OPEN

Acute kidney injury development in polytrauma and the safety of early repeated contrast studies: A retrospective cohort study

Thomas Giles, MD, Natasha Weaver, PhD, Adrian Varghese, BMed, Teagan L. Way, BNurs, MS, Christian Abel, BMed, FRANZCR, EBIR, Peter Choi, MA, MB, BChir, PhD, FRCP, FRACP, Gabrielle D. Briggs, PhD, *and* **Zsolt J. Balogh, MD, PhD, FRACS, FACS**, *Newcastle, Australia*

CONTINUING MEDICAL EDUCATION CREDIT INFORMATION

Accreditation

In support of improving patient care, this activity has been planned and implemented by CineMed and the American Association for the Surgery of Trauma. CineMed is jointly accredited by the Accreditation Council for Continuing Medical Education (ACCME), the Accreditation Council for Pharmacy Education (ACPE), and the American Nurses Credentialing Center (ANCC), to provide continuing education for the healthcare team.

AMA PRA Category 1 Credits™

CineMed designates this enduing material for a maximum of 1 *AMA PRA Category 1 Credit(s)™*. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

JOINTLY ACCREDITED PROVIDER™
INTERPROFESSIONAL CONTINUING EDUCATION

Objectives

After reading the featured articles published in the *Journal of Trauma and Acute Care Surgery*, participants should be able to demonstrate increased understanding of the material specific to the article. Objectives for each article are featured at the beginning of each article and online. Test questions are at the end of the article, with a critique and specific location in the article referencing the question topic.

Disclosure Information

In accordance with the ACCME Accreditation Criteria, CineMed must ensure that anyone in a position to control the content of the educational activity (planners and speakers/authors/discussants/moderators) has disclosed all financial relationships with any commercial interest (termed by the ACCME as "ineligible companies", defined below) held in the last 24 months (see below for definitions). Please note that first authors were required to collect and submit disclosure information on behalf all other authors/contributors, if applicable.

Ineligible Company: The ACCME defines an "ineligible company" as any entity producing, marketing, selling, re-selling, or distributing health care goods or services used on or consumed by patients. Providers of clinical services directly to patients are NOT included in this definition.

Financial Relationships: Relationships in which the individual benefits by receiving a salary, royalty, intellectual property rights, consulting fee, honoraria, ownership interest (e.g., stocks, stock options or other ownership interest, excluding diversified mutual funds), or other financial benefit. Financial benefits are usually associated with roles such as employment, management position, independent contractor (including contracted research), consulting, speaking and teaching, membership on advisory committees or review panels, board membership, and other activities from which remuneration is received, or expected.

Conflict of Interest: Circumstances create a conflict of interest when an individual has an opportunity to affect CME content about products or services of a commercial interest with which he/she has a financial relationship.

The ACCME also requires that CineMed manage any reported conflict and eliminate the potential for bias during the session. Any conflicts noted below have been managed to our satisfaction. The disclosure information is intended to identify any commercial relationships and allow learners to form their own judgments. However, if you perceive a bias during the educational activity, please report it on the evaluation. All relevant financial relationships have been mitigated.

AUTHORS/CONTRIBUTORS

Thomas Giles, Natasha Weaver, Adrian Varghese, Teagan L. Way, Christian Abel, Peter Choi, Gabrielle D. Briggs, and Zsolt J. Balogh have nothing to disclose.

EDITORIAL BOARD MEMBERS

First Name	Last Name	Disclosure?	Name of Commercial Interest	What was Received?	What was the Role?
Michael	Nance	Yes	Endo Pharmaceuticals	Consulting fee	Consultant
Heena	Santry	Yes	NBBJ	Salary	Employee
Jose	Diaz	Yes	Acumed/Acute Innovations	Consulting fee	Consultant
Lena	Napolitano	Yes	Merck Global Negative Advisory Board/Abbvie Critical Care Working Group	Consulting fee	Advisor/ Consultant

Roxie Albrecht, Walter Biffl, Karen Brasel, Clay Cothren Burlew, Raul Coimbra, Todd Costantini, Rochelle Dicker, Tabitha Garwe, Kenji Inaba, Rosemary Kozar, David Livingston, Ali Salim, Deborah Stein, Alex Valadka, Robert Winchell, Bishoy L. Zakhary, and Ben Zarzau have no disclosures or conflicts of interest to report. The Editorial Office staff has no disclosures to report.

Claiming Credit

To claim credit, please visit the AAST website at http://www.aast.org/ and click on the "e-Learning/MOC" tab. You must read the article, successfully complete the post-test and evaluation. Your CME certificate will be available immediately upon receiving a passing score of 75% or higher on the post-test. Post-tests receiving a score of below 75% will require a retake of the test to receive credit.

Credits can only be claimed online

Cost

For AAST members and Journal of Trauma and Acute Care Surgery subscribers there is no charge to participate in this activity. For those who are not a member or subscriber, the cost for each credit is $25.

Questions

If you have any questions, please contact AAST at 800-789-4006. Paper test and evaluations will not be accepted.

BACKGROUND: The role of repeat intravenous contrast doses beyond initial contrast imaging in the development of acute kidney injury (AKI) for multiple injury patients admitted to the intensive care unit (ICU) is not fully understood. We hypothesized that additional contrast doses are potentially modifiable risk factors for worse outcomes.

METHODS: An 8-year retrospective study of our institutional prospective postinjury multiple organ failure database was performed. Adult ICU admissions that survived >72 hours with Injury Severity Score (ISS) of >15 were included. Patients were grouped based on number of repeat contrast studies received after initial imaging. Initial vital signs, resuscitation data, and laboratory parameters were collected. Primary outcome was AKI (Kidney Disease: Improving Global Outcomes criteria), and secondary outcomes included contrast-induced acute kidney injury (CI-AKI; >25% or >44 μmol/L increase in creatinine within 72 hours of contrast administration), multiple organ failure, length of stay, and mortality.

RESULTS: Six-hundred sixty-three multiple injury patients (age, 45.3 years [SD, 9.1 years]; males, 75%; ISS, 25 (interquartile range, 20–34); mortality, 5.4%) met the inclusion criteria. The incidence of AKI was 13.4%, and CI-AKI was 14.5%. Multivariate analysis revealed that receiving additional contrast doses within the first 72 hours was not associated with AKI (odds ratio, 1.33; confidence interval, 0.80–2.21; $p = 0.273$). Risk factors for AKI included higher ISS ($p < 0.0007$), older age ($p = 0.0109$), higher heart rate ($p = 0.0327$), lower systolic blood pressure ($p = 0.0007$), and deranged baseline blood results including base deficit ($p = 0.0042$), creatinine ($p < 0.0001$), lactate ($p < 0.0001$), and hemoglobin ($p = 0.0085$). Acute kidney injury was associated with worse outcomes (ICU length of stay: 8 vs. 3 days, $p < 0.0001$; mortality: 16% vs. 3.8%, $p < 0.0001$; MOF: 42% vs. 6.6%, $p < 0.0001$).

