

Review Article

Hydration Strategies for Preventing Contrast-Induced Acute Kidney Injury: A Systematic Review and Bayesian Network Meta-Analysis

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Aims. Many previous studies have examined the effect of different hydration strategies on prevention of contrast-induced acute kidney injury (CI-AKI), but the optimal strategy is unknown. We performed a network meta-analysis (NWM) of these previous studies to identify the optimal strategy. **Methods and Results.** Web of Science, PubMed, OVID Medline, and Cochrane Library were searched from their inception dates to September 30, 2018. Randomized controlled trials (RCTs) were selected based on strict inclusion criteria, and a Bayesian NWM was performed using WinBUGS V.1.4.3. We finally analyzed 60 eligible RCTs, which examined 21,293 patients and 2232 CI-AKI events. Compared to intravenous 0.9% sodium chloride (reference), intravenous sodium bicarbonate (OR [95% CI]: 0.74 [0.57, 0.93]), hemodynamic guided hydration (0.41 [0.18, 0.93]), and RenalGuard guided hydration (0.32 [0.14, 0.70]) significantly reduced the occurrence of CI-AKI. Oral hydration and intravenous 0.9% sodium chloride were each noninferior to no hydration in preventing CI-AKI. Intravenous 0.9% sodium chloride, sodium bicarbonate, and hemodynamic guided hydration were each noninferior to oral hydration in preventing CI-AKI. Based on surface under the cumulative ranking curve values, the RenalGuard system was best (0.974) and hemodynamic guided hydration was second best (0.849). **Conclusion.** There was substantial evidence to support the use of RenalGuard or hemodynamic guided hydration for preventing CI-AKI in high-risk patients, especially those with chronic kidney disease or cardiac dysfunction.

1. Introduction

Contrast-induced acute kidney injury (CI-AKI), also referred to as contrast-induced nephropathy (CIN), is an iatrogenic complication that can occur following intravascular administration of iodinated contrast medium (CM) prior to radiography. CI-AKI is the third leading cause of hospital-acquired acute renal injury (AKI) [1]. CI-AKI has a low incidence in the general population, but it has a significant incidence in patients with certain risk factors. Moreover, the occurrence of CI-AKI following cardiac catheterization procedures is associated with an in-hospital mortality of 20%, a 1-year mortality of up to 66%, and an even higher mortality in patients who require dialysis [2, 3]. However, even if patients with high risk of CI-AKI can be

identified a priori, no known pharmaceutical treatment can effectively prevent or treat CI-AKI.

Guidelines recommend intravascular hydration to prevent CI-AKI [4, 5], and there are several specific hydration strategies, but researchers have not yet established an optimal strategy [6–9]. Notably, recent randomized controlled trials (RCTs) have led to doubts about the effectiveness of various hydration strategies in prevention of CI-AKI. For example, Nijssen et al. [10] conducted an RCT with 660 high-risk patients and found that no prophylaxis was noninferior or cost-saving relative to intravenous hydration. Weisbord et al. [11] enrolled 5177 high-risk patients and reported no benefit of intravenous sodium bicarbonate relative to normal saline. Another RCT [12] concluded that the benefit of sodium bicarbonate was marginal relative to isotonic

sodium chloride for preventing CI-AKI among critically ill patients. However, other studies indicated that the Renal-Guard System [13–16] and hemodynamic guided hydration [17–19] were safe and effective in preventing CI-AKI. Because of these apparently discrepant results, we conducted a network meta-analysis (NMA) to assess the effects of various hydration strategies on the occurrence of CI-AKI in an effort to identify the optimal strategy for prevention of CI-AKI.

2. Methods

2.1. Data Search. This systematic review and meta-analysis were performed according to Cochrane Handbook guidelines [20]. The Web of Science, PubMed, OVID Medline, and Cochrane Library databases were searched using medical subject headings or keywords. Relevant published original studies that were published up to September 30, 2018, were examined. The search syntax was as follows: “contrast-induced acute kidney injury OR contrast-induced nephropathy OR CIN OR CI-AKI OR contrast acute renal failure OR contrast nephropathy” AND “hydration OR fluid administration OR volume expansion OR intravenous sodium bicarbonate OR saline infusion.”

2.2. Study Selection. An initial eligibility screen of all citations was conducted, and only studies that examined CI-AKI and hydration were selected for further full-text review. All included studies were RCTs; experimental studies were excluded. In addition, all included studies reported the prevention of CI-AKI after intravascular administration of CM; used clinical protocols that were hydration strategies, not pharmaceutical prevention strategies; had clear definitions of CI-AKI; and provided data on the outcome of interest (occurrence of CI-AKI within 2 days to 1 week after procedures).

2.3. Data Extraction and Quality Assessment. Two authors (C. Q. P. and J. R.) independently reviewed each article for eligibility. Any disagreement was resolved by discussion among the authors or involvement of a third author. Data extraction included the year of publication, sample size, patient characteristics, risk factors associated with CI-AKI (old age, diabetes mellitus, renal impairment, heart failure), and type and dosage of contrast medium. The primary endpoint was the occurrence of CI-AKI within 2 days to 1 week after intravascular administration of CM. Two investigators independently evaluated the quality of each study using the Jadad scale, which ranges from 0 (worst) to 5 (best) [21].

2.4. Statistical Analyses. The advantages of Bayesian NMA over traditional meta-analysis are its greater flexibility, its provision of more naturally interpretable results, and its ability to rank treatments by comparative effectiveness [22]. The occurrence of CI-AKI as a dichotomous outcome variable was expressed as an odds ratio (OR) and 95% confidence interval (CI). All *P* values were 2-sided, and a *P* value below 0.05 was considered significant. All analyses

were conducted using the Bayesian Markov chain Monte Carlo method in WinBUGS V.1.4.3 (MRC Biostatistics Unit, Cambridge, United Kingdom) using the Microsoft Excel-based macro NetMetaXL V.1.6.1 (Canadian Agency for Drugs and Technologies in Health, Ottawa, Canada) [23]. A convergence test for each analysis was conducted by checking whether the Monte Carlo error was less than 5% of the SD of the effect estimates or the variance between the studies. Convergence was achieved for all analyses using 1000 “burn in” runs and 1000 model runs. NetMetaXL was also used to generate a forest plot, league table, and “rankogram” with surface under the cumulative ranking curve (SUCRA), which ranges from 0 (worst) to 100% (best). Inconsistency was assessed by comparing the residual deviance and deviance information criterion statistics in fitted consistency and inconsistency models.

3. Results

3.1. Literature Search. We initially identified 3620 publications, assessed 703 RCTs for eligibility by review of the full texts, and ultimately included 60 RCTs which met the eligibility criteria (Figure 1). These studies examined 21,293 patients (median: 222, interquartile range [IQR]: 120, 350) and 2232 CI-AKI events. All included RCTs were full-length journal articles. Agreement between the two reviewers at the full-text review stage was excellent (Cohen’s $\kappa = 0.85$).

3.2. Characteristics of Studies and Participants. Table 1 shows the characteristics of the included studies. The publication date ranged from 2002 to 2018, and about 50% of the studies were published after 2013. The proportion of male patients ranged from 25.0% to 98.1% (median [IQR]: 65.7 [56.9, 74.8]), and the mean age ranged from 56.2 to 82.9 years (67.8 [63.1, 72.5]). Thirty-one studies enrolled 12,519 patients who had high risk of CI-AKI. The baseline serum creatinine (SCr) level ranged from 61.4 to 236.4 $\mu\text{mol/L}$ (117.1 [89.5, 136.9]), and the baseline estimated glomerular filtration rate (eGFR) ranged from 32 to 93.1 mL/min/1.73 m² (49.2 [44.1, 74.2]). Twenty-three studies provided the values of left ventricular ejection fraction (LVEF); the mean LVEF ranged from 25% to 57.8% (49.0 [42.8, 54.5]). The percentage of diabetes mellitus (DM) patients ranged from 8% to 100%, and the percentage with heart failure (HF) ranged from 0.6% to 45.8%. A total of 8176 patients from 32 studies received intravenous low-osmolar nonionic CM, 9993 patients from 17 studies received iso-osmolar nonionic CM, and 317 patients from 2 studies received low-osmolar ionic CM. The mean Jadad score of the 60 RCTs was 3.2 (3 [2, 4]), indicating the overall study quality was good.

3.3. Network Meta-Analysis. Figure 2 shows all the comparisons in the NMA. Thirty-seven studies (13,365 participants) compared the efficacy of intravenous sodium bicarbonate and 0.9% sodium chloride. The other hydration strategies were nonhydration (8 studies, 1396 patients), oral hydration (6 studies, 355 patients), intravenous half iso-osmolar saline (3 studies, 968 patients), intravenous

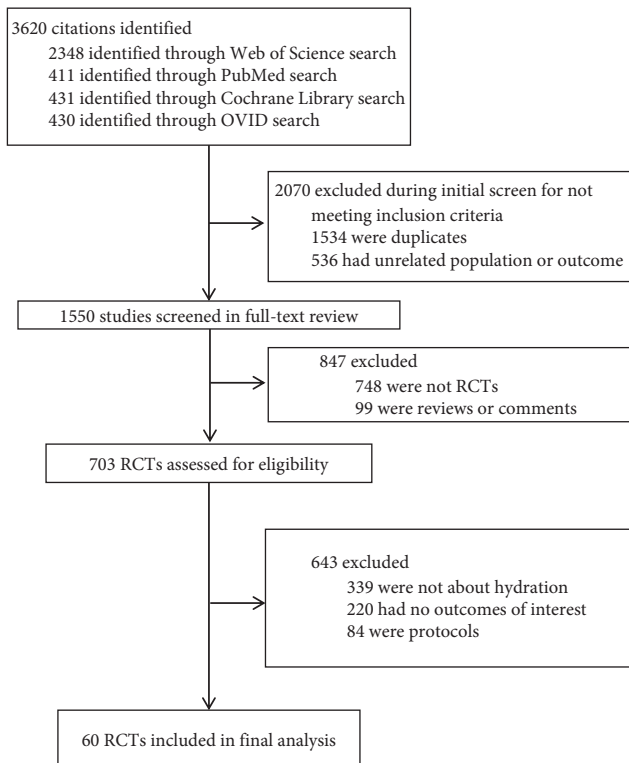


FIGURE 1: Identification and selection of studies for Bayesian network meta-analysis.

hydration, mainly normal saline + diuresis (2 studies [26, 31], 501 patients), hemodynamic guided hydration (3 studies, 458 patients), and RenalGuard system guided hydration (4 studies, 348 patients).

