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Research Article

Acute kidney injury after major orthopedic surgery: A retrospective study of frequency and related risk factors

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ABSTRACT

Objective: This study aimed to analyze the frequency of postoperative kidney injury, the related factors, and its effect on outcomes in major orthopedic surgery cases treated in the postanesthesia intensive care unit (PACU).

Methods: Major orthopedic surgery cases treated in the PACU were included in this study retrospectively. Demographic, operation, and anesthesia characteristics, CCI, ASA risk classes, preoperative biochemistry, and hemogram results of the patients were recorded. Postoperative serum creatinine level, urine output, renal replacement therapy requirement, and hemoglobin levels were recorded. The kidney damage of the patients was evaluated with RIFLE and AKIN criteria. Postoperative complications were recorded.

Results: The frequency of kidney injury in the early postoperative period was 7.1%. When only arthroplasty cases were taken, the frequency was 11%. It was determined that there was a correlation between preoperative ASA, CCI, BMI, K levels, lactate levels, and postoperative kidney damage ($P < 0.05$). It was determined that the frequency and duration of inotropic use, the frequency and duration of noninvasive mechanical ventilation, and the duration of hospitalization increased in patients with postoperative kidney damage, and the frequency of pneumonia, wound infection, atelectasis, sepsis, arrhythmia, atrial fibrillation and mortality increased in the postoperative period ($P < 0.05$).

Conclusion: There is a need for further studies on the relationship between ASA, CCI, BMI, K, and lactate values and postoperative kidney damage. Postoperative kidney injury is associated with prolonged hospitalization and increased morbidity and mortality.

Level of Evidence: Level IV, Therapeutic Study

Introduction

Acute renal failure (ARF) is defined as a sudden change in kidney functions at a level that will prevent the removal of nitrogenous wastes from the body and disrupt the body's fluid and electrolyte balance.[1-3] Identification of perioperative risk factors for renal damage is crucial. In the literature, preoperative diabetes mellitus, surgical techniques, and preoperative renal failure have been identified as risk factors for postoperative acute kidney injury (AKI) and renal failure.[4,5] Risk, injury, failure, loss of function, and end-stage renal disease (RIFLE) and Acute Kidney Injury Network (AKIN) classification are among the most commonly used classifications in order to place a general classification of risk, injury, and failure factors for ARF. Risk, injury, failure, loss of function, and end-stage renal disease criteria are an advantageous classification in determining the risk status of the kidney, kidney damage, and whether or not kidney failure has occurred. In addition, it determines the loss of renal function and the end stage of kidney disease.[4,5] The AKIN classification is also a 3-step classification in which alterations in urine amount and creatinine levels are evaluated.[4,5]

Major surgical procedures are important risk factors for mortality and morbidity, and the effect of preoperative renal function on surgical outcomes is little known. Perioperative fluid shifts in patients undergoing major surgery may reveal pre-existing renal failure, increasing the risk of renal dysfunction and postoperative complications.[5,6] Critical illnesses, major surgical interventions, trauma, burns, sepsis, and cardiac diseases can also be counted among the causes of ARF.[6-9]

In this study, our aim is to evaluate the frequency of early postoperative AKI determined by RIFLE and AKIN criteria, the factors affecting it, and the effects of kidney injury on the outcomes of major orthopedic surgery cases, who are a specific patient group, with indications for treatment in the post-anesthesia intensive care unit (PACU).

Materials and Methods

This study was planned as a retrospective study. After obtaining the approval of the Non-Interventional Ethics Committee (Approval no: 2015/26-04, date:

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November 19, 2015), the patients who were treated in the postoperative intensive care unit of our hospital between 2013 and 2015 were included. Files and follow-up forms of major orthopedic surgery cases were reviewed retrospectively. The criteria for the major orthopedic cases were surgery duration longer than 3 hours, multitrauma patients, and indication of more than 2 units of blood transfusion in patients who are postoperatively followed in the PACU.

Demographic characteristics of patients, operation and anesthesia methods and characteristics, accompanying comorbidities such as preoperative diabetes mellitus (DM), hypertension (HT), congestive heart failure (CHF), coronary artery disease (CAD), chronic obstructive pulmonary disease (COPD), cerebrovascular accident, Parkinson's disease, goiter, asthma, presence of malignancy, American Society of Anesthesiologists (ASA) risk classes, operative characteristics, preoperative biochemistry, and hemogram results were recorded. Charlson Comorbidity Index (CCI) values were determined by a calculator according to the comorbidities of all cases (https://www.mdcalc.com/charlson-comorbidity-index-cci). Body mass index (BMI) values of all cases were calculated with weight and height. The estimated glomerular filtration rate (eGFR) values of the cases were calculated using the "Chronic Kidney Disease Epidemiology Collaboration" equation.

