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. In elective arthroplasties, the occurrence may be 0.5%-19.4%. Perioperative AKI increases the risk of mortality and increases the length of hospital stay. 

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). 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. 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. Some studies have not addressed UOP at all. This is even though diminished UOP alone has been shown to increase mortality.

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. A study of hepatectomy and AKI concluded that postoperative UOP correlated poorly with sCr. A study of cardiac surgeries found that all stages of UOP-diagnosed AKI were associated with the long-term mortality of postoperative patients. Both elevated sCr levels and postoperative oliguria may increase morbidity and mortality. 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. 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. 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. 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 (Efferlit®) 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. Preoperative eGFR was calculated from the baseline sCr taken prior to the operation. 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. 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
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.

## 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 co-morbidities, 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) | .90 |
| ASA3, N (%) | 330 (45.1) | 322 (45.2) | 8 (44.4) | 111 (65.3) | 96 (65.8) | 15 (62.5) | .90 |
| ASA4, N (%) | 28 (3.8) | 24 (3.4) | 4 (22.2) | 39 (22.9) | 32 (21.9) | 7 (29.2) | .90 |
| Preoperative eGFR | | | | | | | | |
| Normal; >90 (mL/min/1.73 m²), 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 m²), N (%) | 332 (45.4) | 324 (45.4) | 8 (44.4) | 94 (55.3) | 81 (55.5) | 13 (54.2) | .90 |
| Moderate decrease; 30-59 (mL/min/1.73 m²), N (%) | 69 (9.4) | 64 (9.0) | 5 (27.8) | 35 (20.6) | 27 (18.5) | 8 (33.3) | .90 |
| Severe decrease or ESRD; <30 (mL/min/1.73 m²), N (%) | 6 (0.8) | 6 (0.8) | 0 | 6 (3.5) | 4 (2.7) | 2 (8.3) | .90 |
| 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) | >.90 |
| Diuretic, N (%) | 230 (31.5) | 219 (30.7) | 11 (61.1) | .009 | 74 (43.5) | 62 (42.5) | 12 (50.0) | >.90 |

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

| Type of operation | Elective N = 731 | AKI (−) N = 713 | AKI (+) N = 18 | P-value | Emergency N = 170 | AKI (−) N = 146 | AKI (+) N = 24 | P-value |
|-------------------|------------------|-----------------|----------------|---------|-----------------|-----------------|--------------|---------|
| Knee arthroplasty, N (%) | 418 (57.2) | 411 (57.6) | 7 (38.9) | .15 | 170 (100) | 146 (100) | 24 (100) |
| Hip arthroplasty, N (%) | 313 (42.8) | 302 (42.4) | 11 (61.1) | .013 | 26 (100) | 20 (100) | 6 (25) |
| Cement used, hip arthroplasty, N (%) | 18 (5.8) | 16 (5.3) | 2 (18.2) | .13 | 13 (7.7) | 9 (6.2) | 4 (16.7) |

Perioperative pharmacotherapy

| Type of pharmacotherapy | Elective N = 731 | AKI (−) N = 713 | AKI (+) N = 18 | P-value | Emergency N = 170 | AKI (−) N = 146 | AKI (+) N = 24 | P-value |
|-------------------------|------------------|-----------------|----------------|---------|-----------------|-----------------|--------------|---------|
| Opioid, per os, N (%) | 647 (88.6) | 631 (88.6) | 16 (88.9) | >.90 | 120 (70.6) | 100 (68.5) | 20 (83.3) |
| Opioid, other, N (%) | 687 (94.1) | 669 (94.0) | 18 (100) | .41 | 163 (95.9) | 141 (96.6) | 22 (91.7) |
| Paracetamol, N (%) | 685 (93.7) | 667 (93.5) | 18 (100) | .40 | 147 (86.5) | 128 (87.7) | 19 (79.2) |
| NSAID, any, N (%) | 98 (13.4) | 94 (13.2) | 4 (22.2) | .27 | 19 (11.2) | 18 (12.3) | 1 (4.2) |
| Ketorolac (LIA), N (%) | 355 (48.6) | 349 (48.9) | 6 (33.3) | .24 | 55 (32.4) | 47 (32.2) | 8 (33.3) |
| Etoricoxib, N (%) | 430 (58.8) | 425 (59.6) | 5 (100) | .27 | 120 (70.6) | 100 (68.5) | 20 (83.3) |
| Antiemetic, N (%) | 262 (35.8) | 256 (35.9) | 6 (33.3) | >.90 | 55 (32.4) | 47 (32.2) | 8 (33.3) |
| Diuretic, N (%) | 67 (9.2) | 63 (8.8) | 4 (22.2) | .074 | 53 (31.2) | 44 (30.1) | 9 (37.5) |