We compared the ORs of the different hydration strategies using a forest plot (Figure 3) and analyzed the results of the random effects consistency NMA using a league table, which shows all pairwise comparisons (Figure 4). Taken together, these results indicate that, relative to typical intravenous 0.9% sodium chloride hydration (reference), the occurrence of CI-AKI was significantly reduced by intravenous sodium bicarbonate (OR [95% CI]: 0.74 [0.57, 0.93]), hemodynamic guided hydration (0.41 [0.18, 0.93]), and RenalGuard system guided hydration (0.32 [0.14, 0.70]). Oral hydration (0.72 [0.28, 1.82]) and intravenous 0.9% sodium chloride (0.64 [0.39, 1.08]) were each noninferior to no hydration for prevention of CI-AKI. Relative to oral hydration (reference), intravenous 0.9% sodium chloride or sodium bicarbonate and hemodynamic guided hydration were each noninferior in prevention of CI-AKI, but RenalGuard guided hydration was superior (0.21 [0.07, 0.63]). Intravenous hydration plus diuresis also did not decrease the risk of CI-AKI relative to oral hydration and no hydration.

A rankogram and SUCRA values indicated the RenalGuard system was best (SUCRA = 0.974) followed by hemodynamic guided hydration (SUCRAs = 0.849; Figure 5). Intravenous sodium bicarbonate had a SUCRA of 0.667. The SUCRAs for intravenous 0.9% sodium chloride, intravenous hydration plus diuresis, oral and no hydration, and the other

treatments ranged from 0.197 to 0.441, and their rankings were similar. Hydration using half iso-osmolar saline alone was the least effective treatment.

3.4. Inconsistency Analysis. We performed network inconsistency assessment for the fixed effect model for the 60 studies (Figure 6). The resulting plot demonstrated that nearly all the studies were near the line of equality and that the results were therefore consistent. However, there was some evidence of inconsistency in 3 noninferiority studies [10, 31]. In particular, Martin-Moreno et al. [31] and Nijssen et al. [10] found that intravenous sodium bicarbonate and 0.9% sodium chloride were noninferior to oral hydration.

4. Discussion

To our knowledge, this is the first NMA to compare different hydration strategies for prevention of CI-AKI. We included 60 RCTs which examined 21,293 participants and 2232 CI-AKI events. Our comparison of 8 hydration strategies for preventing CI-AKI confirmed that, relative to intravenous 0.9% sodium chloride hydration, three treatments during CM administration significantly reduced the risk for CI-AKI: the RenalGuard system, hemodynamic guided hydration, and intravenous sodium bicarbonate. Relative to no hydration, oral hydration and intravenous 0.9% sodium chloride were each noninferior in prevention of CI-AKI. Relative to oral hydration, intravenous 0.9% sodium chloride and sodium bicarbonate were each noninferior in prevention of CI-AKI. Thus, we ranked the RenalGuard system as the best strategy and hemodynamic guided hydration as the second best.

Guidelines for the prevention of CI-AKI in high-risk patients routinely recommend hydration protocols before contrast exposure as an established preventive measure [77, 78]. A recent large RCT [10] led us to reanalyze the efficacy of hydration for prevention of CI-AKI. In particular, the AMAstricht Contrast-Induced Nephropathy Guideline (AMACING) study [10] enrolled 660 patients with high risk of CI-AKI and concluded that, relative to intravenous hydration, no prophylaxis was less expensive and noninferior in prevention of CI-AKI. In our meta-analysis, five studies compared the effectiveness of intravenous 0.9% sodium chloride and three studies compared bicarbonate with nonhydration, leading to our conclusion that, relative to no hydration (reference), oral hydration or hydration with intravenous 0.9% sodium chloride was noninferior in prevention of CI-AKI. These results were unsurprising, because simple oral or intravenous hydration can lead to complications, such as heart failure, pulmonary edema, and electrolyte disorders. Thus, the safety window of hydration is relatively narrow for patients undergoing percutaneous coronary intervention (PCI), and other more effective or precise hydration strategies may be needed to decrease the incidence of CI-AKI.

Most meta-analyses before 2016 [79–83] confirmed that intravenous sodium bicarbonate was more effective than sodium chloride in preventing CI-AKI. However, two recent

TABLE 1: Characteristics of the included studies.

| Studies | Patients (n) | Inclusion criteria/risk of CI-AKI | Mean age (years) | Males (%) | Baseline SCr (mg/dL) | Baseline eGFR (mL/min/1.73 m ²) | Mean LVEF (%) | DM (%) | HF (%) | Treatment groups | Types of CM | CM dosage (mL) | Jaded score | No. of patients | Inclusion criteria/risk of CI-AKI | Mean age | Male (%) | Baseline SCr | Baseline eGFR | Mean LVEF (%) | DM (%) | HF (%) | Groups | Types of CM | Dosage of CM | Jaded score |
|------------------------|--------------|---|------------------|-----------|----------------------|---|--------------------------------------|---------------|-----------|--------------------------|-------------|---|---|---|-----------------------------------|-----------|--------------------------------------|--------------|---------------|-------------------|-----------|--------------------------|--------|-------------|--------------|-------------|
| Weisbord et al. [11] | 4993 | High risk for renal complications and scheduled for angiography | 69.8 | 93.6 | 132.6 | 50.2 | 80.9 | 7.4 | SC vs. SB | Iodixanol or low-osmolar | 85 | 5 | 4993 | High risk for renal complications and scheduled for angiography | 69.8 | 93.6 | 132.6 | 50.2 | 80.9 | 7.4 | SC vs. SB | Iodixanol or low-osmolar | 85 | 5 | | |
| van Mourik et al. [24] | 74 | Symptomatic aortic valve stenosis and impaired renal function who underwent pre-TAVI CTA | 82.9 | 44.6 | 104.3 | 47.4 | 31.1 | SC vs. SB | Iopromide | 90 | 3 | 74 | Symptomatic aortic valve stenosis and impaired renal function who underwent pre-TAVI CTA | 82.9 | 44.6 | 104.3 | 47.4 | 31.1 | SC vs. SB | Iopromide | 90 | 3 | | | | |
| Saratzis et al. [25] | 58 | Elective EVAR for infrarenal AAA | 75 | 89.7 | 65.5 | 13.8 | SC vs. SB | Iomeprol | 126 | 3 | 3 | 58 | Elective EVAR for infrarenal AAA | 75 | 89.7 | 65.5 | 13.8 | SC vs. SB | Iomeprol | 126 | 3 | | | | | |
| Maioli et al. [18] | 296 | Elective coronary angiographic procedures | 71 | 68.2 | 89.3 | 24.7 | SC vs. HDy | Iodixanol | 131 | 3 | 3 | 296 | Elective coronary angiographic procedures | 71 | 68.2 | 89.3 | 24.7 | SC vs. HDy | Iodixanol | 131 | 3 | | | | | |
| Koolman et al. [26] | 333 | CKD patients undergoing elective cardiovascular diagnostic or interventional contrast procedures | 73 | 64.6 | 50.5 | 38.7 | SC vs. SB | Not mentioned | 113 | 3 | 3 | 333 | CKD patients undergoing elective cardiovascular diagnostic or interventional contrast procedures | 73 | 64.6 | 50.5 | 38.7 | SC vs. SB | Not mentioned | 113 | 3 | | | | | |
| Valette et al. [12] | 307 | Critically ill patients with stable renal function who received intravascular CM | 56.2 | 67.8 | 61.4 | 13.4 | SC vs. SB | Low-osmolar | 90 | 4 | 4 | 307 | Critically ill patients with stable renal function who received intravascular CM | 56.2 | 67.8 | 61.4 | 13.4 | SC vs. SB | Low-osmolar | 90 | 4 | | | | | |
| Nijssen et al. [10] | 660 | High-risk patients with eGFR of 30–59 mL/min/1.73 m ² , undergoing an elective procedure requiring CM administration | 72 | 61.7 | 118 | 32.6 | Non vs. SC | Iopromide | 90.5 | 3 | 3 | 660 | High-risk patients with eGFR of 30–59 mL/min/1.73 m ² , undergoing an elective procedure requiring CM administration | 72 | 61.7 | 118 | 32.6 | Non vs. SC | Iopromide | 90.5 | 3 | | | | | |
| Alonso et al. [27] | 93 | Patients receiving CM during CRT devices implantation | 66.5 | 65.3 | 110.5 | 28.5 | SC vs. SB | Iodixanol | 102 | 2 | 2 | 93 | Patients receiving CM during CRT devices implantation | 66.5 | 65.3 | 110.5 | 28.5 | SC vs. SB | Iodixanol | 102 | 2 | | | | | |
| Usmani et al. [28] | 124 | Coronary angiography/PCI with eGFR of less than 60 mL/min/1.73 m ² | 75 | 74 | 130.8 | 84 | SC vs. RenalGuard | Iodixanol | 156 | 3 | 3 | 124 | Coronary angiography/PCI with eGFR of less than 60 mL/min/1.73 m ² | 75 | 74 | 130.8 | 44 | 25 | 84 | SC vs. RenalGuard | Iodixanol | 156 | 3 | | | |
| Tureddi et al. [29] | 172 | Contrast-enhanced CTGA on suspicion of PE with at least one risk factor for CIN | 75.5 | 51.7 | 85.4 | SC vs. SB | Water-soluble, nonionic, low-osmolar | <100 | 3 | 3 | 172 | Contrast-enhanced CTGA on suspicion of PE with at least one risk factor for CIN | 75.5 | 51.7 | 85.4 | SC vs. SB | Water-soluble, nonionic, low-osmolar | <100 | 3 | 3 | | | | | | |

TABLE 1: Continued.

