Published in final edited form as:

Crit Care Nurse. 2017 February ; 37(1): 13–26. doi:10.4037/ccn2017178.

Reducing Contrast-Induced Acute Kidney Injury: How Nurses Can Improve Patient Safety, a qualitative investigation

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Abstract

Background—Contrast-induced nephropathy (CIN) is a common complication after cardiac interventions that use contrast media. In populations with multiple risk factors, CIN can occur in 50% of cases or more. Nurses are uniquely positioned to help reduce the incidence of CIN or contrast-induced acute kidney injury (CI-AKI) in patients undergoing cardiovascular interventional procedures and therefore can reduce patient harm. Nurse leaders in the Northern New England Cardiovascular Disease Study Group (NNE), a ten-center quality improvement consortium in Maine, New Hampshire, and Vermont, formed a nursing task force to reduce CI-AKI following cardiovascular interventional procedures in the northern New England (NNE) region.

Objective—To reduce CI-AKI following cardiovascular interventional procedures in northern New England.

Methods—Nurses of the NNECDSG, in collaboration with physician colleagues, led their organizations in the standardization of institutional practices through evaluation of their hospitals' current practices; implementation of evidenced-based best practices; thorough review of patients' current medications, risk factors and baseline renal function; standardization of patient care processes; influence over type and amount of contrast agents used, and utilization of a quality framework, such as the plan-do-study-act (PDSA) cycle, to monitor outcomes. The intervention occurred over three years. Effectiveness of the intervention strategies were measured from structured qualitative interviews with teams at each site and monthly conference call reports. CI-AKI was ascertained at the patient level and aggregated by month and center.

Results—, Post-intervention measures demonstrated a reduction of the incidence of CI-AKI by 21 to 28 percent among the ten centers, compared to baseline.

Conclusions—This intervention successfully demonstrated that standardization of evidence-based best practices in nursing care may reduce the incidence of CI-AKI.

Keywords

Nurse; acute kidney injury; contrast; angiography; percutaneous coronary intervention

Introduction

Background

Acute kidney injury is a frequent complication associated with administration of intravenous contrast agents during diagnostic cardiac catheterization and percutaneous coronary interventional (PCI) procedures and leads to increased morbidity and mortality ¹. AKI is defined as an acute increase of 0.3 mg/dL or a 50% or greater increase in serum creatinine (SCr) within 48 hours from baseline². The incidence of contrast-induced acute kidney injury (CI-AKI) varies due to differences in definitions, measurement of renal indicators, as well as differences in both patient populations and risk factors, and is dependent on the severity of renal failure ³. Common definitions come from 1) The European Society of Urogenital Radiology, where a serum creatinine increase >0.5 mg/dl or >25% within 3 days of contrast administration marks CI-AKI, and 2) The Acute Kidney Injury Network, which defines CI-AKI as a 0.3 mg/dl increase in serum creatinine, with oliguria.³ CI-AKI is commonly under-recognized due to a lack of post-procedure monitoring of renal function biomarkers.⁴ The incidence of CI-AKI ranges between 3–15%, depending on definition used, and translates to an additional dollar cost of \$15,900 per case compared to surgery patients with no CI-AKI ^{5–9}. This does not include the untold emotional burden to patients and their families that comes along with unexpected complications after interventional procedures or surgery.

CI-AKI occurs in patients with chronic kidney disease (CKD) and in patients with normal kidney function. Patients with CKD have a reduced nephron capacity and are at greater risk of developing CI-AKI. When exposed to contrast, it triggers a transient release of nitric oxide, which induces endothelium-dependent vasodilation. Within the renal vascular arcades, this results in transient renovascular dilation and increased renal blood flow, which lasts for a few minutes. When the water-soluble contrast passes into the glomerulus through the fenestrated endothelium, it enters Bowman's capsule and the urinary space with rapid exposure to the tubular epithelial cells. The contrast material is then taken up by these cells and permeates gap junctions and the basal side of the tubule with entry into the peritubular space. In response, there is tubulo-glomerular feedback through adenosine release from the macula densa, endothelin release, prostaglandin dysregulation, and subsequent decreased nitric oxide synthesis. These mechanisms combine to cause sustained intra-renal vasoconstriction lasting for approximately two hours. During this time, there is a substantial reduction in renal blood flow and accumulation of contrast in the renal medulla, causing further vasoconstriction, prolonged contrast exposure to the renal tubular cells, and direct chemotoxic cellular injury. This phenomenon has been illustrated in numerous case reports of persistent nephrograms, where contrast has been shown to be trapped in the medulla for days and weeks ¹⁰. During this time, the prolonged contrast exposure to renal tubules propagates direct cellular injury inducing tubular apoptosis and cell death (Figure 1) ¹¹.

