ORIGINAL ARTICLES

Factors Associated with the Use of Preventive Care for Contrast-Induced Acute Kidney Injury

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BACKGROUND: The factors that affect the implementation of preventive care for contrast-induced acute kidney injury (CIAKI) are unknown.

OBJECTIVE: To assess patient and provider factors associated with the use of preventive care for CIAKI.

DESIGN: Prospective cohort study.

PARTICIPANTS: Patients with kidney disease undergoing procedures with intravascular iodinated radiocontrast.

MEASUREMENTS: We recorded the use of preventive care defined as the administration of: (1) pre- and post-procedure isotonic intravenous (IV) fluid, (2) N-acetylcysteine, and (3) iso-osmolal radiocontrast. We surveyed patients' providers to assess their knowledge, experience, and training on CIAKI and used multiple logistic regression to assess the independent associations of patient and provider factors with the use of these preventive interventions.

RESULTS: We enrolled 660 patients and 87 providers. Patient factors associated with use of IV fluid and N-acetylcysteine were higher baseline serum creatinine (OR 1.5 and 5.0, $p < 0.05$) and inpatient status (OR 3.0 and 6.3, $p < 0.05$), while higher baseline serum creatinine was associated with the use of iso-osmolal contrast (OR=13.4, $p < 0.01$). The primary provider characteristics associated with the use of IV fluid and N-acetylcysteine were a greater degree of prior training on CIAKI (OR 1.9 and 2.8, $p < 0.05$) and higher number of prior patients with CIAKI (OR 2.7 and 2.6, $p < 0.05$).

CONCLUSIONS: Patient baseline kidney function and provider training and experience with CIAKI are independently associated with the use of preventive care. Efforts to increase and intensify the training providers receive on CIAKI may help decrease the incidence of this costly iatrogenic condition.

KEY WORDS: predictors; contrast-induced acute kidney injury; patients; providers; preventive care.

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INTRODUCTION

Contrast-induced acute kidney injury (CIAKI), commonly defined as an increase in serum creatinine (Scr) of $\geq 25\%$ and/or 0.5 mg/dl has been associated with increased mortality and medical resource utilization. CIAKI is unique in that its risk factors are well known, it is universally iatrogenic, and its timing is highly predictable, which make it particularly amenable to preventive care.¹⁻⁷ Over the past 2 decades, preventive interventions for CIAKI have been identified.⁸⁻¹¹ Randomized clinical trials have demonstrated that isotonic intravenous (IV) fluid is effective and superior to hypotonic IV fluid for the prevention of CIAKI in high-risk patients.^{8,9,11} These observations resulted in clinical recommendations to administer isotonic IV fluid in high-risk patients.^{4,12,13} Clinical trials and meta-analyses have also found that the anti-oxidant N-acetylcysteine (NAC) decreases the risk of CIAKI.^{10,14-16} Although consensus on the effectiveness of NAC is lacking, some experts recommend its use in high-risk patients.⁴ Finally, while studies comparing iso- and low-osmolal contrast report conflicting findings, some studies have found iso-osmolal contrast to be less nephrotoxic, resulting in recommendations from some medical organizations to use iso-osmolal contrast for high-risk patients.¹⁷⁻²³

Despite clinical studies and recommendations supporting the use of these measures, prior studies demonstrate that these preventive interventions are sub-optimally utilized.^{24,25} Factors contributing to the non-uniform implementation of these preventive strategies are not known. Increasing our understanding of the factors that impact translation of existing empiric knowledge and expert recommendations on the prevention of CIAKI into clinical practice is essential to improve the prevention of this iatrogenic condition. We hypothesized that patient factors associated with an increased risk for CIAKI, including higher baseline serum creatinine concentration and provider factors, including prior training on CIAKI, would be associated with the use of preventive care. We undertook this study to assess the patient and provider factors associated with the use of preventive care for CIAKI.

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METHODS

Patient Population

We conducted a prospective, observational study of patients receiving intravascular iodinated radiocontrast at a VA Healthcare System between February 1, 2005 and July 31, 2006. All study procedures were approved by the local Institutional Review Board.