| Studies | Patients (n) | Inclusion criteria/risk of CI-AKI | Mean age (years) | Males (%) | Baseline SCr (mg/dL) | Baseline eGFR (mL/min/1.73 m ²) | Mean LVEF (%) | DM (%) | HF (%) | Treatment groups | Types of CM | CM dosage (mL) | Jaded score | No. of patients | Inclusion criteria/risk of CI-AKI | Mean age | Male (%) | Baseline SCr | Baseline eGFR | Mean LVEF (%) | DM (%) | HF (%) | Groups | Types of CM | Dosage of CM | Jaded score | |
|--|--------------|--|------------------|-----------|----------------------|---|---------------|-----------|-------------------|--------------------------------------|-------------|----------------|-------------|--|---|----------|----------|--------------|---------------|---------------|-------------------|-------------------|--------------------------------------|-------------|--------------|-------------|---|
| CKD and CHF | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Qian et al. [19] | 264 | undergoing coronary procedures | 63.5 | 74.6 | 151 | 37.5 | 39.5 | 47.3 | SC vs. HDy | Iodixanol | 166 | 5 | 264 | undergoing coronary procedures | 63.5 | 74.6 | 151 | 37.5 | 39.5 | 47.3 | SC vs. HDy | SC vs. HDy | Iodixanol | 166 | 5 | | |
| Elective coronary or peripheral angiography with eGFR <45 mL/min/1.73 m ² | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Solomon et al. [30] | 391 | peripheral angiography with eGFR <45 mL/min/1.73 m ² | 72 | 57.5 | 169.3 | 32.8 | 59.1 | 35.5 | SC vs. SB | Not mentioned | 107 | 4 | 391 | peripheral angiography with eGFR <45 mL/min/1.73 m ² | 72 | 57.5 | 169.3 | 32.8 | 59.1 | 35.5 | SC vs. SB | SC vs. SB | Not mentioned | 107 | 4 | | |
| Receiving CM for CT scan | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Martin-Moreno et al. [31] | 130 | Receiving CM for CT scan | 57.5 | 64.3 | 79.6 | | | | Non vs. SB | Not mentioned | 120 | 3 | 130 | Receiving CM for CT scan | 57.5 | 64.3 | 79.6 | | | | Non vs. SB | Non vs. SB | Not mentioned | 120 | 3 | | |
| STEMI undergoing primary PCI | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Jurado-Roman et al. [32] | 408 | STEMI undergoing primary PCI | 63.1 | 73.4 | 89 | 89 | 22.5 | 14.7 | Non vs. SC | Iso-osmolar nonionic | 174 | 2 | 408 | STEMI undergoing primary PCI | 63.1 | 73.4 | 89 | 89 | 22.5 | 14.7 | Non vs. SC | Non vs. SC | Iso-osmolar nonionic | 174 | 2 | | |
| Barbanti et al. [13] | 112 | TAVR | 81 | 40.2 | 87.1 | 51.5 | 54.6 | 25 | SC vs. RenalGuard | Buckinghamshire | 175 | 3 | 112 | TAVR | 81 | 40.2 | 87.1 | 51.5 | 54.6 | 25 | SC vs. RenalGuard | SC vs. RenalGuard | Buckinghamshire | 175 | 3 | | |
| Yeganehkhah et al. [33] | 100 | CAG | 59.7 | 53 | 99.5 | 43.8 | 39 | SC vs. SB | SC vs. SB | Iohexol | 45.4 | 3 | 100 | CAG | 59.7 | 53 | 99.5 | 43.8 | 39 | SC vs. SB | SC vs. SB | Iohexol | 45.4 | 3 | | | |
| Elective cardiovascular procedures including CAG or interventional treatment | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Yang et al. [34] | 320 | Elective cardiovascular procedures including CAG or interventional treatment | 59.2 | 53.1 | 70.2 | 93.1 | 55.1 | 20 | SC+NAC vs. SB+NAC | Iopromide | 125 | 3 | 320 | Elective cardiovascular procedures including CAG or interventional treatment | 59.2 | 53.1 | 70.2 | 93.1 | 55.1 | 20 | SC+NAC vs. SB+NAC | SC+NAC vs. SB+NAC | Iopromide | 125 | 3 | | |
| Elective cardiovascular procedures including CAG or interventional treatment | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Yang et al. [34] | 320 | Elective cardiovascular procedures including CAG or interventional treatment | 59.2 | 53.1 | 70.2 | 93.1 | 55.1 | 20 | SC vs. SB | Iopromide | 125 | 3 | 320 | Elective cardiovascular procedures including CAG or interventional treatment | 59.2 | 53.1 | 70.2 | 93.1 | 55.1 | 20 | SC vs. SB | SC vs. SB | Iopromide | 125 | 3 | | |
| STEMI undergoing primary PCI within 12 hours from the onset of chest pain | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Thayssen et al. [35] | 362 | STEMI undergoing primary PCI within 12 hours from the onset of chest pain | 62.5 | 78.5 | 77 | 90.5 | 50 | 9.7 | SC vs. SB | Iodixanol | 140 | 5 | 362 | STEMI undergoing primary PCI within 12 hours from the onset of chest pain | 62.5 | 78.5 | 77 | 90.5 | 50 | 9.7 | SC vs. SB | SC vs. SB | Iodixanol | 140 | 5 | | |
| Tomography scan using CM or angiography | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nieto-Rivas et al. [36] | 220 | Tomography scan using CM or angiography | 60 | 57.7 | 115.8 | 37.3 | 37.3 | SC vs. SB | SC vs. SB | Iohexol | 100 | 3 | 220 | Tomography scan using CM or angiography | 60 | 57.7 | 115.8 | 37.3 | 37.3 | SC vs. SB | SC vs. SB | Iohexol | 100 | 3 | | | |
| STEMI within 12 h from symptom onset referred for primary angioplasty | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Manari et al. [37] | 592 | STEMI within 12 h from symptom onset referred for primary angioplasty | 65 | 74.8 | 88.5 | 81 | 48 | 16.6 | 11.8 | SC vs. SB | Iodixanol | 198 | 3 | 592 | STEMI within 12 h from symptom onset referred for primary angioplasty | 65 | 74.8 | 88.5 | 81 | 48 | 16.6 | 11.8 | SC vs. SB | SC vs. SB | Iodixanol | 198 | 3 |
| Coronary interventions | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mahmoodi et al. [38] | 350 | Coronary interventions | 64.48 | 51.4 | 103 | 64.8 | 25 | 26.8 | 16.4 | SC vs. SB | Iohexol | 2 | 350 | Coronary interventions | 64.48 | 51.4 | 103 | 64.8 | 25 | 26.8 | 16.4 | SC vs. SB | SC vs. SB | Iohexol | 2 | | |
| Jaou et al. [39] | 216 | STEMI | 67 | 65.7 | 77 | 77.6 | 25 | 26.8 | 16.4 | Non vs. SC | Iopamiron | 234.9 | 3 | 216 | STEMI | 67 | 65.7 | 77 | 77.6 | 25 | 26.8 | 16.4 | Non vs. SC | Non vs. SC | Iopamiron | 234.9 | 3 |
| Koolman et al. [40] | 548 | CKD patients receiving CE-CT | 72.1 | 60.4 | 50.4 | 50.4 | 16.7 | 8 | SC vs. SB | Iomeprol | 105 | 5 | 548 | CKD patients receiving CE-CT | 72.1 | 60.4 | 50.4 | 50.4 | 16.7 | 8 | SC vs. SB | SC vs. SB | Iomeprol | 105 | 5 | | |
| Koolman et al. [41] | 138 | CKD patients receiving CTPA | 70.5 | 50 | 49.2 | 49.2 | 16.7 | 8 | Non vs. SB | Iopromide or iohitridol or iodixanol | 74 | 5 | 138 | CKD patients receiving CTPA | 70.5 | 50 | 49.2 | 49.2 | 16.7 | 8 | Non vs. SB | Non vs. SB | Iopromide or iohitridol or iodixanol | 74 | 5 | | |

TABLE 1: Continued.