Preventive measures have been studied, including the use of normal saline for volume expansion ¹², intravenous (IV) versus oral volume expansion ^{13–18}, normal saline versus sodium bicarbonate IV prophylaxis ¹⁹, medications such as N-acetylcysteine ^{20–22} and ascorbic acid ²³, withholding nephrotoxic medications pre-procedure and post-contrast

dose³, contrast type²⁴ and contrast volumes^{25,26}, and post-procedure hydration. Such studies demonstrated: the use of normal saline alone protects better against renal insufficiency than saline with mannitol or furosemide; oral volume expansion is not inferior to intravenous volume expansion, except in one study (Trivedi et al., n=53), where intravenous hydration was superior; sodium bicarbonate is associated with a significantly lower risk of contrast-induced renal failure than sodium chloride; N-acetylcysteine and ascorbic acid can reduce the risk of CI-AKI compared to saline alone; intra-arterial iso-osmolar contrast medium, but not intravenous, is associated with lower risk of CI-AKI compared to low-osmolar contrast medium; and that incremental increases in contrast volume are associated with a higher risk of CIN^{3,12-26}. These studies were performed primarily by physicians and/or researchers, with only one study (Solomon et al.) identifying one author as a nurse. CIN prevention has been a topic of interest in nursing research, and reviews have published^{27,28}; however, no clear treatment path has been shown to reduce the risk of CI-AKI in all patient populations. This is the first development of a quality improvement task force to reduce CI-AKI led and implemented by nursing professionals.

Local Problem

There has been a lack of literature describing the role of nurses in quality improvement efforts to decrease the incidence of CI-AKI through an organized approach to patient care and monitoring of outcomes. The nursing task force within northern New England (NNE) developed a framework to identify best practices in nursing interventions to reduce CI-AKI and worked towards standardizing these approaches across a region with 10 diverse centers with a 5-fold variation in rates of CI-AKI following percutaneous coronary interventions (PCI, Table 1 and Figure 2)²⁹. Using this framework, we began our process for improvement. It remains to be determined if our findings can be generalized to other patient populations receiving intravenous contrast and other clinical settings.

Intended Improvement

The nurses in the NNE developed a multi-centered collaborative nursing task force to achieve regional consensus on the role nurses can play to reduce CI-AKI and to help disseminate our findings. This quality improvement effort details the elements we identified as essential to improving patient outcomes and demonstrates the regional impact nurses in the collaborative had in standardizing patient care processes for those undergoing cardiac interventional procedures to reduce the incidence of CI-AKI. Specifically we aimed to reduce the occurrence of CI-AKI following PCI over three years by adopting best practices for CI-AKI prevention within the NNE region.

Project Question

We hypothesized high-intensity quality improvement efforts focused on adopting best-practice approaches within the NNE region could reduce the rate of post-PCI CI-AKI. In the following sections, we identify key areas along the processes of care where nurse leaders can be influential in protecting patients from CI-AKI.

Material and Methods

Ethical Issues

The project was funded by the Agency for Healthcare Research and Quality. None of the authors have conflicts of interest. The project was conducted within a regional registry maintaining the highest degree of data security and protections. All measurement was conducted within the context of data elements submitted to the registry and provided no additional risk that centers participating in the registry.

Setting

Hospitals—The Northern New England Cardiovascular Disease Study Group (NNECDSG) is a voluntary regional consortium of clinicians, hospital administrators, and health care research personnel who seek to continually improve the quality, safety, effectiveness, and cost of coronary revascularization. Of ten member hospitals, eight agreed to participate. Patients: Data were prospectively collected on consecutive patients undergoing PCI between January 1, 2007 and June 30, 2012 (n=20,147). Patients were excluded if they were emergent or had a history of renal failure requiring renal replacement therapy. Information was collected on patient characteristics, past medical, past cardiac history, cardiac anatomy and function, procedural priority, indication, process and outcomes using standard data collection instruments (available online at www.nnecdsg.org).³⁰

Planning the Intervention

Provider Education And Behavior Change

The absolute commitment of nurses to implementing proven strategies for the prevention of acute kidney injury following percutaneous coronary intervention is a critical link to ensuring optimal patient outcomes. This could not be accomplished without a carefully planned approach to provide education to effect behavior change and improve healthcare practice.

