Contrast-induced nephropathy—prevention and risk reduction

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Abstract

Contrast-induced nephropathy (CIN) is a serious, but potentially preventable adverse event associated with the use of iodinated contrast media (CM). Studies suggest that the occurrence of CIN is directly related to the number of pre-existing patient risk factors such as pre-existing renal insufficiency (RI) with or without diabetes, advanced age, congestive heart failure and dehydration. Because the risk factors for CIN are common and the consequences serious or even life-threatening, it is important for physicians to implement preventive strategies. Although the optimal strategy for preventing CIN has not been fully established, it is important to first identify patients at risk. The commonly used methods for identifying patients at risk include use of patient questionnaires, review of medical history and measurement of serum creatinine levels prior to the administration of CM. Estimation of the glomerular filtration rate (GFR) before CM administration should be encouraged. To prevent the development of CIN, patients should be well-hydrated and nephrotoxic medications should be withdrawn at least 24 h prior to CM. Use of the minimal necessary CM dose is recommended, as the nephrotoxic effect of CM is dose-dependent. Furthermore, appropriate selection of CM is important. The incidence of CIN has been shown to be lower when an iso-osmolar CM rather than a low-osmolar CM (iohexol) is used in patients with RI and diabetes. Pharmacological intervention with calcium channel blockers, dopamine and N-acetylcysteine have not consistently been shown to reduce the incidence of CIN. This article will review the risk factors for the development of CIN and discuss practical strategies for its prevention in at-risk patients.

Keywords: contrast-induced nephropathy (CIN); iodixanol; iohexol; iso-osmolar; low-osmolar; osmolality; renal insufficiency

Introduction

Contrast-induced nephropathy (CIN) is often a serious adverse event associated with the use of iodinated radiocontrast agents. The pathophysiology of CIN is complex and still not fully understood (Figure 1) [1]. It is thought that renal medullary hypoxia and direct tubular epithelial cell toxicity are the main factors responsible for CIN. Administration of contrast media (CM) causes intrarenal vasoconstriction mediated by a variety of factors including endothelin, vasopressin, calcium and adenosine, with subsequent reduction in blood flow leading to renal ischaemia that is most pronounced in the renal medulla, an area uniquely susceptible to ischaemic injury. This in turn appears to be compounded by the effects of reactive oxygen species produced by polymorphonuclear cells attracted to the site of tissue damage. Generation of these reactive oxygen species may also be mediated by calcium and adenosine, and by iodine in the CM.

The incidence of CIN reported in the literature varies markedly depending on the definition of CIN used, the type of procedure performed, the volume and type of contrast agent, patient risk factors—most notably the pre-existing renal insufficiency (RI) and diabetes—and the length of follow-up. McCullough [2] reported an overall incidence of 14.5% in patients undergoing coronary interventions. In patients without risk factors the incidence is ~2% [3], which appears low, but may amount to 600 000 cases per year in industrialized countries, in view of the large number of radiological examinations using iodinated CM. In patients with mild-to-moderate RI and diabetes, the incidence of CIN is reported in the range of 9 to >50% [4,5] and in patients with chronic diabetic azotaemic nephropathy, CIN can occur in 50–90% of the patients [6,7].

With advancing technology, the number of diagnostic and interventional procedures is growing and with it, the number of patients exposed to CM and at risk for CIN. The average number of whole body computed tomography scans, for example, has increased by 11% annually between 1995 and 2000 [8].

The number of patients with risk factors for CIN is also increasing. Retrospective and prospective studies...
suggest that the occurrence of CIN is directly related to the number of pre-existing patient risk factors [9–11]. The prevalence of certain risk factors, such as advancing age and diabetes (and with it RI) is growing. Projections from the World Health Organization show that the population aged ≥60 years will increase from 600 million in 2000 to 1.2 billion in 2025 [12], and the worldwide prevalence of diabetes will increase from 171 million in 2000 to 366 million in 2030 [13].

There is no cure for CIN and treatment options are limited to supportive care. Because the risk factors for CIN are common and the consequences of this disorder can be serious, it is important for physicians using CM to incorporate preventive strategies into clinical practice [14].