Intraoperative fresh-frozen plasma (FFP), erythrocyte suspension (ES), and fluid therapy including the amount of crystalloid and colloid were recorded using the anesthesia follow-up forms. On postoperative day 1, serum creatinine level, urine output, renal replacement therapy (RRT) requirement, and hemoglobin (Hb) levels were recorded. Patient information was obtained by examining the filled patient forms and patient laboratory parameters in the hospital automation system. According to the data collected, patients were evaluated using RIFLE criteria, risk (R) classification, injury (I) classification and failure (F) classification, and AKIN criteria.[4,5]

Risk, injury, failure, loss of function, and end-stage renal disease criteria, R—risk: creatinine increase × 1.5 or GFR decrease >25% and/or urine output <0.5 mL/kg/h for 6 hours, I—injury: creatinine increase × 2 or GFR decrease >50% and/or urine output <0.5 mL/kg/h for 12 hours, F—failure: creatinine increase x 3 or GFR decrease >75% or creatinine increase >4 mg/dL (acute increase >0.5 mg) and/or urine output was accepted as <0.3 mL/kg/h for 24 hours or anuria for 12 hours.[4,5] Acute Kidney Injury Network criteria, stage I: Increase in serum creatinine more than 0.3 mg/dL or 1.5-2 times and/or urine is less than 0.5 mL/kg/hour for more than 6 hours; Stage II: A 2- to 3-fold increase in serum creatinine and/or urine is less than 0.5 mL/kg/hour for more than 12 hours; Stage III: A 3-fold increase in serum creatinine or a serum creatinine above 4 mg/dL and/or urine below 0.5 mL/kg/hour for more than 24 hours or anuria in the patient for more than 12 hours was considered.[4,5]

HIGHLIGHTS

- Major surgical procedures are important risk factors for mortality and morbidity, and the effect of preoperative renal function on orthopedic surgical outcomes has not been determined. This study aimed to investigate the effects of kidney injury on the outcomes of major orthopedicsurgery cases.
- The results showed a correlation between preoperative American Society of Anesthesiologists score, Charlson Comorbidity Index (CCI), body mass index, potassium and postoperative lactate levels, and postoperative kidney damage.
- The results indicate that postoperative kidney damage is associated with worse outcomes in orthopedic surgery patients. Given the higher mortality in these patients, those who are at increased risk for kidney damage should be cautiously managed. Additionally, CCI is shown to be a risk factor for the first time, and further studies is needed to establish its association with kidney damage.

Postoperative complications were classified as respiratory system complications (hypoxia, atelectasis, aspiration pneumonia, pneumothorax, pulmonary embolism), urinary system complications (urinary retention, oliguria, ARF), postoperative bleeding, postoperative delirium, postoperative wound infection, and death (intraoperative, postoperative) and were recorded. The duration of hospitalization and discharge status of the patients in the postoperative intensive care unit, intensive care unit, and service were recorded as discharge or death.

Presence, type, and severity of complications occurring after admission were obtained from patient files after the patient was discharged. Strict objective criteria were established to define each complication to avoid subjective observer bias. Complications were defined as in-hospital mortality, wound infection (inflammation/purulent discharge, positive swab culture), pneumonia (shading on new chest x-ray, purulent sputum ± positive culture), atelectasis (atelectasis confirmed by lung direct radiograph and no signs of pulmonary infection), pulmonary complications (pulmonary complications other than pneumonia and atelectasis), sepsis (positive culture with 2-point change in the Sequential Organ Failure Assessment [SOFA] score), atrial fibrillation (atrial fibrillation not present before surgery), cardiac arrhythmia (any arrhythmia not present before surgery), other (any other unexpected event requiring treatment or intervention).[10]

Morbidity data

The duration of hospitalization and number of patients hospitalized in the PACU unit were recorded, and the 28th-day mortality of all cases was evaluated.[10] Similar to previous studies, patients with preoperative chronic kidney disease (CKD) or renal failure[11,12] and patients whose records could not be reached were excluded from the study.

Statistical analysis

Statistical Package for the Social Sciences 24.0 package program was used in the statistical analysis of the study (IBM SPSS Corp., Armonk, NY, USA). Variables with continuous values in the study were shown as mean ± standard deviation and variables indicating frequency were shown as frequency (n) and percentage (%). The normal test assumptions of the variables with continuous values were examined by Kolmogorov–Smirnov and Shapiro–Wilk tests. In the study, the data with continuous values were tested using the *t* test, one-way analysis of variance test, Mann–Whitney *U* test, and Kruskal–Wallis test, considering the group numbers and normality test results. Pearson's Chi-square and Fisher's exact Chi-square tests were used for group comparisons of frequency variables. Correlation analyses were performed using the Pearson chi-square test. In the comparative analysis, a binary logistic regression analysis was conducted to calculate odds ratios (ORs) with CIs using the backward stepwise (likelihood ratio) method. Comparisons with a *P* value below 0.05 were considered significant in the study.