We identified patients scheduled for computed tomography (CT) with IV radiocontrast or angiography (coronary or non-coronary) in advance of the procedure, recorded the Scr measured most proximate to and within 60 days of the procedure, and calculated patients' baseline estimated glomerular filtration rate (eGFR) using the four-variable Modification of Diet in Renal Disease study equation.²⁶ Patients scheduled to receive intravascular radiocontrast at our institution are recommended to have Scr measured within 60 days prior to the procedure. We only recruited patients at increased risk for CIAKI based on a pre-procedure eGFR value <60 ml/min/1.73 m². We excluded individuals on maintenance dialysis and subjects unable to provide informed consent based on the need for mechanical ventilation. To enroll patients for whom there was sufficient time for providers to prescribe preventive care, we excluded patients undergoing emergent coronary angiography for ST-elevation myocardial infarction or emergent CT for the diagnosis of acute pulmonary embolism or ruptured aortic aneurysm. To limit the study to patients whose principal risk factor for acute kidney injury was radiocontrast, we excluded patients receiving IV vasopressor or inotropic medications, and hospitalized patients with systolic blood pressure less than 90 mmHg at the time of the procedure. For all eligible patients willing to participate, the study coordinator obtained informed consent in person.

Baseline Patient Data Collection

Using the electronic health record and a standard chart abstraction questionnaire, we recorded patients' demographic characteristics, prescribed medications, and comorbid medical conditions. We tracked whether any IV fluids were administered prior to and following the procedure, including the type, rate, and duration of IV fluid; whether oral and/or IV NAC in any dose was prescribed; and the type and volume of contrast administered.

Provider Recruitment and Data Collection

Following each procedure, we identified the provider who ordered the CT or performed angiography and asked them to complete a written survey on CIAKI. We administered the survey to providers who ordered CT rather than the radiologist who performed the scan, as the ordering providers were responsible for prescribing preventive care. Conversely, for patients who underwent angiography, we surveyed the proceduralist, as they were most responsible for implementing preventive measures. The investigator-designed survey assessed providers' demographic and professional background, understanding of the risk factors for CIAKI, knowledge of preventive care for CIAKI, and prior training and experience with patients with CIAKI (Appendix). For questions pertaining to knowledge of the risk factors and preventive interventions, providers were able to answer yes, no, or not sure. Providers were asked to report their prior training on CIAKI using a 4-point Likert scale ranging from "none" to "a lot." Surveys were mailed to providers along with an informed consent form, and if

not completed and returned within 2 months, remailed. Providers who cared for more than one study patient were asked to complete the survey only once, and data contained on that survey were linked to each of that provider's patients.

Statistical Analyses

Our primary analyses focused on the associations of patient and provider factors with the use of: (1) pre- and post-procedure isotonic IV fluid (NaCl or NaHCO₃), (2) NAC, and (3) iso-osmolal radiocontrast. We centered and scaled continuous patient variables including baseline Scr, blood urea nitrogen (BUN), and age to improve efficiency and report interpretable odds ratios. These variables were centered at values close to the mean or median and scaled by the approximate standard deviation. Baseline Scr was centered at 132.6 μ mol/l (1.5 mg/dl) and scaled by 44.2 μ mol/l (0.5 mg/dl), while baseline BUN was centered at 8.9 μ mol/l (25 mg/dl) and scaled by 3.6 μ mol/l (10 mg/dl). The assumption of linearity was tested for all linear predictors, including age, serum creatinine, BUN, and level of prior training on CIAKI. Univariate associations of patient factors with the use of preventive care were assessed using logistic regression with random intercepts for individual providers. Variables significant at the $p \leq 0.25$ level in univariate analyses were included in multivariable models. We used random effects multiple logistic regression to analyze the independent association of patient factors with the use of these three preventive interventions, accounting for clustering of patients by individual providers with

Figure 1. Patient and provider recruitment.