While the optimal strategy for preventing CIN has not been fully established, physicians can take steps to reduce its occurrence. This article will review the risk factors for the development of CIN and provide practical strategies for preventing CIN in at-risk patients.

Identification of the patient at risk for CIN

Prevention of CIN begins with the identification of the patients who are most at risk. Commonly used methods to ascertain a patient’s risk factors for CIN include use of patient questionnaires and a review of medical history [15,16]. An accurate assessment of kidney function is required and this is best achieved from measurement of serum creatinine (Scr) and estimation of the glomerular filtration rate (GFR) using either the Cockcroft–Gault or Modification of Diet in Renal Disease (MDRD) equations [17,18]. While nephrologists are familiar with these formulas, they should not assume that other medical specialties are similarly aware.

Independent risk factors for the development of CIN have been reported for patients undergoing cardiac catheterization, percutaneous coronary intervention (PCI) and coronary revascularization [2,4,5,10,11,19–22]. Baseline demographic factors include: advanced age; clinical factors which include pre-existing high Scr, pre-existing renal impairment or chronic renal failure, low serum sodium level, low serum albumin, diabetes, hypertension, reduced left ventricular ejection fraction or congestive heart failure (CHF), previous coronary revascularization or bypass surgery, acute myocardial infarction (MI), shock, anaemia, peripheral vascular disease and prior stroke; and procedural factors include multivessel disease, hypotension, use of an intra-aortic balloon pump (IABP), CM type and volume of CM.

Risk assessment may be complicated by the presence of multiple risk factors. To simplify this process, Mehran et al. [10] developed a simple risk score for CIN after PCI for patients with ≥1 risk factor. Data were obtained from 8357 patients in a prospective interventional cardiology database who underwent PCI and had documented pre- and post-procedural Scr data. Patients requiring dialysis because of pre-existing end-stage renal disease (ESRD) were excluded from the analyses as were patients requiring more than one contrast procedure, those receiving PCI after acute MI and those in shock. Each patient was assigned to either a developmental dataset (n=5571) or a validation dataset (n=2786). The definition of CIN used in the analysis was an increase of ≥25% or ≥0.5 mg/dl in baseline Scr at 48 h after PCI.

The mean age of patients in the developmental dataset was 63.8 years, and 28.8% of these patients were female. Mean baseline Scr was 1.12 mg/dl, and 10.5% of the patients had a baseline Scr >1.5 mg/dl indicating chronic kidney disease (CKD). Mean baseline estimated GFR (eGFR) was 72.7 ml/min/1.73 m² and 26.4% had an eGFR <60 ml/min/1.73 m².
indicating moderate renal impairment. Anaemia was present in 25.8% of the patients, diabetes in 30.7%, hypertension in 62.1%, hypercholesterolaemia in 69.8% and CHF in 6.0%. Multivessel disease was present in 26.9% of the patients, 15.8% received treatment to a saphenous vein graft lesion and 4% had treatment to a saphenous vein graft lesion and a native vessel lesion. An IABP was used in 7.1% of the patients (in approximately half of these patients as an emergency). The mean volume of CM was 260.9 ml, and 80.4% of the patients received > 150 ml.

A total of 729 patients (13.1%) exhibited CIN. Candidate variables for conferring a significant risk for CIN were obtained using univariate analysis. The variables that were independently associated with CIN were then identified using multivariate analysis. Multivariate predictors were hypotension, IABP use, CHF, impaired renal function (SCr > 1.5 mg/dl or > 132 μmol/l), age > 75 years, anaemia, diabetes and increasing CM volume. Two multivariate models were used: one in which impaired renal function was defined according to SCr and the other in which it was based on eGFR. A risk stratification scoring system was developed using data from the two multivariate models with an integer score between one and six assigned to each variable (Figure 2).