CONCLUSION: There is a limited role of repeat contrast administration in AKI development in ICU-admitted multiple injury patients. The clinical significance of CI-AKI is likely overestimated, and it should not compromise essential secondary imaging from the ICU. Further prospective studies are needed to verify our results. (*J Trauma Acute Care Surg.* 2022;93: 872–881. Copyright © 2022 The Author(s). Published by Wolters Kluwer Health, Inc.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level III.

KEY WORDS: Acute kidney injury; contrast-induced acute kidney injury; multiple injury; multiple organ failure.

Contrast-induced acute kidney injury (CI-AKI), previously known as contrast-induced nephropathy, is a clinical entity defined by acute kidney injury (AKI) following the administration of intravenous (i.v.) iodinated contrast, in the absence of another etiology.[1] Contrast-induced acute kidney injury has previously been reported as the third leading cause of iatrogenic renal insufficiency, although historically reported incidence of CI-AKI was unclear because of variable definitions for AKI and lack of control groups.[2,3] Nonetheless, AKI associated with contrast administration increases hospital length of stay (LOS), mortality rate, and the likelihood for the need for renal replacement therapy (RRT).[4,5] Mortality rates in medical patients developing renal failure have been reported to be up to 5.5 times greater than those with intact renal function.[6]

There is a paucity of literature about CI-AKI in trauma patients, who have an increased risk of AKI due to hypoperfusion, resuscitation, severe tissue injury, and direct kidney injury. These frequent confounders in major trauma patients make it difficult to comply with the "in the absence of another etiology" criteria for CI-AKI while most of the patients receive i.v. contrast.

Trauma patients have a reported incidence of CI-AKI between 1.9% and 19.4%, which varies because of both the inconsistency of the definition of AKI and study population.[5,7] In general, higher injury severity is a well-established independent predictor of AKI in trauma patients.[8–10] The development of AKI in trauma patients has been shown to worsen outcomes, but it is unclear if contrast administration is an independent risk factor for worse outcomes.[1,4,7,8] Multiple injury patients after the unavoidable initial i.v. contrast-enhanced diagnostic workup and resuscitation are admitted to the intensive care unit (ICU) from where frequently repeated contrast studies are performed as part of protocolled or individualized management. The trauma literature is equivocal about the significance of multiple contrast exposures on AKI.[7,8,10] While the initial imaging from the resuscitation bay is hardly avoidable, secondary contrast studies during the early hospital stay could be timed and tailored better to the patients' risk for CI-AKI and to the overall impact on outcome.

We aimed to describe the incidence, outcomes of trauma patients with repeated contrast studies after ICU admission, the association between secondary contrast studies and AKI, and the predictors of AKI in a high-risk multiple injury cohort. We hypothesized that repeated contrast studies during early ICU stay in multiple injury patients are potentially modifiable independent predictors of worse outcomes.

PATIENTS AND METHODS

Ethics

This study received ethics approval from the local health districts ethics committee (AU202012-10). It adheres to the provision of privacy and confidentiality of patient data and clinical information, including the State of New South Wales Health Records and Information Privacy Act 2002.

Submitted: February 11, 2022, Revised: June 14, 2022, Accepted: June 16, 2022, Published online: July 7, 2022.

From the Department of Traumatology (T.G., A.V., T.L.W., Z.J.B.), John Hunter Hospital; Discipline of Surgery (N.W., C.A., G.D.B., Z.J.B.), School of Medicine and Public Health, University of Newcastle; Department of Interventional Radiology (C.A.), Hunter New England Imaging Service, John Hunter Hospital; and Department of Nephrology (P.C.), John Hunter Hospital, Newcastle, New South Wales, Australia.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

Address for correspondence: Zsolt J. Balogh, MD, PhD, FRACS, FACS, Department of Traumatology, John Hunter Hospital, Lookout Rd, NSW, 2305, Australia; email: zsolt.balogh@health.nsw.gov.au.

DOI: 10.1097/TA.0000000000003735

Definitions

Acute Kidney Injury

The serum creatinine criteria of the Kidney Disease: Improving Global Outcomes (KDIGO) was used to define AKI staging in our cohort.[2] Briefly, AKI 1 is characterized by an increase in serum creatinine of >26.53 μmol/L (0.3 mg/dL) or 1.5 to 1.9 times increase above baseline; AKI 2 by 2.0 to 2.9 times increase above baseline; and AKI 3 by >3 times increase above baseline, an increase of >353.68 μmol/L (4.0 mg/dL), or initiation of RRT. Acute kidney injury was said to be present if these changes occurred within 72 hours from the initial contrast dose.

Contrast-Induced AKI

Contrast-induced AKI was defined as a relative increase of serum creatinine >25% or an absolute increase of >44 μmol/L (0.5 mg/dL) within 72 hours from initial contrast dose.[1,4,5,8,10]

Comorbidities

Comorbidities considered relevant to risk of AKI or CI-AKI were recorded.[11] This included congestive cardiac failure, ischemic heart disease, diabetes mellitus, peripheral vascular disease, chronic kidney disease, and any other specific renal pathology noted within patient records.

Contrast Studies

A contrast study was defined as any i.v. contrast-enhanced computed topography imaging technique used for diagnostic purposes or any i.v. or intra-arterial angiographic procedure that used contrast. This included angiograms, angioembolization, stenting procedures, inferior vena cava filter insertion, and endovascular thoracic aortic rupture repair.

Isolated Head Injury

Isolated head injury was defined as no injuries apart from the head region with Abbreviated Injury Scale greater than one.

Multiple Organ Failure

A Denver score above 3 was used to define multiple organ failure (MOF), which was then categorized as early (present on day 3 or earlier) or late (not present on day 3 but developed later).[12]