Pharmacotherapy, morning prior operation

| Type of pharmacotherapy | Elective N = 731 | AKI (−) N = 713 | AKI (+) N = 18 | P-value | Emergency N = 170 | AKI (−) N = 146 | AKI (+) N = 24 | P-value |
|-------------------------|------------------|-----------------|----------------|---------|-----------------|-----------------|--------------|---------|
| ACE-blocker, N (%) | 25 (3.4) | 25 (3.4) | 0 | >.90 | 4 (2.4) | 4 (2.7) | 0 |
| Sartan, N (%) | 36 (4.9) | 35 (4.9) | 1 (5.9) | .58 | 3 (1.8) | 3 (2.1) | 0 |
| Betablocker, N (%) | 227 (31.1) | 218 (30.6) | 9 (50.0) | .12 | 69 (40.6) | 60 (40.1) | 9 (37.5) |

Type of anesthesia

| Type of anesthesia | Elective N = 731 | AKI (−) N = 713 | AKI (+) N = 18 | P-value | Emergency N = 170 | AKI (−) N = 146 | AKI (+) N = 24 | P-value |
|-------------------|------------------|-----------------|----------------|---------|-----------------|-----------------|--------------|---------|
| General anesthesia, N (%) | 172 (23.5) | 168 (23.6) | 4 (22.2) | >.90 | 35 (20.6) | 30 (20.5) | 5 (20.8) |
| Spinal anesthesia, N (%) | 559 (76.5) | 545 (76.4) | 14 (77.8) | .83 | 135 (79.4) | 116 (79.5) | 19 (79.2) |

Duration, median (25th to 75th percentiles)

| Type of duration | Elective N = 731 | AKI (−) N = 713 | AKI (+) N = 18 | P-value | Emergency N = 170 | AKI (−) N = 146 | AKI (+) N = 24 | P-value |
|-----------------|------------------|-----------------|----------------|---------|-----------------|-----------------|--------------|---------|
| 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) |
| 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) |
| Tourniquet, knee (h:min) | 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)

| Type of fluid | Elective N = 731 | AKI (−) N = 713 | AKI (+) N = 18 | P-value | Emergency N = 170 | AKI (−) N = 146 | AKI (+) N = 24 | P-value |
|---------------|------------------|-----------------|----------------|---------|-----------------|-----------------|--------------|---------|
| Blood loss (mL) | 200 (50-400) | 200 (50-350) | 325 (140-565) | .32 | 300 (200-350) | 300 (200-400) | 300 (200-300) |
| 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) |
| 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) |
| Blood products (mL) | 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] |
| Blood products, N (%) | 21 (2.9) | 18 (2.5) | 3 (16.7) | .013 | 18 (10.7) | 14 (9.6) | 4 (17.4) |
| Colloids, N (%) | 3 (0.4) | 3 (0.4) | 0 | >.90 | 7 (4.1) | 4 (2.7) | 3 (12.5) |

(Continues)
TABLE 2 (Continued)

|                      | Elective AKI (−) | AKI (+) | P-value | Emergency AKI (−) | AKI (+) | P-value |
|----------------------|------------------|---------|---------|------------------|---------|---------|
| **MAP**              |                  |         |         |                  |         |         |
| >60 mm Hg, N (%)     | 527 (72.1)       | 514 (72.1) | 13 (72.2) | 90 (52.9)       | 78 (53.4) | 12 (50.0) | .46 |
| 60-55 mm Hg for over 10 min, N (%) | 11 (1.5) | 11 (1.5) | 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.

*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 diuresis during the day of surgery was significantly lower, and this continued until 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) | 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)** |                  |                 |               |         |                  |                 |               |         |
| 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 (0.0-0.5) | 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 m², 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 m², 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 m², 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 m², 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.