For the member institutions of the NNECDSG, the process of change began with a completely transparent discussion of the incidence of CI-AKI and the comparison of healthcare practices and patient outcomes among the institutions. It became readily apparent to all that CI-AKI was a serious and potentially preventable complication, which demanded a well-crafted approach to solving the problem. A literature review identified strategies to reduce the incidence of CI-AKI, such as the critical importance of hydration, the appropriate selection of type of contrast, and the volume of contrast infused during cardiac catheterization and PCI. During this time, the ACT study was published repudiating the efficacy of acetylcysteine (Mucomyst) for prevention of CI-AKI in patients with chronic kidney disease stage III²⁰. Study results were discussed during a conference call and were also presented and discussed at a quarterly NNE meeting. Thereafter, institutions sharply curtailed their use of Mucomyst except for patients with chronic kidney disease stage IV. The desire to improve each institution's standing relative to the incidence of CI-AKI was a powerful motivator for change. Since organizations have their own unique values and culture, champions were selected from within each institution to share information from

NNE and recruit interested and motivated staff to form multidisciplinary teams charged with the task of developing and implementing strategies to reduce CI-AKI. Teams met regularly within their institutions, and key members participated in monthly NNE Nursing Task Force conference calls, allowing for further sharing of information.

Pre-procedure hydration had been identified as the most critical factor where nurses could make a significant impact to reduce the incidence of CI-AKI. Institutions devised or revised standardized pre-procedure orders to include hydration orders, presenting one primary option for hydration with one alternate option for heart failure patients. Cardiologists, nurse practitioners and physician assistants responsible for ordering cardiac catheterization and PCI and pre-procedure hydration received education to assure compliance using the agreed-upon strategies. Nurses caring for cardiac catheterization and PCI patients in each institution were educated by the nurse champions in their organizations. Upon patient admission, nurses were taught the importance of establishing intravenous access shortly after admission and starting intravenous hydration with normal saline. Nurse leaders engaged their colleagues in meetings and at the bedside, organizational and regional data was shared with all nurses caring for this patient population to outline the problem and incidence of CI-AKI, and information was shared regarding harm and prevention of CI-AKI, generating enthusiasm to achieve active collaboration for improvement in practice. Cath lab staff participated by requesting information related to the patient's hydration status. Nurses monitored compliance with agreed-upon measures.

Champion nurses periodically gathered statistical data within their own institutions, documenting fluid intake and serum creatinine levels pre-procedure, intra-procedure and post-procedure, type of contrast used, and post-procedure serum creatinine levels. Progress toward reducing the incidence of CI-AKI became readily apparent over time, providing tangible evidence of the efficacy of implemented strategies and thus serving as a powerful motivator to strive for process standardization, consistent compliance and to further refine evidence-based strategies.

In the NNE region, we found that surveying clinicians involved in each phase of the cardiac catheterization process – pre-procedure, intra-procedure and post-procedure – was an important first step to determine if clinicians perceived CI-AKI as an important issue and to help clinicians understand which factors impact the incidence of CI-AKI.

For clinicians caring for the patient pre-procedure, oral hydration, appropriate administration of intravenous fluid, and instructing withholding potentially nephrotoxic medications is paramount.

This process exemplifies the positive impact of collaboration within and among institutions and of a team approach to achieve a clearly identified goal.

Patient Education For Prevention Of CI-AKI

Recent evidence has suggested that oral self-hydration is not inferior to IV volume expansion in the prevention of CI-AKI^{13–18}. Based on this evidence and clinical success reported from our centers, it was deemed it important to engage patients through education

and instruction to help prevent acute kidney injury from radio-contrast dye. Benchmarking centers in our region accomplished this through direct patient education, patient oral self-hydration prior to admission, and reaching consensus with anesthesiologists to agree to limit the amount of time a patient is NPO (preferably for only two hours prior to the procedure). The importance of partnering with patients for shared responsibility in the prevention of CI-AKI cannot be overemphasized in patients without congestive heart failure. This can be achieved through a standardized approach, institutional buy-in, and care-coordination before and after arrival to the hospital. Hydration of congestive heart failure patients requires therapy that is individualized to the patient and close observation to prevent volume overload.

