

The Association Between Urine Output, Creatinine Elevation, and Death

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Background. Acute kidney injury can be defined by a fall in urine output, and urine output criteria may be more sensitive in identifying acute kidney injury than traditional serum creatinine criteria. However, as pointed out in the Kidney Disease Improving Global Outcome guidelines, the association of urine output with subsequent creatinine elevations and death is poorly characterized. The purpose of this study was to determine what degrees of reduced urine output are associated with subsequent creatinine elevation and death.

Methods. This was a retrospective cohort study of adult patients (age ≥ 18 years) cared for in a cardiovascular intensive care unit after undergoing cardiac operations in a tertiary care university medical center. All adult patients who underwent cardiac operations and were not receiving dialysis preoperatively were studied. The development of acute kidney injury was defined as an increase in creatinine of more than 0.3 mg/dL or by more than 50% above baseline by postoperative day 3.

Results. Acute kidney injury developed in 1,061 of 4,195 patients (25%). Urine output had moderate discrimination in predicting subsequent acute kidney injury (C statistic = $.637 \pm .054$). Lower urine output and longer duration of low urine output were associated with greater odds of developing acute kidney injury and death.

Conclusions. We found that there is similar accuracy in using urine output corrected for actual, ideal, or adjusted weight to discriminate future acute kidney injury by creatinine elevation and recommend using actual weight for its simplicity. We also found that low urine output is associated with subsequent acute kidney injury and that the association is greater for lower urine output and for low urine output of longer durations. Low urine output ($<0.2 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$), even in the absence of acute kidney injury by creatinine elevation, is independently associated with mortality.

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Acute kidney injury (AKI) occurs commonly in intensive care unit (ICU) patients, affecting 11% to 57% of patients depending on the patient population, the severity of AKI, and the definition [1–5]. AKI is associated with increased death and ICU and hospital lengths of stay [1]. Improved understanding of AKI has been hampered by lack of a uniform definition and a tendency of studies to focus on more severe disease such as AKI requiring renal replacement therapy [1].

The development of consensus criteria for AKI definition and staging based on changes in serum creatinine (AKI-Cr) or urine output (UO; AKI-UO) has been an important advance [2, 3, 6]. The use of Cr values for the diagnosis of AKI in these guidelines is well supported because increases are associated with increased death [7]. However, although the measurement of UO in the ICU is almost de rigueur, the clinical importance of changes in UO is less well understood.

Possible explanations for the lack of research in this area include difficulties in collecting these data and concerns about how to interpret UO in the settings of diuretic medications, variable hydration state, and the presence of urinary obstruction [8]. Despite such limitations, UO remains an important, readily available clinical measure that provides an opportunity to identify AKI before changes in Cr become apparent. In fact, the effect of UO on AKI diagnosis and staging was specifically identified as an area in need of research in recent Kidney Disease Improving Global Outcomes (KDIGO) guidelines, which state, “The influence of urinary output criteria on AKI staging needs to be further investigated. Influence of . . . differing weights (actual, ideal body weight, lean body mass) should be considered. Also, it is currently not known how urine volume criteria should be applied

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(e.g., average vs. persistent reduction for the period specified) [9]."

Although there is overlap, a discordance frequently exists between patients diagnosed with AKI-Cr and AKI-UO. In these situations, whether AKI-Cr and AKI-UO have different or similar prognoses is unclear [6, 10–12]. Several recent studies have shown that AKI-UO is associated with increased death [13–15]. However, two of these studies each only examined a single threshold of low UO ($<7.2 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ [13] and $<500 \text{ mL/day}$ [15]), and one required Cr exceeding 3.5 mg/dL to define AKI [15] and were thus unable to establish a threshold or dose-dependency between AKI-UO and AKI-Cr and between AKI-UO and death. None of the studies evaluated whether the effect of different types of weight (actual, ideal, or adjusted) should be used to adjust UO. Indeed, a more comprehensive examination of the prognostic effect of AKI-UO requires a large database with complete UO and follow-up data.