| Studies | Patients (n) | Inclusion criteria/risk of CI-AKI | Mean age (years) | Males (%) | Baseline SCr (mg/dL) | Baseline eGFR (mL/min/1.73 m ²) | Mean LVEF (%) | DM (%) | HF (%) | Treatment groups | Types of CM | CM dosage (mL) | Jaded score | No. of patients | Inclusion criteria/risk of CI-AKI | Mean age | Male (%) | Baseline SCr | Baseline eGFR | Mean LVEF (%) | DM (%) | HF (%) | Groups | Types of CM | Dosage of CM | Jaded score |
|------------------------|--------------|--|------------------|-----------|----------------------|---|---------------|-------------|-------------|--------------------------------|--------------------------------|----------------|-------------|-----------------|-----------------------------------|----------|----------|--------------|---------------|---------------|-----------|-------------|--------------------------------|---------------|--------------|-------------|
| | | Referred to the cardiac catheterization laboratory with eGFR ≤ 60 mL/min/1.73 m ² and at least one of the following: DM, CHF, hypertension, or age older than 75 years | | | | | | | | | | | | | | | | | | | | | | | | |
| Brar et al. [17] | 396 | | 72 | 61.9 | 123.8 | 48 | 51.3 | 20.5 | 20.5 | SC vs. HDy | Ioxilan | 108 | 3 | 396 | | 72 | 61.9 | 123.8 | 48 | 51.3 | 20.5 | 20.5 | SC vs. HDy | Ioxilan | 108 | 3 |
| | | At least one of the high-risk factors for developing CI-AKI and undergoing CAG and/or PCI | | | | | | | | | | | | | | | | | | | | | | | | |
| Akyuz et al. [42] | 225 | | 63.4 | 68.9 | 79.6 | 84.5 | 47.5 | 60.9 | 7.6 | Oral vs. SC | Not mentioned | 108 | 2 | 225 | | 63.4 | 68.9 | 79.6 | 84.5 | 47.5 | 60.9 | 7.6 | Oral vs. SC | Not mentioned | 108 | 2 |
| | | Stage 3 or higher CKD who underwent cardiac surgery using CPB | | | | | | | | | | | | | | | | | | | | | | | | |
| Kristeller et al. [43] | 92 | | 72.5 | 57.6 | 119.1 | 74.2 | 44.6 | 34.8 | 34.8 | SC vs. SB | Not mentioned | 79 | 5 | 92 | | 72.5 | 57.6 | 119.1 | 74.2 | 44.6 | 34.8 | 34.8 | SC vs. SB | Not mentioned | 79 | 5 |
| | | DM patients | | | | | | | | | | | | | | | | | | | | | | | | |
| Koc et al. [44] | 195 | | 62 | 52.3 | 88.4 | 74.2 | 100 | 20.6 | 0.6 | SC vs. SB | Not mentioned | 90 | 4 | 195 | | 62 | 52.3 | 88.4 | 74.2 | 100 | 20.6 | 0.6 | SC vs. SB | Not mentioned | 90 | 4 |
| | | Coronary angiography or angioplasty | | | | | | | | | | | | | | | | | | | | | | | | |
| Gu et al. [45] | 859 | | 59 | 72.2 | 90.1 | 74.2 | 20.6 | 0.6 | 0.6 | SC vs. SC + diuresis | Not mentioned | 100 | 2 | 859 | | 59 | 72.2 | 90.1 | 74.2 | 20.6 | 0.6 | 0.6 | SC vs. SC + diuresis | Not mentioned | 100 | 2 |
| | | Diabetic patients with impaired renal function, undergoing intra-arterial or intravenous use of CM | | | | | | | | | | | | | | | | | | | | | | | | |
| Boucek et al. [46] | 120 | | 65 | 75 | 165 | 44.1 | 100 | SC vs. SB | SC vs. SB | Low-osmolar nonionic iodinated | Low-osmolar nonionic iodinated | 110 | 5 | 120 | | 65 | 75 | 165 | 44.1 | 100 | SC vs. SB | SC vs. SB | Low-osmolar nonionic iodinated | 110 | 5 | |
| | | CKD undergoing coronary procedures | | | | | | | | | | | | | | | | | | | | | | | | |
| Marenzi et al. [47] | 170 | | 73 | 78.2 | 154.7 | 39 | 51.5 | 36.4 | 36.4 | SC vs. RenalGuard | Iomeprol | 170 | 3 | 170 | | 73 | 78.2 | 154.7 | 39 | 51.5 | 36.4 | 36.4 | SC vs. RenalGuard | Iomeprol | 170 | 3 |
| | | Definitive or suspected coronary artery disease | | | | | | | | | | | | | | | | | | | | | | | | |
| Kong et al. [48] | 80 | | 56.5 | 53.8 | 105 | 43.6 | 23.8 | Oral vs. SC | Oral vs. SC | Iopromide | Iopromide | 152 | 3 | 80 | | 56.5 | 53.8 | 105 | 43.6 | 23.8 | 23.8 | Oral vs. SC | Iopromide | 152 | 3 | |
| | | Renal insufficiency undergoing intravascular contrast procedures | | | | | | | | | | | | | | | | | | | | | | | | |
| Klima et al. [49] | 258 | | 77 | 64 | 137 | 43.6 | 37 | 44 | 44 | SC vs. SB | Not mentioned | 100 | 5 | 258 | | 77 | 64 | 137 | 43.6 | 37 | 44 | 44 | SC vs. SB | Not mentioned | 100 | 5 |
| | | Patients at moderate to high risk for developing CIN who were referred for elective CAG or PCI | | | | | | | | | | | | | | | | | | | | | | | | |
| Gomes et al. [50] | 301 | | 64 | 47.5 | 132.6 | 44.3 | 18.9 | SC vs. SB | SC vs. SB | Not mentioned | Not mentioned | 125 | 2 | 301 | | 64 | 47.5 | 132.6 | 44.3 | 18.9 | 18.9 | SC vs. SB | Not mentioned | 125 | 2 | |
| | | eGFR < 60 mL/min/1.73 m ² who were undergoing coronary angiography | | | | | | | | | | | | | | | | | | | | | | | | |
| Motohiro et al. [51] | 155 | | 72.5 | 69.7 | 136.6 | 44.3 | 55 | 60 | 60 | SC vs. SB | Iopamidol | 135 | 3 | 155 | | 72.5 | 69.7 | 136.6 | 44.3 | 55 | 60 | 60 | SC vs. SB | Iopamidol | 135 | 3 |

TABLE 1: Continued.

| Studies | Patients (n) | Inclusion criteria/risk of CI-AKI | Mean age (years) | Males (%) | Baseline eGFR (mL/min/1.73 m ²) | Baseline SCr (mg/dL) | Mean LVEF (%) | DM (%) | HF (%) | Treatment groups | Types of CM | CM dosage (mL) | Jaded score | No. of patients | Inclusion criteria/risk of CI-AKI | Mean age | Male (%) | Baseline SCr | Baseline eGFR | Mean LVEF (%) | DM (%) | HF (%) | Groups | Types of CM | Dosage of CM | Jaded score | |
|---------------------------------|--------------|---|------------------|-----------|---|----------------------|---------------|--------|--------|-------------------|-----------------------|----------------|-------------|---|---|----------|----------|--------------|---------------|---------------|--------|------------|-------------------|-----------------------|--------------|-------------|---|
| Maioli et al. [52] | 300 | STEMI undergoing primary PCI | 65 | 25 | 42.5 | 95.9 | 21.7 | 24 | 24 | Non vs. SB | Iodixanol | 216 | 3 | 300 | STEMI undergoing primary PCI | 65 | 25 | 95.9 | 42.5 | 21.7 | 24 | Non vs. SB | Iodixanol | 216 | 3 | | |
| Lee et al. [53] | 382 | Diabetic patients with renal disease (serum creatinine >1.1 mg/dl and eGFR <60 ml/min/1.73 m ²) | 68 | 70.9 | 46 | 132.6 | 100 | | | SC vs. SB | Iodixanol | 116.5 | 3 | 382 | Diabetic patients with renal disease (serum creatinine >1.1 mg/dl and eGFR <60 ml/min/1.73 m ²) | 68 | 70.9 | 132.6 | 46 | 100 | | | SC vs. SB | Iodixanol | 116.5 | 3 | |
| Hafiz et al. [54] | 320 | Patients with baseline renal insufficiency scheduled to undergo catheterization | 73 | 56.9 | 47.2 | 141.4 | 47.2 | | | SC vs. SB | Nonionic, low-osmolar | 115 | 3 | 320 | Patients with baseline renal insufficiency scheduled to undergo catheterization | 73 | 56.9 | 141.4 | 47.2 | 47.2 | | | SC vs. SB | Nonionic, low-osmolar | 115 | 3 | |
| Brignoni et al. [55] | 292 | High-risk patients with an eGFR ≤30 ml/min/1.73 m ² and/or a risk score ≥11 | 76 | 65.4 | 32 | 158.7 | 70.2 | 28.4 | | SB vs. RenalGuard | Iodixanol | 140 | 3 | 292 | High-risk patients with an eGFR ≤30 ml/min/1.73 m ² and/or a risk score ≥11 | 76 | 65.4 | 158.7 | 32 | 47 | 70.2 | 28.4 | SB vs. RenalGuard | Iodixanol | 140 | 3 | |
| Wróbel et al. [56] | 102 | Coronary angiography and/or angioplasty, and had comorbidities that increase the risk of CIN | 65.5 | 56.9 | 236.4 | | | | | Oral vs. SC | Loversol | 69.5 | 2 | 102 | Coronary angiography and/or angioplasty, and had comorbidities that increase the risk of CIN | 65.5 | 56.9 | 236.4 | | | | | Oral vs. SC | Loversol | 69.5 | 2 | |
| Vasboghani-Farahani et al. [57] | 72 | CAG, with SCr 1.5 mg/dL, within 2 weeks, having at least 1 of the risk factors | 62 | 79.2 | 44.2 | 151.2 | 34.7 | 45.8 | | 0.45 SC vs. SB | Iohexol | 117.5 | 3 | 72 | CAG, with SCr 1.5 mg/dL, within 2 weeks, having at least 1 of the risk factors | 62 | 79.2 | 151.2 | 44.2 | 36.1 | 34.7 | 45.8 | 0.45 SC vs. SB | Iohexol | 117.5 | 3 | |
| Cho et al. [58] | 91 | Undergoing an elective CAG | 78 | 50.5 | 38.5 | 123 | 17.6 | | | SC vs. SB | Isoversol | 128 | 2 | 91 | Undergoing an elective CAG | 78 | 50.5 | 123 | 38.5 | 17.6 | | | SC vs. SB | Isoversol | 128 | 2 | |
| Vasboghani-Farahani et al. [59] | 265 | Serum creatinine level of 1.5 mg/dL or greater undergoing elective CAG | 63.3 | 83 | 45.9 | 145.4 | 21.5 | | | SC vs. SB | Iohexol | 114 | 5 | 265 | Serum creatinine level of 1.5 mg/dL or greater undergoing elective CAG | 63.3 | 83 | 145.4 | 45.9 | 51.7 | 21.5 | | SC vs. SB | Iohexol | 114 | 5 | |
| Tamura et al. [60] | 144 | Scheduled for elective CAG or PCI | 72.8 | 87.5 | 39.1 | 121.1 | 57.8 | 58.3 | | SC vs. SB | Iohexol | 85 | 3 | 144 | Scheduled for elective CAG or PCI | 72.8 | 87.5 | 121.1 | 39.1 | 57.8 | 58.3 | | SC vs. SB | Iohexol | 85 | 3 | |
| Pakfetrat et al. [61] | 192 | Undergoing elective CAG or PCI | 57.9 | 61.5 | 72.2 | 97.2 | 29.7 | 5.2 | | SC vs. SB | Iodixanol | 65 | 4 | 192 | Undergoing elective CAG or PCI | 57.9 | 61.5 | 97.2 | 72.2 | 50.5 | 29.7 | 5.2 | | SC vs. SB | Iodixanol | 65 | 4 |
| Haase et al. [62] | 100 | At increased risk of postoperative acute renal dysfunction who were scheduled for elective or urgent cardiac surgery necessitating the use of CPB | 71 | 66 | 90.7 | | | | | SC vs. SB | Not mentioned | 5 | 100 | At increased risk of postoperative acute renal dysfunction who were scheduled for elective or urgent cardiac surgery necessitating the use of CPB | 71 | 66 | 90.7 | | | | | | SC vs. SB | Not mentioned | 5 | 100 | |

