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Perioperative acute kidney injury and urine output in lower limb arthroplasties

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Background: This study aimed to evaluate the occurrence and perioperative risk factors of acute kidney injury (AKI) in primary elective hip and knee and emergency hip arthroplasty patients. We also aimed to assess the effect of urine output (UOP) as a diagnostic criterion in addition to serum creatinine (sCr) levels. We hypothesized that emergency arthroplasties are prone to AKI and that UOP is an underrated marker of AKI.

Methods: This retrospective, register-based study assessed 731 patients who underwent primary elective knee or hip arthroplasty and 170 patients who underwent emergency hip arthroplasty at Oulu University Hospital, Finland, between January 2016 and February 2017.

Results: Of the elective patients, 18 (2.5%) developed AKI. The 1-year mortality rate was 1.5% in elective patients without AKI and 11.1% in those with AKI ($P = .038$). Of the emergency patients, 24 (14.1%) developed AKI. The mortality rate was 16.4% and 37.5% in emergency patients without and with AKI, respectively ($P = .024$). In an AKI subgroup analysis of the combined elective and emergency patients, the mortality rate was 31.3% (n = 5) in the sCr group (n = 16), 23.5% (n = 4) in the UOP group (n = 17), and 22.2% (n = 2) in AKI patients who met both the sCr and UOP criteria (n = 9).

Conclusion: Emergency hip arthroplasty is associated with an increased risk of AKI. Since AKI increases mortality in both elective and emergency arthroplasty, perioperative oliguria should also be considered as a diagnostic criterion for AKI. Focusing solely on sCr may overlook many cases of AKI.

Editorial Comment

Hip and knee arthroplasty can lead to perioperative kidney injury and also higher likelihood of postoperative mortality. This retrospective study demonstrated that emergency hip arthroplasty was associated with higher risk of perioperative acute kidney injury and that both increased serum creatinine and oliguria should be considered as diagnostic signs of kidney injury.

1 | INTRODUCTION

The occurrence of perioperative acute kidney injury (AKI) varies from 0.5% to 40%, depending on the type of surgery, patient-dependent risk factors, and the study.[1-5] In elective arthroplasties, the occurrence may be 0.5%-19.4%.[5,6] Perioperative AKI increases the risk of morbidity and mortality and increases the length of hospital stay.[3,5,7]

Perioperative AKI is detected and considered based on diagnostic criteria. The Kidney Disease: Improving Global Outcomes (KDIGO) criteria include both absolute and relative increases in baseline serum creatinine (sCr), diminished urine output (UOP), and/or use of renal replacement therapy (RRT).[8-10] The previous diagnostic criteria for AKI, the Risk, Injury, Failure; Loss, End-Stage Renal Disease (RIFLE), and Acute Kidney Injury Network (AKIN) criteria already included diminished UOP as a criterion for AKI.[8] However, most recent AKI studies focusing on orthopedic patients have ignored the UOP criteria altogether and focused solely on sCr. Most studies acknowledge this, and UOP is generally disregarded because of difficulties obtaining relevant data, especially retrospectively.[6,11-20] Some studies have not addressed UOP at all.[21,22] This is even though diminished UOP alone has been shown to increase mortality.[23-26]

There has been extensive debate regarding how UOP should be observed. Studies have suggested that 6-hours observation blocks should be accurate, and weight-adjusted UOP might both overdiagnose and underdiagnose AKI.[27,28] A study of hepatectomy and AKI concluded that postoperative UOP correlated poorly with sCr.[29] A study of cardiac surgeries found that all stages of UOP-diagnosed AKI were associated with the long-term mortality of postoperative patients.[26] Both elevated sCr levels and postoperative oliguria may increase morbidity and mortality.[26] However, few studies have focused on the relationship between AKI, sCr, and UOP in orthopedic surgeries.

Intraoperatively diminished UOP might not be a sign of present or developing AKI.[10,30] A study of major abdominal surgeries found a median intraoperative diuresis of less than 0.3 mL/kg/h to be independently associated with postoperative AKI, with no correlation between UOP of 0.3-0.5 mL/kg/h.[31] Another study of major noncardiac surgery patients concluded that there is an association between intraoperative oliguria, defined as UOP <0.5 mL/kg/h for 120 minutes, and AKI, defined by an increase in sCr levels.[32] The percentage of orthopedic surgeries in their groups of oliguria for >120 and <120 minutes was 14.3% and 19.6%, respectively.

In light of recent literature, we hypothesized that emergency arthroplasties are associated with an increased risk of both AKI and mortality and that the measurement and interpretation of perioperative UOP are underrated in relation to AKI. This study aimed to evaluate the occurrence and risk factors of perioperative AKI defined by both the sCr and UOP criteria in orthopedic patients undergoing primary elective knee and hip and emergency hip arthroplasty.

2 | METHODS

The ethics committee of Northern Ostrobothnia approved the study on 12.03.2018 (approval number 11/2018). The requirement for written informed consent was waived by the ethics committee. We conducted a retrospective, hospital register-based study of patients who underwent primary knee or hip arthroplasty between January 2016 and February 2017 at the Oulu University Hospital, Oulu, Finland. The inclusion criteria were primary knee or hip arthroplasty (operation codes NFB10-90, NGB10-90), available preoperative sCr, and electronic anesthesia and operation records. Data were collected from the anesthesia and patient records.

Patients received either spinal or general anesthesia. The use of vasoactive drugs was classified to describe whether a patient needed only brief vasoactive administration of <3 boluses or a more continuous support of ≥3 boluses or an infusion. Etilefrine (Effortil®) was administered as boluses, and infusions consisted of noradrenaline (Arterenol®).