Results

A total of 118 major orthopedic surgery cases treated in the postoperative intensive care unit of our hospital between 2013 and 2015 were included in our study. A total of 20 patients were excluded from the study because 8 patients had chronic renal failure in the preoperative period, 2 patients had acute kidney failure, and the data of 10 patients could not be obtained. Data of 98 cases were analyzed; 46 (46.9%) of the cases were male and 52 (53.1%) were female. The mean age of the cases was 67.62 ± 24.68 years. The weight of the

Table 1. Comorbidities determined in the preoperative period in the cases (n, %)

Comorbidity	All cases (n=98)	Cases with AKI (n=7)	Cases without AKI (n=91)	P*
DM	22 (22.4%)	3 (42.9%)	29 (20.9%)	0.186
HT	52 (53.1%)	4 (57.1%)	48 (52.7%)	0.569
CHF	8 (8.2%)	2 (28.6%)	6 (6.6%)	0.100
CAD	27 (27.6%)	4 (57.1%)	23 (25.3%)	0.089
COPD	11 (11.2%)	2 (28.6%)	9 (9.9%)	0.176
CVA	9 (9.2%)	1 (14.3%)	8 (8.8%)	0.502
Dementia	27 (27.6%)	3 (42.9%)	24 (26.4%)	0.294

*Fisher's exact test.
AKI, acute kidney injury; DM, diabetes mellitus; HT, hypertension; CHF, congestive heart failure; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident.

cases was 69.14 ± 19.32, their height was 163.39 ± 11.44, and BMI was 25.73 ± 6.71. It was determined that 18.4% of the cases were smokers and 12.2% of them used alcohol. The comorbidities determined in the preoperative period are shown in Table 1. The CCI value of the cases was determined as 2.90 ± 2.31. Preoperative laboratory and postoperative blood gas values of the cases are shown in Table 2.

Major arthroplasty was performed in 53.1% of the cases, major spine surgery in 16.3%, open reduction internal fixation in 16.3%, amputation in 4.1%, debridement in 4.1%, and other surgeries in 6.1%. As a method of anesthesia, general anesthesia was applied to 83 (84.7%) of the cases, spinal anesthesia was applied to 11 (11.2%), and peripheral block was applied to 4 (4.1%). Sevoflurane was used as an inhalation agent in all patients who underwent general anesthesia. While oxygen/nitrogen protoxide was used as the carrier gas in only 1 case, oxygen/dry air was used in 82 cases. The average duration of anesthesia in the cases was 118.31 ± 110.91 minutes. The amount

Table 2. Preoperative laboratory and postoperative blood gas values of the cases (mean ± SD)

Parameter	All cases (n=98)	Cases with AKI (n=7)	Cases without AKI (n=91)	P*
Creatinine (mg/dL)	0.82 ± 0.36	0.95 ± 0.47	0.81 ± 0.35	0.432
e-GFR	82.44 ± 30.14	71.42 ± 19.75	83.33 ± 30.74	0.322
Na (mmol/L)	139.81 ± 3.45	139.00 ± 4.08	139.87 ± 3.42	0.664
K (mmol/L)	4.13 ± 0.60	4.49 ± 0.88	4.11 ± 0.57	0.174
Cl (mmol/L)	107.81 ± 4.34	106.42 ± 6.26	107.92 ± 4.18	0.817
Ca (mg/dL)	7.47 ± 0.62	7.59 ± 0.94	7.46 ± 0.60	0.464
AST (U/L)	42.77 ± 48.48	32.42 ± 32.77	43.57 ± 49.54	0.250
ALT (U/L)	22.98 ± 21.49	22.00 ± 33.47	23.06 ± 20.56	0.128
BUN (mg/dL)	22.87 ± 12.19	25.80 ± 7.35	22.65 ± 12.48	0.147
Glucose (mg/dL)	150.38 ± 50.75	156.71 ± 78.63	149.88 ± 48.55	0.587
Albumin (g/dL)	2.49 ± 0.53	2.38 ± 0.57	2.50±0.53	0.794
Protein (g/dL)	4.91 ± 0.78	4.93 ± 0.90	4.91 ± 0.77	0.905
WBC (10^3/L)	12.73 ± 5.70	14.37 ± 6.33	12.61±5.67	0.540
Hemoglobin (g/dL)	9.88 ± 1.37	9.34 ± 1.09	9.92 ± 1.39	0.332
Hematocrit (%)	29.46 ± 4.24	28.62 ± 3.49	29.53 ± 4.31	0.743
Thrombocyte (10^3/μL)	222.84 ± 119.04	245.28 ± 101.94	221.10 ± 120.59	0.403
RDW (%)	15.83 ± 2.76	17.07 ± 3.14	15.74 ± 2.73	0.161
PCT (%)	0.18 ± 0.08	0.19 ± 0.07	0.18 ± 0.08	0.655
MPV (fL)	8.47 ± 1.29	7.91 ± 0.98	8.51 ± 1.30	0.289
pH	7.36 ± 0.07	7.35 ± 0.11	7.36 ± 0.07	0.915
pO_2 (mmHg)	159.99 ± 70.21	129.37 ± 58.12	162.43 ± 70.80	0.362
pCO_2 (mmHg)	37.77 ± 10.66	36.95 ± 18.63	37.77 ± 9.94	0.087
Lactate (mmol/L)	1.43 ± 1.08	3.65 ± 2.17	1.25 ± 0.71	<0.001
Bicarbonate (mmol/L)	21.62 ± 3.84	20.31 ± 3.84	21.73 ± 3.88	0.421