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

*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.
Mortality and postoperative outcomes of arthroplasty patients with and without perioperative AKI

|                      | Elective knee and hip (N = 731) | AKI (−) (N = 7310) | 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)                | 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*    | 1 (0.1)                 | 1 (0.1)            | 0               | >.90    | 4 (2.4)                | 2 (1.4)          | 2 (8.3)          | .096    |

Abbreviation: AKI, acute kidney injury.

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

**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               | Odds ratio | 95% confidence intervals | P-value |
|-------------------|------------|--------------------------|---------|
| 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**

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

**Elective and emergency patients combined**

| Age               | Odds ratio | 95% confidence intervals | P-value |
|-------------------|------------|--------------------------|---------|
| 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**

| Operation         | Odds ratio | 95% confidence intervals | P-value |
|-------------------|------------|--------------------------|---------|
| Elective knee     | 2.40       | 0.89-6.45                | .083    |
| Emergency hip     | 12.22      | 4.24-35.17               | <.001   |

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

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

**TABLE 2** (Continued)

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

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.
ACKNOWLEDGEMENTS
The authors declare no conflicts of interest. However, EJ and TA received a grant for data collection from the Finnish State Research Fund appointed to the Department of Anaesthesiology, Oulu University Hospital. Further, ON received a grant from the Finnish Kidney Foundation.