Table 1. Baseline Patient Characteristics*

Demographics	(N=660)
Mean age (years) †	69±10
Male sex	630 (95)
Race (white)	594 (90)
Race (African-American)	48 (7)
Inpatient	188 (29)
Ambulatory	451 (68)
Long-term care	21 (3)
Comorbid conditions	
Diabetes mellitus	300 (45)
Liver disease	76 (12)
Congestive heart failure	133 (20)
Peripheral vascular disease	125 (19)
Cerebrovascular disease	95 (14)
Procedure characteristics	
CT scan	421 (64)
Coronary angiogram	181 (27)
Non-coronary angiogram	58 (9)
Low-osmolar contrast	92 (14)
Iso-osmolar contrast	568 (86)
Volume contrast (ml)‡	140 (100,150)
Baseline eGFR (ml/min/1.73m ²)‡	52 (47, 56)
Prescribed medications	
Non-steroidal anti-inflammatory medications	67 (10)
Loop diuretics	175 (27)
ACEIs/ARBs§	306 (46)
Theophylline	4 (0.6)
Calcium channel blockers	173 (26)

*Data are presented as n (%) unless otherwise specified

†Mean ± standard deviation

‡Median (interquartile range)

§ACEI = angiotensin converting enzyme inhibitor; ARB = angiotensin receptor blocker

a random intercept for each provider. All 660 study patients were included in these analyses.

We used these same analysis methods to assess the univariate and multivariable associations of provider factors with the use of the three preventive measures. Due to significant collinearity of provider variables using a $p \leq 0.25$ for inclusion in the multivariable model, we only included provider variables that were significant at the $p \leq 0.1$ level in univariate analyses. Since provider age and years in practice were highly correlated, we only considered years in practice in these analyses. These analyses were restricted to the 362 patients that were linked to provider surveys.

We also conducted sensitivity analyses in which both patient and provider factors were analyzed in a single model. These analyses included a separate intercept for patients with completed provider surveys and utilized all 660 patients. All analyses were conducted using STATA version 10 (College Station, Tx) and SAS version 9.1 (Cary, NC). A p -value < 0.05 represented statistical significance.

RESULTS

Patient Population

We screened 11,410 patients undergoing radiographic procedures, of whom 1,884 (17%) were scheduled to receive intravascular radiopaque contrast and had a baseline eGFR < 60 ml/min/1.73m². Of these, 258 did not show up for the procedure, 141 were unavailable for recruitment, and 254 did not receive intravascular contrast. Of the remaining 1,231

potentially eligible patients, 247 (20%) refused to participate, and 324 (26%) had one or more exclusion criteria, resulting in a study population of 660 patients (Fig. 1). Four hundred twenty-one patients (64%) underwent CT, 181 (27%) underwent coronary angiography, and 58 (9%) underwent non-coronary angiography (Table 1).

Provider Population

Of the 243 eligible study providers, 87 (36%) completed the study survey. These 87 providers managed 362 study patients (55% of overall study population) (Fig. 1). The median age of providers was 36 years, 61 (70%) were white, and 38 (44%) were trainees (e.g., intern, resident, fellow). Fifty-four providers (62%) reported little to no prior training on CIAKI (Table 2). Providers with fewer than 6 years in practice were more likely to have cared for patients undergoing coronary angiography than CT scan (95% vs 33%) and for inpatients compared to outpatients (81% vs 41%).

Use of Preventive Care

Overall, 157 patients (24%) received pre- and post-procedure isotonic IV fluid, 259 (39%) received NAC, 568 (86%) received iso-osmolar contrast, and 120 (18%) received all three interventions. Use of all three interventions was highest with coronary angiography (37% of patients) and lowest with CT (9% of patients) (Table 3). Among patients with diabetes mellitus, who were at highest risk for CIAKI, the use of IV fluid and NAC was higher with angiography than CT scan, while the frequency of use of iso-osmolar contrast was similar for both procedures (Fig. 2). The frequency of use of IV fluids in the present study, specifically for patients who underwent coro-

Table 2. Provider Characteristics*

Demographics	N=87
Age †	36 (31, 49)
Male sex	46 (53)
Race (white)	61 (73)
Race (Asian)	23 (27)
Professional characteristics	
Intern/resident	16 (18)
Fellow	22 (25)
Attending physician	25 (29)
Nurse practitioner/physician assistant	20 (23)
Internal medicine or specialty	57 (66)
Years in practice†	5 (0, 18)
Outpatient clinics per week	2 (1, 4)
<2 weekly outpatient clinics	39 (46)
2-3 weekly outpatient clinics	20 (24)
>3 weekly outpatient clinics	25 (30)
Experience with CIAKI	
No. monthly studies ordered with contrast†	10 (4,16)
No. prior patients with CIAKI†	3 (0,10)
<6 prior patients with CIAKI	54 (70)
6-10 prior patients with CIAKI	13 (17)
>10 prior patients with CIAKI	10 (13)
Training on CIAKI	
None	15 (17)
A little bit	39 (45)
A moderate amount	26 (30)
A lot	7 (8)