The purposes of this study were to determine (1) what type of weight (actual, ideal, or adjusted) should be used to adjust for hourly UO, (2) what, if any, level of UO is a harbinger of AKI-Cr, and (3) is AKI-UO associated with death in patients after cardiac operations?

Patients and Methods

Study Population

This single-center retrospective study was approved by the Institutional Review Board, which waived informed consent because it was an analysis of deidentified data and performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All adult (age ≥ 18 years) patients who underwent cardiac operations between January 1, 2006, and December 31, 2011, and were not receiving dialysis preoperatively were studied. Patients with chronic kidney disease were included.

All patients received general anesthesia and were routinely monitored with arterial catheters. Almost all patients received hypothermic cardiopulmonary bypass. In the ICU, pulmonary artery catheters were continued until the patient was liberated from mechanical ventilation and on no more than low-dose inotropes or vasopressors. Arterial catheters were generally continued until just before ICU discharge.

Table 1. Patients Meeting Kidney Disease Improving Global Outcomes Creatinine Criteria for Acute Kidney Injury by the Start of Postoperative Days 1, 2, and 3 or on Any Day

KDIGO	Day 1 No.	Day 2 No.	Day 3 No.	Any Day No.
No	3,738	3,388	3,545	3,134
Stage 1	416	658	507	851
Stage 2	38	108	100	138
Stage 3	3	41	53	72

KDIGO = Kidney Disease Improving Global Outcomes Creatinine Criteria.

The occurrence of low UO ($<0.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$) was investigated by a member of the ICU team. If low UO was thought to be from hypovolemia, based on physical examination and central and systemic blood pressures, a fluid bolus of albumin or crystalloid was given. Hetastarches were not used. If sufficient anemia (hematocrit of $\sim 25\%$ at the start of the study, decreasing to 20% by the end of the study) was present, red blood cell transfusion would be given. If the low UO was thought to be related to low cardiac output, a fluid bolus would be given if there was associated hypovolemia, otherwise an inotrope would be added or increased. If associated with hypotension (mean arterial pressure <60 to 65 mm Hg) and a normal or elevated cardiac output, then depending on presumed volume status, a fluid bolus or a vasopressor would be used. Finally, if low UO was present despite

Table 2. Characteristics of Patients With and Without Acute Kidney Injury^a

Characteristic	AKI—Yes (n = 1,061)		AKI—No (n = 3,134)		p Value
	No.	%	No.	%	
Male	710	67	2,073	66	0.673
Hypertension	777	73	1,973	63	<0.001
Diabetes mellitus	264	25	625	20	<0.001
Cerebrovascular disease	129	12	299	10	0.018
Stroke	73	7	140	5	0.003
Peripheral vascular disease	94	9	194	6	0.004
Type of operation					<0.001
CABG only	95	9	488	16	<0.001
CABG and valve	85	8	190	6	0.073
Valve only	239	23	798	26	0.029
Aortic only	80	8	231	7	0.746
Aortic and valve and/or CABG	488	46	1,160	37	<0.001
Other	6	0.6	11	0.4	0.486
Chronic lung disease					<0.001
None	865	82	2,702	86	<0.001
Mild	110	10	264	8	0.061
Moderate	48	5	103	3	0.131
Severe	38	4	65	2	0.008
Race					<0.001
White	895	84	2,790	89	<0.001
Black	111	10	141	4	<0.001
Other	49	5	174	6	0.268
	Mean	SD	Mean	SD	
Age, y	63	14	61	14	<0.001
Height, cm	172	11	172	11	0.779
Ejection fraction	.53	.15	.55	.14	0.008
Preoperative creatinine, mg/dL	1.2	0.4	1.0	0.3	<0.001

^a Missing data: age (n = 1), height (n = 9), and ejection fraction (n = 144).

AKI = acute kidney injury; CABG = coronary artery bypass grafting.

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