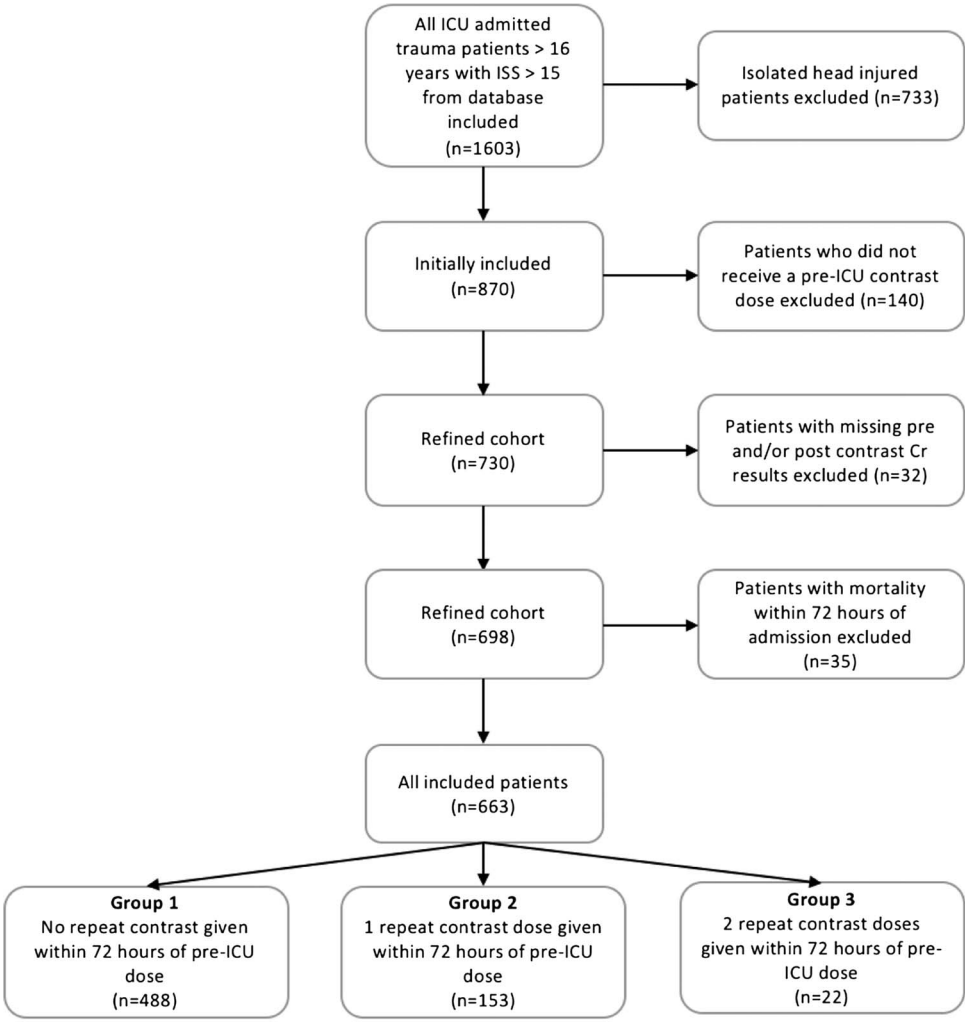

Figure 1. Flowchart showing patient inclusion, exclusion, and final grouping into groups based on number of repeat contrast studies.

Study Design and Participants

Eight-year retrospective study ending on December 31, 2019, was performed on all consecutive ICU admitted trauma patients with an Injury Severity Score (ISS) greater than 15, and 16 years and older admitted to our level 1 trauma center. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement guidelines were used to ensure that all necessary components of our study design were included (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C630). Figure 1 shows the exclusion and inclusion criteria as well as the grouping process of the various contrast exposure groups within our final population. Eight-hundred-seventy patients were considered after all patients with isolated head injuries were excluded. Further exclusions were made based on the lack of pre-ICU contrast studies (n = 140), missing precontrast and/or postcontrast laboratory data (n = 32), and death within 72 hours of admission (n = 35). After the application of all exclusions, 663 patients were considered for analysis, and they were divided into 3 contrast exposure groups based on number of repeat contrast doses received within 72 hours of initial pre-ICU dose. The three contrast exposure groups formed were those receiving no repeat contrast dose after initial pre-ICU contrast (n = 488), those receiving one repeat contrast dose (n = 153), and those receiving two repeat contrast doses within this time frame (n = 22).

Variables and Data Collection

Variables extracted from the Trauma Registry, prospective institutional MOF database, and focused chart review included demographics (age, sex), emergency department admission date, heart rate and systolic blood pressure (SBP) at admission, ISS, mortality, MOF, daily ICU Denver scores, ICU LOS, hospital LOS, and fluid and blood product volume within the first 24 hours of admission.

Data extracted from patient records included comorbidities relevant to CI-AKI and whether RRT was required as well as type of RRT and duration of RRT. Data relevant to contrast studies were also extracted including the timing and date, the dose of contrast, type of contrast study performed, whether i.v. or intra-arterial contrast was used, and if the procedure was suprarenal or infrarenal.

Laboratory values extracted included lactate, base deficit, hemoglobin, and creatinine before the first administration of i.v. contrast. Further laboratory values collected included daily creatinine for duration of ICU stay and the highest creatinine post i.v. contrast administration within 72 hours.

Study Outcomes

The primary outcome of the study was the development of AKI. Secondary outcomes included the development of CI-AKI, development of MOF, need for RRT, mortality, ICU LOS, and hospital LOS. Routine RRT for patients previously requiring hemodialysis for chronic kidney disease was not included in patients requiring RRT.

Statistical Analysis

Demographic, clinical, and hospital admission variables were compared for patients with and without AKI and were also compared by exposure group (determined by whether the patient had zero, one, or two repeat contrast procedures). Quantitative variables were summarized as mean and SD or as median and interquartile range if the distribution was skewed. Categorical variables were summarized as frequency count and percentage.

p Values for comparisons of AKI versus no AKI were from *t* tests or Wilcoxon-Mann-Whitney tests for quantitative variables and χ^2 tests for categorical variables. *p* Values for comparison of the three exposure groups were from analysis of variance or Kruskal-Wallis test for quantitative variables and χ^2 tests for categorical variables.

Logistic regression was used to investigate the effect of exposure on AKI, with results presented as odds ratios with 95% confidence intervals and Wald *p* values. The exposure group variable was dichotomized as "any" versus "no" repeat contrast procedures because of there being only a small number of patients with two repeats. Multivariate modeling was performed to reduce confounding bias in the exposure effect estimate by adjusting for patient age, sex, injury severity, and creatinine before first contrast procedure. Other covariates such as SBP, prior base excess, and prior lactate were rejected for inclusion in the model for two reasons: there were considerable missing data for these variables, and the interval estimates for the exposure variable were similar in models with and without them. The Hosmer-Lemeshow test for goodness of fit indicated no evidence against the chosen model.

Statistical significance was set at 0.05. Analysis was performed in SAS 9.4 (SAS Institute, Cary, NC).

RESULTS

Population Characteristics

The mean age of the study population was 45 years (SD, 19.1 years), 497 patients (75%) were male, and the median ISS was 25.[8,13–26] Characteristics of the overall cohort are shown in Table 1. A total of 75 patients (11%) developed MOF. The median ICU LOS and hospital LOS within the entire cohort were 4 (1–9) days and 17 (9–33) days, respectively. Within the study population, a total of 36 patients (5.4%) died.

Primary Outcome: Incidence of AKI Among Trauma Patients

There was a total of 89 patients (13.4%) within the cohort who developed AKI as per the KDIGO criteria within 72 hours of initial contrast dose. Of these, 62 (70%) had stage 1, 11 (12%) had stage 2, and 16 (18%) had stage 3. Applying the most frequently used criteria for defining CI-AKI in trauma patients, it was found that 96 patients (14.5%) were classified as having CI-AKI.