During the initial office visit, along with a thorough history and physical examination, a baseline serum creatinine was obtained and estimated glomerular filtration rate (eGFR) was calculated to identify “at risk” patients (e.g. eGFR <60, diabetes, preexisting renal dysfunction and hypertension). Patient education utilizing a standardized pre-procedure approach explained the critical importance of oral hydration with eight glasses of water (eight ounces each) starting the evening before and up to two hours before the scheduled procedure. Patients were told to come early the day of their procedure, explaining the need to have continued hydration with intravenous normal saline. Patients were instructed to withhold potentially nephrotoxic medication (i.e., diuretics, ACEIs/ARBs, NSAIDs). Patients with CHF were instructed to comply with the fluid restriction set by their clinician. The nurses monitored the efficacy of patient instructions and compliance.

Patient education methods varied across centers. Some included, but are not limited to:

- Distribution of a standardized printed instruction sheet from their provider when scheduled for cardiac catheterization, providing concise instructions outlining fluid/food intake restrictions and individualized medication instructions (which medications to take the morning of the procedure and which medications to withhold).
- Pre-procedure phone call from a nurse (knowledgeable in cardiac care) from the admitting hospital one to three days prior to the procedure to ensure patient understanding of all instructions, stressing the importance of hydration, which medications to hold and ensuring that all pre-procedure laboratory testing has been completed.
- Posting of a detailed patient information pamphlet on the admitting hospital’s website, accessible to patients with internet access.

Discharge planning is a critical component of patient education. The use of standardized discharge instructions helps to decrease misunderstanding and improve patient compliance. Instructions should include stressing the importance of post-procedure self-hydration, identifying which medications and supplements to take and which to withhold or discontinue, scheduling of outpatient laboratory evaluation approximately 48–72 hours after the procedure, and scheduling provider follow-up.

To effectively monitor the incidence of post-procedure CI-AKI, patients were instructed to obtain laboratory work as ordered generally 48–72 hours post-procedure. To further decrease the chance of CI-AKI they were told not to resume any potentially nephrotoxic medications (unless instructed otherwise by the provider) until the follow up laboratory work has been completed, generally 48 to 72 hours post-procedure, and cleared by the managing clinician. Similar to the pre-procedure education methods, a phone call 48–72 hours post-procedure by the cardiac catheterization laboratory personnel, unit nurse or office nursing staff is valuable to assess for any potential complications and provides an opportunity to ensure patient understanding of all instructions.

Hydration

Although it is well known that adequate hydration/volume expansion (VE) is a key factor in decreasing the risk of CI-AKI, there is currently no standard for the quantity and timing of oral and intravenous fluids. Throughout the NNE region there are many variations in practice. The following section will summarize best practice for pre-, intra- and post-procedure hydration.

Same Day Admission

Patients with an eGFR <30 (Chronic Kidney Disease (CKD) stage 4 or greater) should be considered for admission the night prior to the procedure for initiation of hydration with intravenous normal saline at 1 mL/kg/hr overnight. If this is not possible, it is recommended that they arrive three hours prior to their scheduled procedure in order to allow sufficient time for adequate hydration and not be scheduled as the 0700 case. Same-day patients with an eGFR >60 (CKD stage <2) may be scheduled at 0700, to be followed by patients with an eGFR 30–59 (CKD stage 3).

Pre-procedure

NPO Status—Patients (except those with symptomatic heart failure) are encouraged to drink *eight glasses* of clear fluids (eight ounces/glass) starting the evening before their procedure until two hours before the procedure. Current practice guidelines for anesthesiology state that patients having a procedure requiring sedation are allowed clear liquids until 2 hours prior to the procedure^{31,32}. Referencing these practice guidelines can be helpful to reach institutional consensus regarding NPO orders prior to cardiac catheterization.

IV Hydration

Out-patients—IV access is obtained upon arrival to the hospital. IV normal saline should be started as soon as possible following admission and run at 500 mL/hr for one hour or 200mL/hr for two hours, and then decreased to 100 mL/hr until the start of the procedure. The goal is to infuse at minimum 500 mL of normal saline prior to exposure to contrast. For centers utilizing sodium bicarbonate and the Merten protocol, it is recommended to run normal saline until the sodium bicarbonate IV infusion is initiated, then administering sodium bicarbonate at 3 mL/kg/hr for one hour immediately prior to the procedure and

continued at 1 mL/kg/hr for 6 hours following the procedure¹⁹. If the procedure is delayed, the IV infusion can be titrated back to 1 mL/kg/hr until the start of the procedure.