The estimated glomerular filtration rate (eGFR) was calculated using the Chronic Kidney Disease Epidemiology Collaboration formula.[33] Preoperative eGFR was calculated from the baseline sCr taken prior to the operation.[28] Postoperative eGFR was estimated from the peak sCr on postoperative days 1, 2-3, and 4-7. If the patient had a diagnosis of any kidney disease in their patient records, such as cancer of the kidney, diabetic nephropathy, or chronic kidney disease (CKD), they were classified as having a prediagnosed kidney disease.

The patients were divided into elective and emergency cases and analyzed separately (Figure 1). AKI was evaluated based on the sCr and UOP criteria of the KDIGO classification.[8] Intraoperative diuresis was not considered a diagnostic criterion; only postoperative diuresis was considered. Due to the UOP data being incomplete for some cases and the study's retrospective nature, we had to modify the UOP criteria for AKI. It was not possible to observe hourly UOP from the available data; rather, we could only calculate the average daily UOP. The UOP criteria used for AKI were an average UOP of <0.5 mL/kg/h over 48 hours and the availability of at least one full day of UOP data after this 48-hours period. Two consecutive days of low UOP were chosen after an analysis which showed that most patients with a single 24 hours of UOP of <0.5 mL/kg/h were generally healthier and were mostly elective patients whose UOP registration was incomplete. Patients with available UOP data had a fluid balance chart, but the measurement method was impossible to determine retrospectively. AKI was defined using the KDIGO sCr criteria, our modified UOP criteria, or both sCr and UOP criteria simultaneously. The mortality of patients at the 1-year point was obtained from the patient records, which automatically updated the information from a national digital and population data services agency.

2.1 | Statistical analyses

The data were analyzed using SPSS for Windows (IBM Corp., released 2016, version 24.0). No formal sample-size

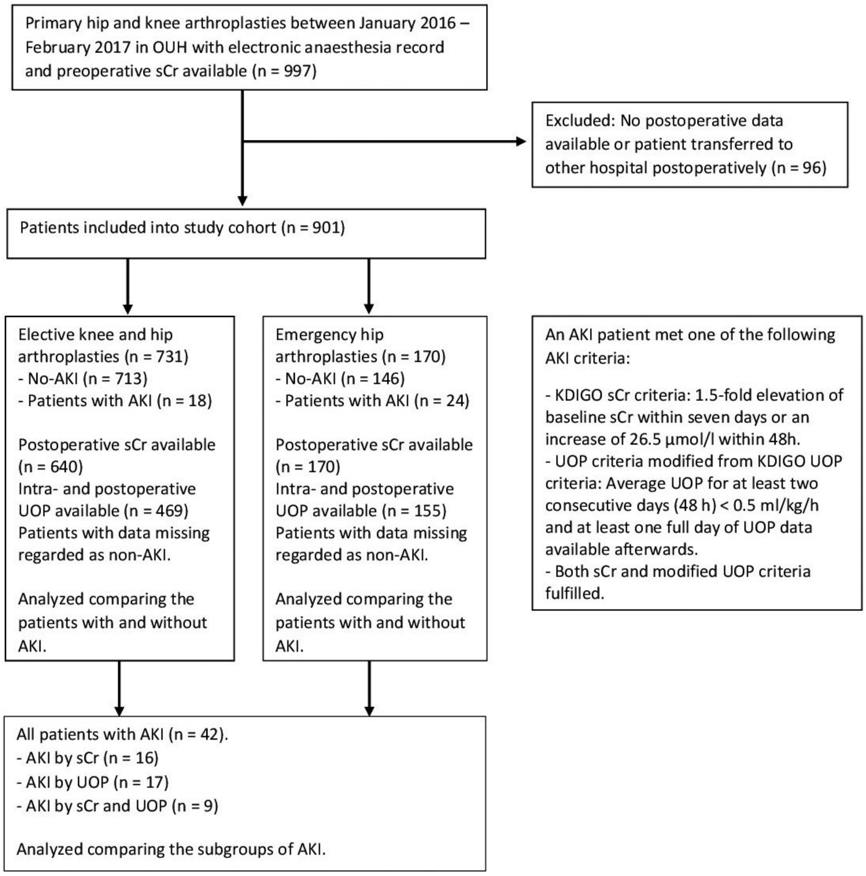

FIGURE 1 Flow diagram of patient classification into AKI or no AKI groups and further into subgroups of AKI according to the diagnostic criteria met. AKI, acute kidney injury; KDIGO, Kidney Disease, Improving Global Outcomes; OUH, Oulu University Hospital; sCr, serum creatinine; UOP, urine output

calculations were performed. Continuous variables were analyzed using the Mann–Whitney U test when two groups were compared and the Kruskal–Wallis test when three groups were compared. Continuous data are presented as medians with 25th to 75th percentiles unless otherwise stated. Categorical variables were analyzed using the Fisher's exact test or Pearson's chi-square test. Three different multivariable logistic regression models for AKI were created separately for elective and emergency surgeries and the two combined. Based on known risk factors and univariate analysis of demographics, age, body mass index (BMI) (<30 and ≥30 kg/m^2), American Society of Anesthesiologists (ASA) class (1-2 vs 3-5), preoperative eGFR, presence of diagnosed diabetes, kidney disease, hypertension, and cardiovascular disease were entered one by one into the logistic regression model and were left in the model if the *P*-value was less than .05 or if there was a significant effect on the model (the value of −2 log-likelihood function decreased significantly). In the models, age was categorized into quartiles, and preoperative eGFR was categorized as ≥90, 60-89, and <60 mL/min/1.73 m^2. Furthermore, in the combined model, the type of operation (knee/elective hip/emergency hip) was considered a potential risk factor. The logistic regression model results are reported as odds ratios with 95% confidence intervals (95% CI). Two-tailed *p*-values are presented.

