3 (1.9)	8.9 (1.4)	0.318
% Fluid Overload at RRT Initiation	6.1% (9.4)	5.8% (9.5)	6.3% (9.5)	0.818
>10% Fluid Overload at RRT Initiation	24	12 (50%)	12 (50%)	0.544

[a]Values for continuous variables are presented as means (SD). Values for categorical variables are presented as counts (% of total).
ESRD = end-stage renal disease; AKI = acute kidney injury; ATN = acute tubular necrosis; RRT = renal replacement therapy; CRRT = continuous renal replacement therapy; IHD = intermittent hemodialysis therapy; BUN = blood urea nitrogen.

RRT was 38.6 days and mean eGFR at time of dialysis discontinuation was of 38.1 mL/min/1.73 m^2.

Inpatient predictors of renal recovery

Patient baseline characteristics by renal recovery are shown in Table 1. Patients who did not recover were marginally older than those that did recover. Compared to black patients, white patients were significantly more likely to recover (47.4% vs. 16.7%, P = 0.029). Nonrecovering patients had a higher Charlson comorbidity score and lower baseline eGFR compared to those that recovered. DM and CHF were marginally associated with lower likelihood of renal recovery. Patients who recovered had significantly higher baseline eGFR than those that did not recover (73.6 vs. 51.6 mL/min/1.73 m^2, P < 0.001). Figure 1 shows renal function recovery over time, overall and by underlying CKD status.

Inpatient characteristics and their association with renal outcomes are shown in Table 2. The cause of AKI was important in predicting renal recovery: more than half (55.9%) of patients with ATN recovered renal function compared to only 9.1% of patients with hepatorenal or cardiorenal syndrome, and 18.2% of patients with glomerulonephritis (P = 0.002). A higher proportion of patients with initial dialysis modality of CRRT experienced renal recovery compared to those that started on

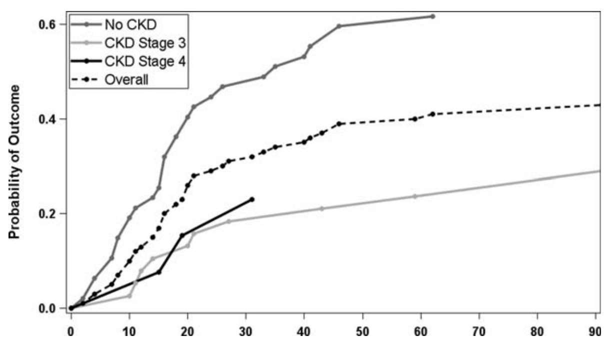

Figure 1 Outpatient renal function recovery during the initial 90 days after hospital discharge, overall and by underlying CKD status.

Table 3 Patient characteristics at time of discharge/first outpatient dialysis, overall and by 90-day outcome

		90-Day outcome		
Variable[a]	Overall (n = 100)	Off dialysis (n = 43)	ESRD or death (n = 57)	P value
Inpatient RRT days	14.9 (11.8)	16.3 (13.7)	13.8 (10.1)	0.314
Urine output (last 24 h of hospitalization)	453 (605)	684 (733)	279 (416)	0.002
Discharge labs:				
Serum creatinine, mg/dL	4.79 (2.19)	4.99 (2.45)	4.63 (1.97)	0.423
BUN, mg/dL	43.5 (20.6)	43.6 (20.4)	43.4 (21.0)	0.956
Albumin, g/dL	3.0 (0.6)	3.1 (0.4)	2.9 (0.6)	0.075
Hemoglobin, g/dL	8.7 (1.2)	8.8 (1.2)	8.6 (1.3)	0.535
% Fluid overload at discharge	−2.1 (11.8)	−3.9 (12.1)	−0.8 (11.5)	0.224
Change in fluid overload from RRT initiation	−8.3 (11.2)	−9.9 (12.7)	−7.1 (9.9)	0.238

[a]Values for continuous variables are presented as means (SD). Values for categorical variables are presented as counts (% of total).
ESRD = end-stage renal disease; RRT = renal replacement therapy; BUN = blood urea nitrogen.

IHD (70.1% vs. 31.4%, P < 0.001). There were no differences between recovery groups in biochemical parameters or degree of fluid overload at time of dialysis initiation.