*Mann–Whitney *U* test.
SD, standard deviation; WBC, white blood cells; AKI, acute kidney injury; Na, sodium; K, potassium; Cl, chlorine; Ca, calcium; AST, Aspartate aminotransferase; ALT, alanine aminotransferase; BUN, blood urea nitrogen; RDW, red cell distribution width; PCT, plateletcrit; MPV, mean platelet volume.

of crystalloid given to the cases in the intraoperative period was 1954.63 ± 1386.41 mL, the amount of colloid was 523.40 ± 436.29 mL, the amount of FFP is 0.22 ± 0.89 units, and the amount of ES was determined as 1.09 ± 1.19 units. The amount of crystalloid given to the cases within the first 24 hours in the postoperative intensive care unit (PACU) was 1569.87 ± 812.83 mL, the amount of colloid was 157.89 ± 303.02 mL, the amount of FFP was 0.11 ± 0.52 units, the amount of ES was determined as 45 ± 0.80 units. The urine volumes at the arrival of PACU of the cases are 439.10 ± 387.09 mL, postoperative 6th-hour urine volumes are 449.29 ± 351.61 mL, postoperative 12th-hour urine volumes are 834.70 ± 571.87 mL, postoperative 24th-hour urine volume was determined as 931.38 ± 624.97 mL. After the postoperative intensive care follow-up, 90 (91.8%) cases were followed up in the inpatient care unit, and 8 (8.2%) of them were followed up in the anesthesiology intensive care unit. Postoperative day 1 creatinine, e-GFR, and BUN values were determined as 0.88 ± 0.51, 80.54 ± 32.66, and 24.38 ± 13.18, respectively, and postoperative day 7 creatinine, e-GFR, and BUN values were determined as 0.79 ± 0.68, 86.82 ± 34.62, and 21.39 ± 13.22, respectively. Post-anesthesia intensive care unit follow-up period of the cases was determined as 1.35 ± 1.16 days. Inotrope was started in 11 (11.2%) of the patients during PACU follow-up. The mean duration of inotropic use was found to be 80.20 ± 297.32 minutes in patients who were started on inotropes and 79 (80.6%) of the cases were followed in invasive mechanical ventilator. Invasive mechanical ventilation follow-up times of the cases were found to be 598.53 ± 598.68 minutes on average and 9 (9.2%) of the cases were followed on non-invasive mechanical ventilator. The mean duration of non-invasive mechanical ventilation follow-up of the cases was 30.56 ± 111.35 minutes. The mean total hospital stay of the cases was determined as 19.73 ± 20.88 days.

In the postoperative period, 91 (92.9%) cases included in our study were evaluated as normal according to the RIFLE and AKIN criteria. In 7 cases (7.1%) included in our study, different levels of kidney damage were determined according to the RIFLE and AKIN criteria. When the cases were evaluated according to RIFLE classification, 3 (3.1%) were "r," 2 (2.0%) were "i," 2 (2.0%) were "f," when evaluated according to AKIN classification, 3 (3.1%) stage I, 2 (2.0%) stage II, 2 (2%) stage III. Renal replacement therapy was administered to 3 (3.1%) of the patients who developed ARF during follow-up. In the subgroup analysis, the rate of kidney damage in the first 24 hours postoperatively was determined as 11% in patients who underwent hip arthroplasty.

When the relationship between the kidney injury observed in the cases and the comorbidities determined in the preoperative period was examined, no statistical relationship was found between the preoperative comorbidities DM, HT, CHF, CAD, COPD, CVA, and dementia, and the kidney injury, RIFLE and AKIN scores determined in the postoperative period ($P > 0.05$) (Chi-square test). When the CCI values determined by examining all of the preoperative comorbidities of the patients included in our study were examined, the mean CCI of the patients who developed kidney damage in the postoperative period was 5.71 ± 2.81 and the mean CCI of the patients who did not develop kidney damage was found to be 2.68 ± 2.13. The mean CCI of the patients who developed kidney damage in the postoperative period was significantly higher than the mean CCI of the patients who did not develop kidney damage ($P = 0.006$, Mann–Whitney *U* test). When the CCI determined in the preoperative period was compared according to the degree of kidney damage determined according to the RIFLE and AKIN index in the postoperative period,

Table 3. Preoperative ASA risk scores (n, %), CCI, BMI, K and postoperative lactate values, and postoperative kidney damage grades (mean ± SD) of the cases