In-patients—For patients with normal renal function at baseline, normal saline should be started at 5:00 AM running at 200 mL/hr for two hours, and then decreased to 100 mL/hr until the start of the procedure. Patients with an eGFR <60 (CKD stage 3 or greater) should have normal saline started at 10:00 PM the night before the procedure at a rate of 1mL/kg/hr until the start of the procedure.

Congestive Heart Failure (CHF) patients—Oral and IV fluid strategies for volume expansion for patients with congestive heart failure (CHF) should be determined by the attending provider or, preferably, the heart failure team prior to the procedure. We suggested CHF patients well maintained on current therapies without any signs of heart failure should follow the CI-AKI prevention hydration protocols as described above. Patients with signs of heart failure should be assessed on an individual basis to first determine appropriate timing of the procedure and to assess the patient's tolerance of IV fluids. Patients undergoing right-heart catheterization for evaluation of right heart hemodynamics or pulmonary artery pressures should have individualized fluid orders, since contrast agents are not used during these procedures, with no risk for CI-AKI.

Hydration During the Procedure

Normal saline infusion rate should be increased to 200 mL/hr at the start of the procedure.

Hydration Post-procedure

Out-patients with femoral artery procedural access sites—Normal saline is continued at 200 mL/hour with a goal of a total of 1000 mL post-procedure prior to discharge.

Out-patients with radial artery procedural access sites—Normal saline is continued at 250 mL/hr, with a goal of a total of 750 mL, and an additional 500 mL of oral fluid intake post-procedure prior to discharge.

Patients (except those with symptomatic CHF) are encouraged to drink at least 1000 mL of fluid within 24 hours following discharge.

In-patients—Patients should receive normal saline at 200 mL/hr or 1mL/kg/hr or sodium bicarbonate for 6 hours post-procedure unless contraindicated.

Heart failure patients—Patients well maintained on current therapies without any signs of heart failure will follow the CI-AKI prevention hydration protocols as described above. Heart failure patients with signs of heart failure will be assessed on an individual basis for post-procedure hydration.

Cardiac Catheterization Laboratory

As a patient is transported into the cardiac catheterization laboratory setting, the level of concern for CI-AKI remains a priority. Identification of the patient deemed at risk for developing CI-AKI should be communicated to the entire team. This can be communicated in the handoff report as well as in the electronic medical record. Documentation includes acknowledgement of the risk and plan for addressing prevention of CI-AKI. Hand off communication includes patient history, maximum acceptable contrast dose (MACD: 5mL contrast x body weight in Kg / baseline serum creatinine), or Gurm equation of $3 \times \text{CV} : \text{CrCl}$ Ratio, eGFR, and hydration status^{25,33,34}. These are key points that must be communicated prior to the start of the procedure and acknowledged with the final time out^{25,33,34}. As our region demonstrated in the past, exceeding a safe dose of contrast significantly increases the risk of CI-AKI (Figure 3).

Current intra-procedure strategies for prevention of CI-AKI included the selection of a nonionic iso-osmolar contrast agent that will be least toxic to the patient. The latest generation of contrast agents is the nonionic iso-osmolar agent. This type of agent has been associated with a lower incidence of CI-AKI in the higher risk population with a history of diabetes, CKD, and reduced eGFR²⁴. However, our top-performing centers utilize a low-osmolar contrast agent and maintain a low Ci-AKI rate.

A center wrote the MACD on a white board in the room for the procedural staff to see as a reminder. Many cardiac catheterization laboratories have discontinued the use of the manifold system for contrast injections and are using an advanced Acist® contrast injection device³⁵. The Acist® continuously counts the amount of contrast delivered. Thus, the nursing staff can immediately communicate to physicians when they are approaching the MACD to prevent inadvertent excess administration of contrast. The ability to measure accurate real time contrast volumes allows the physician to adjust the plan of care for the patient approaching the MACD.

Consideration may be given to staging an intervention or forgoing a ventriculogram in order not to exceed the MACD. Nurses play a vital role in communicating information related to effective hydration during the case, as well as blood pressure, and contrast utilization.