Characteristics Among AKI Trauma Patients

Patients with AKI had a mean age of 50.1 years (SD, 19.5 years), and 73 (82%) of these patients were male. Median ISS was 29 (22–41), and median creatinine at time of admission before initial scan was 117 (88–141). Other laboratory values at admission, vital signs at admission, and fluid and blood product management in first 24 hours are shown in Table 1. Of the patients with AKI, 13 (15%) had comorbidities. The number of AKI patients needing an interventional radiographic contrast procedure during their admission was 16 (18%), and of these, 9 (10%) had the procedure within 72 hours. Six (75%) of these patients received suprarenal

TABLE 1. Characteristics and Outcomes of Patients With AKI and Those Without AKI

Characteristic	Whole Cohort (n = 663)	AKI (n = 89)	No AKI (n = 574)	*p*
General characteristics				
Age, y	45.3 (19.1)	50.1 (19.5)	44.6 (18.9)	0.0109
ISS	25.0 (20.0, 34.0)	29.0 (22.0, 41.0)	25.0 (20.0, 33.0)	0.0007
Sex, male	497 (75%)	73 (82%)	424 (74%)	0.0985
Comorbidities	71 (11%)	13 (15%)	58 (10%)	0.2034
Interventional radiology procedure performed within 72 h	53 (8.0%)	9 (10%)	44 (7.7%)	0.4284
Infrarenal intra-arterial contrast received within 72 h	16 (31%)	2 (25%)	14 (33%)	0.994
Suprarenal intra-arterial contrast received within 72 h	35 (69%)	6 (75%)	29 (67%)	0.803
Initial dose, mL	100 (75, 100)	100 (75, 100)	100 (75, 100)	0.3963
Hospital admission				
SBP, mm Hg	115.0 (96.5, 132.0)	103.0 (90.0, 124.5)	116.0 (98.5, 134.0)	0.0007
HR, bpm	99.0 (82.0, 115.0)	105.5 (85.0, 120.0)	99.0 (81.0, 115.0)	0.0327
Hb, g/L	135.0 (119.0, 147.0)	128.0 (113.0, 140.0)	136.0 (120.0, 147.0)	0.0085
Lactate, mmol/L	2.8 (1.8, 3.8)	3.5 (2.4, 5.1)	2.6 (1.8, 3.6)	<0.0001
BD, mEq/L	−2.8 (−5.5, −0.8)	−4.2 (−7.3, −1.3)	−2.7 (−5.3, −0.7)	0.0042
Creatinine, μmol/L	92.0 (75.0, 115.0)	117.0 (88.0, 141.0)	90.0 (74.0, 109.0)	<0.0001
Creatinine, mg/dL	1.0 (0.8, 1.3)	1.3 (1.0, 1.6)	1.0 (0.8, 1.2)	<0.0001
Blood and fluid product management (initial 24 h)				
Received PRBC	312 (47%)	64 (72%)	248 (43%)	<0.0001
Received FFP	223 (34%)	47 (53%)	176 (31%)	<0.0001
Received cryoprecipitate	167 (25%)	35 (39%)	132 (23%)	0.0010
Received platelets	81 (12%)	26 (29%)	55 (9.6%)	<0.0001
Received tranexamic acid	28 (4.2%)	5 (5.6%)	23 (4.0%)	0.4820
Received albumin	65 (9.8%)	11 (12%)	54 (9.4%)	0.3836
Received prothrombinex	6 (0.9%)	3 (3.4%)	3 (0.5%)	0.0083
Quantity PRBC	4 (2, 8)	6 (3, 12)	4 (2, 6)	0.0006
Quantity FFP	4 (2, 6)	4 (3, 8)	4 (2, 5)	0.0038
Quantity cryoprecipitates	10 (5, 10)	10 (5, 10)	10 (5, 10)	0.1805
Quantity platelets	1 (1, 2)	1 (1, 2)	1 (1, 1)	0.2242
Crystalloid, mL	3,000 (2,000, 5,000)	4,000 (2,350, 6,797)	3,000 (2,000, 4,900)	0.0003
AKI — KDIGO				
AKI	89 (13.4%)			
AKI grade 1	62 (70%)			
AKI grade 2	11 (12%)			
AKI grade 3	16 (18%)			
Outcomes				
ICU LOS, d	4.0 (1.0, 9.0)	8.0 (4.0, 14.0)	3.0 (1.0, 7.0)	<0.0001
Hospital LOS, d	17.0 (9.0, 33.0)	24.0 (14.0, 46.0)	15.5 (8.0, 30.0)	<0.0001
Mortality	36 (5.4%)	14 (16%)	22 (3.8%)	<0.0001
MOF	75 (11%)	37 (42%)	38 (6.6%)	<0.0001
Early MOF	57 (76%)	33 (89%)	24 (63%)	<0.001
Late MOF	18 (24%)	4 (11%)	14 (37%)	
RRT	22 (3.3%)	17 (20%)	5 (0.9%)	<0.0001
MOF (highest Denver score during ICU admission)				
Hepatic grade 1	74 (11%)	18 (20%)	56 (9.8%)	<0.001
Hepatic grade 2	14 (2.1%)	6 (6.7%)	8 (1.4%)	
Hepatic grade 3	9 (1.4%)	4 (4.5%)	5 (0.9%)	
Renal grade 1	50 (7.5%)	28 (31%)	22 (3.8%)	<0.001
Renal grade 2	19 (2.9%)	11 (12%)	8 (1.4%)	
Renal grade 3	25 (3.8%)	20 (22%)	5 (0.9%)	
Cardiac grade 1	145 (22%)	20 (22%)	125 (22%)	<0.001
Cardiac grade 2	103 (16%)	29 (33%)	74 (13%)	
Cardiac grade 3	25 (3.8%)	11 (12%)	14 (2.4%)	
Respiratory grade 1	71 (11%)	12 (13%)	59 (10%)	<0.001

Continued next page

TABLE 1. *(Continued)*

Characteristic	Whole Cohort (n = 663)	AKI (n = 89)	No AKI (n = 574)	*p*
Respiratory grade 2	180 (27%)	36 (40%)	144 (25%)	
Respiratory grade 3	50 (7.5%)	16 (18%)	34 (5.9%)	
Denver score — hepatic median	0 (0, 0)	0 (0, 1)	0 (0, 0)	<0.0001
Denver score — renal median	0 (0, 0)	1 (0, 2)	0 (0, 0)	<0.0001
Denver score — cardiac median	0 (0, 1)	1 (0, 2)	0 (0, 1)	<0.0001
Denver score — respiratory median	0 (0, 2)	2 (0, 2)	0 (0, 2)	<0.0001

Quantitative variables are summarized as either mean (SD) or median (quartile 1, quartile 3). Categorical variables are summarized as frequency count and percentage. *p* Values for comparison of AKI versus no AKI were from *t* tests or Wilcoxon-Mann-Whitney tests for quantitative variables and χ^2 tests for categorical variables.

BD, base deficit; Hb, hemoglobin; HR, heart rate; FFP, fresh frozen plasma.

intra-arterial contrast, and two (25%) received infrarenal intra-arterial contrast. The median dose of contrast received within 72 hours was 100 mL (100–150 mL).

Secondary Outcomes Among Trauma Patients With AKI

Fourteen (16%) of the 89 AKI patients died. The mortality among non-AKI patients was 22 (3.8%). Thirty-seven (42%) AKI patients developed MOF. Comparatively, 38 patients (6.6%) without AKI developed MOF. Twenty AKI patients (22%) had a grade 3 Denver renal score during their admission in ICU, and 60 (67%) of these patients needed inotropic support. The highest grades given for other components of the Denver score and the median of the highest score obtained during ICU admission are shown in Table 1. Median ICU LOS and hospital LOS for trauma patients with AKI were 8 (4–14) days and 24 (14–46) days, respectively. Seventeen (20%) of the patients with AKI needed RRT during their hospital admission.