Discharge and outpatient predictors of renal recovery

Patient characteristics at the time of discharge are shown in Table 3. UOP 24 hours prior to discharge was significantly different between groups, (684 vs. 279 mL, P = 0.002). Albumin was marginally higher among patients that subsequently recovered compared to those that did not (3.1 vs. 2.9 g/dL, P = 0.075), but there were no differences in other biochemical parameters. The degree of fluid overload at discharge was similar between the recovery and nonrecovery groups, and there was also no difference in the change of fluid overload from RRT initiation to discharge (a surrogate for net volume of inpatient ultrafiltration).

Outpatient dialysis treatment characteristics during the first week postdischarge are shown in Table 4. Hemodynamic parameters at beginning and end of dialysis treatment were similar between the recovery and nonrecovery groups. Patients with nonrecovery of renal function had marginally more episodes of intradialytic hypotension, and a significantly greater proportion of these patients had 3 or more episodes of intradialytic hypotension during the week (24.6% vs. 9.3%, P = 0.049).

Table 4 Outpatient dialysis treatment characteristics, overall and by 90-day outcome

		90-Day outcome		
Variable[a]	Overall (n = 100)	Off dialysis (n = 43)	ESRD or death (n = 57)	P value
Duration of dialysis session, hours	3.3 (0.6)	3.2 (0.7)	3.4 (0.6)	0.305
Predialysis weight (first session), kg	88.5 (23.0)	91.3 (25.7)	86.4 (20.8)	0.306
Predialysis MAP, mmHg	94.0 (17.5)	96.8 (17.6)	91.8 (17.3)	0.159
Postdialysis MAP, mmHg	91.4 (14.5)	92.5 (14.9)	90.6 (14.3)	0.507
Change in MAP, mmHg	2.6 (11.1)	4.3 (12.8)	1.3 (9.4)	0.195
Hypotension				
# Episodes	1.6 (3.7)	0.9 (2.9)	2.1 (4.2)	0.104
Any Episode	25	8 (32%)	17 (68%)	0.200
≥3 Episodes	18	4 (22.2%)	14 (77.8%)	0.049
Ultrafiltration per session, L	1.60 (0.95)	1.37 (0.97)	1.77 (0.90)	0.037
Ultrafiltration rate, mL/kg/h	5.4 (3.2)	4.68 (3.16)	6.02 (3.15)	0.041
One-way travel distance, miles	17.1 (21.2)	19.3 (22.5)	15.4 (20.2)	0.370

[a]Values for continuous variables are presented as means (SD). Values for categorical variables are presented as counts (% of total).
ESRD = end-stage renal disease; MAP = mean arterial pressure.

Table 5 Logistic regression model predicting renal function recovery at 90 days post-hospital discharge

Variable	OR	95% CI	P value
Black race (vs. White)	0.14	0.02–0.84	0.031
Baseline eGFR (per mL/min)	1.22	1.02–1.47	0.034
IHD vs. CRRT	0.19	0.06–0.61	0.006
Urine output at discharge (per 100 mL)	1.14	1.03–1.26	0.011
$\geq$ 3 Episodes of hypotension	0.26	0.06–1.22	0.088

eGFR = estimated glomerular filtration rate; IHD = intermittent hemodialysis; CRRT = continuous renal replacement therapy.

Multivariate analysis

Table 5 shows the results of a multivariate logistic regression model to predict recovery of renal function at 90 days post-hospital discharge. Significant negative predictors of renal recovery were black compared to white race, and initial RRT modality of IHD compared to CRRT. The development of 3 or more episodes of intradialytic hypotension was also marginally significant in predicting nonrecovery.

DISCUSSION

In this cohort study of patients with AKI-D who survived to hospital discharge but remained dialysis-dependent, we found that postdischarge renal recovery was common. Overall, 43% of patients recovered adequate renal function to discontinue hemodialysis therapy by 90 days, including 16% that fully recovered to prior baseline renal function. A novel aspect of this study was the examination of outpatient dialysis practices in this population. Notably, when examining postdischarge dialysis care, greater fluid removal, and more frequent hypotensive episodes appeared to be associated with decreased likelihood of renal recovery.