*Data presented as n (%) unless otherwise specified

†Median (interquartile range)

Table 3. Use of Preventive Interventions for CIAKI by Procedure Type*

Interventions	Overall (N=660)	CT scan (N=421)	Coronary angiogram (N=181)	Non-coronary angiogram (N=58)	P-value†
Isotonic IV fluid	157 (24)	57 (14)	82 (45)	18 (31)	<0.001
N-acetylcysteine	259 (39)	73 (17)	152 (84)	34 (59)	<0.001
Iso-osmolal contrast	568 (86)	362 (86)	151 (83)	58 (100)	0.08
All three interventions	120 (18)	37 (9)	67 (37)	16 (28)	<0.001

*Data denote n (%) of patients

†P-values based on Fisher's exact test

nary angiography, was generally comparable to past estimates of the use of this preventive intervention.²⁵

Associations of Patient Characteristics with the Use of Preventive Care

The only patient factor independently associated with the use of each of the three preventive interventions was baseline Scr (Table 4). Each 44.2 $\mu\text{mol/l}$ (0.5 mg/dl) increment in baseline Scr above 132.6 $\mu\text{mol/l}$ (1.5 mg/dl) was associated with a greater odds of using isotonic IV fluid (OR=1.5, 95% CI 1.1–2.1), NAC (OR=5.0, 95% CI=2.5–10.1), and iso-osmolal contrast (OR=13.4, 95% CI 5.1–35.2). Inpatient status at the time of the procedure and the performance of coronary angiography (versus CT) were independently associated with the use of IV fluid and NAC. The performance of non-coronary angiography was independently associated with the use of NAC.

Associations of Provider Factors with the Use of Preventive Care

A greater degree of prior training on CIAKI was independently associated with the use of isotonic IV fluid (OR=1.9, 95% CI 1.1–3.2) and with the use of NAC (OR=2.8, 95% CI 1.7–4.5) (Table 5). Providers who had cared for ten or more patients with CIAKI were more likely to use isotonic IV fluid (OR=2.7, 95% CI 1.1–6.5) and NAC (OR=2.6, 95% CI 1.1–6.2). Providers who had practiced less than 6 years (including trainees) were more likely to administer IV fluids (OR=11.4, 95% CI 3.0–43.5) and prescribe NAC (OR=4.4, 95% CI 1.8–10.7). Providers with fewer than two weekly outpatient clinics were more likely to prescribe NAC.

Overall, patients whose providers had two to three weekly outpatient clinics and ten or fewer prior patients with CIAKI were more likely to receive iso-osmolal contrast. However, we recognized during the course of the study that decisions on the type of contrast for patients undergoing CT were made by radiology personnel and not the provider who had ordered the scan and completed our study survey. Therefore, we repeated the analyses of the association of provider factors with the use of iso-osmolal contrast among the 144 patients who had undergone angiography and to whom provider data could be linked. In these analyses, providers who had ordered five or fewer monthly studies with contrast were more likely to use iso-osmolal contrast (OR=10.3, 95% CI 1.2–84.5), as were providers from non-internal medicine disciplines (OR=6.9, 95% CI 1.4–33.9). However, non-internal medicine providers and those ordering fewer studies were more likely to be linked with non-coronary angiograms, for which iso-osmolal contrast was used uniformly.

In sensitivity analyses in which patient and provider variables that were independently associated with the use of

preventive care in individual models were combined, there was no impact on patient factors and only a mildly attenuating effect of provider training on the use of isotonic IV fluids. There were no differences in the use of the three preventive interventions between patients whose providers completed the survey and those whose provider did not.

DISCUSSION

In this prospective observational study, lower baseline kidney function and inpatient status were the primary patient factors associated with the use of preventive care for CIAKI, while a greater degree of prior training on CIAKI, a higher number of prior patients with this condition, and fewer years in practice were the principal provider factors associated with use of preventive care. These novel findings should help shape future efforts to train providers on how to most effectively prevent this iatrogenic condition.