Analysis of the incidence of CIN according to risk score demonstrated a significant trend for predicting CIN as the risk score increased (P < 0.0001). Using the frequencies of CIN in patients in the developmental dataset in relation to their risk scores, it was possible to categorize these patients into four groups according to the relative risk for CIN (Figure 2): low risk (scores ≤ 5), moderate risk (scores 6–10), high risk (scores 11–15) and very high risk (scores ≥ 16).

The predictive value of the risk score for CIN was assessed using data from the patients in the validation dataset. Out of these, 386 patients (13.9%) developed CIN after PCI. Patients in the validation and developmental datasets were assigned to risk categories based on their risk scores. The rates for CIN were similar for the validation and developmental datasets within each risk category (Figure 2). In addition, the incidence of in-hospital dialysis (Figure 3A) and 1 year mortality (Figure 3B) were also shown to be greater for patients in the higher-risk categories compared with those in the lower-risk categories (Figure 3A and B). The development of this risk scoring system shows that individual patient risk for CIN and its associated complications following PCI can be estimated from a risk score calculated according to the patient’s risk factors.

**Nephrotoxic drugs**

Exposure to nephrotoxic drugs should be restricted in at-risk patients undergoing contrast procedures. Agents that should be avoided for at least 24 h prior to administration of CM include non-steroidal anti-inflammatory drugs (both cyclo-oxygenase-1 and cyclo-oxygenase-2 inhibitors), aminoglycosides, ciclosporin, tacrolimus and amphotericin B [23,24].

**Diuretics, angiotensin-converting enzyme inhibitors and statins**

Furosemide and mannitol are diuretics that have been proposed as preventive agents for patients at risk for CIN because of their effects on renal blood flow. Furosemide inhibits electrolyte transport and attenuates medullary hypoxia. Mannitol is an osmotic diuretic with renal vasodilatory effects, although it is not known whether it increases blood flow to the renal medulla or to the cortex [25]. To date, clinical trial findings with these agents have been disappointing. The Prevention of Radiocontrast Induced Nephropathy Clinical Evaluation (PRINCE) Study was a prospective, randomized, controlled trial of forced diuresis with furosemide and mannitol (the latter was given to patients with pulmonary capillary wedge pressure < 20 mmHg) along with intravenous (IV) crystalloid, and low-dose dopamine vs IV
crystalloid plus matching placebos in 98 patients with RI undergoing elective coronary angiography. Mean change in SCr at 48 h was not significantly different between the furosemide/mannitol/dopamine and control arms, and the rates of renal failure according to six different definitions were similar for both trial arms [26]. In two previous trials enrolling patients with RI undergoing coronary angiography or computed tomography, concurrent use of furosemide or furosemide/mannitol was associated with an increased incidence of CIN [27,28].

Because angiotensin-converting enzyme (ACE) inhibitors reduce renal perfusion, these agents have been thought to increase the risk for CIN. Limited data from a single randomized study of 71 diabetic patients undergoing coronary angiography showed that treatment with captopril, starting 1 h before contrast administration and continuing for 3 days afterwards, was associated with a 79% lower incidence of CIN (defined as a 0.5 mg/dl increase in SCr) [29]. More studies are needed to confirm the renoprotective effect of ACE inhibitors during CM administration.

Statins have been shown to have pleiotropic effects on the vasculature along with their efficacy for treating dyslipidemia. The renoprotective effects of statins were investigated retrospectively in a study of 29409 patients in whom baseline demographics and SCr were evaluated before and after PCI. Pre-procedural use of a statin was associated with a significantly lower incidence of CIN, defined as an increase in SCr of ≥0.5 mg/dl (4.37 vs 5.93%, P < 0.0001). These values correspond to an odds ratio (OR) for CIN of 0.87 [95% confidence intervals (CI), 0.77–0.99; P = 0.03] with statin use (after adjustment for comorbidities) [30]. Data from prospective, randomized studies are needed to confirm the efficacy of statins for preventing CIN.

**Hydration**

Hydration is a universally accepted component of protocols for preventing CIN [31–33]. The rationale for hydration is to prevent the renal vasoconstriction and subsequent hypoxia caused by contrast agents. The IV administration of saline before infusion of CM normalizes plasma volume; saline administration afterwards reduces osmotic diuresis [34].