The vast majority of studies of patients with severe AKI have focused on the inpatient setting, with relatively little attention paid to the care of patients who survive to hospital discharge but still require dialysis as outpatients. Recent studies have begun to shed some light on the epidemiology and outcomes of these patients. Hickson and colleagues reported the Mayo Clinic experience with 281 patients and observed that 21% recovered to dialysis-independence in the 6 months postdischarge.[12] Baseline renal impairment (eGFR <30 mL/min) and CHF were associated with decreased likelihood of renal recovery. Of note, patients in the Mayo study appeared to have greater comorbidity burden compared to our cohort (mean Charlson Index of 7 compared to 2.75). Gautam and colleagues recently described 119 patients with AKI treated at a University of Virginia facility developed specifically to provide dialysis for AKI outpatients. Overall, 42% developed dialysis-independence within 90 days of discharge.[13] In univariate analyses, predictors of nonrecovery included CHF, prior AKI within 6 months, and lower baseline eGFR. The most consistent finding from all 3 studies is the association between baseline renal impairment and risk for renal nonrecovery. Of note, patients with baseline eGFR >60 mL/min made up 48% of the UVA cohort and 43% of our cohort; conversely, in the Mayo cohort only 15% of patients had baseline GFR >60 mL/min, which may account for the lower recovery rate seen in that study. CHF was also identified as a negative predictor of recovery in all 3 studies, although this was only a marginally significant finding in our cohort. In adjusted analyses, in contrast to other studies, we no longer found a history of CHF to be a significant predictor of renal function nonrecovery. Potential explanations include the relatively small sample size or differences in severity of CHF (not captured) between study populations. It's also possible that the association between CHF and renal nonrecovery is mediated by increased risk for intradialytic hypotension, which we adjusted for in our models; however, in subgroup analysis there was no significant difference in hypotensive episodes between CHF vs. non-CHF patients (1.7 vs. 1.5 episodes, $P = 0.781$). Larger studies are needed to further elucidate the relationship between CHF and renal function recovery after an episode of AKI.

The predictive factors identified above are nonmodifiable. While this information may be helpful in counseling patients and planning care, it does not provide insight into practices that may improve renal recovery rates. Our study is novel in that it is the first to evaluate outpatient dialysis treatment factors and their effect on renal outcomes. Compared to patients with renal recovery, we found that patients with nonrecovery of renal function had higher net fluid removal and ultrafiltration rates, despite these groups having similar degrees of fluid overload at the time of discharge. Similarly, patients with nonrecovery of renal function suffered from more frequent episodes of intradialytic hypotension. It is possible that this association reflects underlying patient severity of illness as opposed to being a causative factor in nonrecovery of renal function. However, there is ample evidence of the harms of intradialytic hypotension on other organ systems,[18–20] lending biologic plausibility to a pathologic role in impairing renal recovery. Our results provide preliminary support to recent recommendations calling for a conservative approach to fluid removal in AKI patients with the goal of minimizing risk of intradialytic hypotension.[4]

Our study also has timely implications due to recent Medicare policy changes. The "Trade Bill" (passed on June 29, 2015 and effective January 1, 2017) allows Medicare to reimburse for dialysis care provided to AKI outpatients at ESRD facilities, a reversal from the previous position.[11] As such, it is likely that more AKI patients will be entering a realm which is most accustomed to chronic dialysis patients where the prospect of recovery of renal function is remote, and clinician focus is on achieving effective dialysis and establishing dry weight. For AKI patients, clinicians will need to be vigilant in monitoring for renal function recovery and in avoiding complications such as intradialytic hypotension. This further underscores the need to complete more definitive studies of treatment related parameters that may affect renal recovery.

Our study has important limitations. As an observational study, we cannot establish a causative role of fluid removal or intradialytic hypotension in contributing to renal function nonrecovery. Additionally, this study is single-center, which may confound generalizability. However, we were able to examine treatment parameters in a granular fashion, which is not currently otherwise feasible with existing regional or national data sources. We limited our analysis of outpatient dialysis treatment to the first week postdischarge, and it is possible that treatment factors beyond the first week played a role in subsequent renal function recovery or nonrecovery. We chose to limit to this timeframe for feasibility reasons (decreasing patient numbers beyond 1 week due to recovery), and also because we believe that the first week is the most vulnerable period for complications and thus the most important to characterize.

In summary, among patients with AKI surviving to hospital discharge but remaining dialysis-dependent, we observed a high rate of subsequent renal function recovery. We have identified both nonmodifiable and potentially modifiable risk factors for nonrecovery. At the very least, this information can inform clinicians when counseling these patients and their families. Our data also suggest an association between outpatient dialysis prescription factors and subsequent renal recovery. Clinical trials are needed to determine whether strategies to minimize intradialytic hypotension may be beneficial in promoting renal function recovery.