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REFERENCES
1. Levey AS, Coresh J. Chronic kidney disease. Lancet. 2012;379:165-180.
2. Chawla LS, Eggers PW, Star RA, Kimmel PL. Acute kidney injury and chronic kidney disease as interconnected syndromes. N Engl J Med. 2014;371:85-96.
3. Borthwick E, Ferguson A. Perioperative acute kidney injury: risk factors, recognition, management, and outcomes. BMJ. 2010;341:85-91.
4. Louise YS, Duminda NW, Gordon AT, Beattie WS. Association of intraoperative hypotension with acute kidney injury after elective noncardiac surgery. Anesthesiol. 2015;123:515-522.
5. Jämä P, Jämsen E, Lyytikäinen L, Kalliovalkama J, Eskelinen A, Oksala N. Risk factors associated with acute kidney injury in a cohort of 20,575 arthroplasty patients. Acta Orthop. 2017;88:370-376.
6. Kimmel PL, Wilson S, Jannard JD, Liew SM, Walker RG. Incidence of acute kidney injury following total joint arthroplasty: a retrospective review by RIFLE criteria. Clin Kidney J. 2014;7:546-551.
7. O’Connor ME, Hewson RW, Kirwan CJ, Ackland GL, Pearse RM, Prowle JR. Acute kidney injury and mortality 1 year after major non-cardiac surgery. Br J Surg. 2017;104:868-876.
8. The Kidney Disease Improving Global Outcomes (KDIGO) Working Group. Definition and classification of acute kidney injury. Kidney Int. 2012;79:2139-2150.
9. Vanmassenhove J, Kielstein J, Jörres A, Biesen WV. Management of patients at risk of acute kidney injury. Lancet. 2017;389:2139-2151.
10. Goren O, Matot I. Perioperative acute kidney injury. Br J Anaesth. 2015;115:13-14.
11. Porter CJ, Moppett IK, Juurlink I, Nightingale J, Moran CG, Devonald MAJ. Acute and chronic kidney disease in elderly patients with hip fracture: prevalence, risk factors and outcome with development and validation of a risk prediction model for acute kidney injury. BMC Nephrol. 2017;18:20.
12. Rantalaiho I, Gunn J, Kukkonen J, Kaipia A. Acute kidney injury following hip fracture. Injury. 2019;50:2268-2271.
13. Perregaard H, Damholt MB, Solgaard S, Petersen MB. Renal function after elective total hip replacement. Acta Orthop. 2016;87:235-238.
14. Bell S, Dekker FW, Vadiveloo T, et al. Risk of postoperative acute kidney injury in patients undergoing orthopaedic surgery—development and validation of a risk score and effect of acute kidney injury on survival: observational cohort study. BMJ. 2015;351:5639.
15. Nikkinen O, Nieminen T, Alahuhta S, Ohtonen P, Vakkala M. Chronic kidney disease and acute kidney injury in arthroplasty patients over 65 years of age. Acta Anaesthesiol Scand. 2019;63:859-870.
16. Pedersen AB, Christiansen CF, Gammelager H, Kahlert J, Sorensen HT. Risk of acute renal failure and mortality after surgery for a fracture of the hip. Bone Joint J. 2016;98:1112-1118.
17. Nowicka A, Selvaraj T. Incidence of acute kidney injury after elective lower limb arthroplasty. J Clin Anesth. 2016;34:520-523.
18. Yadaw A, Alijanipour P, Ackerman CT, Karanth S, Hozack WJ, Filipponi EJ. Acute kidney injury following failed total hip and knee arthroplasty. J Arth. 2018;33:3297-3303.
19. Edelstein Al, Okroy KT, Rogers T, Della Valle CJ, Sporer SM. Nephrotoxicity after the treatment of periprosthetic joint infection with antibiotic-loaded cement spacers. J Arth. 2018;33:2225-2229.
20. Berliner ZP, Mo AZ, Porter DA, et al. In-hospital acute kidney injury after TKA revision with placement of an antibiotic cement spacer. J Arth. 2018;33:209-212.
21. Kateros K, Doulgerakis C, Galanakos SP, Sakellariou VL, Papadakis SA, Macheras GA. Analysis of kidney dysfunction in orthopaedic patients. BMC Nephrol. 2012;13:101.
22. Lai W, Rau C, Wu S, et al. Post-traumatic acute kidney injury: a cross-sectional study of trauma patients. Scand J Trauma Resusc Emerg Med. 2016;24:136.
23. Thomas ME, Blaine C, Dawnay A, et al. The definition of acute kidney injury and its use in practice. Kidney Int. 2015;87:62-73.
24. Mandelbaum T, Lee J, Scott DJ, et al. Empirical relationships among oliguria, creatinine, mortality, and renal replacement therapy in the critically ill. Intensive Care Med. 2013;39:414-419.
25. Macedo E, Malhotra R, Bouchard J, Wynn SK, Mehta RL. Oliguria is an early predictor of higher mortality in critically ill patients. Kidney Int. 2011;80:760-767.
26. Petjä L, Vaara S, Luihanen S, et al. Acute kidney injury after cardiac surgery by complete KDIGO criteria predicts increased mortality. J Cardiothorac Vasc Anesth. 2017;31:827-836.
27. Macedo E, Malhotra R, Granado RC, Fedullo P, Mehta RL. Defining urine output criterion for acute kidney injury in critically ill patients. Nephrol Dial Transplant. 2011;26:509-515.
28. Fliser D, Laville M, Covic A, et al. A European Renal Best Practice (ERBP) position statement on the Kidney Disease Improving Global Outcomes (KDIGO) Clinical Practice Guidelines on acute kidney injury: part 1: definitions, conservative management and contrast-induced nephropathy. Nephrol Dial Transplant. 2012;27:4623-4627.
29. Joliat G, Labgaa I, Demartines N, Halkic N. Acute kidney injury after liver surgery: does postoperative urine output correlate with postoperative serum creatinine? HPB. 2020;22:144-150.
30. Zarbock A, Koyner JL, Hoste EAJ, Kellum JA. Update on perioperative acute kidney injury. Anesth Analg. 2018;127:1236-1245.
31. Mizota T, Yamamoto Y, Hamada M, Matsuoka S, Shimizu S, Kai S. Intraoperative oliguria predicts acute kidney injury after major abdominal surgery. Br J Anaesth. 2017;119:1127-1134.
32. Shiba A, Uchino S, Fujii T, Takinami M, Uezono S. Association between intraoperative oliguria and acute kidney injury after major noncardiac surgery. Anesth Analg. 2018;127:1229-1235.
33. Levey AS, Stevens LA, Schmid CH, et al. A new equation to estimate glomerular filtration rate. Ann Inter Med. 2009;150:604-612.
34. Quan S, Pannu N, Wilson T, et al. Prognostic implications of adding urine output to serum creatinine measurements for staging of acute kidney injury after major surgery: a cohort study. Nephrol Dial Transplant. 2016;31:2049-2056.
35. Blitz JD, Shoham MH, Fang Y, et al. Preoperative renal insufficiency: underreporting and association with readmission and major post-operative morbidity in an academic medical center. Anesth Analg. 2016;123:1500-1515.

How to cite this article: Nikkinen O, Jämsä E, Aaltonen T, Alahuhta S, Ohtonen P, Vakkala M. Perioperative acute kidney injury and urine output in lower limb arthroplasties. Acta Anaesthesiol Scand. 2021;00:1-11. https://doi.org/10.1111/aas.13834