Research into the optimal hydration protocol for preventing CIN has been limited by ethical considerations that preclude withholding any type of hydrating treatment and because controlled studies of hydration vs no hydration have not been possible owing to the lack of a placebo substitute for an IV infusion [32,33,35]. However, a few key studies have provided useful information on different hydration regimens for the prevention of CIN.

Trivedi et al. [36] prospectively compared the effects of IV hydration with normal saline with the provision of unrestricted oral fluids on the development of CIN in 53 patients who underwent non-emergency coronary angiography. Nearly all of the patients were male, 18.9% had diabetes, 43.4% had an acute MI and 34.0% received angioplasty and stent placement. The mean volume of CM used was 194.4 ml. The definition of CIN was a ≥0.5 mg/dl (≥44.2 μmol/l) increase in SCr within 48 h of CM use. A total of 10 patients developed CIN. IV hydration with normal saline was associated with a significantly lower incidence of CIN compared with unrestricted oral fluids (3.7 vs 34.6%; P = 0.005). These results support the use of IV hydration to reduce the risk of CIN in patients undergoing contrast procedures.

The type of fluid used for hydration has been investigated in two studies. The first was a prospective, randomized, controlled, open-label trial that compared the incidence of CIN in 1383 patients receiving normal (0.9%) or half-normal (0.45%) saline before elective or emergency coronary angioplasty [37]. Out of these patients, 74.4% were male, 20.7% had chronic renal disease and 15.7% had diabetes. Almost 60% of the coronary interventions were emergencies, and about 50% of the coronary lesions were complex.
The definition of CIN for the analysis was an increase in SCr $\geq 0.5$ mg/dl ($\geq 44$ μmol/l) within 48 h of CM administration.

A total of 19 patients developed CIN: five in the normal saline group and 14 in the half-normal saline group, corresponding to $0.7\%$ (95% CI 0.1–1.4) and $2.0\%$ (95% CI 1.0–3.1), of patients, respectively (Figure 4; $P = 0.04$). The incidence of CIN was also analysed in three pre-defined subgroups: women, patients with diabetes and patients receiving $\geq 250$ ml of CM. For all three subgroups, infusion with normal saline was associated with a significantly lower incidence of CIN compared with infusion of half-normal saline ($P = 0.01$).

Analysis of cardiac complications was performed using data from 530 consecutive patients who had stent implantation. The incidence of major adverse cardiac events was not significantly different in the two study groups (Figure 4). The incidence of peripheral vascular complications was analysed in all the enrolled patients ($n = 1620$). No significant difference was found in the incidence of peripheral vascular complications in the two study groups (Figure 4).

Because CIN is believed to involve production of reactive oxygen species, hydration that alkalinizes the urine may confer greater protection against CIN than hydration that merely expands plasma volume. In animal models of acute ischaemic renal failure, pre-treatment with sodium bicarbonate is more protective than saline. Merten and colleagues [38] compared isotonic sodium bicarbonate hydration ($n = 60$) with saline hydration ($n = 59$) for the prevention of CIN in patients with stable SCr of $\geq 1.1$ mg/dl ($\geq 97.2$ μmol/l). Out of these patients, 75% were male and 48% were patients with diabetes. More patients with severe RI (defined as SCr $\geq 221$ μmol/l) were randomized to the sodium bicarbonate group than to the saline group (eight patients vs two). The definition of CIN in this study was an increase in SCr $\geq 25\%$ from baseline within 2 days of CM administration.

CIN occurred in one patient (1.7%) in the bicarbonate group compared with eight patients (13.6%) given saline ($P = 0.02$). While these results are encouraging, this trial has a number of limitations: it was conducted in a single institution on a relatively small sample size, the investigators were not blinded and the statistical significance of the difference between the two groups depended on a single event. Confirmation of the potential of hydration with sodium bicarbonate is required in a large multicentre double-blind trial.