TABLE 1: Continued.

| Studies | Patients (n) | Inclusion criteria/risk of CI-AKI | Mean age (years) | Males (%) | Baseline eGFR (mL/min/1.73 m ²) | Baseline SCr (mg/dL) | Mean LVEF (%) | DM (%) | HF (%) | Treatment groups | Types of CM | CM dosage (mL) | Jaded score | No. of patients | Inclusion criteria/risk of CI-AKI | Mean age | Male (%) | Baseline SCr | Baseline eGFR | Mean LVEF (%) | DM (%) | HF (%) | Groups | Types of CM | Dosage of CM | Jaded score | |
|--|--------------|-----------------------------------|------------------|-----------|---|----------------------|---------------|--------|--------|------------------|----------------------|----------------|-------------|-----------------|--|----------|----------|--------------|---------------|---------------|--------|--------|------------|----------------------|--------------|-------------|--|
| Nonemergent CAG, baseline serum creatinine >1.0 mg/dL, and availability of serum creatinine values at days 1-3 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Budhiraja et al. [63] | 187 | | 68 | | 57.2 | 125.8 | 30.5 | | | SC vs. SB | Iopromide | 199 | 2 | 187 | | 68 | | 125.8 | 57.2 | 30.5 | | | SC vs SB | Iopromide | 199 | 2 | |
| Scheduled for elective CAG, with or without PTCA with a baseline SCr < 140 µmol/L | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Angoulvant et al. [64] | 201 | | 62 | 80.6 | 86.2 | | | | | Oral vs. SC | Not mentioned | 290 | 3 | 201 | Scheduled for elective CAG, with or without PTCA with a baseline SCr < 140 µmol/L | 62 | 80.6 | 86.2 | | | | | Oral vs SC | Not mentioned | 290 | 3 | |
| Undergoing coronary angiographic procedures with estimated creatinine clearance <60 ml/min | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Maioli et al. [65] | 502 | | 74 | 59 | 107 | 46.5 | 59.1 | | | SC vs. SB | Iodixanol | 165 | 3 | 502 | Undergoing coronary angiographic procedures with estimated creatinine clearance <60 ml/min | 74 | 59 | 107 | 46.5 | 59.1 | | | SC vs SB | Iodixanol | 165 | 3 | |
| Myocardial ischemia (angina or positive exercise treadmill) PCI, with SCr < 1.5 mg/dL | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chen et al. [66] | 660 | | 60 | 85 | 114.9 | 54 | 8 | | | Non vs. SC | Iso-osmolar nontonic | 285 | 2 | 660 | Myocardial ischemia (angina or positive exercise treadmill) PCI, with SCr < 1.5 mg/dL | 60 | 85 | 114.9 | 54 | 8 | | | Non vs SC | Iso-osmolar nontonic | 285 | 2 | |
| Myocardial ischemia (angina or positive exercise treadmill) scheduled for PCI, with SCr < 1.5 mg/dL | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chen et al. [66] | 276 | | 63 | 82 | 221 | 41 | 22 | | | Non vs. SC | Iso-osmolar nontonic | 298 | 2 | 276 | Myocardial ischemia (angina or positive exercise treadmill) scheduled for PCI, with SCr < 1.5 mg/dL | 63 | 82 | 221 | 41 | 22 | | | Non vs SC | Iso-osmolar nontonic | 298 | 2 | |
| Patients with stable renal disease and undergoing CAG | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Brar et al. [67] | 353 | | 71 | 63.9 | 131.7 | 48 | 57 | 44.5 | 27.2 | SC vs. SB | Ioxilan | 132 | 5 | 353 | Patients with stable renal disease and undergoing CAG | 71 | 63.9 | 131.7 | 48 | 57 | 44.5 | 27.2 | SC vs SB | Ioxilan | 132 | 5 | |
| Stable renal insufficiency and undergoing elective diagnostic or interventional coronary angiography | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Adolph et al. [68] | 145 | | 72.6 | 77.9 | 132.6 | 33.8 | | | | SC vs. SB | Iodixanol | 140 | 5 | 145 | Stable renal insufficiency and undergoing elective diagnostic or interventional coronary angiography | 72.6 | 77.9 | 132.6 | 33.8 | | | | SC vs SB | Iodixanol | 140 | 5 | |
| Scheduled for CAG or PCI and had a baseline creatinine level >1.2 mg/dL | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Schmidt et al. [69] | 96 | | 67.6 | 74 | 146.7 | 64.6 | | | | SC vs. SB | Optiray | 186 | 2 | 96 | Scheduled for CAG or PCI and had a baseline creatinine level >1.2 mg/dL | 67.6 | 74 | 146.7 | 64.6 | | | | SC vs SB | Optiray | 186 | 2 | |
| Ozcan et al. [70] | 264 | | 69 | 74.6 | 122.9 | 45.1 | 26.5 | | | SC vs. SB | Ioxaglate | 110 | 2 | 264 | Scheduled for CAG or PCI and had a baseline creatinine level >1.2 mg/dL | 69 | 74.6 | 122.9 | 45.1 | 26.5 | | | SC vs SB | Ioxaglate | 110 | 2 | |

TABLE 1: Continued.

| Studies | Patients (n) | Inclusion criteria/risk of CI-AKI | Mean age (years) | Males (%) | Baseline eGFR (mL/min/1.73 m ²) | Baseline SCr (mg/dL) | Mean LVEF (%) | DM (%) | HF (%) | Treatment groups | Types of CM | CM dosage (mL) | Intrad score | No. of patients | Inclusion criteria/risk of CI-AKI | Mean age | Males (%) | Baseline SCr | Baseline eGFR | Mean LVEF (%) | DM (%) | HF (%) | Groups | Types of CM | Dosage of CM | Intrad score | |
|---------------------|--------------|--|------------------|-----------|---|----------------------|---------------|--------|--------|----------------------|-----------------------|----------------|--------------|-----------------|--|----------|-----------|--------------|---------------|---------------|--------|--------|---------------|----------------------|-----------------------|--------------|---|
| Masuda et al. [71] | 59 | Scheduled to undergo an emergency coronary angiography or intervention | 75 | 44.1 | 116.2 | 30.5 | 30.5 | 30.5 | 30.5 | SC vs. SB | lopamidol | 116 | 3 | 59 | Scheduled to undergo an emergency coronary angiography or intervention | 75 | 44.1 | 116.2 | 30.5 | 30.5 | 30.5 | 30.5 | SC vs SB | lopamidol | 116 | 3 | |
| Dussol et al. [72] | 156 | GKD, who were undergoing radiological procedures with CM | 65 | 67.9 | 204.5 | 28.8 | 16 | 28.8 | 16 | SC vs. SC + diuresis | Nonionic, low osmolar | 117 | 5 | 156 | undergoing radiological procedures with CM | 65 | 67.9 | 204.5 | 33.1 | 28.8 | 16 | 28.8 | 16 | SC vs SC + diuresis | Nonionic, low osmolar | 117 | 5 |
| Mueller et al. [73] | 425 | Scheduled for elective or emergency PCI | 64 | 75 | 89 | 16 | 16 | 16 | 16 | 0.45 SC vs. SC | lopromide | 226 | 2 | 425 | Scheduled for elective or emergency PCI | 64 | 75 | 89 | 89 | 16 | 16 | 16 | 0.45 SC vs SC | lopromide | 226 | 2 | |
| Merten et al. [74] | 119 | Stable renal insufficiency undergoing diagnostic or interventional procedures requiring radiographic contrast, SCr > 1.1 mg/dL | 68 | 74.8 | 159.1 | 47.9 | 47.9 | 47.9 | 47.9 | SC vs. SB | lopamidol | 132 | 3 | 119 | Stable renal insufficiency undergoing diagnostic or interventional procedures requiring radiographic contrast, SCr > 1.1 mg/dL | 68 | 74.8 | 159.1 | 47.9 | 47.9 | 47.9 | 47.9 | SC vs SB | lopamidol | 132 | 3 | |
| Trivedi et al. [75] | 53 | Scheduled to undergo nonemergency CAG | 67.9 | 98.1 | 106.4 | 52.1 | 18.9 | 52.1 | 18.9 | Oral vs. SC | Ionic, low-osmolar | 148 | 2 | 53 | Scheduled to undergo nonemergency CAG | 67.9 | 98.1 | 106.4 | 52.1 | 18.9 | 18.9 | 18.9 | Oral vs SC | Ionic, low-osmolar | 148 | 2 | |
| Mueller et al. [76] | 1383 | Scheduled for elective or emergency CAG | 64 | 74.4 | 81.77 | 15.7 | 15.7 | 15.7 | 15.7 | 0.45 SC vs. SC | Ultravist or inmeron | 234 | 2 | 1383 | Scheduled for elective or emergency CAG | 64 | 74.4 | 81.77 | 81.77 | 15.7 | 15.7 | 15.7 | 0.45 SC vs SC | Ultravist or inmeron | 234 | 2 | |

CI-AKI: contrast-induced acute kidney injury; SCr: serum creatinine; eGFR: estimated glomerular filtration rate; LVEF: left ventricular ejection fraction; DM: diabetes mellitus; HF: heart failure; CM: contrast media; CTA: computed tomography angiography; TAVI: transcatheter aortic valve implantation; EVAR: elective endovascular aneurysm repair; AAA: abdominal aortic aneurysm; CKD: chronic kidney disease; CRT: cardiac resynchronization therapy; CTPA: computed tomography pulmonary angiography; PE: pulmonary embolism; CIN: contrast-induced nephropathy; CHF: chronic heart failure; CT: computed tomography; TAVR: transcatheter aortic valve replacement; CAG: coronary angiography; CE-CT: contrast media-enhanced computed tomography; CPB: cardiopulmonary bypass; PTCA: percutaneous transluminal coronary angioplasty; NAC: N-acetylcysteine. Treatment groups: SC: intravenous 0.9% sodium chloride; SB: intravenous sodium bicarbonate; Non: nonhydration; Oral: oral hydration; RenalGuard: RenalGuard system; HDy: hemodynamic guided hydration; SC + diuresis: intravenous 0.9% sodium chloride + diuresis; 0.45 SC: 0.45% sodium chloride.