It is not surprising that preventive care was more common among hospitalized patients independent of serum creatinine, as outpatient radiology and angiography suites may not be equipped or staffed to deliver therapies such as IV fluid on a routine basis. Our observation that higher baseline Scr was the only patient factor associated with the use of each of the three preventive interventions likely reflects widespread recognition that underlying kidney disease is the principal risk factor for CIAKI. However, heart failure, which increases risk for CIAKI, and diabetes mellitus, which significantly amplifies risk among patients with chronic kidney disease, were not associated with greater use of preventive care.^{3,27} Efforts to educate providers about CIAKI should not only emphasize the

Figure 2. Use of preventive care by procedure type in patients with diabetes mellitus.

Table 4. Associations of Patient Factors with Use of Preventive Interventions

Factor	Association with IV fluid use		Association with NAC use		Association with iso-osmolar contrast use	
	Unadjusted OR	Adjusted OR	Unadjusted OR	Adjusted OR	Unadjusted OR	Adjusted OR
Demographic/clinical factors						
Age	0.8 (0.6–1.0)	0.9 (0.7–1.1)	0.9 (0.7–1.1)	–	0.9 (0.7–1.1)	–
Race (African-American)	1.5 (0.6–3.4)	–	3.8 (1.4–10.7)	1.3 (0.5–3.3)	4.5 (1.0–19.7)	1.8 (0.4–8.4)
Race (other/unknown)	1.4 (0.4–5.7)	–	0.4 (0.1–2.2)	0.6 (0.1–2.5)	0.8 (0.2–3.1)	0.6 (0.1–2.3)
Race (white)*	1.0	–	1.0	1.0	1.0	1.0
Inpatient status	3.1 (1.9–5.0)	3.0 (1.8–4.9)	6.5 (3.5–12.3)	6.3 (3.7–10.9)	0.7 (0.4–1.1)	–
Long-term care	0.9 (0.2–3.9)	1.7 (0.4–7.3)	0.4 (0.1–2.5)	0.8 (0.2–4.0)	0.9 (0.2–3.5)	–
Outpatient status*	1.0	–	1.0	1.0	1.0	–
Laboratory variables						
Serum creatinine †	1.8 (1.3–2.4)	1.5 (1.1–2.1)	6.1 (3.1–11.9)	5.0 (2.5–10.1)	15.9 (6.4–39.5)	13.4 (5.1–35.2)
Blood urea nitrogen ‡	1.4 (1.2–1.7)	1.0 (0.8–1.3)	1.7 (1.3–2.1)	1.0 (0.7–1.3)	1.6 (1.2–2.2)	1.1 (0.8–1.5)
Clinical conditions						
Diabetes mellitus	1.6 (1.0–2.5)	1.3 (0.8–2.1)	1.6 (1.0–2.6)	1.1 (0.7–1.8)	0.9 (0.6–1.5)	–
Congestive heart failure	1.4 (0.8–2.5)	0.8 (0.5–1.5)	2.0 (1.1–3.6)	1.0 (0.5–1.8)	1.1 (0.6–2.0)	–
Peripheral vascular disease	1.3 (0.7–2.4)	–	2.3 (1.2–4.3)	1.5 (0.8–2.7)	1.4 (0.7–2.7)	–
Procedural factors						
Coronary angio	7.5 (3.6–15.5)	6.3 (3.2–12.5)	35.8 (17.7–72.6)	38.5 (19.8–74.8)	0.9 (0.5–1.5)	0.7 (0.4–1.3)
Non-coronary angio	5.4 (2.1–14.2)	2.3 (0.9–6.3)	10.6 (4.7–24.1)	3.5 (1.5–8.4)	2.9 (0.8–10.3)	1.5 (0.4–5.5)
CT*	1.0	1.0	1.0	1.0	1.0	1.0

Data presented as odds ratio (OR) and 95% confidence interval

*Referent category

– Not included in model as $p > 0.25$ in univariate analyses

†OR represents increased odds of use of preventive intervention for each 44.2 $\mu\text{mol/l}$ (0.5 mg/dl) increase in baseline Scr above 132.6 $\mu\text{mol/l}$ (1.5 mg/dl)

‡OR represents increased odds of use of preventive intervention for each 3.6 $\mu\text{mol/l}$ (10 mg/dl) increase in baseline BUN above 8.9 $\mu\text{mol/l}$ (25 mg/dl)

importance of chronic kidney disease, but should raise awareness of the importance of heart failure and diabetes mellitus in determining patients' level of risk.