**N-acetylcysteine**

N-acetylcysteine (NAC) has a number of properties including anti-oxidant functions and mediation of renal vasodilation that suggest it could help prevent CIN [39]. Indeed, NAC is a part of the protocols to prevent CIN in many hospitals on the basis of the initial clinical study by Tepel et al. [40] and a number of subsequent clinical trials demonstrating renoprotective effects in patients receiving iodinated contrast agents. Other attributes of NAC that make it an attractive option include its ease of administration, good tolerability and low cost. However, NAC has been the subject of a comprehensive review, and overall there appears to be insufficient evidence to support the universal use of NAC to prevent CIN [39,41,42].

For example, the meta-analysis reported by Kshirsagar et al. [41] included 16 prospective, controlled trials that enrolled patients with RI (SCr $\geq 1.2$ mg/dl or CrCl $< 70$ ml/min/1.73 m$^2$). Patients in the NAC groups were given the drug orally at a dose of 600 mg twice a day, 1 day before and on the day of exposure to CM in the majority of studies [41]. Findings for these trials were highly heterogeneous, such that it was not possible to estimate a meaningful summary effect of NAC on the risk for CIN (Figure 5). Meta-regression analysis identified several study and patient characteristics, with some evidence of association with study-specific estimates such as timing of NAC administration, volume and type of CM, advanced patient age and diabetes. It was not possible, however, to identify subsets of studies that were homogeneous enough to aggregate. The authors concluded that while study and patient characteristics may be the cause of some, but not all, of the heterogeneity, the results are too inconsistent to recommend the routine use of NAC for the prevention of CIN in patients with RI.

Finally, it should be noted that NAC may affect SCr levels independently of GFR. NAC appears to affect creatinine metabolism through activation of creatinine kinase [43], and in healthy volunteers who were given NAC, SCr levels were reduced but levels of cystatin-C were unchanged [44].
Haemodialysis and haemofiltration

The rationale for haemodialysis in patients at high risk for CIN is to remove the CM from the patient’s body as quickly as possible. Data on the efficacy of haemodialysis for preventing CIN is conflicting. A study reported by Moon et al. [45] in which 13 patients with RI and seven patients with end-stage renal failure underwent 6 h post-procedure haemodialysis found that 60–90% of the CM was removed and that none of the patients with RI demonstrated further deterioration of renal function. In a study of haemodialysis performed during coronary angiography in patients with advanced RI, no significant effects on renal function were observed in the patients who underwent haemodialysis compared with those who did not [46]. Finally, a study reported by Vogt et al. [47] found that haemodialysis performed after CM administration in patients with renal impairment was associated with a significantly greater mean peak in SCr ($P < 0.05$) compared with those who did not undergo haemodialysis. On the basis of these data, haemodialysis cannot be recommended because of the potential for deleterious effects on renal function.

Haemofiltration has also been proposed for rapid removal of CM in high-risk patients. The efficacy of haemofiltration for preventing CIN was compared with isotonic saline hydration as a control procedure in a prospective randomized trial enrolling 114 patients with chronic renal failure (SCr $>2$ mg/dl) who were undergoing coronary interventions [48]. The haemofiltration procedure was conducted in an intensive care unit, and both haemofiltration and hydration were started 4–8 h before the contrast procedure and were continued for 18–24 h afterward. Mean SCr and blood urea nitrogen (BUN) were significantly lower for the haemofiltration group compared with the control group on days 1 through the discharge day (Figure 6). Mean urine output was significantly greater for the haemofiltration group compared with the control group on days 2 and 3. The incidence of CIN (defined as an increase in SCr $\geq 25\%$) was 5% in the haemofiltration group compared with 50% for the control group ($P < 0.001$). The rates for several other adverse outcomes were significantly lower for the haemofiltration group compared with the control group including in-hospital events (9 vs 52%, $P < 0.001$), in-hospital mortality (2 vs 14%, $P = 0.02$) and cumulative 1 year mortality (10 vs 30%, $P = 0.01$).

These findings on the effectiveness of haemofiltration for the prevention of CIN in patients with chronic renal failure are promising but require confirmation. The authors note that haemofiltration is a complex and costly procedure, but suggest that it may be considered for patients at a very high risk for CIN.

Contrast media

One method of classifying iodinated CM is on the basis of their osmolality. The high-osmolar CM (HOCM; e.g. diatrizoate, iothalamate, ioxithalamate) have an osmolality five to seven times greater than that of blood. These agents were developed in the 1950s and for many years were the mainstay of contrast-mediated procedures, but they are now rarely given by the intravascular route. Despite their rather misleading name, the low-osmolar CM (LOCM) introduced in the 1970s (e.g. iohexol, iopamidol, iopromide) are in fact hyperosmolar: two to three times greater than that of blood, and the newest class of contrast agent (e.g. iodixanol) is iso-osmolar to blood.

Within these three classes (high-, low- and iso-osmolar), it is possible to further subdivide CM in terms of their molecular structure (monomer vs dimer) and ionicity (ionic vs non-ionic) (Table 1) [49].

Nephrotoxicity of contrast media—clinical evidence

Although pre-clinical findings suggested that LOCMs would be less nephrotoxic than HOCMs, the clinical relevance of this was disputed for at least a decade. Several studies found no statistically or clinically significant differences in nephrotoxicity between HOCMs and LOCMs [4,27,50–53]. However, a meta-analysis reported by Barrett and Carlisle [54] demonstrated that LOCMs were associated with a significantly lower incidence of CIN than HOCMs ($P = 0.02$, using data from 5146 patients in 31 trials; results from 22 of the 31 trials in which these data were available favoured LOCMs). The OR for CIN (defined as a mean increase in SCr of 44 $\mu$mol/l) with LOCMs was found to be 0.61 (95% CI 0.48–0.77; data were available for >4000 patients in 25 trials) [54].
Despite the statistical significance of these results, Barrett and Carlisle [54] qualify the interpretation of these findings. Given the number of patients included in these analyses and the trend among the studies favouring LOCMs over HOCMs, the $P$-value of 0.02 for the incidence of CIN with LOCMs compared with HOCMs should not be interpreted as indicating a high level of significance. Furthermore, the pooled OR of

![Fig. 6](https://academic.oup.com/ndt/article-abstract/21/suppl_1/i11/1852196/17) Changes in SCr, BUN and urine output for the haemofiltration and the control (isotonic saline hydration) groups during a study of 114 consecutive patients with chronic renal failure undergoing coronary interventions. Significant differences between the two groups were noted for SCr and BUN on day 1 through the day of discharge and for urine output on days 2 and 3. Reprinted with permission [48].

| Table 1. Physicochemical properties of contrast media. Adapted with permission [49] |
|----------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Osmolality (mOsm/kg H$_2$O)            | High-osmolar (2100) | Low-osmolar (577) | Low-osmolar (610–915) | Iso-osmolar (290) |
| Ionicity                              | Ionic            | Ionic           | Non-ionic        | Non-ionic       |
| No. of benzene rings                  | Monomer          | Dimer           | Monomer          | Dimer           |
| Viscosity at 37°C (cP)                | 8.4              | 9.5             | 7.8–11.2         | 11.1            |
| Example                               | Diatrizoate      | Ioxaglate       | Iohexol          | Iodixanol       |
|                                       |                  |                 | Iopamidol        |                 |
|                                       |                  |                 | Ioversol         |                 |
|                                       |                  |                 | Iopromide        |                 |
patients receiving IOCM and LOCM. Conducted (NEPHRIC) Study is the most definitive study to
patients receiving iohexol (15 patients receiving iodixanol compared with that for
other reasons to use LOCMs rather than HOCMs in
In a prospective, single-centre, randomized,
unblinded trial, the incidence of CIN with the IOCM iodixanol and the LOCM iohexol, were compared
in 124 patients with SCr increased by
If contrast osmolality plays an important role in
and diabetes mellitus (DM), the incidence of CIN (defined as an increase in
patients with normal renal function at baseline was 0.75 (95% CI 0.52–1.1). These findings indicate
in five European countries (Denmark, France, Germany, Spain and Sweden), this randomized,
double-blind, prospective, multicentre study trial compared the renal effects of the IOCM iodixanol with those of the LOCM iohexol in 135 patients undergoing coronary or aortofemoral angiography who were at a high risk for CIN because of diabetes (type 1 and 2) and chronic renal failure (SCr 1.3–3.5 mg/dl for women and 1.5–3.5 mg/dl for men).
The study protocol recommended that all patients be
well-hydrated according to the institutional regimens of the study centres before the start of angiography. The protocol recommended the following for all the study patients: 500 ml of water orally and/or 500 ml of saline IV followed by 11 of 0.9% saline or similar fluids IV from the start of the procedure [59].
The primary endpoint was the peak increase in SCr between days 0 and 3 after CM administration. The secondary endpoints included the number of patients who developed CIN according to two definitions [an increase in SCr ≥0.5 mg/dl (44.2 μmol/l) on days 0 to 3 and a peak increase in SCr ≥1.0 mg/dl (88.4 μmol/l) on days 0 to 3] and the change in SCr from day 0 to 7.
The demographics and baseline clinical characteristics of the iodixanol and iohexol groups were not significantly different with the exception of mean body mass index (BMI; 26.8 vs 28.5 kg/m²) and the mean duration of diabetes (12.8 vs 18.0 years). The difference in BMI between the two groups was small. The difference in reported duration of diabetes between the two groups is unlikely to be relevant to the analysis of the study results. With type 2 DM, the actual duration of the disease is virtually impossible to determine exactly because a patient may be glucose intolerant for several years before it is detected clinically.
The mean peak increase in SCr on days 0 to 3 was significantly lower for patients receiving iodixanol [0.13 mg/dl (11.2 μmol/l)] compared with that for patients receiving iohexol [0.55 mg/dl (48.2 μmol/l); P = 0.001] (Figure 7A). Analysis of the mean peak increase in SCr between days 0 and 3 according to baseline SCr revealed another difference between the two treatment groups. A higher baseline SCr was associated with a greater mean peak SCr for patients receiving iohexol but not for patients receiving iodixanol (P for interaction <0.001). The results of the secondary endpoints in the NEPHRIC study were also consistent with the greater nephrotoxicity of the LOCM (Figure 7B and C). A smaller proportion of patients in the iodixanol group developed CIN according to the two study definitions: SCr increased by ≥0.5 mg/dl in 3 and 26% of the iodixanol and iohexol groups, respectively (P = 0.002), and by ≥1.0 mg/dl in 0 and 15% of the iodixanol and iohexol groups, respectively (Figure 7B). The odds of developing CIN using the definition of an increase in SCr ≥0.5 mg/dl was 11 times greater for the iohexol group than the iodixanol group. The mean change in SCr between days 0 and 7 was significantly lower for the iohexol group [0.07 mg/dl (6.3 mmol/l)]
compared with that for the iohexol group [0.24 mg/dl (21.4 mmol/l); \( P = 0.003; \) Figure 7C].

Seven serious adverse events were judged to be contrast-induced, all in the patients who received iohexol: five with acute renal failure and one with both acute renal failure and arrhythmia. Out of these six patients, three recovered, two died and one had persistent renal failure.

**Contrast media—osmolality or viscosity?**

The relative importance of osmolality and viscosity of CM in CIN is the subject of some debate. While some experimental studies might suggest that the higher viscosity of dimeric CM could be problematic because, for example, it could limit the flow in renal tubules [60], there is no evidence from randomized prospective clinical trials to support the contention that contrast viscosity causes CIN. In fact, although the pathogenesis of CIN is still not completely understood, clinical evidence to date suggests that contrast osmolality plays a far more significant role in CIN [57–59], and as the osmolality of CM has steadily decreased with the introduction of new agents, from HOCM to LOCM, and most recently from LOCM to IOCM, the
incidence of CIN in clinical studies has declined most notably in patients at risk.

**Contrast media volume and nephrotoxicity**

Studies by McCullough et al. [2] and Freeman et al. [61] in which patient enrolment was not restricted to those with RI, noted an association between CM volume and development of CIN. However, CM volume is an especially important issue for patients with RI. A retrospective study by Taliercio et al. [62] of 139 patients with renal impairment (SCr ≥2.0 mg/dl) undergoing coronary angiography found that administration of ≥125 ml CM was a significant risk factor for CIN (defined as increase in SCr >1.0 mg/dl at any point between days 1 and 5) compared with the use of <125 ml (P = 0.05), particularly in patients without additional risk factors. Similar results were observed for patients with RI by Gruberg et al. [22] and Briguori et al. [63]. Repeat procedures within 72 h have been associated with CIN in patients with renal impairment [14,62]. For patients with very low eGFR (<30 ml/min), even small volumes of CM have been associated with an increased risk of CIN. A study by Manske et al. [6] of risk factors for CIN (defined as an increase in SCr >25% at 48 h) in 59 azotaemic, insulin-dependent patients undergoing coronary angiography observed a 50% incidence of CIN. Independent risk factors for CIN by univariate analysis included ejection fraction ≤50%, low mean arterial pressure and CM volume ≥30 ml. The latter was associated with an OR of 10.6 (95% CI 2.08–60.6; P = 0.002), and linear regression revealed that every 5 ml increment of CM was associated with an OR for CIN of 1.44 (95% CI 1.07–1.94; P = 0.03).

The high-risk patients in the study by Manske et al. [6] received the LOCMs iohexol or iopamidol. A retrospective study by Tadros et al. [64] assessed the correlation between volume of ioxidanol used and development of CIN in 117 patients with CKD (GFR <60 ml/min) undergoing cardiac catheterization. These patients received a mean of 84.3 ± 67.3 ml of ioxidanol. The mean peak in SCr was 0.03 ± 0.07 mg/dl, and the incidence of CIN (SCr increase by >0.5 mg/dl or >25%) was 18.8%. The mean volume of ioxidanol received by patients who developed CIN was not significantly different from that received by patients who did not (P = 0.922). Linear regression revealed no significant correlation between the volume of ioxidanol and the change in SCr (r = 0.0011; P = 0.7254) (Figure 8). Subanalysis of data from 18 patients with severe RI (eGFR <30 ml/min) and 25 patients with severe RI and diabetes also showed no significant correlation between ioxidanol volume and SCr change (data not shown).

**An algorithm for management of patients undergoing contrast investigation**

Although the optimal strategy for preventing CIN has not been fully established, several preventive measures are supported by clinical trial data. Figure 9 provides an algorithm adapted from Goldenberg and Matetzky [65], outlining the management of patients undergoing contrast procedures.

The first step is to estimate the patient’s risk for CIN. The commonly used methods for identifying patients at risk include use of patient questionnaires, review of medical history and measurement of SCr levels prior to administration of CM. Calculation of the eGFR should be encouraged, and the more formal, yet simple scoring system developed by Mehran et al. [66] can provide a semi-quantitative estimate of the patient’s risk.

For the high-risk patient, alternative diagnostic modalities should be considered. If, however, no viable alternatives exist, nephrotoxic medications should be withdrawn for at least 24 h and IV normal saline hydration should be provided before and after the procedure. The smallest volume of CM should be used. HOCM should be avoided; instead, a LOCM,
Conflict of interest statement. See full declaration on the appropriate contrast agent.

Saline hydration and use of the lowest volume possible of CIN. These include assessment of patient risk, IV risk and practical strategies to reduce the incidence cardiologists regarding the identification of patients at nephrologist can provide guidance to radiologists and strategies into their clinical practices. The consulting physicians using CM should incorporate preventive which treatment options are limited to supportive care, Because CIN is a potentially serious adverse event for expensive and supported by only limited data, may be considered for patients at a very high risk. 

Conclusions

Because CIN is a potentially serious adverse event for which treatment options are limited to supportive care, physicians using CM should incorporate preventive strategies into their clinical practices. The consulting nephrologist can provide guidance to radiologists and cardiology regarding the identification of patients at risk and practical strategies to reduce the incidence of CIN. These include assessment of patient risk, IV saline hydration and use of the lowest volume possible of the appropriate contrast agent.


References

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