Predictors of AKI and the Role of Additional Contrast

Injury Severity Score was found to be higher in those developing AKI (29 vs. 25, $p = 0.0007$). Older age (50.2 vs. 44.6, $p = 0.0109$), a lower SBP (103 vs. 116, $p = 0.0007$), and higher heart rate (99 vs. 105.5, $p = 0.0327$) at admission were also associated with the development of AKI. All other laboratory values showed a statistically significant difference with a greater level of derangement being seen within the AKI group. There was no statistically significant difference regarding intra-arterial contrast within the initial 72-hour period for both suprarenal and infrarenal contrast in the development of AKI. There was no difference seen in the initial contrast dose among AKI patients and non-AKI patients (100 vs. 100, $p = 0.3963$). Patients who developed AKI were shown to be more likely to receive additional packed red blood cells (PRBCs), fresh frozen plasma, and crystalloid (see Table 1 for incidences and *p* values).

Because of low numbers within the two-repeat-contrast group, this group was combined with the one-repeat-contrast group as a binary outcome for logistic regression. Univariate analysis showed that repeat contrast was associated with increased odds of AKI (odds ratio, 1.79; confidence interval, 1.12–2.87; $p = 0.015$). However, multivariate analysis, which adjusted for sex, age, ISS, and creatinine before scan, revealed no statistical association between repeat contrast and AKI (odds ratio, 1.33; confidence interval, 0.80–2.21; $p = 0.273$).

Incidence of AKI Among Contrast Groups

The no-repeat-contrast group had 56 patients (11.5%) who developed AKI. There were 29 (19%) in the one-repeat-contrast group who developed AKI, and the two-repeat-contrast group had 4 patients (18.2%) meeting AKI criteria. In the group with no repeat contrast, 41 (73%) had stage 1, 7 (13%) had stage 2, and 8 (14%) had stage 3. The one-repeat group had 18 patients (62%) with stage 1, 4 (14%) with stage 2, and 7 (24%) with stage 3. The two-repeat-contrast group, however, had no patients meeting stage 2 criteria although had three patients (75%) meeting stage 1 criteria and one patient (25%) meeting criteria for stage 3. The number of patients meeting CI-AKI criteria in the no-repeat-contrast group was 60 (12.1%), 31 (20.4%) in the one-repeat-contrast group and 5 (22.7%) in the two-repeat-contrast group.

Characteristics Among Contrast Groups

The median ISS was 24 (19–33) in the no-repeat group, 29 (22–38) in the one-repeat group, and 32 (22–42) in the two-repeat group. Of the three groups, the two-repeat group had 18 males (82%), compared with 113 (74%) in the one-repeat group and 366 (75%) in the no-repeat group. Those who received an interventional contrast procedure within 72 hours from initial scan, location of contrast, and vital signs and laboratory values on admission for all three groups are shown in Table 2. The two-repeat-contrast group had a prescan creatinine median value of 105 μmol/L (76–126 μmol/L), compared with the one-repeat and no-repeat group with medians of 98 μmol/L (81–124 μmol/L) and 90 μmol/L (74–110 μmol/L), respectively. The daily median creatinine value for the first 5 days for the various groups is shown in Figure 2. The median of the absolute change from baseline creatinine for the various groups within 72 hours is shown in Figure 3. The number of patients within the two-repeat group requiring PRBCs within 24 hours of admission was 16 (73%). The one-repeat group had 97 (63%), and the no-repeat group had 199 (41%) requiring PRBC. The number of patients within the groups requiring other blood products is found within Table 2. The median volume (mL) of crystalloid solution given to the one-repeat group within 24 hours was 4,000 (2,500–5,700), and the median for those in the two-repeat group was 3,600 (2,500–5,000).

TABLE 2. Patient Characteristics and Outcomes by Exposure Group

Characteristic	No Repeat Within 72 h (n = 488)	One Repeat Within 72 h (n = 153)	Two Repeats Within 72 h (n = 22)	*p*
General characteristics				
Age, y	45.6 (19.2)	44.5 (18.5)	43.6 (21.3)	0.7370
ISS	24.0 (19.0, 33.0)	29.0 (22.0, 38.0)	31.5 (22.0, 42.0)	<0.0001
Initial dose, mL	100 (75, 100)	100 (75, 100)	100 (100, 100)	0.1572
Sex, male	366 (75%)	113 (74%)	18 (82%)	0.7221
Comorbidities	55 (11%)	13 (8.5%)	3 (14%)	0.5620
Interventional radiology procedure performed within 72 h	1 (0.2%)	39 (25%)	13 (59%)	<0.0001
Infrarenal intra-arterial contrast received within 72 h	1 (100.0%)	12 (32%)	3 (25%)	0.454
Suprarenal intra-arterial contrast received within 72 h	0	26 (68%)	9 (75%)	<0.001
Hospital admission				
SBP, mm Hg	116.5 (100.0, 134.0)	108.5 (90.0, 127.0)	105.5 (93.0, 129.0)	0.0164
HR, bpm	99.0 (82.0, 115.0)	99.0 (84.0, 117.0)	110.0 (80.0, 120.0)	0.6127
Hb, g/L	136.0 (120.0, 147.0)	129.0 (113.0, 145.0)	132.0 (114.0, 150.0)	0.0442
Lactate, mmol/L	2.5 (1.7, 3.5)	3.3 (2.3, 4.5)	3.8 (3.0, 5.1)	<0.0001
BD, mEq/L	−2.5 (−5.3, −0.5)	−3.1 (−5.6, −1.3)	−4.1 (−7.7, −2.3)	0.0549
Creatinine, μmol/L	90.0 (73.5, 109.5)	98.0 (81.0, 124.0)	104.5 (76.0, 126.0)	0.0013
Creatinine, mg/dL	1.0 (0.8, 1.2)	1.1 (0.9, 1.4)	1.2 (0.9, 1.4)	0.0013
Blood and fluid product management (initial 24 h)				
Received PRBC	199 (41%)	97 (63%)	16 (73%)	<0.0001
Received FFP	138 (28%)	72 (47%)	13 (59%)	<0.0001
Received cryoprecipitate	103 (21%)	54 (35%)	10 (45%)	0.0002
Received platelets	38 (7.8%)	39 (25%)	4 (18%)	<0.0001
Received tranexamic acid	16 (3.3%)	10 (6.5%)	2 (9.1%)	0.1115
Received albumin	44 (9.0%)	19 (12%)	2 (9.1%)	0.4636
Received prothrombinex	6 (1.2%)	0	0	0.3377
Quantity PRBC	4 (2, 6)	4 (2, 9)	5 (3, 7)	0.0646
Quantity FFP	4 (2, 4)	4 (2, 7)	4 (2, 6)	0.3584
Quantity cryoprecipitates	9 (5, 10)	10 (5, 10)	7.5 (5, 10)	0.3225
Quantity platelets	1 (1, 1)	1 (1, 2)	1 (1, 2)	0.8017
Crystalloid, mL	3,000 (2,000, 4,686)	4,000 (2,500, 5,700)	3,600 (2,500, 5,000)	<0.0001
KDIGO				
AKI	56 (11%)	29 (19%)	4 (18%)	0.0486
AKI grade 1	41 (73%)	18 (62%)	3 (75%)	0.7270
AKI grade 2	7 (13%)	4 (14%)	0	
AKI grade 3	8 (14%)	7 (24%)	1 (25%)	
Outcomes				
ICU LOS, d	3.0 (1.0, 7.0)	5.0 (2.0, 11.0)	8.0 (2.0, 11.0)	0.0003
Hospital LOS, d	15.0 (8.0, 30.0)	21.0 (12.0, 39.0)	22.0 (10.0, 59.0)	0.0005
Mortality	22 (4.5%)	12 (7.8%)	2 (9.1%)	0.2105
MOF	51 (10%)	22 (14%)	2 (9.1%)	0.3943
Early MOF	38 (75%)	18 (82%)	1 (50%)	0.5456
Late MOF	13 (25%)	4 (18%)	1 (50%)	0.5456
RRT	13 (2.7%)	8 (5.3%)	1 (4.5%)	0.2737
MOF (highest Denver score during ICU admission)				
Hepatic grade 1	45 (9.2%)	25 (16%)	4 (18%)	0.099
Hepatic grade 2	10 (2.0%)	3 (2.0%)	1 (4.5%)	
Hepatic grade 3	5 (1.0%)	3 (2.0%)	1 (4.5%)	
Renal grade 1	32 (6.6%)	16 (10%)	2 (9.1%)	0.050
Renal grade 2	12 (2.5%)	7 (4.6%)	0	
Renal grade 3	13 (2.7%)	10 (6.5%)	2 (9.1%)	
Cardiac grade 1	91 (19%)	44 (29%)	10 (45%)	0.013
Cardiac grade 2	76 (16%)	24 (16%)	3 (14%)	
Cardiac grade 3	17 (3.5%)	7 (4.6%)	1 (4.5%)	