Post-procedure strategies are also dependent on communicating what transpired during the procedure. Clear handoff nurse-to-nurse should include the type and amount of contrast used in relation to the MACD, the amount of intravenous volume administered, and patient hemodynamics. One center uses a contrast stamp which includes the MACD and the actual amount administered (see stamp below) in order to help strategize which post-procedure laboratory tests and interventions should be performed. The plan for continued hydration and medication therapies must be ordered and documented.

Contrast Stamp

Patient: _____

Date: _____

Contrast Stamp

Baseline serum creatinine:	_____ (mg/dL)
eGFR or Creatinine Clearance:	_____ (mL/min/m ²)
Contrast Volume: Creatinine Clearance Limit:	_____ (mL)
Actual weight max dose contrast amount limit:	_____ (mL)
Ideal weight max dose contrast amount limit:	_____ (mL)
Actual contrast amount given:	_____ (mL)

Post-Procedure

Opportunities for identification of CI-AKI include the development of a standardized approach to complete a thorough laboratory assessment of renal function on all post-procedure patients, not limited to patients identified at high risk. Currently, there is controversy regarding the appropriate timing of post-procedure assessment of renal function and the determination of the person who should be responsible for tracking post-procedure serum creatinine and eGFR. For patients identified with CI-AKI, should the patient be evaluated by the interventional cardiologist, should a nephrology consultation be arranged, or is it sufficient to follow up with the patient's primary care provider only? Appropriate follow-up must be clearly delineated by each institution. Standardized laboratory slips or instructions with the FAX number of the person/office responsible for tracking post-procedure serum creatinine and eGFR would help to ensure that this data is collected. We recommended obtaining post-procedural serum creatinine and eGFR measurement 48–72 hours after the procedure. Each institution should determine the course of action to implement if CI-AKI is identified, including the intervals for continued laboratory monitoring and the appropriateness of nephrology consultation.

Planning the Study of the Intervention**Identification of Benchmark and Intervention Hospitals**

Using data from January 1, 2007 to October 30 2008, two hospitals were identified as having significantly lower rates of CI-AKI (2.3% v. 6.6%, $p < 0.001$) than the other six hospitals. These hospitals were identified as “benchmark” sites. Their experience was used to inform the intervention but these sites did not take part in the active intervention.^{29,30}

Quality Improvement Intervention Phase

The intervention phase began on November 1, 2008 and continued through June 30, 2012 directly following a two-day regional meeting focused on CI-AKI as an improvement target for NNECDSG hospitals. Participating hospitals agreed to: 1) form multidisciplinary teams including interventional cardiologists, cardiac catheterization lab managers and technicians, nursing representation from the intensive care unit and/or holding areas, cardiology administration, and nephrologists; 2) participate in monthly conference calls facilitated by a microsystems quality improvement coach; 3) participate in a process of identifying best practices through a formal review of the literature and structured interviews with benchmark sites; 4) participate in annual structured focus groups to capture qualitative data on barriers

and successes to improvement; 5) have adjusted CI-AKI rates by hospital added to the NNECDSG bi-annual reports provided to all hospitals, administrators, and health professionals. In addition, hospitals were encouraged to have one member from each team undergo six months of quality improvement training in microsystems coaching. During the first year of the intervention, teams identified best practices by formal review of the literature as summarized by the primary investigator and a series of structured interviews with benchmark sites. Sites were encouraged but not required to implement identified best practices. In addition to monthly conference calls and annual focus groups, representatives from each hospital attended three regional NNECDSG meetings each year where reporting on trends of CI-AKI and discussions about implementing best practices, and novel approaches to minimize contrast were presented and discussed.³⁰

Determination of CI-AKI

The last pre-procedure serum creatinine and highest post-procedure serum creatinine obtained prior to discharge were used to determine the incidence of CI-AKI. As data was collected in the routine process of care there was no protocol-mandated collection of post-procedure serum creatinine at a given time period. CI-AKI was defined using the KDIGO Guidelines definition: 0.3 (mg/dL) within 48 hours of the procedure or 50% increase in serum creatinine from baseline at any time during the hospitalization.³⁶ Patients were hospitalized on average for 2.7 (median 2.0) during the baseline period and 2.6 (median 2.0) during the follow-up period.³⁰

Methods of Evaluation

Real time data surveillance is important to help clinicians understand the impact of their collective actions on patients. One method to convey this information is to post information on data walls.