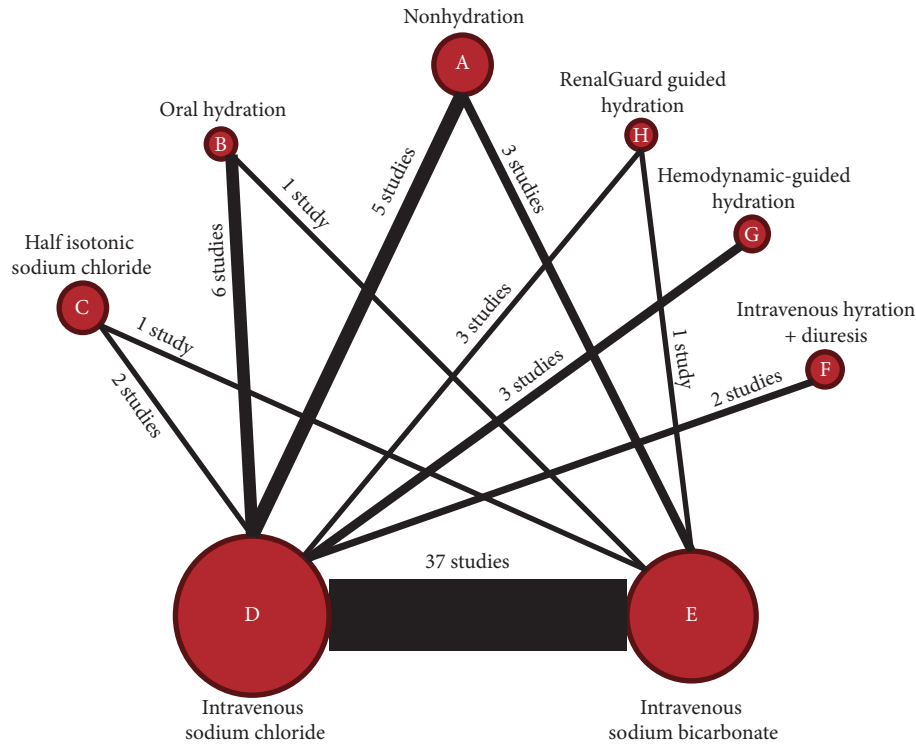


FIGURE 2: Network diagram of eight hydration strategies used to prevent contrast-induced acute kidney injury in the 60 included studies. Circles represent hydration strategies and lines represent direct comparisons. Circle size indicates the number of participants who received each treatment, and line thickness indicates the number of studies in each comparison.

influential studies concluded that intravenous sodium bicarbonate provided no benefit over intravenous sodium chloride in high-risk patients [11] and critically ill patients [12]. Our NMA included 37 studies that compared intravenous sodium chloride with sodium bicarbonate, and our results also indicated that intravenous sodium bicarbonate led to a reduced risk for CI-AKI, although the effect size was small (OR [95% CI]: 0.74 [0.57, 0.93]). Alkalinization with bicarbonate perfusion could theoretically reduce the formation of reactive oxygen species by decreasing the production of hydroxyl radicals due to inhibition of the Haber-Weiss and Fenton reactions [84]. However, the HYDRAREA study [12] assessed 307 critically ill patients with stable renal function and found that hydration with bicarbonate provided no benefit relative to hydration with isotonic sodium chloride. These researchers also noted that bicarbonate provided a greater benefit in the smaller studies, suggesting publication bias. Recently, Weisbord et al. [11] enrolled 5177 patients with high risk for renal complications and found that administration of sodium bicarbonate did not reduce the occurrence of CI-AKI. This result supports the interpretation that sodium bicarbonate is not more effective than sodium chloride in preventing CI-AKI or longer-term adverse outcomes after angiography. However, there was high heterogeneity among our 60 studies regarding concurrent medications, comorbidities (CHF, DM), types of CM, periprocedural hydration protocols, concentrations and dosages of sodium bicarbonate, and radiographic procedures [12]. Thus, we

do not recommend alkalinization with intravenous sodium bicarbonate as a single strategy, and a more effective hydration strategy is needed to prevent CI-AKI.

Several recent RCTs of high risk patients [13, 28, 47, 55] showed that furosemide-induced high-volume forced diuresis with matched hydration using the RenalGuard system effectively prevented CI-AKI. RenalGuard is a closed-loop fluid-management system, in which each volume of urine that enters the collection bag leads to the infusion of an equal volume of saline into the patient. Two meta-analyses [14, 16] of RCTs concluded that the RenalGuard system significantly reduced the risk of CI-AKI and the need for renal replacement therapy in high-risk patients undergoing coronary angiography. Our rankogram analysis indicated that the RenalGuard system of guided hydration had the highest rank, with a SUCRA of 0.974. However, we did not assess the effectiveness of intravenous hydration plus diuresis without a guided system, and the rankogram indicated that hemodynamic guided hydration was the second best method, with a SUCRA of 0.849. Brar et al. [17] used left ventricular end-diastolic pressure to guide fluid administration and demonstrated that this method was safe and effective in prevention of CI-AKI among patients undergoing cardiac catheterization. Another study [19] demonstrated that central venous pressure-guided fluid administration safely and effectively reduced the risk of CI-AKI in patients with CKD and CHF. Maioli et al. [18] assessed body fluid level using bioimpedance vector analysis (BIVA), which allows adjustment of intravascular

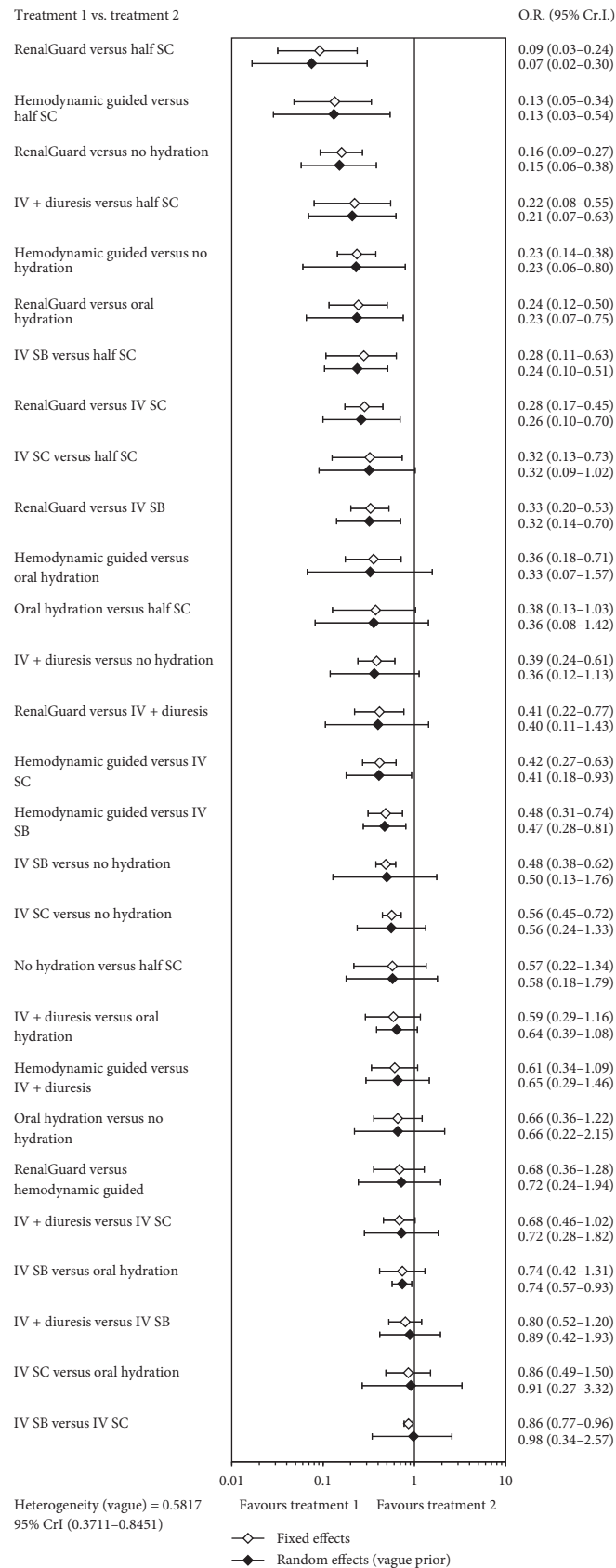


FIGURE 3: Forest plot showing the effect of different hydration strategies. Summary estimates from the pooled studies with 95% confidence intervals are indicated for fixed effects (open diamonds) and random effects (filled diamonds) models.

OR <1 means the treatment in top left is better

| | | | | | | | | |
|---------------------|-----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------|--|
| RenalGuard | | | | | | | | |
| 0.58 (0.18–1.79) | Hemodynamic guided | | | | | | | |
| 0.32 (0.14–0.70) | 0.56 (0.24–1.33) | IV SB | | | | | | |
| 0.24 (0.10–0.51) | 0.41 (0.18–0.93) | 0.74 (0.57–0.93) | IV SC | | | | | |
| 0.23 (0.06–0.80) | 0.40 (0.11–1.43) | 0.72 (0.24–1.94) | 0.98 (0.34–2.57) | IV + diuresis | | | | |
| 0.21 (0.07–0.63) | 0.36 (0.12–1.13) | 0.65 (0.29–1.46) | 0.89 (0.42–1.93) | 0.91 (0.27–3.32) | Oral hydration | | | |
| 0.15 (0.06–0.38) | 0.26 (0.10–0.70) | 0.47 (0.28–0.81) | 0.64 (0.39–1.08) | 0.66 (0.22–2.15) | 0.72 (0.28–1.82) | No hydration | | |
| 0.07 (0.02–0.30) | 0.13 (0.03–0.54) | 0.23 (0.07–0.75) | 0.32 (0.09–1.02) | 0.33 (0.07–1.57) | 0.36 (0.08–1.42) | 0.50 (0.13–1.76) | Half SC | |

FIGURE 4: League table, showing all pairwise comparisons of studies.