We found that providers' prior level of training on and experience with CIAKI were the primary factors associated with the use of isotonic IV fluid and NAC. However, well over half of providers surveyed reported receiving little to no prior training on this condition. The successful translation of empiric knowledge

and implementation of clinical recommendations on the prevention of CIAKI appear to be highly dependent on the provision of adequate education and training. Although we did not assess the form of training our providers had received, future efforts should seek to delineate the most effective means of disseminating information on CIAKI to clinicians and promote educational programs to broaden the number of providers who receive training on this subject.

Table 5. Associations of Provider Factors with Use of Preventive Interventions

Factor	Association with IV fluid use		Association with NAC use	
	Unadjusted OR	Adjusted OR	Unadjusted OR	Adjusted OR
Knowledge of CIAKI†				
CKD as strongest risk	0.3 (0.1–1.1)	0.6 (0.2–1.3)	0.5 (0.2–1.9)	–
Isotonic saline	3.4 (0.9–12.3)	1.1 (0.3–3.8)	5.8 (1.4–23.6)	1.2 (0.5–3.3)
Isotonic bicarbonate	3.2 (1.1–9.3)	1.1 (0.4–2.7)	6.2 (1.8–20.8)	1.8 (0.8–3.7)
Demographics				
Non-internal medicine	0.3 (0.1–1.0)	1.2 (0.4–3.9)	0.3 (0.1–1.2)	0.7 (0.3–1.6)
Female sex	0.2 (0.1–0.5)	0.7 (0.2–1.9)	0.5 (0.1–1.6)	–
Weekly clinic sessions				
≥4*	1.0	1.0	1.0	1.0
<2	21.0 (3.1–141.5)	2.8 (0.6–14.1)	128.3 (18.6–883.9)	19.6 (4.1–92.4)
2–3	8.6 (1.1–69.0)	3.2 (0.6–17.3)	15.9 (2.1–121.0)	3.8 (0.7–19.6)
Years in practice				
≥6*	1.0	1.0	1.0	1.0
<6	17.6 (6.5–47.6)	11.4 (3.0–43.5)	16.1 (5.3–49.0)	4.4 (1.8–10.7)
Training and experience with CIAKI				
Level of prior training‡	1.8 (0.9–3.4)	1.9 (1.1–3.2)	3.6 (1.6–7.9)	2.8 (1.7–4.5)
<10 patients with CIAKI*	1.0	1.0	1.0	1.0
≥10 patients with CIAKI	6.2 (1.5–26.5)	2.7 (1.1–6.5)	18.3 (3.1–107.7)	2.6 (1.1–6.2)

Data presented as odds ratio (OR) and 95% confidence interval

*Referent category

– Not included in model as $p > 0.1$ in univariate analyses

†Denotes provider response of "yes" to knowledge of chronic kidney disease (CKD) as strongest risk factor for CIAKI and efficacy of isotonic saline and isotonic bicarbonate for prevention of CIAKI

‡Denotes increase in odds of use of preventive intervention with each additional degree of training based on 4-point Likert scale (1 = none to 4 = a lot)

Interestingly, providers with fewer outpatient clinics and those who had been practicing for fewer years were more likely to administer preventive care. Assuming that providers with fewer years in practice were trainees who spend a disproportionate amount of time in the hospital setting and that providers with fewer outpatient clinics provide more inpatient care, these findings suggest that hospital-based providers may be more likely to implement preventive care for CIAKI. Although providers with fewer years in practice were more likely to have cared for inpatients and those undergoing coronary angiography, in whom the use of preventive care may be easier to deliver, determining the extent to which the proportion of time spent caring for inpatients is associated with the provision of preventive care for CIAKI is highly relevant given the trend in medicine towards dividing the care of patients between hospitalists and outpatient providers. Studies in other patient populations, including those with pneumonia and heart failure, demonstrate that hospitalists are more likely than community providers to deliver evidence-based care to inpatients.^{28,29} While we did not categorize providers according to the hospitalist model, our findings suggest hospital-based clinicians may be more likely to implement preventive care for CIAKI.