Key metrics to monitor and analyze should include: amount of fluid intake consumed prior to admission, withholding of potentially nephrotoxic agents, baseline serum creatinine and eGFR, amount of intravenous normal saline and/or sodium bicarbonate administered pre-procedure, amount of intra-procedure normal saline administered, volume and type of contrast administered during the procedure, amount of normal saline or sodium bicarbonate administered in the initial hours post-procedure, and post-procedure serum creatinine and eGFR. Once centers analyze their own data and identify their own rates of CI-AKI, they can implement strategies to modify their practice of care to reduce the incidence of CI-AKI for all patients²⁹.

Compliance can be measured by reviewing intake and output (I&O) data, determining the frequency and appropriateness of oral and intravenous hydration orders, and reviewing home medication lists and hospital medication administration records.

Analysis

Patient, disease, and procedural characteristics were compared between baseline and intervention time periods, overall and stratified by exposure: intervention and benchmark (Supplement Table S1). We used Chi-square tests for categorical data and Students t-tests for

continuous data. We used multilevel XTME poisson regression clustering to the patient and hospital level to calculate adjusted risk ratios (RR) with 95% confidence intervals (95%CI) of CI-AKI between the intervention and baseline periods adjusting for age, gender, body mass index, smoking, diabetes, hypertension, chronic obstructive pulmonary disease, peripheral vascular disease, heart failure, urgent priority, prior PCI, prior coronary artery bypass graft surgery (CABG), number of diseased vessels > 70% stenosis, number of vessels attempted, and number of stents, radial access, and baseline eGFR rate based on National Kidney Foundation definition using the Modification of Diet in Renal Disease equation.^{37–39} To show temporal trends in the rates of CI-AKI we performed interrupted time series analyses and plotted monthly rates of CI-AKI adjusting for covariates in the poisson model. Since most improvement efforts and protocols were targeted towards high-risk patients with eGFR <60 (mL/min/m²), analyses were repeated for patients with baseline eGFR <60 (mL/min/1.73 m²). All statistical analyses were conducted in STATA (Stata 11.2, College Station, TX, USA).³⁰

Evaluation of Quality Improvement Interventions

Annual structured focus groups of the multidisciplinary clinical teams were conducted at all hospitals. Teams were asked guided open-ended questions about improvement efforts, barriers, successes, and quality improvement training. A research coordinator facilitated and taped all meetings. Field notes were recorded. All notes and meeting transcriptions were systematically evaluated using the grounded theory approach.⁴⁰ We used open coding to develop initial themes, followed by axial and selective coding and aggregated across hospitals to find unifying themes. We aggregated key themes into domains.³⁰

Results

The absolute commitment of nurses to implement strategies for the prevention of CI-AKI is a critical link to ensuring optimal patient outcomes. Despite challenges, the teams were successful in reducing the incidence of CI-AKI. The region followed 6,983 consecutive patients undergoing PCI prior to the quality improvement interventions and 14,084 consecutive patients following the start of the quality improvement interventions. Overall, the medical centers undergoing the quality improvement interventions reduced CI-AKI by 21 percent compared to the pre-intervention phase and by 28 percent among patients with pre-existing chronic kidney disease (Figure 4)³⁰.

We leveraged the qualitative findings to help inform how teams (and medical centers) improved during the intervention period (Table 2). We discovered that high functioning teams had multidisciplinary members with clinical champions. Teams reported struggling with key barriers to improvement efforts including variation in physician ordering, changing NPO orders, and the need to unlearn old protocols. However, the teams reported important improvement successes that included changing behavior with an increased awareness of CI-AKI prevention strategies, implementing hydration protocols, standardizing order sets, minimizing contrast volume by reducing test injections and eliminating ventriculography, mandating procedure delays to allow for IV fluid bolus, and staging procedures. A full description of the qualitative findings and modeling has been previously described³⁰.