RIFLE/AKIN	ASA (n, %) II/III/IV	CCI	BMI	Preoperative K	Postoperative lactate
Normal (n=91)	37(40)/47(51.6)/7(7.7)	2.68 ± 2.13	25.13 ± 6.16	4.11 ± 0.57	1.25 ± 0.71
r/grade I (n=3)	0(0)/2(66.7)/1(33.3)	3.67 ± 3.05	35.71 ± 12.09	4.21 ± 1.12	3.46 ± 3.25
i/grade II (n=2)	0(0)/2(100)/0(0)	6.00 ± 0.00	37.95 ± 0.69	4.11 ± 0.59	3.50 ± 0.42
f/grade III (n=2)	0(0)/0(0)/2(100)	8.50 ± 0.70	25.52 ± 4.93	5.30 ± 0.14	4.10 ± 2.54
All cases (n=98)	37(37.8)/51(52)/10(10.2)	2.90 ± 2.31	25.73 ± 6.71	4.13 ± 0.60	1.43 ± 1.08
P	0.001*	0.015**	0.055**	0.147**	0.003**
Correlation coefficient (*r*) (AKI)	0.307****	0.339****	0.322****	0.165	0.583****
Correlation coefficient (*r*) (RIFLE/AKIN)	0.322****	0.406****	0.226***	0.228***	0.555****

*Pearson Chi-square test;
**Kruskal–Wallis test;
***$P < 0.05$ (Pearson correlation analysis);
****$P < 0.01$ (Pearson correlation analysis).
RIFLE, risk, injury, failure, loss of function, and end-stage renal disease; AKIN, Acute Kidney Injury Network; CCI, Charlson Comorbidity Index;BMI, body mass index;K, potassium; SD, standard deviation;ASA, American Society of Anesthesiologists.

it was determined that there was a significant relationship between the preoperative CCI increase and the kidney damage determined in the postoperative period ($P = 0.015$, Kruskal–Wallis test). In the correlation analysis, a weak positive correlation was found between CCI and postoperative kidney damage ($r = 0.339$, $P = 0.001$; Pearson correlation analysis) and between CCI and the grade of kidney damage determined by RIFLE and AKIN scores ($r = 0.406$, $P < 0.001$; Pearson correlation analysis) (Table 3). Weak positive correlation between the preoperative ASA risk scores of the cases and the occurrence of postoperative kidney damage ($r = 0.307$, $P = 0.001$; Pearson correlation analysis) and weak positive correlation between the ASA risk score and the RIFLE and AKIN scores were determined ($r = 0.322$, $P < 0.001$; Pearson correlation analysis). Weak positive correlation between BMI and presence of postoperative kidney damage ($r = 0.322$, $P = 0.001$; Pearson correlation analysis) and weak positive correlation between BMI and the degree of kidney damage determined by RIFLE and AKIN scores (r = 0.226, $P < 0.026$; Pearson correlation analysis) were found (Table 3). When the relationship between preoperative laboratory tests and blood gas values at admission to the postoperative intensive care unit and postoperative kidney damage determined by RIFLE and AKIN scores of the cases was evaluated, there was a weak positive correlation between preoperative K levels and the degree of kidney damage ($r = 0.228$, $P = 0.024$; Pearson correlation analysis). Correlation relationship between blood gas lactate levels at admission to the postoperative intensive care unit and postoperative kidney damage determined by RIFLE and AKIN scores revealed a moderately positive correlation ($r = 0.583$, $P < 0.001$; Pearson correlation analysis). It was determined that there was a moderately positive ($r = 0.555$, $P < 0.001$; Pearson correlation analysis) correlation relationship between the grades (Table 3). According to the results of the logistic regression analysis, CCI (OR: 2.278; 95% CI: 1.30-5.83) and postoperative lactate values (OR: 8.26; 95% CI: 1.73-39.29) were associated with postoperative AKI.

No statistically significant correlation was found between the anesthesia method, duration of anesthesia, the amount of crystalloid, colloid, FFP, and ES given during the intraoperative and postoperative period and postoperative kidney damage determined by RIFLE and AKIN scores ($P > 0.05$).

There was statistically significant relationship between the occurrence of postoperative kidney damage and the duration of inotrope use ($P = 0.002$, Mann–Whitney *U* test) and non-invasive mechanical ventilator time ($P = 0.001$, Mann–Whitney *U* test), between the postoperative RIFLE and AKIN scores and PACU hospital stay in the postoperative period ($P = 0.047$, Kruskal–Wallis test), frequency of inotropic use ($P < 0.001$, Chi-square test), duration of inotropic use ($P = 0.002$, Kruskal–Wallis test), non-invasive mechanical ventilator between frequency of use ($P < 0.001$, Chi-square test) and duration of non-invasive mechanical ventilator ($P < 0.001$, Kruskal–Wallis test). It was determined that there was a weak positive correlation relationship between the duration of postoperative kidney damage and use of non-invasive mechanical ventilators ($r = 0.331$; $P = 0.001$, Pearson correlation analysis), between the duration of postoperative kidney damage and duration of inotrope use ($r = 0.304$; $P = 0.002$, Pearson correlation analysis), and between the postoperative RIFLE and AKIN scores and duration of inotrope use in the postoperative period ($r = 0.300$; $P = 0.003$, Pearson correlation analysis). Similarly, there was a weak positive correlation between the duration of hospitalization with the development of postoperative kidney damage in cases ($r = 0.293$, $P = 0.003$; Pearson correlation analysis) and between RIFLE and AKIN scores and duration of hospital ($r = 0.283$, $P = 0.005$; Pearson correlation analysis) (Table 4).