The strongest predictor of the use of iso-osmolal contrast was patients' baseline serum creatinine level, while provider factors had little impact on the choice of contrast agent. These findings, when considered in light of the overwhelming use of iso-osmolal contrast in our study population, suggest that many providers perceive a lower risk for CIAKI with iso-osmolal compared to low-osmolal contrast. Studies on the comparative nephrotoxicity of iso- and low-osmolal contrast have reported conflicting findings, with some studies reporting less risk with iso-osmolal Iodixanol compared to low-osmolal Iohexol (GE Healthcare, Princeton, NJ), which is the low-osmolal contrast agent used at our institution. Future research will need to more clearly delineate the factors that affect providers' choice of contrast agent and how those decisions impact patient outcomes.

This study has certain limitations. First, we did not assess system-level factors that could have influenced the use of preventive care (standard protocols for IV fluids or NAC, assessment of post-procedure Scr). However, at the time of this study, there were no standard protocols for the prevention of CIAKI at our institution. Nonetheless, this was a single-center study, and our findings may not be generalizable to the broader medical community or be applicable to medical institutions with protocols in place for the prevention of CIAKI. Second, our study survey was not validated prior to use, and we cannot be certain that the data collected accurately reflected provider's true knowledge or experience. Third, more than half of providers did not return the study survey, which may have biased our assessment of the association of provider factors with the use of preventive care. However, adjusting our analyses for survey completion did not alter our findings. Fourth, our analyses were predicated on the idea that NAC and iso-osmolal contrast (compared to low osmolal contrast) are effective preventive interventions. However, there continues to be some clinical equipoise on the efficacy of these two interventions that could have affected our assessment of the associations of provider characteristics with the use of these measures. Finally, our observation that providers with fewer years in practice, which included trainees, were more likely to use preventive care may be confounded by the structure of

care at our institution, in which trainees work under the supervision of an attending physician. Patients treated by trainees may have been more likely to receive preventive care because they had multiple providers involved in their care.

In conclusion, patient factors, including baseline kidney function and inpatient status, as well as provider characteristics including level of training and prior experience with CIAKI, are associated with the use of preventive care for CIAKI. Informing clinicians of empiric data and expert recommendations on the prevention of CIAKI should be a primary focus of efforts seeking to reduce the incidence and adverse outcomes of this iatrogenic condition.

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Conflict of Interest: Dr. Weisbord has served as a consultant to and previously served as an investigator on a multi-site study of GE Healthcare. None of the other authors have any potential conflicts of interest.

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APPENDIX: PROVIDER SURVEY

Instructions: Below is a list of questions about you and your knowledge of radiocontrast nephropathy. Please check the appropriate box when appropriate and answer other questions to the best of your ability.

Today's date _____

1. How old are you currently? _____ years
2. Gender: Male ☐ Female ☐
3. Year of professional school graduation: _____
4. Are you currently?
 - a) ☐ Intern (PG1)
 - b) ☐ Resident (PG 2 or greater)
 - c) ☐ Fellow
 - d) ☐ Attending physician
 - e) ☐ Nurse practitioner or physician assistant
 - f) ☐ Other → (specify): _____
5. If you have finished your clinical training, how many years have you been practicing medicine? _____ years

☐ Not applicable – I have not finished clinical training
6. What is your medical specialty?
 - a) ☐ Internal medicine
 - b) ☐ Subspecialty in internal medicine (specify): _____
 - c) ☐ Surgery including subspecialties
 - d) ☐ Emergency medicine
 - e) ☐ Other → (specify): _____
7. What is your ethnicity?
 - a) ☐ Hispanic or Latino
 - b) ☐ Non Hispanic or Latino
8. What is your primary race affiliation?
 - a) ☐ American Indian/Alaskan Native
 - b) ☐ Asian
 - c) ☐ Native Hawaiian or Pacific Islander
 - d) ☐ Black or African American
 - e) ☐ White
9. How many months each year do you spend on the in-patient wards? _____
10. How many ½ days per week do you spend in out-patient clinic? _____
11. What percentage of your time do you spend teaching? _____%
12. What percentage of your time do you spend doing research? _____%
13. How often do you order a radiographic study using intravascular radiocontrast (including computed tomography scan, coronary angiogram, or non-coronary angiogram) during a typical month? _____
14. How much training have you received on the prevention of radiocontrast-induced acute renal failure?
 - a) ☐ None
 - b) ☐ A little bit of training
 - c) ☐ A moderate amount of training
 - d) ☐ A lot of training
15. How many patients have you taken care of who developed radiocontrast-induced acute renal failure at any time in the past? _____

16. Which of the following conditions do you believe increases the risk for acute renal failure from radiocontrast dye?

1. Hypertension.....	Yes ☐	No ☐	Not sure ☐
2. Chronic kidney disease.....	Yes ☐	No ☐	Not sure ☐
3. Allergy to radiocontrast dye.....	Yes ☐	No ☐	Not sure ☐
4. Chronic obstructive lung disease.....	Yes ☐	No ☐	Not sure ☐
5. Coronary artery disease.....	Yes ☐	No ☐	Not sure ☐
6. Diabetes mellitus.....	Yes ☐	No ☐	Not sure ☐
7. Peripheral vascular disease.....	Yes ☐	No ☐	Not sure ☐
8. Intravascular volume depletion.....	Yes ☐	No ☐	Not sure ☐
9. Anemia.....	Yes ☐	No ☐	Not sure ☐
10. Congestive heart failure.....	Yes ☐	No ☐	Not sure ☐
11. Atrial fibrillation.....	Yes ☐	No ☐	Not sure ☐

17. Please select the clinical condition from the list in the previous question that is the strongest risk factor for radiocontrast-induced acute renal failure. Enter the number here _____

18. Which of the following interventions do you believe have been shown conclusively from clinical trials to decrease the risk for radiocontrast-induced acute renal failure? Check all that apply.

a) loop diuretics such as lasix	Yes ☐	No ☐	Not sure ☐
b) calcium channel blockers	Yes ☐	No ☐	Not sure ☐
c) intravenous isotonic saline infusion	Yes ☐	No ☐	Not sure ☐
d) intravenous isotonic bicarbonate infusion	Yes ☐	No ☐	Not sure ☐
e) intravenous dextrose in water infusion	Yes ☐	No ☐	Not sure ☐
f) beta-blockers	Yes ☐	No ☐	Not sure ☐
g) fenoldopam (corlopam)	Yes ☐	No ☐	Not sure ☐
h) low dose of radiocontrast dye	Yes ☐	No ☐	Not sure ☐
i) n-acetylcysteine (mucomyst)	Yes ☐	No ☐	Not sure ☐
j) dopamine	Yes ☐	No ☐	Not sure ☐
k) mannitol	Yes ☐	No ☐	Not sure ☐
l) theophylline/aminophylline	Yes ☐	No ☐	Not sure ☐
m) using low or iso-osmolar contrast	Yes ☐	No ☐	Not sure ☐
n) other? Specify _____	Yes ☐	No ☐	

19. When you order a radiographic study that utilizes radiocontrast dye in a patient at increased risk for acute renal failure, what do you do to prevent the development of radiocontrast-induced acute renal failure?

	Sometimes	Always	Never
a) loop diuretics such as lasix	☐	☐	☐
b) calcium channel blockers	☐	☐	☐
c) intravenous isotonic saline infusion	☐	☐	☐
d) intravenous isotonic bicarbonate infusion	☐	☐	☐
e) intravenous dextrose in water infusion	☐	☐	☐
f) beta-blockers	☐	☐	☐
g) fenoldopam (corlopam)	☐	☐	☐
h) low dose of radiocontrast dye	☐	☐	☐
i) n-acetylcysteine (mucomyst)	☐	☐	☐
j) dopamine	☐	☐	☐
k) mannitol	☐	☐	☐
l) theophylline/aminophylline	☐	☐	☐
m) using low or iso-osmolar contrast	☐	☐	☐
n) other? Specify _____	☐	☐	

20. At what level of serum creatinine does the risk for radiocontrast nephropathy increase significantly? (Choose the best response)
- a) ☐ > 1.0 mg/dl
 - b) ☐ > 1.5 mg/dl
 - c) ☐ > 2.0 mg/dl
 - d) ☐ depends on the patients age and race
21. Estimate the glomerular filtration rate for which the risk for radiocontrast nephropathy increases significantly? _____ ml/min/1.73m²
22. Radiocontrast-induced acute renal failure has been associated with which of the following? Check all that apply
a) increased risk for in-hospital death	Yes ☐	No ☐	Not sure ☐
b) potential need for dialysis	Yes ☐	No ☐	Not sure ☐
c) increased hospital length of stay	Yes ☐	No ☐	Not sure ☐