Discussion

Overall, teams were successful in reducing the occurrence of CI-AKI by more than 20%. Teams developed innovative solutions for CI-AKI prevention. As previously discussed, educational materials were built into patient instructions to encourage patients to self-hydrate before and after PCI. Recent clinical trials have supported the use of oral fluids as an effective alternative to IV fluids^{13,41}. Teams were also innovative in developing stops in the patient process of care by delaying a procedure if the patient had not received an adequate fluid bolus.³⁰

There have been many studies of interventions to reduce the risk of CI-AKI, however, there have been no investigations of a nurse-driven quality improvement efforts to reduce CI-AKI. The most recent improvement attempt at CI-AKI was over a decade ago when the Michigan Cardiovascular Consortium reported on contrast nephropathy and multiple quality indicators from a 1998 to 2002 intervention.⁴² Moscucci and colleagues used similar techniques and demonstrated significant improvement across multiple quality indicators including contrast nephropathy.⁴² In our improvement effort largely driven by nurse-champions and using a high-intensity quality improvement design and leveraging quality improvement coaching, we promoted change from within organizations to apply the best evidence based medicine to prevent CI-AKI. We did this by forming multidisciplinary teams including nursing, provided a structure for protocol transparency and sharing, data feedback mechanisms, and quality improvement training (microsystems coaching).³⁰

Our project has several limitations. While we did not conduct a randomized controlled trial, we did control for differences in patient risk factors between the baseline and intervention periods. Second, patients were hospitalized for a short time, averaging 48 hours, and did not allow for the routine measurement of serum creatinine commonly used in randomized trials.⁴³ We were limited to our registry data which included a pre-procedure and highest post-procedure serum creatinine. Therefore we may underestimate the true incidence of CI-AKI and true benefit of the intervention. However, the average length of stay was 2.7 days (median 2 days) for the baseline period and 2.6 days (median 2 days) for the follow-up period; therefore most patients at least had 48 hours of follow-up prior to discharge. Third, starting in 2010 our quality improvement effort competed in some centers with efforts to introduce radial access as a key quality driver to reduce length of stay and bleeding complications. Qualitative data captured from teams confirmed radial access was a competing quality target with CI-AKI and may have diverted AKI improvement team efforts from mitigating AKI towards focusing on radial access adoption, leading to an underestimate of the true potential effect of our intervention. Lastly, responses to focus groups may be subject to recall bias. Teams not meeting their goals or who felt they were under performing due to barriers or attitudes towards improvement could be more likely to recall adverse aspects of their performance or institutional buy-in. Teams that performed well may have been more easily or willing to recall successes or fail to recall failures or barriers to improvement.³⁰

Conclusions

In summary, a regional collaborative took on the task to reduce the incidence of CI-AKI through basic, team-based quality improvement methods. Multidisciplinary teams were formulated and leveraged a culture of collaboration and transparency, implementing methods in quality improvement coaching to redesign systems of care to reduce CI-AKI. Each team worked within their own medical centers to encourage patient self hydration, standardize intravenous fluid orders for volume expansion, delay cases to ensure adequate volume expansion, reduce the NPO time to 2–4 hours prior to the procedure, influence type of contrast used, and limit contrast volume. Overall, the hospitals participating in the intervention significantly reduced CI-AKI by 21 percent using simple team-based quality improvement and coaching³⁰

Acknowledgments

Funding: This project was supported by grant HS018443 (Brown) from the Agency for Healthcare Research and Quality and the Northern New England Cardiovascular Disease Study Group participating medical centers.

We thank the NNECDSG hospitals, and quality improvement teams participating in the CI-AKI quality improvement initiative. All authors have no conflicts of interest to disclose.

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Figure 1. Illustration of AKI Pathophysiology

Pathophysiology of contrast-induced nephropathy and acute tubular necrosis. Used with permission. (From Brown and McCullough,¹¹ with permission).

Figure 2. Adjusted rates of AKI by rank and NNE center

Adjusted rates of AKI by center are rank ordered with 95 percent confidence intervals. The regional rate of AKI was 6.28 percent (red dashed line). (From Brown et. al.,²⁹ with permission).

MACD Ratio and AKI

Figure 3. Maximum Acceptable Contrast Dose and AKI

Calculated ratios of contrast volume to the predicted maximum acceptable contrast dose (*MACD*) are plotted by the crude (*red bars*) and risk-adjusted (*blue diamonds*) rates of AKI. (From Brown et al.,²⁵ with permission).

Figure 4. NNE Adjusted Rates of AKI Over Time

Adjusted rates of AKI are plotted by month for the NNE intervention hospitals (red) using interrupted time series analysis. The vertical dashed line represents the start of the quality improvement intervention. (Adapted from Brown et. al.,³⁰ with permission).