When the complications that developed during the postoperative hospital follow-up were analyzed, it was determined that there was a statistically significant relationship between the postoperative RIFLE

Table 4. Postoperative kidney damage degrees and duration of PACU, hospitalization, inotropic, and non-invasive mechanical ventilator use of the cases

RIFLE/AKIN	Frequency of inotropic use (n,%)	Inotrope usage time (minutes) (mean ± SD)	Frequency of NIV use (n,%)	NIV usage time (minutes) (mean ± SD)	PACU length of stay (days)	Length of hospital stay (days)
Normal (n=91)	7 (7.7)	55.27 ± 251.18	5 (5.5)	20.38 ± 93.80	1.32 ± 1.16	18.04 ± 18.84
r/grade I (n=3)	2 (66.7)	476.66 ± 551.02	3 (100)	380.00 ± 125.29	2.66±1.52	44.00 ± 14.00
i/grade II (n=2)	0 (0)	0.00 ± 0.00	0 (0)	0.00 ± 0.00	1.00 ± 0.00	25.50 ± 30.40
f/grade III (n=2)	2 (100)	700.00 ± 989.94	1 (50)	0.00 ± 0.00	1.00 ± 0.00	54.50 ± 67.17
All cases (n=98)	11 (11.2)	80.20 ± 297.32	9 (9.2)	30.56 ± 111.35	1.35 ± 1.16	19.73 ± 20.88
P	<0.001*	0.002**	<0.001*	<0.001**	0.047**	0.126**
Correlation coefficient (*r*) (AKI)	0.403****	0.304****	0.461****	0.331****	0.085	0.293****
Correlation coefficient (*r*) (RIFLE/AKIN)	0.401****	0.300****	0.322****	0.130	0.006	0.283****

*Pearson Chi-square test;
**Kruskal–Wallis test;
***$P < 0.05$ (Pearson correlation analysis);
****$P < 0.01$ (Pearson correlation analysis).
RIFLE, risk, injury, failure, loss of function, and end-stage renal disease; AKIN, Acute Kidney Injury Network; SD, standard deviation; PACU, post-anesthesia intensive care unit; NIV, Noninvasive ventilation.

Table 5. Postoperative RIFLE and AKIN scores and postoperative complications, n(%)

	Normal (n = 91, %)	*r*/grade I (n = 3, %)	*i*/grade II (n = 2, %)	*f*/grade III (n = 2, %)	All cases (n = 98, %)	*P**
Pneumonia	17 (18.7)	2 (66.7)	1 (50)	2 (100)	22 (22.4)	**0.008**
Surgical site infection	14 (15.4)	2 (66.7)	1 (50)	1 (50)	18 (18.4)	**0.049**
Atelectasis	5 (5.5)	1 (33.3)	0 (0)	1 (50)	7(7.1)	**0.027**
Anemia	64 (70.3)	2 (66.7)	2 (100)	2 (100)	70 (71.4)	0.640
Sepsis	6 (6.6)	1 (33.3)	1 (50)	2 (100)	10 (10.2)	**<0.001**
Arrhythmia	25 (27.5)	2 (66.7)	2 (100)	2 (100)	31 (31.6)	**0.011**
Atrial fibrillation	13 (14.3)	2 (66.7)	1 (50)	1 (50)	17 (17.3)	**0.034**
Mortality	4 (4.4)	1 (33.3)	2 (100)	2 (100)	9 (9.2)	**<0.001**

*Pearson Chi-square test. Bold text indicates a statistically significant correlation with a *P*-value less than 0.05.
RIFLE, risk, injury, failure, loss of function, and end-stage renal disease; AKIN, Acute Kidney Injury Network.

and AKIN scores and the frequency of pneumonia, wound infection, atelectasis, sepsis, arrhythmia, atrial fibrillation, and mortality in the postoperative period ($P < 0.05$) (Table 5). According to the results of the logistic regression analysis, mortality (OR: 21.89; 95% CI: 1.76-271.03 was associated with postoperative AKI.

Discussion

Acute kidney injury is among the most common complications after major orthopedic surgeries.[9] In studies that generally included all orthopedic surgical interventions, the risk of developing postoperative AKI was reported to be between 9% and 11%.[13] However, the frequency varies according to many factors such as the type of surgery performed, age characteristics of the patient group included in the study, ethnic characteristics, follow-up periods of the cases, gender distribution, country of study, year of study and is distributed in a wide range from 1.1%[14] up to 28.4%[15] in the literature analysis.

Gharaibeh et al[14] retrospectively evaluated 8949 patients who underwent total hip arthroplasty and reported that 1.1% of the patients had AKI. Risk factors associated with AKI were found to be advanced age, male gender, presence of CKD, CHF, DM, and hypertension (HT).[14] Abar et al[16] retrospectively evaluated 1719 patients who underwent elective total hip or knee arthroplasty and determined that 3.1% of the cases developed AKI in the postoperative period. They emphasized that AKI was significantly associated with a prolonged hospital stay and an increase in hospital costs. High BMI, bilateral surgery in a single session, high blood loss, long surgery time, high preoperative creatinine levels, high decrease in Hb level in the postoperative period, and high ASA score were determined as factors associated with the development of AKI.[16]

Lee YJ et al[17] retrospectively evaluated 351 patients who underwent total hip or knee arthroplasty, and the incidence of AKI was determined as 3.7%. They found that preoperative e-GFR and Hb levels were risk factors for AKI. A relationship between the use of crystalloid or colloid and the amount of fluid used in the perioperative period and AKI could not be determined. Researchers emphasized that patients with CKD and low Hb levels should be followed closely for renal functions after orthopedic surgery.[17] Kang et al[18] performed a study on 550 patients who underwent an operation due to hip fracture and emphasized that although the rate of AKI development in the postoperative period was 4.4%, the mortality rate in these cases was 24%. In the study, it was emphasized that the risk factors for AKI were determined as an estimated blood loss above 766.5 mL and postoperative albumin levels below 2.8 g/dL.[18]

A recent study by Agar et al[19] retrospectively evaluated 589 patients over 80 years of age who were operated for hip fractures between 2015 and 2020 and found that the rate of AKI in the postoperative period was 9.8%. In the study, smoking, preoperative and postoperative low albumin levels, high K and high urea levels, high amount of intraoperative bleeding, and prolonged surgery time were determined as risk factors for the development of postoperative AKI. Although the mortality rate was found to be high in cases with AKI, it was reported that no statistical significance could be determined in this regard in the study. As a result of the study, it was emphasized that AKI that developed in the postoperative period in patients with femur fracture increased the length of hospital stay and the frequency of morbidity.[19] In a study by Ko et al.[20] including 5757 patients who had undergone total knee arthroplasty, the rate of postoperative AKI was determined as 10%. Important factors for the development of postoperative AKI were determined as preoperative high creatinine levels, administration of general anesthesia, male gender, high ASA (>3), use of renin–angiotensin–aldoste rone system inhibitor drugs, and not using tranexamic acid.[20] In a single-center retrospective cohort study, organized by Shin et al.[21] the records of 481 patients over the age of 60 who underwent hip fracture surgery were examined and the incidence of postoperative AKI was determined as 11.8%. In the study, the presence of CKD and early postoperative albumin levels of <2.9 g/dL were determined as independent risk factors for AKI for the first 2 postoperative days.[21]

In our study, the frequency of AKI was determined as 7.1% for the first postoperative day in major orthopedic surgery cases followed in the intensive care unit in the postoperative period and as 11% when only arthroplasty cases were taken into account. Similar to previous research,[11,12] cases with a previous history of CKD were not included in our study. In our study, the frequency of AKI in the first 24 hours of hospitalization in the intensive care unit was evaluated. We think that these parameters are among the reasons for obtaining different frequency results in many other studies. It is seen that in our study, frequency results were obtained in parallel with previous studies with similar materials and methods.[19,20] We think that the high age, BMI values, and ASA scores of the arthroplasty cases included in our study caused the high incidence of postoperative AKI in this group than in other patients.[14,16,21]

In our study, increased BMI, high ASA risk classification, and high K levels were determined among the factors related to postoperative AKI. In these respects, our study is similar to previous studies[14,16,19-21] with similar factors. Charlson Comorbidity Index is a risk factor identified in our study for the first time, and it should definitely be evaluated extensively in future studies.

Similar to our study, in another study organized by Pedersen et al.[22] investigating the frequency and risk factors of AKI after hip fracture surgery and including 13 529 cases between 2005 and 2011, the frequency of AKI in the first 5 days postoperatively was 11.9% in patients with normal weight, 10.1% in low-weight patients, 12.5% in the overweight group, and 17.9% in the obese patients. In the study, it was emphasized that the risk of AKI increased in obese patients compared to normal-weight patients.[22]

In another study, organized by Hennrikus et al.[13] patients who underwent orthopedic surgery over a period of 2 years were evaluated and it was determined that obesity is an independent risk factor for the development of postoperative AKI. Intake of ACE inhibitor and angiotensin receptor blocker was evaluated as a risk factor for postoperative AKI only in non-obese cases.[13] In our study, it was determined that there was a correlation between postoperative acute renal injury and BMI. In this respect, our results are similar to previous studies.[13,22]

Ulucay et al[23] prospectively evaluated 165 patients who underwent hip fracture surgery, and the incidence of AKI was determined as 15.3%. They reported that 1.8% of patients needed RRT, long hospitalization was reported in patients with AKI, and mortality rates and treatment costs were determined to be high. In the study, basal renal functions were determined as an independent risk factor for the development of postoperative AKI.[23]

Jöbsis et al[24] evaluated 208 patients who underwent spinal instrumentation surgery, and the incidence of postoperative AKI was determined as 17%. In the study, it was reported that the frequency of AKI and the amount of fluid administered during the intraoperative period were inversely proportional. It has been emphasized that exposure to nephrotoxic agents is significantly higher in cases with AKI. In the study, it was emphasized that the frequency of postoperative AKI was high after spinal instrumentation.[24]

McKeag et al[25] retrospectively evaluated 500 patients who were operated on for hip surgery, and the incidence of AKI was determined as 19.2%. In the study, it was determined that the risk of developing AKI was higher in patients with CKD. The study also found that the risk of developing AKI was higher in cases with 2 or more comorbidities. In the study, it was reported that there was no relationship between the type of surgery and the development of AKI.[25] In our study, high CCI is associated with an increased number of comorbidities. In this respect, our study results are similar to studies,[25] emphasizing the high risk of AKI in cases with high comorbidity.

Hong et al[26] retrospectively evaluated 450 geriatric patients who underwent hip fracture surgery and determined that 21.1% of the patients developed AKI. Basal creatinine levels, use of ACE inhibitor or angiotensin-II receptor antagonist, ES transfusion, and history of CAD were determined as risk factors for the development of AKI. It was determined that patients with AKI were hospitalized for a significantly longer time, and their in-hospital and long-term mortalities were higher.[26] Braüner et al[15] retrospectively evaluated patients with hip fracture and over 65 years of age, and the incidence of postoperative AKI was determined as 28.4%. In the study, it was determined that AKI was associated with increased length of hospital stay and 30-day mortality. As a result of the multivariable analysis, advanced age, presence of heart disease, and postoperative blood transfusion were determined to be associated with AKI. In addition, it has been emphasized that patients with AKI have high postoperative C-reactive protein levels and low diastolic blood pressure levels. In our study, it was determined that the hospital stay was long and the morbidity and mortality rates were high in patients with postoperative AKI. In this respect, our results are consistent with previous studies.[15,23,26]

In a study, organized by Siddiqi et al.[27] conducted as literature analysis, 447 abstracts were identified and 336 studies were analyzed in relation to AKI after total knee arthroplasty operations. As a result of the examination, high BMI, metabolic syndrome, perioperative antibiotics, antihypertensive drugs, and antibiotic-impregnated cement use were found to be associated with AKI after total knee arthroplasty. It has been reported that perioperative AKI is associated with prolonged hospitalization and increased mortality.[27]

When the meta-analyses on the subject were evaluated, the incidence of AKI after hip fracture surgery was determined as 17% in a meta-analysis organized by Li et al.[9] in which a total of 11 studies and 16 421 patients were evaluated. In the study, postoperative serum albumin value was found to be a significant predictor of AKI. Although it was determined that the incidence of AKI increased with age and the use of ACE inhibitors, there was no statistical significance.[9] Another meta-analysis, organized by Thongprayoon C et al.[28] that aimed to determine the frequency of AKI after total hip arthroplasty included 17 studies and a total of 24 158 patients, and the incidence of AKI was determined as 6.3%. In the subgroup analysis performed in the same study, this rate was determined as 9.2% in Asian countries, 8.1% in Australia, 7.4% in Europe, and 2.8% in North America. In the study, the rate of patients with severe AKI and requiring RRT was determined as 0.5%.[28] In another meta-analysis organized by Zhou et al[29] evaluating the markers of AKI after hip surgery, 10 studies and 34 potential factors were identified. In the initial analysis, 12 factors were associated with postoperative AKI after hip surgery. These factors were determined as male gender, advanced age, myocardial infarction, HT, DM, CKD, ACE inhibitor/angiotensin receptor blocker use, excessive intraoperative blood loss, high preoperative BUN level, high preoperative creatinine level, and low preoperative E-GFR.[29]

In conclusion, in our study, the frequency of early postoperative AKI was 7.1% in patients with major orthopedic surgery who were treated in the intensive care unit during the postoperative period and did not have previous kidney injury and 11% in cases of arthroplasty. There is a correlation between preoperative ASA risk classification, CCI, BMI, K and postoperative lactate levels, and postoperative AKI. It has been determined that, in cases with postoperative AKI, the frequency and duration of inotropic use, the frequency and duration of non-invasive mechanical ventilation, and the duration of hospitalization increase, and the frequency of pneumonia, wound infection, atelectasis, sepsis, arrhythmia, atrial fibrillation and mortality were increased in the postoperative period.

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