3 | RESULTS

A total of 997 patients met the inclusion criteria. Ninety-six patients were transferred from recovery to a private hospital, and no postoperative data were available from these patients. Therefore, they were excluded. Elective knee and hip arthroplasties were performed on 731 patients, and 18 (2.5%) developed AKI. Emergency hip arthroplasties were performed in 170 patients, and 24 (14.1%) developed AKI. Sixteen patients met the sCr criteria for AKI, 17 met the UOP criteria, and 9 met both criteria (Figure 1).

The baseline clinical and demographic data are presented in Table 1. In elective arthroplasties, the patients who developed AKI were older, had a higher BMI, a higher ASA status, more comorbidities, and more medications. In emergency hip arthroplasties, patients with AKI usually had a preoperative eGFR >90 mL/min/1.73 m^2.

The perioperative characteristics and intraoperative data are presented in Table 2. Elective knee arthroplasty was performed in 418 patients, and 7 (1.7%) developed AKI. Elective hip arthroplasty was performed in 313 patients and (3.5%) had AKI. In elective operations, patients with AKI spent more time in the operation and recovery rooms, experienced slightly more blood loss, and received more blood products. Although the patients with AKI received vasoactive medication and were normotensive (mean arterial pressure; MAP >60 mm Hg) as often as patients with no AKI, the patients with

TABLE 1 Baseline clinical and demographic characteristics of elective and emergency arthroplasty patients with and without perioperative AKI stages 1-3

	Elective N = 731	AKI (−) N = 713	AKI (+) N = 18	*P*-value	Emergency N = 170	AKI (−) N = 146	AKI (+) N = 24	*P*-value
Demographics								
Age, median (25th to 75th percentiles)	69 (61-77)	68 (60-77)	77 (72-83)	.002	82 (77-87)	82 (76-87)	86 (79-92)	.061
Female, N (%)	446 (61.0)	437 (61.3)	9 (50.0)	.46	112 (65.9)	97 (66.4)	15 (62.5)	.82
BMI, median (25th to 75th percentiles)	28.1 (25.1-32.0)	28.0 (25.1-31.9)	31.7 (28.1-35.1)	.015	23.8 (21.5-26.0)	23.7 (21.4-25.6)	24.6 (22.6-28.6)	.11
ASA status								
ASA1, N (%)	43 (5.9)	43 (6.0)	0	.013	2 (1.2)	1 (0.7)	1 (4.2)	.28
ASA2, N (%)	330 (45.1)	324 (45.4)	6 (33.3)		18 (10.6)	17 (11.6)	1 (4.2)	
ASA3, N (%)	330 (45.1)	322 (45.2)	8 (44.4)		111 (65.3)	96 (65.8)	15 (62.5)	
ASA4, N (%)	28 (3.8)	24 (3.4)	4 (22.2)		39 (22.9)	32 (21.9)	7 (29.2)	
Preoperative eGFR								
Normal; >90 (mL/min/1.73 m^2), N (%)	324 (44.3)	318 (44.7)	5 (27.8)	.070	35 (20.6)	34 (23.3)	1 (4.2)	.029
Mild decrease;								
60-89 (mL/min/1.73 m^2), N (%)	332 (45.4)	324 (45.4)	8 (44.4)		94 (55.3)	81 (55.5)	13 (54.2)	
Moderate decrease								
30-59 (mL/min/1.73 m^2), N (%)	69 (9.4)	64 (9.0)	5 (27.8)		35 (20.6)	27 (18.5)	8 (33.3)	
Severe decrease or ESRD								
<30 (mL/min/1.73 m^2), N (%)	6 (0.8)	6 (0.8)	0		6 (3.5)	4 (2.7)	2 (8.3)	
Medical history								
Diabetes Mellitus, N (%)	140 (19.2)	133 (18.7)	7 (38.9)	.040	33 (19.4)	27 (18.5)	6 (25.0)	.42
Diagnosed kidney disease, N (%)	44 (6.0)	41 (5.8)	3 (16.7)	.088	14 (8.2)	12 (8.2)	2 (8.3)	>.90
Hypertension, N (%)	453 (62.0)	437 (61.3)	16 (88.9)	.024	105 (61.8)	88 (60.3)	17 (70.8)	.37
Cardiovascular disease, N (%)	307 (42.0)	292 (41.0)	15 (83.3)	<.001	104 (61.2)	87 (59.6)	17 (70.8)	.37
Pharmacotherapy								
Sartan, N (%)	209 (28.6)	197 (27.6)	12 (66.7)	.001	37 (21.8)	31 (21.9)	5 (20.8)	>.90
Betablocker, N (%)	293 (40.1)	279 (39.1)	14 (77.8)	.001	91 (53.5)	77 (52.7)	14 (58.3)	.66
Diuretic, N (%)	230 (31.5)	219 (30.7)	11 (61.1)	.009	74 (43.5)	62 (42.5)	12 (50.0)	.51

Note: Proportion of AKI describes the percentage of AKI patients within the variable in question. *P*-values are presented for AKI (−) and AKI (+) comparisons.

Abbreviations: AKI, acute kidney injury; BMI, body mass index; eGFR, estimated glomerular filtration rate; ESRD, end stage renal disease;KDIGO, Kidney Disease: Improving Global Outcomes.