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REFERENCES

1 Bagshaw SM, Laupland KB, Doig CJ, et al. Prognosis for long-term survival and renal recovery in critically ill patients with severe acute renal failure: A population-based study. *Crit Care.* 2005; **9**:R700–R709.

2 Susantitaphong P, Cruz DN, Cerda J, et al. World incidence of AKI: A meta-analysis. *Clin J Am Soc Nephrol.* 2013; **8**:1482–1493.

3 Hoste EA, Schurgers M. Epidemiology of acute kidney injury: How big is the problem?. *Crit Care Med.* 2008; **36**:S146–S151.

4 Cerda J, Liu KD, Cruz DN, et al. Promoting kidney function recovery in patients with AKI requiring RRT. *Clin J Am Soc Nephrol.* 2015; **10**:1859–1867.

5 Uchino S, Kellum JA, Bellomo R, et al. Beginning, ending supportive therapy for the kidney I. Acute renal failure in critically ill patients: A multinational, multicenter study. *JAMA.* 2005; **294**:813–818.

6 Hsu RK, McCulloch CE, Dudley RA, Lo LJ, Hsu CY. Temporal changes in incidence of dialysis-requiring AKI. *J Am Soc Nephrol.* 2013; **24**:37–42.

7 Brown JR, Rezaee ME, Hisey WM, Cox KC, Matheny ME, Sarnak MJ. Reduced mortality associated with acute kidney injury requiring dialysis in the United States. *Am J Nephrol.* 2016; **43**:261–270.

8 Schmitt R, Coca S, Kanbay M, Tinetti ME, Cantley LG, Parikh CR. Recovery of kidney function after acute kidney injury in the elderly: A systematic review and meta-analysis. *Am J Kidney Dis.* 2008; **52**:262–271.

9 Wald R, Shariff SZ, Adhikari NK, et al. The association between renal replacement therapy modality and long-term outcomes among critically ill adults with acute kidney injury. A retrospective cohort study*. *Crit Care Med.* 2014; **42**:868–877.

10 Heung M, Wolfgram DF, Kommareddi M, Hu Y, Song PX, Ojo AO. Fluid overload at initiation of renal replacement therapy is associated with lack of renal recovery in patients with acute kidney injury. *Nephrol Dial Transplant.* 2012; **27**:956–961.

11 Heung M, Faubel S, Watnick S, et al. Outpatient dialysis for patients with AKI: A policy approach to improving care. *Clin J Am Soc Nephrol.* 2015; **10**: 1868–1874.

12 Hickson LJ, Chaudhary S, Williams AW, et al. Predictors of outpatient kidney function recovery among

patients who initiate hemodialysis in the hospital. *Am J Kidney Dis*. 2015; **65**:592–602.
13 Gautam SC, Brooks CH, Balogun RA, Xin W, Ma JZ, Abdel-Rahman EM. Predictors and outcomes of post-hospitalization dialysis dependent acute kidney injury. *Nephron*. 2015; **131**:185–190.
14 Swartz R, Pasko D, O'toole J, Starmann B. Improving the delivery of continuous renal replacement therapy using regional citrate anticoagulation. *Clin Nephrol*. 2004; **61**:134–143.
15 Levey AS, Stevens LA, Schmid CH, et al. New equation to estimate glomerular filtration rate. *Ann Intern Med*. 2009; **150**:604–612.
16 Selewski DT, Cornell TT, Lombel RM, et al. Weight-based determination of fluid overload status and mortality in pediatric intensive care unit patients requiring continuous renal replacement therapy. *Intensive Care Med*. 2011; **37**:1166–1173.
17 Flythe JE, Xue H, Lynch KE, Curhan GC, Brunelli SM. Association of mortality risk with various definitions of intradialytic hypotension. *J Am Soc Nephrol*. 2015; **26**: 724–734.
18 Stefansson BV, Brunelli SM, Cabrera C, et al. Intradialytic hypotension and risk of cardiovascular disease. *Clin J Am Soc Nephrol*. 2014; **9**:2124–2132.
19 Eldehni MT, Odudu A, McIntyre CW. Randomized clinical trial of dialysate cooling and effects on brain white matter. *J Am Soc Nephrol*. 2015; **26**:957–965.
20 Odudu A, Eldehni MT, McCann GP, McIntyre CW. Randomized controlled trial of individualized dialysate cooling for cardiac protection in hemodialysis patients. *Clin J Am Soc Nephrol*. 2015; **10**:1408–1417.