Continued next page

TABLE 2. *(Continued)*

Respiratory grade 1	49 (10%)	18 (12%)	4 (18%)	0.692
Respiratory grade 2	127 (26%)	46 (30%)	7 (32%)	
Respiratory grade 3	37 (7.6%)	11 (7.2%)	2 (9.1%)	
Denver score — hepatic median	0 (0, 0)	0 (0, 0)	0 (0, 1)	0.0124
Denver score — renal median	0 (0, 0)	0 (0, 0)	0 (0, 0)	0.0065
Denver score — cardiac median	0 (0, 1)	0 (0, 1)	1 (0, 1)	0.0294
Denver score — respiratory median	0 (0, 2)	0 (0, 2)	1 (0, 2)	0.3435

Quantitative variables are summarized as either mean (SD) or median (quartile 1, quartile 3). Categorical variables are summarized as frequency count and percentage. *p* Values for comparison of exposure groups were from *t* tests or Wilcoxon-Mann-Whitney tests for quantitative variables and χ^2 tests for categorical variables.

BD, base deficit; Hb, hemoglobin; FFP, fresh frozen plasma.

Secondary Outcomes Among Contrast Groups

Two patients (9.1%) died in the two-repeat-contrast group. Within the other groups, those receiving one repeat contrast had 12 patients die (7.8%), and those not receiving repeat contrast had 22 (4.5%). Median ICU LOS was 8 (2–11) days in the two-repeat group, 5 (2–11) days in the one-repeat group, and 3 (1–7) days in the no-repeat group. Hospital LOS showed a median of 22 (10–59) days in the two-repeat group, 21 (12–39) days in the one-repeat group, and 15 (8–30) days in the no-repeat group. The number of patients with MOF for the no-repeat group, one-repeat group, and the two-repeat group was 51 (10%), 22 (14%), and 2 (9.1%), respectively. The proportion of those with late and early MOF is shown in Table 2. Within the two-repeat group, 14 patients (64%) required some degree of inotropic support. Comparatively, there were 75 patients (50%) needing inotropic support in the one-repeat group and 184 (39%) in the no-repeat group. Renal replacement therapy was required by 1 patient (4.5%) within the two-repeat group, 8 (5.3%) within the one-repeat group, and 13 (2.7%) within the no-repeat group.

DISCUSSION

This study was a retrospective observational study aimed at investigating the role of additional contrast doses on the development of AKI in multiple injury patients. Using the KDIGO criteria applied within 72 hours after initial contrast dose, we found an overall AKI incidence of 13.4%. Multivariate analysis demonstrated no statistically increased risk of AKI with additional contrast within the initial ICU period within our cohort. We found higher ISS, older age, higher heart rate, lower SBP, and deranged baseline blood results (base excess, creatinine, lactate, and hemoglobin) to be associated with the development of AKI. Outcomes such as mortality, LOS, and the development of MOF were all worse in those with AKI.

The complexity and multifactorial nature of AKI in multiple injury patients make its etiology difficult to distinguish, occurring as the result of various physiological insults including hemorrhagic shock, rhabdomyolysis, infectious complications, organ cross-talk, and nephrotoxic drug administration.[27–30] The pathophysiology of trauma related AKI is therefore complex, involving multiple mechanisms and pathways. It is then

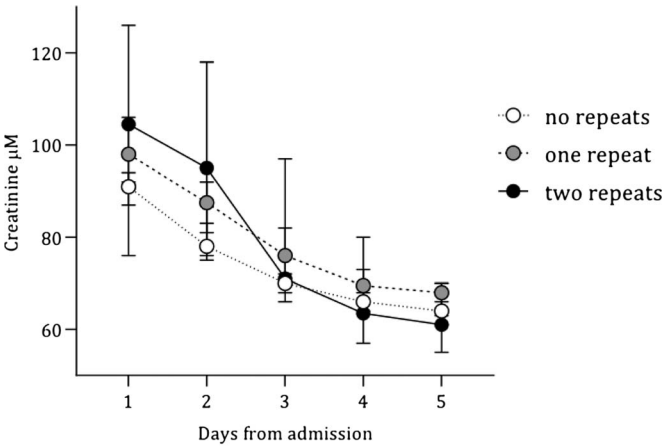

Figure 2. Daily median creatinine values with interquartile ranges.

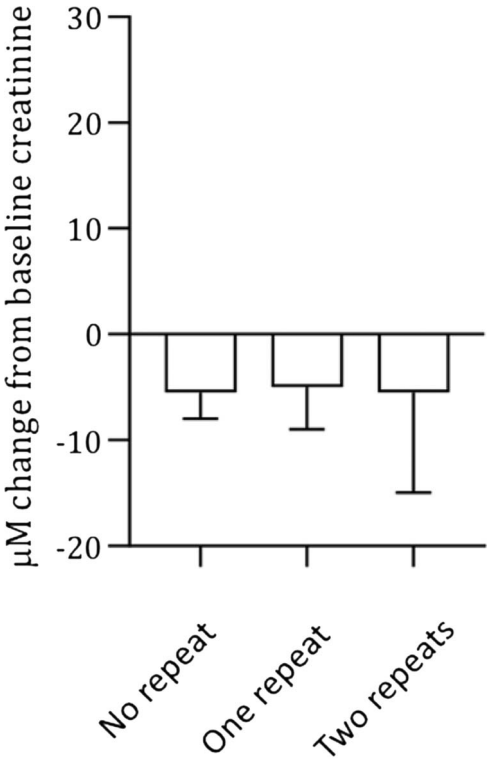

Figure 3. Median absolute change in baseline creatinine within 72 hours with interquartile ranges.

important to appreciate that contrast likely plays a limited role in the development of AKI within this cohort.

Our study reported an incidence of AKI of 13.4% in a cohort of ICU patients at high risk for MOF. The incidence of AKI in trauma patients varies greatly with rates being reported between 6% and 74%.[9,29,31–33] The variety in incidence is likely due to differences in defining AKI, length of follow-up, and the severity of trauma, which varies between studies. Incidence of AKI using the KDIGO criteria has been reported between 13% and 64%.[13–15] It is important to note that, within our study, we used a follow-up period of 72 hours to focus results on the acute ICU period, which is shorter than most other studies. We did not identify any other studies that used the latest KDIGO criteria within a similar cohort and follow-up period to compare to our results.

This study also aimed to determine the incidence of CI-AKI. When the common criteria for CI-AKI in trauma patients are applied to our cohort, we found an incidence of 14.5%. This incidence is greater than the overall rate of AKI as per the KDIGO criteria and is likely an overestimation of the true incidence of CI-AKI. To assign all responsibility to contrast for the development of AKI in these patients ignores the various other possible etiologies that have likely led to an initial rise in creatinine. Studies that have applied these criteria to trauma patients have reported incidences of CI-AKI between 1.9% and 19.4% with higher incidences relating to more severely injured cohorts.[1,4,5,7,8,10,16,17] It is likely that the current literature has overestimated the true incidence of CI-AKI and created undue fear regarding the administration of contrast in trauma patients. This highlights the need for a more nuanced criteria that consider the various etiologies that exist within trauma patients.

Within nontrauma patients, there is a growing body of literature suggesting that the administration of contrast is of little consequence to patients' renal function. In critically ill ICU patients, it was found that contrast is not a risk factor for the development of AKI.[18] For nontrauma medical patients, it has been shown that contrast is not a risk factor for the development of AKI, that contrast exposure does not worsen outcomes for those admitted for AKI, and that transient rises of serum creatinine meeting the criteria of CI-AKI occur sporadically in hospitalized medical patients without contrast exposure.[19–22] These findings are important to consider when reevaluating the concern for contrast administration in trauma patients.

Within trauma patients, while concern for CI-AKI exists, it is inevitable that patients will receive an initial contrast dose as a part of their workup. Most noncritically injured patients will not require further repeat contrast scans past this point.[23] However, the subset of patients requiring ICU admission and who are already at high risk for MOF frequently require further contrast studies beyond initial emergency department work-up.[24,25] It is therefore repeat doses in the ICU for these high-risk patients that must be tailored to balance the benefit of diagnostic imaging and emergency angiography with the risk of AKI. Notably, multivariate analysis showed that patients who received additional contrast doses within 72 hours from their initial dose were not associated with increased odds of developing AKI. There are currently conflicting results in the trauma literature regarding contrast exposure as a risk factor for AKI. Contrast dose and exposure have been found to be a risk factor for the development of AKI within trauma patients.[7,14] However, conflicting results have been reported, demonstrating contrast exposure and/or dose to not be associated with a risk of AKI development.[5,8–10,31] The latter findings support our results and the notion that the benefit of adequate imaging studies and angiography far outweighs the risk of repeat contrast exposure within multiple injury patients.

Older age, higher ISS, higher heart rate, and lower SBP at admission were found to be risk factors for the development of AKI. These are well-defined risk factors for AKI among trauma patients with increased injury severity and physiological derangement being important driving forces for the development of AKI in trauma patients.[8,9,29,31] This relationship would explain our findings that showed a higher incidence of blood product administration within those patients who developed AKI. There have been other risk factors that have been identified for AKI in trauma patients that our study did not control for including genitourinary trauma, arterial injuries, sepsis, ethnicity, and the use of nephrotoxic drugs.[7,13,26] The literature currently is equivocal regarding the risk posed by emergency angiography in trauma patients. Our study found that emergency angiography in trauma patients did not increase the risk of AKI. This finding has been previously reported with angioembolization being found to not increase the risk of AKI in trauma patients.[29] However, a potential risk for AKI with angiography has been demonstrated with an incidence rate of 1.1% compared with 0.5% ($p < 0.01$) in a cohort of 230,776 patients.[34]

As expected, AKI within our cohort was linked to an increase in mortality, MOF, LOS in both ICU and hospital, and need for RRT. These are well-defined outcomes for trauma patients developing AKI.[4,5,9,13,29]

Limitations

There are several important limitations to our study. First, the retrospective nature of the study lends itself to a variety of well-known potential issues including selection bias. It is possible that patients with a perceived increased risk of CI-AKI were not given additional contrast by clinicians during the early stages of their ICU admission. Another limitation is the incomplete nature of the variables that were collected that may have cofounded results. Importantly, the low patient numbers in the two-repeat group did not allow for a more nuanced statistical analysis of the effect of exposure to additional repeat contrast procedures. There were also no data available for dose of contrast received during interventional radiology procedures. This prevented statistical analysis of contrast dose and its association with outcomes.

CONCLUSION

We found an AKI incidence of 13.4% within 72 hours from admission for multiple injury patients admitted to ICU. Acute kidney injury was associated with increased mortality, MOF, hospital, and ICU LOS and need for RRT. Importantly, repeat contrast exposure in the initial ICU period within multiple injury patients does not appear to be associated with the development of AKI.

AUTHORSHIP

T.G. contributed in the literature review, study design, data collection, data interpretation, and writing. Z.J.B. contributed in the conception, design, writing, data interpretation, critical revision, and supervision. N.W. contributed in the data analysis and data interpretation. A.V. contributed in the data collection. T.L.W. contributed in the data collection. C.A. contributed in the critical revision. P.C. contributed in the critical revision.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Kelemen JA, Kaserer A, Jensen KO, Stein P, Seifert B, Simmen HP, et al. Prevalence and outcome of contrast-induced nephropathy in major trauma patients. *Eur J Trauma Emerg Surg*. 2020;48(2):907–913.
2. Davenport MS, Perazella MA, Yee J, Dillman JR, Fine D, McDonald RJ, et al. Use of intravenous iodinated contrast media in patients with kidney disease: consensus statements from the American College of Radiology and the National Kidney Foundation. *Radiology*. 2020;294(3):660–668.
3. Nash K, Hafeez A, Hou S. Hospital-acquired renal insufficiency. *Am J Kidney Dis*. 2002;39(5):930–936.
4. Bashir AA, Kong V, Skinner D, Bruce J, Laing G, Brysiewicz P, et al. Contrast-induced nephropathy following CT scan for trauma is not rare and is associated with increased mortality in South African trauma patients. *Eur J Trauma Emerg Surg*. 2018;45(6):1129–1135.
5. McGillicuddy EA, Schuster KM, Kaplan LJ, Maung AA, Lui FY, Maerz LL, et al. Contrast-induced nephropathy in elderly trauma patients. *J Trauma*. 2010;68(2):294–297.
6. Levy EM, Viscoli CM, Horwitz RI, Rich GF. The effect of acute renal failure on mortality. A cohort analysis. *Sur Anesthesiol*. 1997;41(5):310.
7. Bethea A, Keslar L, Silhy R, Samanta D, Chumbe JT. An evaluation of the relationship between traumatic injuries and the development of contrast-associated acute kidney injury. *Dent Traumatol*. 2018;20(2):100–107.
8. Matsushima K, Peng M, Schaefer EW, Pruitt JH, Kashuk JL, Frankel HL. Posttraumatic contrast-induced acute kidney injury: minimal consequences or significant threat? *J Trauma*. 2011;70(2):415–419.
9. Kim DY, Kobayashi L, Costantini TW, Chang D, Fortlage D, Curry T, et al. Is contrast exposure safe among the highest risk trauma patients? *J Trauma Acute Care Surg*. 2012;72(1):61–66.
10. Colling KP, Irwin ED, Byrnes MC, Reicks P, Dellich WA, Reicks K, et al. Computed tomography scans with intravenous contrast: low incidence of contrast-induced nephropathy in blunt trauma patients. *J Trauma Acute Care Surg*. 2014;77(2):226–230.
11. McCullough PA, Choi JP, Feghali GA, Schussler JM, Stoler RM, Vallabahn RC, et al. Contrast-induced acute kidney injury. *J Am Coll Cardiol*. 2016;68(13):1465–1473.
12. Fröhlich M, Wafaisade A, Mansuri A, Koenen P, Probst C, Maegele M, et al. Which score should be used for posttraumatic multiple organ failure? — comparison of the MODS, Denver- and SOFA- scores. *Scand J Trauma Resusc Emerg Med*. 2016;24(1):130.
13. Søvik S, Isachsen MS, Nordhuus KM, Tveiten CK, Eken T, Sunde K, et al. Acute kidney injury in trauma patients admitted to the ICU: a systematic review and meta-analysis. *Intensive Care Med*. 2019;45(4):407–419.
14. Emigh BJ, Sahi SL, Teal LN, Blake JC, Heron CH, Teixeira PG, et al. Incidence and risk factors for acute kidney injury in severely injured patients using current kidney disease: improving global outcomes definitions. *J Am Coll Surg*. 2020;231(3):326–332.
15. Bjornstad EC, Smith ZH, Muronya W, Munthali CK, Mottl AK, Marshall SW, et al. High risk of acute kidney injury in Malawian trauma patients: a prospective observational cohort study. *BMC Nephrol*. 2021;22(1):354.
16. Hipp AC. The incidence of contrast-induced nephropathy in trauma patients. *Acad Emerg Med*. 2006;13(5Supplement 1):S140.
17. Tremblay LN, Tien H, Hamilton P, Brenneman FD, Rizoli SB, Sharkey PW, et al. Risk and benefit of intravenous contrast in trauma patients with an elevated serum creatinine. *J Trauma*. 2005;59(5):1162–1166.
18. Ehrmann S, Badin J, Savath L, Pajot O, Garot D, Pham T, et al. Acute kidney injury in the critically ill: is iodinated contrast medium really harmful? *Crit Care Med*. 2013;41(4):1017–1026.
19. Naicker S, Muteba M, Duarte R, Manga P, Dix-Peek T, Naicker S, et al. Risk factors and outcomes of contrast-induced nephropathy in hospitalised South Africans. *S Afr Med J*. 2016;106(7):699–703.
20. Newhouse JH, Kho D, Rao QA, Starren J. Frequency of serum creatinine changes in the absence of iodinated contrast material: implications for studies of contrast nephrotoxicity. *AJR Am J Roentgenol*. 2008;191(2):376–382.
21. Goulden R, Rowe BH, Abrahamowicz M, Strumpf E, Tamblyn R. Association of intravenous radiocontrast with kidney function: a regression discontinuity analysis. *JAMA Intern Med*. 2021;181(6):767–774.
22. Yan P, Zhang NY, Luo XQ, Wang M, Deng YH, Wu T, et al. Is intravenous iodinated contrast medium administration really harmful in hospitalized acute kidney injury patients: a propensity score-matched study. *Eur Radiol*. 2021;32(2):1163–1172.
23. Livingston DH, Lavery RF, Passannante MR, Skurnick JH, Fabian TC, Fry DE, et al. Admission or observation is not necessary after a negative abdominal computed tomographic scan in patients with suspected blunt abdominal trauma: results of a prospective, multi-institutional trial. *J Trauma*. 1998;44(2):273–280; discussion 80-2.
24. Livingston DH, Deitch EA. Multiple organ failure: a common problem in surgical intensive care unit patients. *Ann Med*. 1995;27(1):13–20.
25. Fröhlich M, Lefering R, Probst C, Paffrath T, Schneider MM, Maegele M, et al. Epidemiology and risk factors of multiple-organ failure after multiple trauma: an analysis of 31,154 patients from the TraumaRegister DGU. *J Trauma Acute Care Surg*. 2014;76(4):921–927.
26. Chang E, Li J, Wang N, Raghavendran K, Park P, Napolitano L, et al. Acute kidney injury after serious motor vehicle crashes. *Crit Care Med*. 2014;42:A1617.
27. Messerer DAC, Halbgebauer R, Nilsson B, Pavenstädt H, Radermacher P, Huber-Lang M. Immunopathophysiology of trauma-related acute kidney injury. *Nat Rev Nephrol*. 2021;17(2):91–111.
28. Harrois A, Libert N, Duranteau J. Acute kidney injury in trauma patients. *Curr Opin Crit Care*. 2017;23(6):447–456.
29. Harrois A, Soyer B, Gauss T, Hamada S, Raux M, Duranteau J. Prevalence and risk factors for acute kidney injury among trauma patients: a multicenter cohort study. *Crit Care*. 2018;22(1):344.
30. Stewart IJ, Faulk TI, Sosnov JA, Clemens MS, Elterman J, Ross JD, et al. Rhabdomyolysis among critically ill combat casualties: associations with acute kidney injury and mortality. *J Trauma Acute Care Surg*. 2016;80(3):492–498.
31. Skinner DL, Hardcastle TC, Rodseth RN, Muckart DJ. The incidence and outcomes of acute kidney injury amongst patients admitted to a level I trauma unit. *Injury*. 2013;45(1):259–264.
32. Podoll AS, Kozar R, Holcomb JB, Finkel KW. Incidence and outcome of early acute kidney injury in critically-ill trauma patients. *PLoS One*. 2013;8(10):e77376.
33. Ülger F, Pehlivanlar Küçük M, Küçük AO, İlkaya NK, Murat N, Bilgiç B, et al. Evaluation of acute kidney injury (AKI) with RIFLE, AKIN, CK, and KDIGO in critically ill trauma patients. *Eur J Trauma Emerg Surg*. 2017;44(4):597–605.
34. Yamamoto R, Cestero RF, Yoshizawa J, Maeshima K, Sasaki J. Emergency angiography for trauma patients and potential association with acute kidney injury. *World J Emerg Surg*. 2021;16(1):56.