TABLE 2 Perioperative characteristics of elective knee and hip and emergency hip arthroplasty patients with and without perioperative AKI stages 1-3

	Elective N = 731	AKI (–) N = 713	AKI (+) N = 18	*P*-value	Emergency N = 170	AKI (–) N = 146	AKI (+) N = 24	*P*-value
Type of operation								
Knee arthroplasty, N (%)	418 (57.2)	411 (57.6)	7 (38.9)	.15	-	-	-	
Hip arthroplasty, N (%)	313 (42.8)	302 (42.4)	11 (61.1)		170 (100)	146 (100)	24 (100)	
Cement used, hip arthroplasty, N (%)	18 (5.8)	16 (5.3)	2 (18.2)	.13	133 (78.2)	112 (76.7)	21 (87.5)	.30
Perioperative pharmacotherapy								
Opioid, per os, N (%)	647 (88.6)	631 (88.6)	16 (88.9)	>.90	120 (70.6)	100 (68.5)	20 (83.3)	.16
Opioid, other, N (%)	687 (94.1)	669 (94.0)	18 (100)	.41	163 (95.9)	141 (96.6)	22 (91.7)	.26
Paracetamol, N (%)	685 (93.7)	667 (93.5)	18 (100)	.40	147 (86.5)	128 (87.7)	19 (79.2)	.33
NSAID, any, N (%)	98 (13.4)	94 (13.2)	4 (22.2)	.27	19 (11.2)	18 (12.3)	1 (4.2)	.42
Ketorolac (LIA), N (%)	355 (48.6)	349 (48.9)	6 (33.3)	.24	-	-	-	
Etoricoxib, N (%)	430 (58.8)	425 (59.6)	5 (27.8)	.008	5 (2.9)	5 (3.4)	0	>.90
Antiemetic, N (%)	262 (35.8)	256 (35.9)	6 (33.3)	>.90	55 (32.4)	47 (32.2)	8 (33.3)	>.90
Diuretic, N (%)	67 (9.2)	63 (8.8)	4 (22.2)	.074	53 (31.2)	44 (30.1)	9 (37.5)	.48
Pharmacotherapy, morning prior operation								
ACE-blocker, N (%)	25 (3.4)	25 (3.4)	0	>.90	4 (2.4)	4 (2.7)	0	>.90
Sartan, N (%)	36 (4.9)	35 (4.9)	1 (5.9)	.58	3 (1.8)	3 (2.1)	0	>.90
Betablocker, N (%)	227 (31.1)	218 (30.6)	9 (50.0)	.12	69 (40.6)	60 (40.1)	9 (37.5)	.83
Type of anesthesia								
General anesthesia, N (%)	172 (23.5)	168 (23.6)	4 (22.2)	>.90	35 (20.6)	30 (20.5)	5 (20.8)	>.90
Spinal anesthesia, N (%)	559 (76.5)	545 (76.4)	14 (77.8)		135 (79.4)	116 (79.5)	19 (79.2)	
Duration, median (25th to 75th percentiles)								
Operation +recovery room (h:min)	6:35 (5:38-7:38)	6:34 (5:37-7:36)	7:48 (6:17-9:07)	.019	6:32 (5:50-7:36)	6:29 (5:48-7:33)	6:41 (6:12-7:48)	.25
Operation (h:min)	1:29 (1:13-1:50)	1:29 (1:13-1:49)	1:23 (1:08-2:23)	.68	1:16 (1:06-1:26)	1:15 (1:05-1:26)	1:17 (1:08-1:22)	.68
Tourniquet, knee (h:min) (N = 351)	1:31 (1:14-1:47)	1:30 (1:15-1:46)	1:52 (0:57-1:58)	.42	-	-	-	
Fluids, median (25th to 75th percentiles)								
Blood loss (mL)	200 (50-400)	200 (50-350)	325 (140-565)	.32	300 (200-350)	300 (200-400)	300 (200-300)	.31
Diuresis (mL/kg/h)	0.84 (0.48-1.40)	0.86 (0.48-1.41)	0.80 (0.49-0.88)	.20	1.23 (0.73-1.84)	1.30 (0.78-2.02)	0.82 (0.51-1.26)	.001
Infusion of fluids (mL/kg/h)	3.7 (2.8-4.9)	3.7 (2.8-4.9)	3.3 (3.0-4.0)	.23	5.2 (4.0-6.7)	5.2 (4.0-6.9)	5.4 (3.8-6.6)	.81
Blood products (ml)[a]	0 (0-0)	0 (0-0)	0 (0-0)[90th percentile 530]	<.001	0 (0-0)	0 (0-0)	0 (0–0){90th percentile 415}	.25
Blood products, N (%)[a]	21 (2.9)	18 (2.5)	3 (16.7)	.013	18 (10.7)	14 (9.6)	4 (17.4)	.28
Colloids, N (%)	3 (0.4)	3 (0.4)	0	>.90	7 (4.1)	4 (2.7)	3 (12.5)	.059

(Continues)

TABLE 2 (Continued)

	Elective N = 731	AKI (−) N = 713	AKI (+) N = 18	P-value	Emergency N = 170	AKI (−) N = 146	AKI (+) N = 24	P-value
MAP								
>60 mm Hg, N (%)	527 (72.1)	514 (72.1)	13 (72.2)	.005	90 (52.9)	78 (53.4)	12 (50.0)	.46
60-55 mm Hg for over 10 min, N (%)	11 (1.5)	11 (11.5)	0		2 (1.2)	1 (0.7)	1 (4.2)	
<55 mm Hg for less than 20 min, N (%)	181 (24.8)	179 (25.1)	2 (11.1)		68 (40.0)	58 (39.7)	10 (41.7)	
<55 mm Hg for over 20 min, N (%)	12 (1.6)	9 (1.3)	3 (16.7)		10 (5.9)	9 (6.2)	1 (4.2)	
Vasoactive use								
Not used, N (%)	338 (46.2)	330 (46.3)	8 (44.4)	>.90	39 (22.9)	35 (24.0)	4 (16.7)	.32
<3 bolus, N (%)	103 (14.1)	100 (14.0)	3 (16.7)		8 (4.7)	8 (5.5)	0	
≥3 bolus or infusion, N (%)	290 (39.7)	283 (39.7)	7 (38.9)		123 (72.4)	103 (70.5)	20 (83.3)	

Abbreviations: AKI, acute kidney injury; KDIGO, Kidney Disease: Improving Global Outcomes; LIA, local infiltration anesthesia; MAP, mean arterial pressure; NSAID, nonsteroidal anti-inflammatory drug, excluding etoricoxib.

[a]Blood products include all kind of blood products, such as red blood cells and platelets. *P*-values are presented for AKI (−) and AKI (+) comparisons.

AKI suffered from a prolonged period of low MAP more often. In emergency arthroplasties, patients with AKI had lower intraoperative diuresis.

Postoperative data are presented in Table 3. In elective arthroplasties, patients with AKI more often received diuretics, and their blood pressure medication was altered more often. They experienced more fever but did not receive any more antibiotics than patients without AKI. Their diuresis during the day of surgery was significantly lower, and this continued until postoperative day one. The patients received more fluids on the first postoperative day. The preoperative eGFR was lower, and the eGFR gradually deteriorated during the postoperative period.

In emergency arthroplasties, patients with AKI had more frequent alterations in their blood pressure medications. They experienced more hypotensive episodes than patients without AKI. Their median diuresis during the day of surgery was lower, and this continued during postoperative Day 1. Patients with AKI had a lower preoperative eGFR, which further deteriorated during the postoperative days.

The outcomes are shown in Table 4. None of the patients received RRT. In elective patients, mortality was 1.5% in those without AKI and 11.1% in those with AKI (*P* = .038). Mortality in emergency patients was 16.4% in those without AKI and 37.5% in those with AKI (*P* = .024). The location of follow-up treatment in elective patients with AKI was in the majority of cases at home, with 63.7% of patients without AKI going home, while 38.9% of patients with AKI went home (*P* = .074). Most emergency arthroplasty patients without AKI went either to a health center ward (44.8%) or were transferred to another hospital ward (51.0%), while those with AKI went less often to a health center ward (29.2%) and more often to a hospital ward (58.3%, *P* = .049).

Table 5 presents the results for the different AKI subgroups. The 1-year mortality rate was 31.3% (n = 5) in the sCr group, 23.5% (n = 4) in the UOP group, and 22.2% (n = 2) in patients with AKI who met both the sCr and UOP criteria (*P* > .90). The location of follow-up treatment was mostly not at home. Overall, only 6.3% of patients in the sCr group, 29.4% in the UOP group, and 22.2% in the AKI patient group fulfilling both criteria were discharged home (*P* = .27). Most AKI patients had stage 1 AKI (n = 38), and only four had stage 3 AKI. None had stage 2 AKI. A comparison of these stages was impossible due to the low occurrence of AKI other than stage 1. The median UOP on the operation day was lower than the intraoperative UOP in all subgroups. In patients with sCr-based AKI, the UOP improved the following day. eGFR did not decline in patients with UOP-based AKI. The eGFR and UOP statistics between AKI and non-AKI patients and between the AKI subgroups are shown in Figure 2.

Table 6 shows the multivariable regression model separately for elective and emergency patients and both combined. Higher age and BMI increased the risk of AKI in all three models. Additionally, the risk for AKI increased if an elective patient had cardiovascular disease or if an emergency patient had abnormal preoperative eGFR. Furthermore, emergency patients had a higher risk of AKI in the combined model.

4 | DISCUSSION

Emergency arthroplasty is associated with an increased risk of both AKI and mortality. Our data suggest that attention needs to be paid to the patient's diuresis in the postoperative ward, especially if the patient's UOP on the operation day is low. Regardless of whether the diagnosis is based on sCr, UOP, or both, AKI may increase mortality.[26,34] SCr and UOP do not often correlate.[23,26,29] In studies regarding orthopedic surgery procedures and perioperative AKI, postoperative UOP should also be considered a diagnostic criterion for AKI, as not all AKI patients will otherwise be recognized. This remains challenging due to the availability and reliability of postoperative UOP data.

TABLE 3 Postoperative characteristics of elective and emergency arthroplasty patients with and without perioperative AKI stages 1-3 at postoperative hospital ward

	Elective N = 731	AKI (-) N = 713	AKI (+) N = 18	*P*-value	Emergency N = 170	AKI (-) N = 146	AKI (+) N = 24	*P*-value
Pharmacological therapy at the ward								
Diuretics, N (%)	219 (30.9)	206 (28.9)	13 (72.2)	<.001	103 (60.6)	84 (57.7)	19 (79.2)	.070
Etoricoxib, N (%)	371 (50.8)	364 (51.1)	7 (38.9)	.35	5 (2.9)	5 (3.4)	0	>.90
NSAID, any N (%)	152 (22.4)	159 (22.3)	5 (27.8)	.78	41 (24.3)	39 (26.9)	2 (8.3)	.069
Antibiotic treatment started, N (%)	23 (3.1)	22 (3.1)	1 (5.6)	.41	30 (17.6)	25 (17.1)	5 (20.8)	.77
Blood pressure medication altered or initiated, N (%)	158 (21.6)	146 (20.5)	12 (66.7)	<.001	92 (54.1)	73 (50.0)	19 (79.2)	.008
Blood pressure trend, >2 measurements								
Normal, N (%)	596 (81.8)	579 (81.4)	17 (94.4)	.89	115 (68.5)	102 (70.8)	13 (54.2)	.027
Hypotension <100/60 mm Hg, N (%)	43 (5.9)	43 (6.0)	0		17 (10.1)	11 (7.6)	6 (25.0)	
Hypertension >140/90 mm Hg, N (%)	62 (8.5)	61 (8.6)	1 (5.6)		18 (10.7)	17 (11.8)	1 (4.2)	
Both hypotension and hypertension, N (%)	5 (0.7)	5 (0.7)	0		5 (3.0)	3 (2.1)	2 (8.3)	
BP at least once <90/60 mm Hg, N (%)	23 (3.2)	23 (3.2)	0		13 (7.7)	11 (7.6)	2 (8.3)	
Temperature >38.0°C								
Temperature once >38.0°C, N (%)	73 (10.0)	71 (10.0)	2 (11.1)	.006	36 (21.3)	29 (20.0)	7 (29.2)	.47
Temperature >38.0°C 2 times or more, N (%)	51 (7.0)	46 (6.5)	5 (27.8)		42 (24.9)	38 (26.2)	4 (16.7)	
Fluid balance, the whole day of operation, median (25th to 75th percentiles)								
Diuresis (mL/kg/h), N = 485/157[a]	0.63 (0.42-0.92)	0.63 (0.44-0.94)	0.43 (0.38-0.52)	.004	0.74 (0.49-1.06)	0.77 (0.56-1.07)	0.45 (0.38-0.63)	<.001
Fluid intake (mL/kg/h), N = 681/154	1.4 (1.1-1.8)	1.4 (1.1-1.8)	1.3 (1.1-1.7)	.46	2.0 (1.5-2.5)	2.1 (1.5-2.5)	1.8 (1.7-2.2)	.55
Diuresis at the ward, median (25th to 75th percentiles)								
First postop. day (mL/kg/h), N = 469/155	0.94 (0.56-1.3)	0.97 (0.59-1.35)	0.42 (0.34-0.64)	<.001	0.86 (0.53-1.13)	0.90 (0.65-1.12)	0.46 (0.38-0.83)	<.001
Second postop. day (mL/kg/h), N = 274/129	0.65 (0.39-1.0)	0.66 (0.39-1.04)	0.54 (0.37-1.01)	.62	0.66 (0.37-1.12)	0.67 (0.40-1.13)	0.49 (0.28-0.90)	.089
Fluid intake measured on the ward, median (25th to 75th percentiles)[b]								
First postop. day (mL/kg/h), N = 641/155	0.4 (0.2-0.8)	0.4 (0.2-0.8)	0.6 (0.4-1.3)	.027	0.9 (0.5-1.3)	0.9 (0.5-1.3)	0.9 (0.6-1.6)	.25
Second postop. day (mL/kg/h), N = 277/120	0.1 (0-0.5)	0.0 (0.0-0.4)	0.3 (0.1-0.7)	.069	0.5 (0.2-0.8)	0.5 (0.1-0.8)	0.6 (0.3-0.8)	.33
eGFR statistics, median (25th to 75th percentiles)								
Preop. baseline eGFR (mL/min/1.73 m^2), N = 731/170	88 (75-97)	88 (75-97)	70 (57-91)	.008	77 (61-88)	78 (63-89)	68 (41-79)	.005
Postop. eGFR first day (mL/min/1.73 m^2), N = 622/169	91 (82-100)	92 (82-100)	62 (40-94)	.001	81 (62-90)	83 (71-91)	53 (34-78)	<.001
Postop. eGFR days 2-3 (mL/min/1.73 m^2), N = 433/156	87 (75-98)	87 (76-98)	50 (37-87)	<.001	80 (60-88)	82 (65-89)	40 (31-69)	<.001
Postop. eGFR days 4-7 (mL/min/1.73 m^2), N = 223/96	85 (74-93)	85 (75-93)	40 (32-75)	<.001	72 (52-84)	77 (59-85)	38 (28-68)	<.001

Abbreviations: AKI, acute kidney injury; BP, blood pressure; eGFR, estimated glomerular filtration rate; NSAID, nonsteroidal anti-inflammatory drug.

[a]The N describes N = (total number of elective patients with the data available/total number of emergency patients with the data available).

[b]The N is the number of patients with the respective information available, disregarding whether there was, for example, only one measurement available, thus giving a conclusion that a patient's fluid intake was not monitored thoroughly at the ward. *P*-values are presented for AKI (−) and AKI (+) comparisons.

TABLE 4 Mortality and postoperative outcomes of arthroplasty patients with and without perioperative AKI

	Elective knee and hip (N = 731)	AKI (−) (N = 7130	AKI (+) (N = 18)	P-value	Emergency hip (N = 170)	AKI (−) (N = 143)	AKI (+) (N = 24)	P-value
Length of hospital stay (d), median (25th–75th percentiles)	3 (2–3)	3 (2–3)	3 (2.75–4)	.092	2 (2–3)	2 (2–3)	2 (2–3)	>.90
Renal replacement therapy	0	0	0		0	0	0	
Intensive care, N (%)	10 (1.4)	10 (1.4)	0	>.90	7 (4.1)	6 (4.1)	1 (4.2)	>.90
Location of follow-up treatment, N (%)								
Home	460 (63.1)	453 (63.7)	7 (38.9)	.074	7 (4.2)	6 (4.2)	1 (4.2)	.049
Health center ward	153 (21.0)	149 (21.0)	4 (22.2)		71 (42.5)	65 (44.8)	7 (29.2)	
Hospital	115 (15.8)	108 (15.2)	7 (38.9)		87 (52.1)	73 (51.0)	14 (58.3)	
Death during primary treatment period	0	0	0		2 (1.2)	0	2 (8.3)	
Mortality, N (%)								
1-year mortality	13 (1.8)	11 (1.5)	2 (11.1)	.038	33 (19.4)	24 (16.4)	9 (37.5)	.024
14-day mortality[a]	1 (0.1)	1 (0.1)	0	>.90	4 (2.4)	2 (1.4)	2 (8.3)	.096

Abbreviation: AKI, acute kidney injury.

[a]Within 14 days after the end of hospital stay. P-values are presented for AKI (−) and AKI (+) comparisons.

The AKI criteria and data available have varied greatly in previous orthopedic studies, with AKI incidence varying from 0.5% to 19.4% in elective hip or knee arthroplasties.[5,6,13] A study of 337 elective knee and hip arthroplasty patients found the incidence to be 6.2%, which increased to 16.3% if the preoperative eGFR was <60 mL/min/1.73 m^2.[17] All the results mentioned above were based on the measurements of sCr alone. In our study, preoperative eGFR was generally lower in patients with AKI than in non-AKI patients. Preoperative eGFR results of <60 mL/min/1.73 m^2 were overrepresented in both elective and emergency arthroplasty AKI patients. This is in line with the results presented by Blitz et al, who concluded that the risk for postoperative AKI is at least doubled if the preoperative eGFR is <60 mL/min/1.73 m^2 compared to >60 mL/min/1.73 m^2.[35] It is noteworthy that patients with a UOP-based diagnosis of AKI had a higher preoperative eGFR than the other AKI subgroups.

Emergency hip arthroplasty increases the risk of both AKI and mortality. A study of 13,529 hip fracture patients that defined AKI by sCr alone reported an AKI incidence rate of 12.7% and one-year mortality rates of 25.0% and 18.3%, respectively, for those with and without AKI.[16] This difference in mortality is consistent with our findings of 37.5% and 16.4%, respectively. Two other hip fracture studies with sCr as the sole AKI criterion found the proportion of AKI to be 24.0% and 8.4%, with a 1-year mortality rate of 44.7% and 90-day mortality of 35.0%, respectively.[11,12]

A study of perioperative AKI after hepatectomy described 25 patients with sCr-based AKI, 54 with oliguria-based AKI, and 10 patients with both.[29] They also concluded that UOP correlates poorly with sCr, a finding similar to that reported in other studies.[23,26] In our study, eGFR in the UOP groups did not decline but did decline in the sCr and combined (sCr +UOP) criteria groups. The proportions of these different subgroups were somewhat similar in our study, although the authors found that more patients fulfilled the UOP criteria. This may be because they could monitor postoperative UOP more accurately and used a daily mean of UOP, while we had to modify this criterion. Oliguria without a concomitant increase in sCr has been shown to increase mortality and perioperative events.[23,26] In the present study, AKI patients diagnosed by UOP also had elevated mortality compared to patients without AKI, but the number of patients in this group was too low to draw similar conclusions.

Increased mortality was also observed in a study of cardiac surgery patients, in which 76 patients with sCr-based AKI, 45 with UOP-based AKI, and 36 fulfilling both criteria were identified. Their 2.5-year mortalities were 17.1%, 17.0%, and 22.2%, respectively, compared to 5.1% for patients without AKI.[26] The aforementioned study of AKI after hepatectomy found that sCr-based AKI independently predicts the 30-day mortality rate, but they did not observe the mortality rate further.[29] Both studies were based on operations very different from lower limb arthroplasty. Our results also imply that mortality is elevated regardless of the AKI subgroup. There is a lack of orthopedic studies that examine the relationship between AKI diagnosed by UOP and mortality.

Two previous studies suggested that some degree of low intraoperative diuresis increases the risk of AKI.[31,32] In both

TABLE 5 Characteristics of elective and emergency arthroplasty patients with AKI diagnosed by sCr, UOP, or both

	Met sCr criteria N = 16	Met UOP criteria N = 17	Met both criteria N = 9	*P*-value
Emergency arthroplasty	11 (68.8)	8 (47.1)	5 (55.6)	.52
Diuresis, median (25th to 75th percentiles)				
Operation +recovery room (mL/kg/h)	0.86 (0.54-1.30)	0.75 (0.38-0.88)	0.67 (0.31-1.09)	.26
The day of operation (mL/kg/h)	0.60 (0.42-0.91)	0.40 (0.32-0.45)	0.47 (0.44-0.58)	.12
1st postoperative day (mL/kg/h)	0.82 (0.57-1.31)	0.39 (0.34-0.43)	0.40 (0.33-0.45)	<.001
eGFR statistics, median (25th to 75th percentiles)				
Preop. baseline eGFR (mL/min/1.73 m^2)	56 (45-70)	81 (72-90)	61 (39-73)	.005
Postop. eGFR first day (mL/min/1.73 m^2)	46 (38-62)	84 (76-97)	34 (32-47)	<.001
Postop. eGFR third day (mL/min/1.73 m^2)	39 (29-53)	83 (68-95)	35 (28-39)	<.001
Postop. eGFR seventh day (mL/min/1.73 m^2)	35 (26-43)	81 (67-93)	32 (25-39)	.001
Criteria for AKI met at				
First postoperative day	3 (18.8)	0	6 (66.7)	<.001
Second postoperative day	0	15 (88.2)	3 (33.3)	
Third postoperative day	7 (43.8)	2 (11.8)	0	
Fourth postoperative day or further	6 (37.5)	0	0	
AKI stage				
Stage 1	15 (93.8)	15 (88.2)	8 (88.9)	>.90
Stage 2	0	0	0	
Stage 3	1 (6.3)	2 (11.8)	1 (11.1)	
Location of follow-up treatment				
Home N (%)	1 (6.3)	5 (29.4)	2 (22.2)	.27
Other than home[b] N (%)	15 (93.8)	12 (70.6)	7 (77.8)	
1-y mortality N (%)	5 (31.3)	4 (23.5)	2 (22.2)	>.90

Note: KDIGO-criteria for tage 1 AKI: An absolute increase of sCr by 26.5 μmol/L within 48 hours or a 1.5-fold increase of sCr within 7 days or UOP <0.5 mL/kg/h for >6 h. Stage 2: A twofold increase in sCr or UOP <0.5 mL/kg/h for >12 h. Stage 3: A threefold increase of sCr or dialysis or UOP <0.3 mL/kg/h for >24 h or anuria for >12 h. The diagnosis criteria of AKI by UOP in this material were UOP <0.5 mL/kg/h for 48 h at the postoperative ward for Stage 1 and <0.3 mL/kg/h for 48 h for Stage 3.

Abbreviations: AKI, acute kidney injury; eGFR, estimated glomerular filtration rate; KDIGO, Kidney Disease, Improving Global Outcomes; MAP, mean arterial pressure; sCr, serum creatinine; UOP, urine output.

[a]The subgroups included are MAP 60-55 mm Hg for over 10 min., <55 mm Hg for less than 20 min., and <55 mm Hg for over 20 min.

[b]The subgroups included are hospital, health care center, and death during primary treatment. *P*-values are presented for comparison of all three criteria groups.

studies, the observation of diuresis was limited to the intraoperative period, and AKI was defined using sCr alone. In our study, we found that only emergency arthroplasty AKI patients had low intraoperative diuresis. However, the diuresis of AKI patients was low for the entire day of the operation, regardless of the elective or emergency setting. Our results suggest that low diuresis on the operation day might indicate that a patient is at risk of developing AKI.

Our study has several limitations. First, this was a retrospective study. The findings can only imply association, not causation. The UOP criteria had to be modified to identify patients with AKI from this retrospective data, leaving a margin for error in both directions.

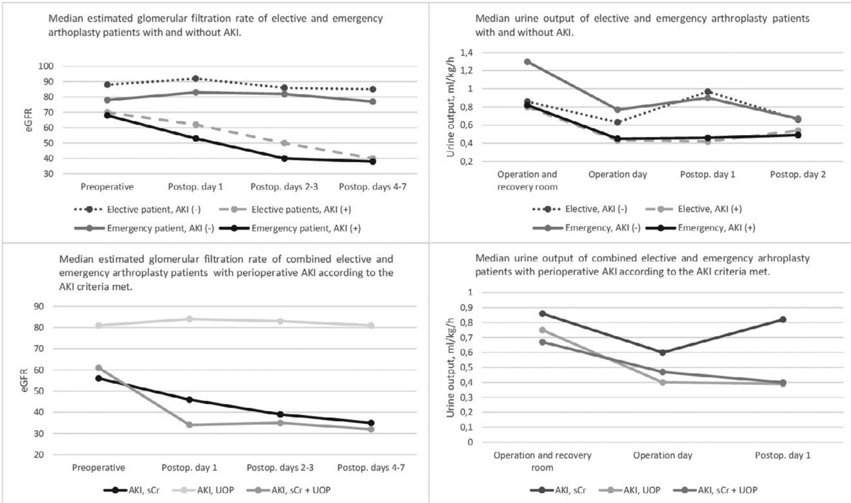

FIGURE 2 eGFR and UOP statistics of elective and emergency arthroplasty patients with and without AKI and by the criteria the AKI was met by the AKI (+) patients. Top left and bottom left figures: The *Y*-axis: Median estimated glomerular filtration rate. The *X*-axis: The time of eGFR measurement. Top right and bottom right figures: The *Y*-axis: Median urine output. The *X*-axis: The time of measurement. The criteria for the AKI groups in the bottom left and right figures are as follows: AKI, sCr, An absolute increase of sCr by 26.5 μmol/L within 48 hours or a 1.5-fold increase of sCr within 7 days; AKI, UOP, UOP <0.5 mL/kg/h for 48h at the postoperative ward; AKI, sCr +UOP, an AKI patient meeting both sCr and UOP criteria. AKI, acute kidney injury; eGFR, estimated glomerular filtration rate; sCr, serum creatinine; UOP, urine output

TABLE 6 Multivariable regression models for acute kidney injury

Elective patients	Odds ratio	95% confidence intervals	*P*-value
Age			
62-69 y	0.89	0.05-14.52	>.90
70-77 y	5.91	0.70-49.60	.10
>78 y	7.80	0.91-66.88	.061
BMI >30	4.93	1.67-14.60	.004
Cardiovascular disease	4.16	1.15-15.06	.030
Emergency patients			
Age			
78-82 y	1.18	0.26-5.45	.83
83-87 y	1.10	0.25-4.76	.90
>88 y	2.86	0.71-11.60	.14
BMI >30	5.57	1.27-24.51	.023
Preoperative eGFR			
60-89 mL	3.19	0.34-29.76	.31
<60 mL	7.72	0.82-73.01	.075
Elective and emergency patients combined			
Age			
63-71 y	2.27	0.41-12.55	.35
72-80 y	4.49	0.87-23.19	.073
>81 y	6.74	1.21-37.50	.029
BMI >30	5.05	2.18-11.71	<.001
Type of operation			
Elective knee	2.40	0.89-6.45	.083
Emergency hip	12.22	4.24-35.17	<.001

TABLE 2 (Continued)

Elective patients	Odds ratio	95% confidence intervals	*P*-value
Preoperative eGFR			
60-89	1.13	0.38-3.31	.83
<60 mL	2.52	0.79-8.01	.12

Note: Analysis was made separately for elective and emergency patients and to them combined.

Abbreviations: BMI, body mass index;eGFR, estimated glomerular filtration rate.

For example, we may still have some patients with AKI in the no AKI group and vice versa, and we may have underestimated the degree of UOP-based AKI. Besides, the number of patients in the AKI subgroups was very low, and the results should be considered to be hypothesis generating. In addition, a large number of statistical tests increase the probability of a false positive. The combination of both sCr and UOP was not available for all patients. A single preoperative sCr might not fully describe steady-state kidney function, especially in emergency arthroplasty patients. It might also be difficult to distinguish CKD from AKI, and we probably have patients with a combination of CKD and AKI in our data.

In conclusion, emergency hip arthroplasty is associated with an increased risk of both AKI and mortality. Perioperatively, low diuresis should also be considered as a diagnostic criterion for AKI. Studies focusing solely on sCr may overlook many cases of AKI. AKI diagnosed by sCr, UOP, or a combination of both may be associated with increased mortality. Further studies are needed to determine the role and effect of UOP in AKI, especially in arthroplasty patients.

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