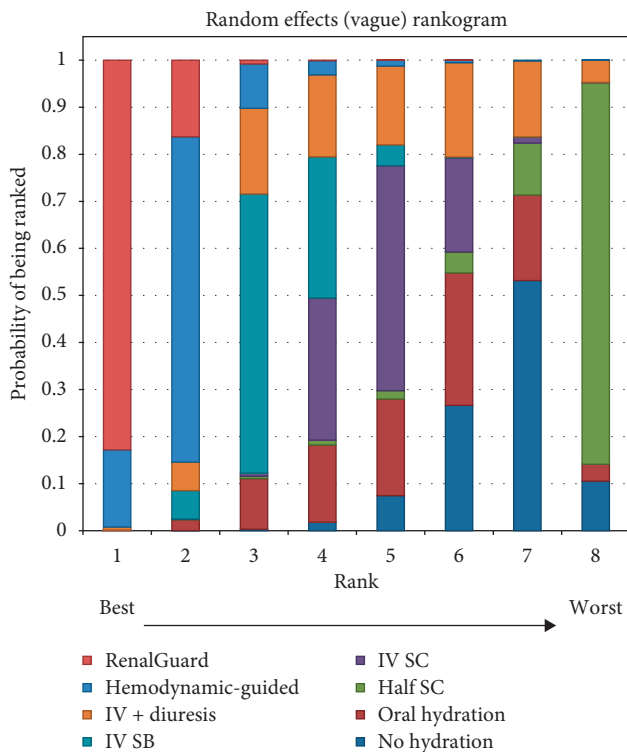


FIGURE 5: Rankogram of the effect of different hydration strategies in reducing the risk of contrast-induced acute kidney injury.

volume expansion, and this led to a lower incidence of CI-AKI after angiographic procedures. Therefore, our results indicate that the RenalGuard system and hemodynamic guided hydration are best for patients with high-risk for CI-AKI, especially those with CKD and cardiac dysfunction.

5. Limitations

It is essential to note several limitations of our study. Firstly, the hydration protocol should have a substantial

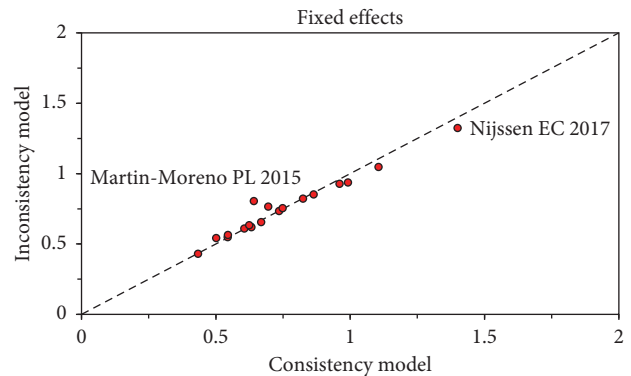


FIGURE 6: Inconsistency plot of enrolled studies, showing the posterior mean deviance of each study from the consistency model (horizontal axis) and the inconsistency model (vertical axis).

influence on CI-AKI, but because of the high heterogeneity of specific protocols used in the included studies, we could not analyze distinct protocols, such as the effect of different concentrations of sodium bicarbonate, and the effect of hydration duration. Secondly, several confounding factors that we did consider may have impacted the effects of hydration, including dosage and types of CM, risk status of patients for CI-AKI, and other factors. Finally, it may be inappropriate to define hemodynamic guided hydration based on the use of different indexes, such as left ventricular end-diastolic pressure, central venous pressure, and bioimpedance.

6. Conclusion

This Bayesian NMA provided substantial evidence to support the use of RenalGuard or hemodynamic guided hydration to prevent CI-AKI in high-risk patients, especially those with CKD or cardiac dysfunction.

Abbreviations

| | |
|--------|---|
| CI- | Contrast-induced acute kidney injury |
| AKI: | |
| SCr: | Serum creatinine |
| eGFR: | Estimated glomerular filtration rate |
| LVEF: | Left ventricular ejection fraction |
| DM: | Diabetes mellitus |
| HF: | Heart failure |
| CM: | Contrast medium |
| CTA: | Computed tomography angiography |
| TAVI: | Transcatheter aortic valve implantation |
| EVAR: | Elective endovascular aneurysm repair |
| AAA: | Abdominal aortic aneurysm |
| CKD: | Chronic kidney disease |
| CRT: | Cardiac resynchronization therapy |
| CTPA: | Computed tomography pulmonary angiography |
| PE: | Pulmonary embolism |
| CIN: | Contrast-induced nephropathy |
| CHF: | Chronic heart failure |
| CT: | Computed tomography |
| TAVR: | Transcatheter aortic valve replacement |
| CAG: | Coronary angiography |
| CE-CT: | Contrast media-enhanced computed tomography |
| CPB: | Cardiopulmonary bypass |
| PTCA: | Percutaneous transluminal coronary angioplasty. |

Conflicts of Interest

All authors have no conflicts of interest and no relationships with industry.

Authors' Contributions

Qiuping Cai and Ran Jing contributed equally to this paper. C. Q. P. and J. R. carried out meta-analysis, participated in data extraction, and drafted manuscript. Z. W. F. and T. Y. S. carried out quality assessment. L. X. P. participated in study design and performed statistical analysis. L. T. Q. conceived the study and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

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References

- [1] T. G. Gleeson and S. Bulugahapitiya, "Contrast-induced nephropathy," *American Journal of Roentgenology*, vol. 183, no. 6, pp. 1673–1689, 2004.
- [2] C. S. Rihal, S. C. Textor, D. E. Grill et al., "Incidence and prognostic importance of acute renal failure after percutaneous coronary intervention," *Circulation*, vol. 105, no. 19, pp. 2259–2264, 2002.
- [3] P. A. McCullough, R. Wolyn, L. L. Rocher, R. N. Levin, and W. W. O'Neill, "Acute renal failure after coronary intervention: incidence, risk factors, and relationship to mortality," *The American Journal of Medicine*, vol. 103, no. 5, pp. 368–375, 1997.
- [4] H. S. Thomsen and S. K. Morcos, "Contrast media and the kidney: European Society of Urogenital Radiology (ESUR) guidelines," *The British Journal of Radiology*, vol. 76, no. 908, pp. 513–518, 2003.
- [5] J. A. Kellum, N. Lameire, P. Aspelin et al., "Kidney disease: improving global outcomes (KDIGO) acute kidney injury work group. KDIGO clinical practice guideline for acute kidney injury," *Kidney International Supplements*, vol. 2, pp. 1–138, 2012.
- [6] W. Zhang, J. Zhang, B. Yang et al., "Effectiveness of oral hydration in preventing contrast-induced acute kidney injury in patients undergoing coronary angiography or intervention: a pairwise and network meta-analysis," *Coronary Artery Disease*, vol. 29, no. 4, pp. 286–293, 2018.
- [7] Y. Jiang, M. Chen, Y. Zhang et al., "Meta-analysis of prophylactic hydration versus no hydration on contrast-induced acute kidney injury," *Coronary Artery Disease*, vol. 28, no. 8, pp. 649–657, 2017.
- [8] S. K. Agarwal, S. Mohareb, A. Patel et al., "Systematic oral hydration with water is similar to parenteral hydration for prevention of contrast-induced nephropathy: an updated meta-analysis of randomised clinical data," *Open Heart*, vol. 2, Article ID e000317, 2015.
- [9] S. Zoungas, T. Ninomiya, R. Huxley et al., "Systematic review: sodium bicarbonate treatment regimens for the prevention of contrast-induced nephropathy," *Annals of Internal Medicine*, vol. 151, no. 9, pp. 631–638, 2009.
- [10] E. C. Nijssen, R. J. Rennenberg, P. J. Nelemans et al., "Prophylactic hydration to protect renal function from intravascular iodinated contrast material in patients at high risk of contrast-induced nephropathy (AMACING): a prospective, randomised, phase 3, controlled, open-label, non-inferiority trial," *The Lancet*, vol. 389, no. 10076, pp. 1312–1322, 2017.
- [11] S. D. Weisbord, M. Gallagher, H. Jneid et al., "Outcomes after angiography with sodium bicarbonate and acetylcysteine," *New England Journal of Medicine*, vol. 378, no. 7, pp. 603–614, 2018.
- [12] X. Valette, I. Desmeulles, B. Savary et al., "Sodium bicarbonate versus sodium chloride for preventing contrast-associated acute kidney injury in critically ill patients: a randomized controlled trial," *Critical Care Medicine*, vol. 45, no. 4, pp. 637–644, 2017.
- [13] M. Barbanti, S. Gulino, P. Capranzano et al., "Acute kidney injury with the RenalGuard system in patients undergoing transcatheter aortic valve replacement: the PROTECT-TAVI trial (PROphylactic effect of furosemide-induced diuresis with matched isotonic intravenous hydration in transcatheter aortic valve implantation)," *JACC: Cardiovascular Interventions*, vol. 8, no. 12, pp. 1595–1604, 2015.
- [14] A. Putzu, M. Boscolo Berto, A. Belletti et al., "Prevention of contrast-induced acute kidney injury by furosemide with matched hydration in patients undergoing interventional procedures: a systematic review and meta-analysis of randomized trials," *JACC: Cardiovascular Interventions*, vol. 10, no. 4, pp. 355–363, 2017.
- [15] G. Visconti, A. Focaccio, M. Donahue et al., "RenalGuard system for the prevention of acute kidney injury in patients

- undergoing transcatheter aortic valve implantation,” *Euro-Intervention*, vol. 11, no. 14, pp. e1658–e1661, 2016.
- [16] R. Shah, S. J. Wood, S. A. Khan, A. Chaudhry, M. Rehan Khan, and M. S. Morsy, “High-volume forced diuresis with matched hydration using the RenalGuard system to prevent contrast-induced nephropathy: a meta-analysis of randomized trials,” *Clinical Cardiology*, vol. 40, no. 12, pp. 1242–1246, 2017.
- [17] S. S. Brar, V. Aharonian, P. Mansukhani et al., “Haemodynamic-guided fluid administration for the prevention of contrast-induced acute kidney injury: the POSEIDON randomised controlled trial,” *The Lancet*, vol. 383, no. 9931, pp. 1814–1823, 2014.
- [18] M. Maioli, A. Toso, M. Leoncini et al., “Bioimpedance-guided hydration for the prevention of contrast-induced kidney injury: the HYDRA study,” *Journal of the American College of Cardiology*, vol. 71, no. 25, pp. 2880–2889, 2018.
- [19] G. Qian, Z. Fu, J. Guo, F. Cao, and Y. Chen, “Prevention of contrast-induced nephropathy by central venous pressure-guided fluid administration in chronic kidney disease and congestive heart failure patients,” *JACC: Cardiovascular Interventions*, vol. 9, no. 1, pp. 89–96, 2016.
- [20] J. Higgins and S. Green, *Cochrane Handbook for Systematic Reviews of Interventions*, The Cochrane Collaboration, London, UK, 2011.
- [21] A. R. Jadad, R. A. Moore, D. Carroll et al., “Assessing the quality of reports of randomized clinical trials: is blinding necessary?,” *Controlled Clinical Trials*, vol. 17, no. 1, pp. 1–12, 1996.
- [22] A. E. Ades, M. Sculpher, A. Sutton et al., “Bayesian methods for evidence synthesis in cost-effectiveness analysis,” *Pharmacoeconomics*, vol. 24, no. 1, pp. 1–19, 2006.
- [23] S. Brown, B. Hutton, T. Clifford et al., “A microsoft-excel-based tool for running and critically appraising network meta-analyses—an overview and application of NetMetaXL,” *Systematic Reviews*, vol. 3, p. 110, 2014.
- [24] M. S. van Mourik, F. van Kesteren, R. N. Planken et al., “Short versus conventional hydration for prevention of kidney injury during pre-TAVI computed tomography angiography,” *Netherlands Heart Journal*, vol. 26, no. 9, pp. 425–432, 2018.
- [25] A. Saratzis, V. Chiochia, A. Jiffry et al., “HYDRation and bicarbonate to prevent acute renal injury after endovascular aneurysm repair with suprarenal fixation: pilot/feasibility randomised controlled study (HYDRA pilot trial),” *European Journal of Vascular and Endovascular Surgery*, vol. 55, no. 5, pp. 648–656, 2018.
- [26] J. Kooiman, J. P. M. de Vries, J. Van der Heyden et al., “Randomized trial of one-hour sodium bicarbonate vs standard periprocedural saline hydration in chronic kidney disease patients undergoing cardiovascular contrast procedures,” *PLoS One*, vol. 13, Article ID e0189372, 2018.
- [27] P. Alonso, J. Sanz, A. García-Orts et al., “Usefulness of sodium bicarbonate for the prevention of contrast-induced nephropathy in patients undergoing cardiac resynchronization therapy,” *The American Journal of Cardiology*, vol. 120, no. 9, pp. 1584–1588, 2017.
- [28] T. Usmiani, A. Andreis, C. Budano et al., “AKIGUARD (acute kidney injury GUARding device) trial: in-hospital and one-year outcomes,” *Journal of Cardiovascular Medicine*, vol. 17, no. 7, pp. 530–537, 2016.
- [29] S. Turedi, E. Erdem, Y. Karaca et al., “The high risk of contrast-induced nephropathy in patients with suspected pulmonary embolism despite three different prophylaxis: a randomized controlled trial,” *Academic Emergency Medicine*, vol. 23, no. 10, pp. 1136–1145, 2016.
- [30] R. Solomon, P. Gordon, S. V. Manoukian et al., “Randomized trial of bicarbonate or saline study for the prevention of contrast-induced nephropathy in patients with CKD,” *Clinical Journal of the American Society of Nephrology*, vol. 10, no. 9, pp. 1519–1524, 2015.
- [31] P. L. Martin-Moreno, N. Varo, E. Martínez-Ansó et al., “Comparison of intravenous and oral hydration in the prevention of contrast-induced acute kidney injury in low-risk patients: a randomized trial,” *Nephron*, vol. 131, no. 1, pp. 51–58, 2015.
- [32] A. Jurado-Román, F. Hernández-Hernández, J. García-Tejada et al., “Role of hydration in contrast-induced nephropathy in patients who underwent primary percutaneous coronary intervention,” *The American Journal of Cardiology*, vol. 115, no. 9, pp. 1174–1178, 2015.
- [33] M. R. Yeganehkhah, L. Iranirad, F. Dorri et al., “Comparison between three supportive treatments for prevention of contrast-induced nephropathy in high-risk patients undergoing coronary angiography,” *Saudi Journal of Kidney Diseases and Transplantation: An Official Publication of the Saudi Center for Organ Transplantation, Saudi Arabia*, vol. 25, no. 25, pp. 1217–1223, 2014.
- [34] K. Yang, W. Liu, W. Ren, and S. Lv, “Different interventions in preventing contrast-induced nephropathy after percutaneous coronary intervention,” *International Urology and Nephrology*, vol. 46, no. 9, pp. 1801–1807, 2014.
- [35] P. Thyssen, J. F. Lassen, S. E. Jensen et al., “Prevention of contrast-induced nephropathy with N-acetylcysteine or sodium bicarbonate in patients with ST-segment-myocardial infarction: a prospective, randomized, open-labeled trial,” *Circulation: Cardiovascular Interventions*, vol. 7, no. 2, pp. 216–224, 2014.
- [36] J. F. Nieto-Rios, W. A. Salazar, O. M. Sanchez et al., “Prevention of contrast induced nephropathy with sodium bicarbonate (the PROMEC study),” *Jornal Brasileiro de Nefrologia*, vol. 36, pp. 360–366, 2014.
- [37] A. Manari, P. Magnavacchi, E. Puggioni et al., “Acute kidney injury after primary angioplasty: effect of different hydration treatments,” *Journal of Cardiovascular Medicine*, vol. 15, no. 1, pp. 60–67, 2014.
- [38] K. Mahmoodi, B. Sohrabi, F. Ilkchooyi, M. Malaki, M. E. Khaniani, and M. Hemmati, “The efficacy of hydration with normal saline versus hydration with sodium bicarbonate in the prevention of contrast-induced nephropathy,” *Heart Views: The Official Journal of the Gulf Heart Association*, vol. 15, no. 15, pp. 33–36, 2014.
- [39] Y. Luo, X. Wang, Z. Ye et al., “Remedial hydration reduces the incidence of contrast-induced nephropathy and short-term adverse events in patients with ST-segment elevation myocardial infarction: a single-center, randomized trial,” *Internal Medicine*, vol. 53, no. 20, pp. 2265–2272, 2014.
- [40] J. Kooiman, Y. W. J. Sijpkens, J.-P. P. M. de Vries et al., “A randomized comparison of 1-h sodium bicarbonate hydration versus standard peri-procedural saline hydration in patients with chronic kidney disease undergoing intravenous contrast-enhanced computerized tomography,” *Nephrology Dialysis Transplantation*, vol. 29, no. 5, pp. 1029–1036, 2014.
- [41] J. Kooiman, Y. W. J. Sijpkens, M. van Buren et al., “Randomised trial of no hydration vs. sodium bicarbonate hydration in patients with chronic kidney disease undergoing acute computed tomography-pulmonary angiography,” *Journal of Thrombosis and Haemostasis*, vol. 12, no. 10, pp. 1658–1666, 2014.

- [42] S. Akyuz, T. Kemaloglu Oz, S. Altay et al., "Efficacy of oral hydration in the prevention of contrast-induced acute kidney injury in patients undergoing coronary angiography or intervention," *Nephron Clinical Practice*, vol. 128, no. 1-2, pp. 95-102, 2014.
- [43] J. L. Kristeller, G. S. Zavorsky, J. E. Prior et al., "Lack of effectiveness of sodium bicarbonate in preventing kidney injury in patients undergoing cardiac surgery: a randomized controlled trial," *Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy*, vol. 33, no. 7, pp. 710-717, 2013.
- [44] F. Koc, K. Ozdemir, F. Altunkas et al., "Sodium bicarbonate versus isotonic saline for the prevention of contrast-induced nephropathy in patients with diabetes mellitus undergoing coronary angiography and/or intervention: a multicenter prospective randomized study," *Journal of Investigative Medicine*, vol. 61, no. 5, pp. 872-877, 2013.
- [45] G.-Q. Gu, R. Lu, W. Cui et al., "Low-dose furosemide administered with adequate hydration reduces contrast-induced nephropathy in patients undergoing coronary angiography," *Cardiology*, vol. 125, no. 2, pp. 69-73, 2013.
- [46] P. Boucek, T. Havrdova, O. Oliyarnyk, J. Skibova, V. Pecenkova, and D. Sarkady, "Prevention of contrast-induced nephropathy in diabetic patients with renal function impairment: sodium bicarbonate versus sodium chloride-based hydration," *Diabetologia*, vol. 55, pp. S469-S70, 2012.
- [47] G. Marenzi, C. Ferrari, I. Marana et al., "Prevention of contrast nephropathy by furosemide with matched hydration: the MYTHOS (induced diuresis with matched hydration compared to standard hydration for contrast induced nephropathy prevention) trial," *JACC: Cardiovascular Interventions*, vol. 5, no. 1, pp. 90-97, 2012.
- [48] D.-G. Kong, Y.-F. Hou, L.-L. Ma, D.-K. Yao, and L.-X. Wang, "Comparison of oral and intravenous hydration strategies for the prevention of contrast-induced nephropathy in patients undergoing coronary angiography or angioplasty: a randomized clinical trial," *Acta Cardiologica*, vol. 67, no. 5, pp. 565-569, 2012.
- [49] T. Klima, A. Christ, I. Marana et al., "Sodium chloride vs. sodium bicarbonate for the prevention of contrast medium-induced nephropathy: a randomized controlled trial," *European Heart Journal*, vol. 33, no. 16, pp. 2071-2079, 2012.
- [50] V. O. Gomes, R. Lasevitch, V. C. Lima et al., "Hydration with sodium bicarbonate does not prevent contrast nephropathy: a multicenter clinical trial," *Arquivos Brasileiros de Cardiologia*, vol. 99, no. 6, pp. 1129-1134, 2012.
- [51] M. Motohiro, H. