Impaired Kidney Function at Hospital Discharge and Long-Term Renal and Overall Survival in Patients Who Received CRRT

Susanne Stads,† Gijs Fortrie,* Jasper van Bommel,† Robert Zietse,* and Michiel G.H. Betjes**

Summary

Background and objectives Critically ill patients with AKI necessitating renal replacement therapy (RRT) have high in-hospital mortality, and survivors are at risk for kidney dysfunction at hospital discharge. The objective was to evaluate the association between impaired kidney function at hospital discharge with long-term renal and overall survival.

Design, setting, participants, & measurements Degree of kidney dysfunction in relation to long-term effects on renal survival and patient mortality was investigated in a retrospective cohort study of 1220 adults admitted to an intensive care unit who received continuous RRT between 1994 and 2010.

Results After hospital discharge, median follow-up of survivors (n=475) was 8.5 years (range, 1–17 years); overall mortality rate was 75%. Only 170 (35%) patients were discharged with an estimated GFR (eGFR) >60 ml/min per 1.73 m^2. Multivariate proportional hazards regression analysis demonstrated that age, nonsurgical type of admission, preexisting kidney disease, malignancy, and eGFR of 29–15 ml/min per 1.73 m^2 (hazard ratio [HR], 1.62; 95% confidence interval [CI], 1.01 to 2.58) and eGFR <15 ml/min per 1.73 m^2 (HR, 1.93; 95% CI, 1.23 to 3.02) at discharge were independent predictors of increased mortality. Renal survival was significantly associated with degree of kidney dysfunction at discharge. An eGFR of 29–15 ml/min per 1.73 m^2 (HR, 26.26; 95% CI, 5.59 to 123.40) and <15 ml/min per 1.73 m^2 (HR, 172.28; 95% CI, 37.72 to 786.75) were independent risk factors for initiation of long-term RRT.

Conclusions Most critically ill patients surviving AKI necessitating RRT have impaired kidney function at hospital discharge. An eGFR <30 ml/min per 1.73 m^2 is a strong risk factor for decreased long-term survival and poor renal survival.

Clin J Am Soc Nephrol 8: 1284–1291, 2013. doi: 10.2215/CJN.06650712

*Department of Nephrology and Transplantation and †Department of Intensive Care, Erasmus Medical Center, Rotterdam, The Netherlands

Correspondence: Dr. Susanne Stads, Department of Intensive Care, Erasmus Medical Center, H-626, PO Box 2040, 3000 CA Rotterdam, the Netherlands. Email: s.stads@erasmusmc.nl

Introduction

Recently, several studies have shown the interplay between AKI, progressive CKD, and long-term mortality (1–6). A recent study indicated that even patients who seem to have complete recovery of renal function after AKI have a two-fold increased risk for *de novo* CKD, which modified the hazard ratio for mortality (7). These data confirm the notion that AKI is not an innocent event but rather constitutes a significant risk factor for subsequent development of CKD. In addition, the findings are in accordance with the well established association between progressive CKD and increased mortality found in large epidemiologic studies (8).

Given these data, it is important to identify the risk factors for death and poor renal recovery after AKI in the intensive care unit (ICU). In addition, the factors associated with CKD at hospital discharge and subsequent development of ESRD or death should be studied. Many studies have identified the following as risk factors for increased mortality after AKI: age older than 65 years, elevated Acute Physiology and Chronic Health Evaluation score, associated organ dysfunction, and the need for continuous renal replacement therapy (CRRT) during ICU stay (9–12). The need for CRRT during ICU stay is associated with an estimated in-hospital mortality between 14% and 60%, depending on the reason for ICU admission and the cause of renal failure (9,13). However, our current knowledge about the long-term effects of AKI that necessitates dialysis in critically ill patients after hospital discharge on mortality and renal survival is far from complete. It is clear that incomplete recovery of renal function, specifically dependence on long-term RRT, after an episode of AKI is associated with increased mortality at follow-up (14,15). However, definitions of AKI and long-term outcome after an episode of AKI vary among studies, and the degree of kidney function impairment at discharge was not calculated per GFR (6,12,16).

The objective of this study was to evaluate the degree of renal function at hospital discharge as an independent risk factor for long-term renal survival

and overall long-term mortality after an episode of AKI that necessitates RRT in the ICU.

Materials and Methods

Setting

A retrospective cohort study was performed in the ICU of a large academic hospital (Erasmus Medical Center, Rotterdam, The Netherlands). All critically ill patients with AKI who required RRT were treated with continuous arteriovenous hemodialysis (30%) or continuous veno-venous hemofiltration. All patients included after 2005 were treated according to the local protocol: Anticoagulation was performed using citrate, unless contraindicated; in that case, heparin was used as an anticoagulant. Before 2005, the standard anticoagulation used was heparin, unless contraindicated. Intermittent hemodialysis was not performed in this group of patients because most patients in our ICU ward were hemodynamically unstable and the ICU lacks facilities to perform intermittent hemodialysis. The study was approved by the medical ethical review board of the Erasmus Medical Center, which waived the requirement of informed consent, because of its retrospective nature.

Study Population and Data Collection

All patients older than 18 years receiving CRRT in the ICU between 1994 and 2010 were included in a database. Patients with RRT or a kidney transplant before ICU admission were excluded from analysis (n=75). Data were collected using the hospital electronic patient registry (EPR). Long-term RRT after hospital discharge was defined as peritoneal dialysis or hemodialysis for more than 3 months or having received a kidney transplant; these data were obtained from the Dutch national RENINE database (RENINE, The Netherlands) or the hospital electronic patient registry. In the population eligible for analysis, the following clinical and demographic data were collected: age, sex, type and date of ICU admission, medical history, duration of ICU admission, cause of AKI, kidney function at discharge, and the need for long-term RRT after discharge. Most patients were mechanically ventilated during their ICU stay; therefore, it was not possible to test the predictive value of mechanical ventilation on outcome.

Definitions

Type of ICU admission was defined as surgical when any surgical procedure was performed in the period before ICU admission. This included abdominal, trauma, transplantation, or thoracic (including cardiac and pulmonary) surgery. Nonsurgical reason for admission included all other admission types, including sepsis, cardiopulmonary resuscitation, cardiac diseases, and intoxication. These are further specified in Table 1. For medical history we included data on diabetes mellitus; cardiac disease (defined as myocardial infarction before admission, cardiac valvular disease, or heart failure); malignancy; hypertension; cardiac, liver, or lung transplantation; or preexisting CKD. Preexisting CKD was defined as any documented impairment in renal function in the years before ICU admission that did not necessitate long-term RRT or kidney transplant. Because information on kidney function impairment was not available at a standardized preadmission time point and for some patients it was not available at all, we did not attempt to categorize these data according to stage of CKD. Preadmission kidney function was considered normal when the patient had documented normal kidney function at the time of admission or within the previous 2 years, without major events that could have compromised kidney function. Furthermore, we categorized causes of AKI as sepsis, hypotension, and toxic/other. Sepsis was defined as the presence of a systemic inflammatory response with a documented or presumed infection. In the group defined as having AKI caused by hypotension, all prerenal causes were included. All patients with AKI due to toxic drugs, contrast agents, and other nephrotoxic substances were categorized in the "toxic/other" group. Patients who experienced AKI as a result of any other cause (*e.g.*, rhabdomyolysis, vasculitis, or other disorders) were also categorized in this group.

Table 1. Clinical characteristics of 475 patients treated with renal replacement therapy in the intensive care unit and discharged from the hospital alive

Characteristic	Value
Median age ± SD (yr)	59 (19–84)
Men	314 (66)
Surgical/medical admission (*n*/*n*)	301/174
Median hospital (range) (*d*)	47 (2–297)
Median ICU (range) (*d*)	18 (1–209)
Cause of AKI, *n* (%)	
Sepsis	119 (25)
Hypotension	191 (40)
Toxic/other	68 (14)
Indication for ICU admission, *n* (%)	
Sepsis	83 (17)
Transplantation	41 (9)
Thoracic surgery	118 (25)
Cardiac disease	67 (14)
General surgery	62 (13)
Bleeding	6 (1)
Cardiopulmonary resuscitation	16 (3)
Trauma	14 (3)
Intoxication/other	69 (15)
Medical history, *n* (%)	
CKD	97 (20)
Diabetes mellitus	110 (23)
Cardiovascular disease	241 (50)
Heart transplant	24 (5)
Lung transplant	1 (0.2)
Liver transplant	27 (6)
Malignancy	67 (14)
Liver disease	54 (11)
Hypertension	141 (30)

Study Outcomes

The main study outcome measures were overall and renal survival; renal survival was defined as the time until long-term RRT. Survival and the need for long-term RRT are reported at 6 and 12 years after discharge. Furthermore, we evaluated whether degree of kidney dysfunction at discharge was associated with both overall and renal survival. We defined the kidney function at discharge arbitrarily per estimate GFR (eGFR) category using the

Modification of Diet in Renal Disease (MDRD) formula for the estimation of GFR. Because the MDRD formula performs best in patients with an eGFR <60 ml/min per 1.73 m^2, we grouped together the patients with eGFR >60 ml/min per 1.73m^2. The second category is defined as eGFR of 30–59 ml/min per 1.73m^2, the third category is defined as eGFR of 15–29 ml/min per 1.73 m^2, and the last category is defined as eGFR <15 ml/min per 1.73 m^2 with or without the need for long-term RRT at discharge.

Statistical Analyses

Continuous variables are expressed as median and range. Categorical variables are expressed as number of cases and percentages. Curves for patient survival and renal survival censored for death were generated for each eGFR category by Kaplan-Meier analysis. Log-rank test was used to analyze differences between these curves. Cox regression analysis was used to evaluate independent predictors of long-term mortality. Separate analyses were performed to evaluate changing hazards, for follow-up in the first 90 days and from 90 days to the end of follow-up. Potential risk factors for increased mortality were tested with univariate analysis. When variables were significant in univariate analysis ($P<0.05$), they were included in a multivariate proportional hazards Cox regression analysis using a multiple forward stepwise approach. Statistical significance was defined by $P<0.05$. Time-dependent variables were created to evaluate whether hazards were proportionate. Predictive ability of the multivariate proportional hazards model was tested by Harrel C-statistic. Analyses were performed with SPSS software, version 19.0, (SPSS Inc., an IBM company, Chicago, IL).

Results

Clinical Characteristics of RRT-treated ICU Patients Discharged from the Hospital Alive

Between 1994 and 2010, a total of 1220 patients received CRRT in the ICU (Figure 1). Seventy-five patients (6%) were known to have received dialysis or have undergone kidney transplantation before hospital admission and were excluded from further analysis. Of the remaining patients, 670 (55%) died in the hospital. Patients alive at hospital discharge (n=475 [39%]) were divided into categories according to their eGFR at discharge (Figure 1). Median hospital length of stay was 47 days (range, 2–297 days). More than 60% of the patients had eGFR loss at hospital discharge, of whom 12% needed long-term RRT at this time.

The baseline characteristics of the 475 patients are depicted in Table 1. The largest group of patients was admitted to the ICU after thoracic surgery, followed by 83 patients admitted for sepsis. Table 1 provides all indications for ICU admission, along with medical history of patients before admission. Preexisting CKD was known in 97 patients (20%), and 229 patients (48%) had normal preadmission kidney function.

Association of Long-term Patient Survival with eGFR at Hospital Discharge

Follow-up after hospital discharge varied from 1 to 17 years, with a median follow-up of 8.5 years. Survival rates for patients alive at hospital discharge at 6 years and 12 years were 62% and 44%, respectively. Cumulative survival per category was determined by Kaplan-Meier analysis (Figure 2). A log-rank test comparing all categories showed a significant difference in patient long-term survival ($P<0.001$). Compared with patients discharged with an eGFR >60 ml/min per 1.73 m^2, survival curves for patients with an eGFR of 15–29 ml/min per 1.73 m^2 (hazard ratio [HR], 1.62; 95% confidence interval [CI], 1.01 to 2.58) and an eGFR <15 ml/min per 1.73 m^2 at hospital discharge were significantly worse (HR, 1.93; 95% CI, 1.23 to 3.02). The unadjusted 6- and 12-year patient survival rates per category are shown in Table 2. Most of the patients discharged with an eGFR <15 ml/min per 1.73 m^2 experienced acute-on-chronic kidney injury (56% of patients in this category had preexisting CKD).

Univariate analysis identified several clinical variables associated with worse long-term patient survival, as shown in Table 3. Age, date of ICU admission, nonsurgical reason for ICU admission, malignancy, and eGFR <30 ml/min per 1.73m^2 at hospital discharge remained significantly associated with patient survival after multivariate proportional hazards analysis (Table 3). Separate analysis for the first 90 days after discharge and from 90 days until the end of follow-up showed that hazards were proportionate during follow-up. The predictive ability of this multivariate proportional hazards model was tested by Harrel C-statistics. We found a concordance of 0.69 (SEM, 0.02).

Association of eGFR at Hospital Discharge with Renal Survival

Renal survival rates after hospital discharge at 6 and 12 years were 83% and 74%, respectively. Comparing renal survival censored for death showed an overall significant difference between eGFR categories ($P<0.001$) (Figure 3). Compared with patients discharged with an eGFR >60 ml/min per 1.73 m^2, renal survival curves for patients with an eGFR <30 ml/min per 1.73 m^2 at hospital discharge were worse (eGFR 15–29 ml/min per 1.73 m^2: HR, 27.40 [95% CI, 5.79 to 129.60]; eGFR<15 ml/min per 1.73 m^2: HR, 176.96 [95% CI, 38.59 to 811.50]). The unadjusted 6- and 12-year renal survival censored for death per eGFR category shows the association between an increased incidence of initiation of RRT and impaired eGFR at hospital discharge (Table 2).

After multivariate proportional hazards analysis, the following variables were strongly associated with decreased renal survival: preexisting CKD (compared with patients with documented normal prior kidney function) and an eGFR <30 ml/min per 1.73 m^2 at hospital discharge (Table 4). Hazards were proportionate during follow-up.

The results show that an eGFR <30 ml/min per 1.73 m^2 at hospital discharge is an independent and strong predictor of poor long-term renal survival. The predictive ability of this multivariate proportional hazards model was tested by Harrel C-statistics. We found a concordance of 0.96 (SEM, 0.03).

Discussion

The results of this study show that after an episode of AKI necessitating RRT in the ICU, long-term survival and

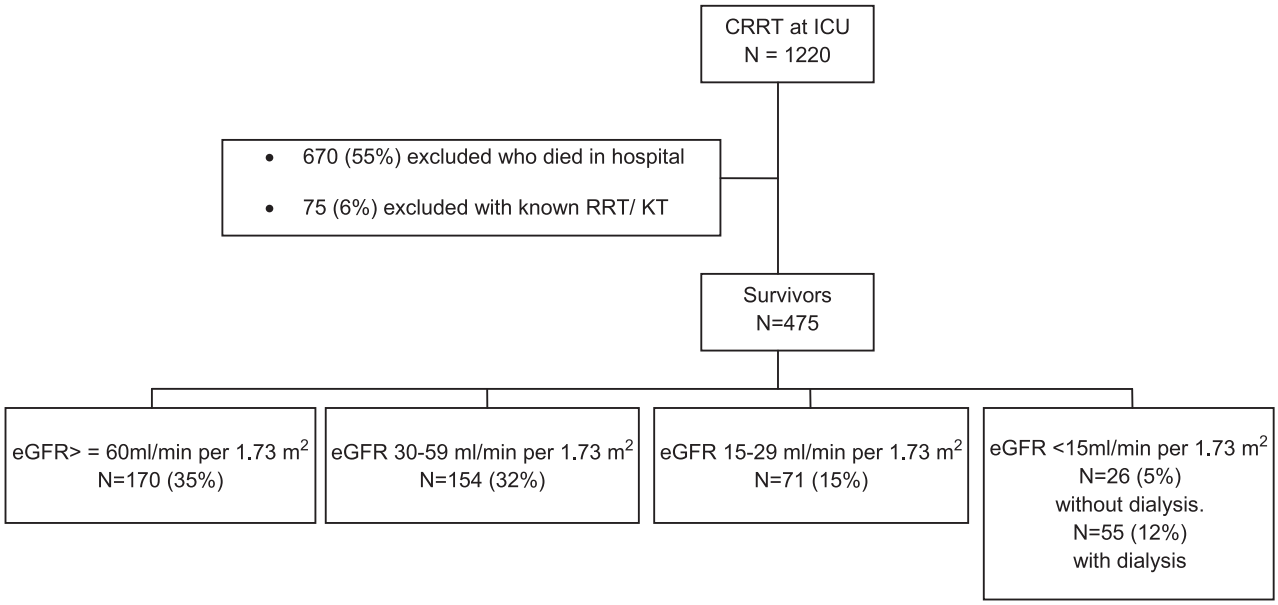

Figure 1. | **Flowchart of inclusion and eGFR classification at hospital discharge.** eGFR, estimated GFR; KT, kidney transplant; RRT, renal replacement therapy.

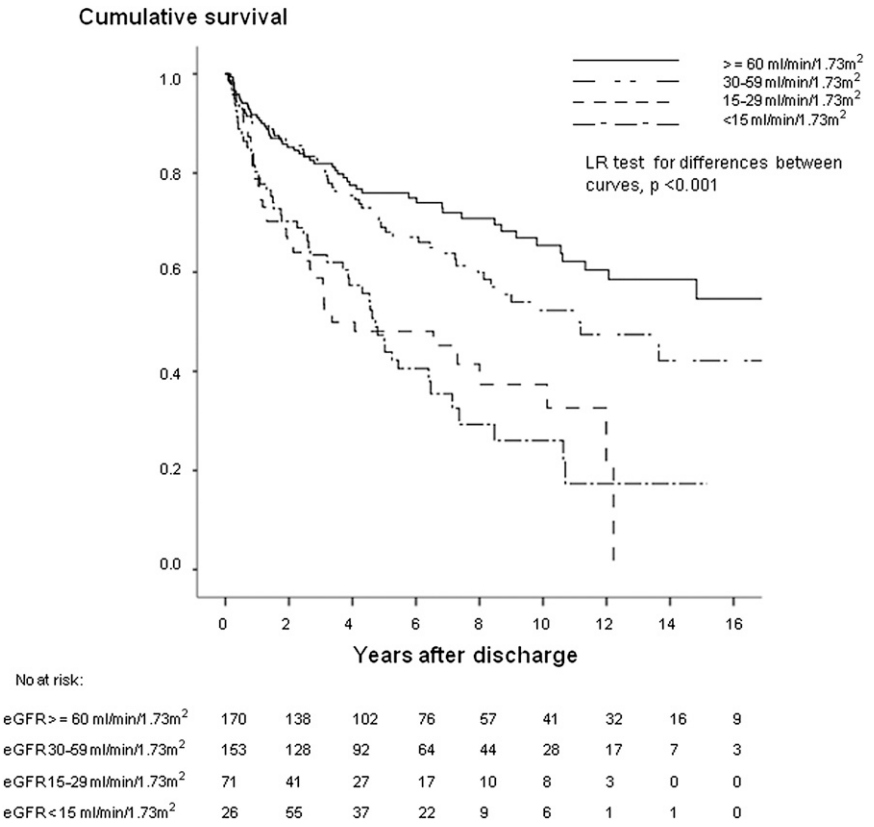

Figure 2. | **Kaplan-Meier curves for survival after hospital discharge, per category at hospital discharge.**

renal survival were both strongly related to the degree of kidney function impairment at hospital discharge. In particular, an eGFR <30 ml/min per 1.73 m^2 is an independent predictor of death and worse renal survival at long-term follow-up. About a third of all patients who survive their ICU stay and leave the hospital are discharged with an eGFR <30 ml/min per 1.73 m^2. In addition, the majority of patients in our cohort (>60%) had

Table 2. Patient and renal survival of 475 patients treated with renal replacement therapy in the intensive care unit and discharged from the hospital alive

Variable	6-yr Overall Survival (%)	12-yr Overall Survival (%)	6-yr Renal Survival (%)	12-yr Renal Survival (%)
eGFR ≥ 60 ml/min per 1.73 m^2	75	60	100	96
eGFR 30–59 ml/min per 1.73 m^2	67	47	95	93
eGFR 15–29 ml/min per 1.73 m^2	48	22	86	47
eGFR < 15 ml/min per 1.73 m^2	41	17	21	9

Data are given as percentages of initial number of patients alive (overall survival) or without renal replacement therapy (renal survival) at 6 years and 12 years stratified per category at hospital discharge.

Table 3. Univariate and multivariate analysis of the variables associated with long-term survival

Variable	Univariate Analysis		Multivariate Analysis	
	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
Age	1.04 (1.03 to 1.05)	<0.001	1.04 (1.02 to 1.05)	<0.001
Medical	0.68 (0.51 to 0.89)	0.01	0.60 (0.43 to 0.83)	0.002
Kidney function at admission				
Normal	1		1	
Preexisting CKD	2.21 (1.57 to 3.09)	<0.001	1.42 (0.96 to 2.10)	0.08
No data available	1.14 (0.82 to 1.59)	0.44	0.84 (0.58 to 1.21)	0.34
Admission diagnosis				
Sepsis	0.70 (0.46 to 1.06)	0.09	0.80 (0.51 to 1.24)	0.31
Thoracic surgery	1.11 (0.80 to 1.52)	0.54	0.99 (0.66 to 1.50)	0.97
Other	1		1	
eGFR at discharge				
60 ml/min per 1.73 m^2	1		1	
30–59 ml/min per 1.73 m^2	1.35 (0.93 to 1.96)	0.12	1.06 (0.71 to 1.57)	0.78
15–29 ml/min per 1.73 m^2	2.87 (1.90 to 4.35)	<0.001	1.62 (1.01 to 2.58)	0.04
<15 ml/min per 1.73 m^2	2.94 (1.99 to 4.36)	<0.001	1.93 (1.23 to 3.02)	0.004
Malignancy	1.85 (1.29 to 2.65)	0.001	1.73 (1.17 to 2.55)	0.006
Cardiovascular disease	1.66 (1.25 to 2.20)	0.001	1.22 (0.85 to 1.74)	0.28
Diabetes mellitus	1.69 (1.25 to 2.30)	0.001	1.15 (0.83 to 1.59)	0.40
Hypertension	1.72 (1.29 to 2.30)	<0.001	0.94 (0.69 to 1.29)	0.71
Year of admission	0.98 (0.95 to 1.01)	0.21	0.96 (0.92 to 0.99)	0.02

Variables tested in multivariate analysis: age, medical admission type, preexisting CKD, admission diagnosis sepsis, thoracic surgery or other, class of estimated GFR at discharge, malignancy, cardiovascular disease, diabetes mellitus, hypertension, and year of admission. HR, hazard ratio; CI, confidence interval; eGFR, estimated GFR (categorical class at discharge, compared with eGFR ≥60 ml/min per 1.73 m^2).

impaired kidney function at hospital discharge. Therefore, our findings are clinically relevant because they indicate that most of the patients who have received RRT in the ICU are at risk for CKD and, therefore, further deterioration of kidney function and increased mortality in the years thereafter.

A recently published large systematic review evaluated 15 studies on long-term mortality after an episode of AKI defined by different criteria in different patient populations. Remarkably, none of these studies had patient follow-up as long as or a cohort as diverse as in our study (17). Overall, it is apparent that an episode of AKI with or without the need for RRT is independently associated with an increased risk (relative risk, 1.6–3.9) for death at follow-up. A meta-analysis performed on 13 cohort studies evaluated the association of AKI with the risk of developing CKD. The results showed that AKI was a strong independent risk factor for development of CKD (HR, 8.8) and ESRD (HR, 3.1) (18).

Some studies have described the relation between impaired kidney function at hospital discharge and long-term survival. In a study performed by Liaño *et al.*, patients with complete renal recovery after an episode of AKI were compared with patients who had only partial recovery.

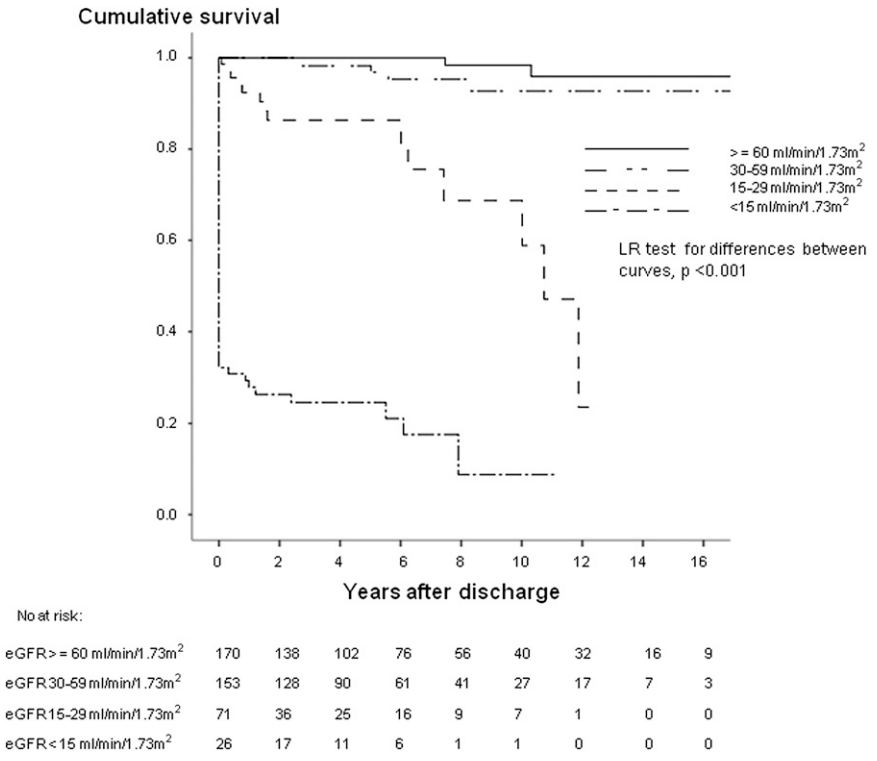

Figure 3. | **Kaplan-Meier renal survival curves, defined as years after discharge until chronic renal replacement therapy is initiated, censored for death.**

Table 4. Univariate and multivariate analysis of the variables associated with long-term renal survival

Variable	Univariate Analysis		Multivariate Analysis	
	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
Age	1.01 (1.00 to 1.03)	0.14	1.00 (0.98 to 1.01)	0.66
Medical	0.63 (0.41 to 0.97)	0.04	1.13 (0.69 to 1.83)	0.63
Kidney function at admission				
Normal	1		1	
Preexisting CKD	9.19 (5.34 to 15.82)	<0.001	1.82 (1.01 to 3.33)	0.05
No data available	0.97 (0.49 to 1.95)	0.94	0.49 (0.23 to 1.04)	0.06
Admission diagnosis				
Sepsis	0.54 (0.28 to 1.02)	0.06	1.06 (0.54 to 2.08)	0.88
Thoracic surgery	0.37 (0.19 to 0.72)	0.003	0.74 (0.34 to 1.62)	0.46
Other	1		1	
Class of eGFR				
≥60 ml/min per 1.73 m^2	1		1	
30–59 ml/min per 1.73 m^2	3.18 (0.62 to 16.40)	0.17	3.77 (0.72 to 19.77)	0.12
15–29 ml/min per 1.73 m^2	27.19 (6.09 to 121.46)	<0.001	27.40 (5.79 to 129.60)	<0.001
<15 ml/min per 1.73 m^2	184.69 (43.32 to 787.37)	<0.001	176.96 (38.59 to 811.50)	<0.001
Malignancy	1.51 (0.86 to 2.65)	0.15	1.56 (0.85 to 2.85)	0.15
Cardiovascular disease	0.87 (0.56 to 1.33)	0.51	1.07 (0.65 to 1.78)	0.79
Diabetes mellitus	1.57 (0.98 to 2.52)	0.06	0.85 (0.50 to 1.46)	0.56
Hypertension	3.09 (2.00 to 4.76)	<0.001	1.29 (0.78 to 2.15)	0.32
Year of admission	1.00 (0.95 to 1.05)	0.98	0.98 (0.93 to 1.04)	0.56

Variables tested in multivariate analysis: age, medical admission type, preexisting CKD, admission diagnosis sepsis, thoracic surgery or other, class of estimated GFR at discharge, malignancy, cardiovascular disease, diabetes mellitus, hypertension and year of admission. HR, hazard ratio; CI, confidence interval; eGFR, estimated GFR (categorical class at discharge, compared with eGFR ≥60 ml/min per 1.73 m^2).

Survival was worse in the latter group. However, the degree of renal insufficiency at discharge was not shown, and the study included patients who developed AKI but were not admitted to an ICU or treated with RRT (19).

Only a few studies have evaluated the mortality rate and renal survival of patients who received RRT in the ICU after their hospital discharge (6,20–22). The largest study population was described by Wald *et al.* and consisted of 3769 patients enrolled during a 10-year period; the patients were compared with matched control ICU patients without AKI or RRT (6). The AKI group had a significantly increased risk for long-term RRT (HR, 3.23), but overall survival (50% mortality after 8 years) was similar to that in the control ICU patient group. In our study, patients discharged with an eGFR <30 ml/min per 1.73 m^2 (including patients receiving long-term RRT) showed a persistent association with long-term mortality after multivariate analysis. Only one published study is similar in design to ours (14); that study followed 226 survivors of RRT in the ICU for 5 years. Cumulative survival at 5 years was 47%, and partial recovery of renal function after RRT in the ICU was an independent predictor of poor long-term survival.

Of interest is the lack of association of cardiovascular risk factors, such as hypertension and diabetes mellitus, with survival and between preexisting CKD and survival. The significance of these relationships was lost in the multivariate analysis in which age and ESRD were the major risk factors for decreased survival. In the large cohort evaluated by Wald *et al.*, patients who needed RRT during the first 30 days after hospital discharge were excluded from analysis (6). According to our results, this would be the group of patients with worse long-term survival and could therefore at least partly explain the lack of association with mortality in their study. It is possible that some degree of renal recovery may still take place after hospital discharge, leading to underestimation of the true rate of renal recovery; unfortunately, data on renal recovery after hospital discharge were not available in our cohort (14,23).

We cannot conclude with certainty that the association between an eGFR <30 ml/min per 1.73 m^2 at hospital discharge and worse long-term survival implies causality. However, the association persisted even after adjustment for possible covariates that included known risk factors for CKD and progression of CKD, such as age and cardiovascular risk factors and preexisting CKD. Many studies have consistently shown that patients developing ESRD are at higher risk for cardiovascular events and have a higher mortality risk (8,24,25). All these observations agree with data from the general population in which mortality risk exponentially increases when GFR decreases below 60 ml/min per 1.73 m^2 (8). Therefore, prevention of (further) renal function deterioration in patients experiencing AKI by avoiding nephrotoxic drugs as much as possible could improve overall survival and prevent patients from reaching ESRD. Long-term nephrologic follow-up is necessary for patients who experience incomplete renal recovery after an episode of AKI, especially patients discharged with an eGFR <30 ml/min per 1.73 m^2, to minimize the complications of CKD.

Limitations of our study include its retrospective single-center cohort design. We did not calculate GFR by inulin clearance or a 24-hour urine collection but rather used eGFR according to the MDRD formula. Although this formula considers sex and age, it cannot correct for changes in body composition, as may be expected in formerly critically ill patients. However, because a substantial loss of muscle mass has most likely occurred in ICU patients, the eGFR at hospital discharge probably overestimates the true GFR and subsequently underestimates the number of patients discharged with an eGFR <30 ml/min per 1.73 m^2. Therefore, the effect of eGFR loss may be even greater than recorded in this study. On the other hand, follow-up of kidney function after discharge is not available in our cohort, and some patients may have shown a variable degree of recovery of eGFR over time that we could not account for in our analysis.

Because of the large time span of our patient registry, we depended on the analog and digital patient data management systems that have been used over time. Organ failure scores are available only since 2005 and have not always been used in our ICU; unfortunately, it is not possible to analyze the influence of severity of illness on overall and renal survival. In addition, treatment modalities for RRT and overall treatment strategies for ICU patients have changed over time. Date of admission was therefore included in our multivariate analyses but did not affect the overall conclusions.

The in-hospital mortality rate (55%) in our cohort, the percentage of patients discharged with the need for long-term RRT, and the overall survival of our patients after hospital discharge are similar to the results of previous studies (12,14,26–29). Furthermore, our cohort contains a diverse population of ICU patients, including a large group of patients admitted after thoracic surgery and septic patients. We found no differences in survival between admission types after multivariate analysis. Therefore, the patients in our cohort seem to represent an average population of ICU patients.

These findings add credibility to the generalization of our major finding that impaired kidney function at hospital discharge is independently associated with worse long-term overall and renal survival.

Acknowledgments

The abstract of the manuscript was selected for a poster presentation at the annual scientific meeting of the American Society of Nephrology, November 2011, in Philadelphia, Pennsylvania.

Disclosures

None.

References

1. Ishani A, Xue JL, Himmelfarb J, Eggers PW, Kimmel PL, Molitoris BA, Collins AJ: Acute kidney injury increases risk of ESRD among elderly. *J Am Soc Nephrol* 20: 223–228, 2009
2. Lo LJ, Go AS, Chertow GM, McCulloch CE, Fan D, Ordoñez JD, Hsu CY: Dialysis-requiring acute renal failure increases the risk of progressive chronic kidney disease. *Kidney Int* 76: 893–899, 2009
3. Lafrance JP, Miller DR: Acute kidney injury associates with increased long-term mortality. *J Am Soc Nephrol* 21: 345–352, 2010
4. Chawla LS, Amdur RL, Amodeo S, Kimmel PL, Palant CE: The severity of acute kidney injury predicts progression to chronic kidney disease. *Kidney Int* 79: 1361–1369, 2011

5. Tsagalis G, Akrivos T, Alevizaki M, Manios E, Theodorakis M, Laggouranis A, Vemmos KN: Long-term prognosis of acute kidney injury after first acute stroke. *Clin J Am Soc Nephrol* 4: 616–622, 2009
6. Wald R, Quinn RR, Luo J, Li P, Scales DC, Mamdani MM, Ray JG; University of Toronto Acute Kidney Injury Research Group: Chronic dialysis and death among survivors of acute kidney injury requiring dialysis. *JAMA* 302: 1179–1185, 2009
7. Bucaloiu ID, Kirchner HL, Norfolk ER, Hartle JE 2nd, Perkins RM: Increased risk of death and de novo chronic kidney disease following reversible acute kidney injury. *Kidney Int* 81: 477–485, 2012
8. Go AS, Chertow GM, Fan D, McCulloch CE, Hsu CY: Chronic kidney disease and the risks of death, cardiovascular events, and hospitalization. *N Engl J Med* 351: 1296–1305, 2004
9. Bagshaw SM, Laupland KB, Doig CJ, Mortis G, Fick GH, Mucenski M, Godinez-Luna T, Svenson LW, Rosenal T: Prognosis for long-term survival and renal recovery in critically ill patients with severe acute renal failure: A population-based study. *Crit Care* 9: R700–R709, 2005
10. Hoste EA, Schurgers M: Epidemiology of acute kidney injury: How big is the problem? *Crit Care Med* 36[Suppl]: S146–S151, 2008
11. de Mendonça A, Vincent JL, Suter PM, Moreno R, Dearden NM, Antonelli M, Takala J, Sprung C, Cantraine F: Acute renal failure in the ICU: Risk factors and outcome evaluated by the SOFA score. *Intensive Care Med* 26: 915–921, 2000
12. Uchino S, Kellum JA, Bellomo R, Doig GS, Morimatsu H, Morgera S, Schetz M, Tan I, Bouman C, Macedo E, Gibney N, Tolwani A, Ronco C; Beginning and Ending Supportive Therapy for the Kidney (BEST Kidney) Investigators: Acute renal failure in critically ill patients: a multinational, multicenter study. *JAMA* 294: 813–818, 2005
13. Loef BG, Epema AH, Smilde TD, Henning RH, Ebels T, Navis G, Stegeman CA: Immediate postoperative renal function deterioration in cardiac surgical patients predicts in-hospital mortality and long-term survival. *J Am Soc Nephrol* 16: 195–200, 2005
14. Schiffl H, Fischer R: Five-year outcomes of severe acute kidney injury requiring renal replacement therapy. *Nephrol Dial Transplant* 23: 2235–2241, 2008
15. Triverio PA, Martin PY, Romand J, Pugin J, Perneger T, Saudan P: Long-term prognosis after acute kidney injury requiring renal replacement therapy. *Nephrol Dial Transplant* 24: 2186–2189, 2009
16. Hoste EA, Clermont G, Kersten A, Venkataraman R, Angus DC, De Bacquer D, Kellum JA: RIFLE criteria for acute kidney injury are associated with hospital mortality in critically ill patients: A cohort analysis. *Crit Care* 10: R73, 2006
17. Coca SG, Yusuf B, Shlipak MG, Garg AX, Parikh CR: Long-term risk of mortality and other adverse outcomes after acute kidney injury: A systematic review and meta-analysis. *Am J Kidney Dis* 53: 961–973, 2009
18. Coca SG, Singanamala S, Parikh CR: Chronic kidney disease after acute kidney injury: A systematic review and meta-analysis. *Kidney Int* 81: 442–448, 2012
19. Liaño F, Felipe C, Tenorio MT, Rivera M, Abraira V, Sáez-de-Urturi JM, Ocaña J, Fuentes C, Severiano S: Long-term outcome of acute tubular necrosis: A contribution to its natural history. *Kidney Int* 71: 679–686, 2007
20. Morgera S, Kraft AK, Siebert G, Luft FC, Neumayer HH: Long-term outcomes in acute renal failure patients treated with continuous renal replacement therapies. *Am J Kidney Dis* 40: 275–279, 2002
21. Ahlström A, Tallgren M, Peltonen S, Räsänen P, Pettilä V: Survival and quality of life of patients requiring acute renal replacement therapy. *Intensive Care Med* 31: 1222–1228, 2005
22. Van Berendoncks AM, Elseviers MM, Lins RL; SHARF Study Group: Outcome of acute kidney injury with different treatment options: Long-term follow-up. *Clin J Am Soc Nephrol* 5: 1755–1762, 2010
23. Schiffl H: Renal recovery after severe acute renal injury. *Eur J Med Res* 13: 552–556, 2008
24. Drey N, Roderick P, Mullee M, Rogerson M: A population-based study of the incidence and outcomes of diagnosed chronic kidney disease. *Am J Kidney Dis* 42: 677–684, 2003
25. Herzog CA, Ma JZ, Collins AJ: Poor long-term survival after acute myocardial infarction among patients on long-term dialysis. *N Engl J Med* 339: 799–805, 1998
26. Bahar I, Akgul A, Ozatik MA, Vural KM, Demirbag AE, Boran M, Tasdemir O: Acute renal failure following open heart surgery: risk factors and prognosis. *Perfusion* 20: 317–322, 2005
27. Lopes JA, Fernandes P, Jorge S, Resina C, Santos C, Pereira A, Neves J, Antunes F, Gomes da Costa A: Long-term risk of mortality after acute kidney injury in patients with sepsis: A contemporary analysis. *BMC Nephrol* 11: 9, 2010
28. Aldawood A: Outcome and prognostic factors of critically ill patients with acute renal failure requiring continuous renal replacement therapy. *Saudi J Kidney Dis Transpl* 21: 1106–1110, 2010
29. Akposso K, Hertig A, Couprie R, Flahaut A, Alberti C, Karras GA, Haymann JP, Costa De Beauregard MA, Lahlou A, Rondeau E, Sraer JD: Acute renal failure in patients over 80 years old: 25-years' experience. *Intensive Care Med* 26: 400–406, 2000

Received: July 3, 2012 **Accepted:** March 3, 2013

Published online ahead of print. Publication date available at www.cjasn.org.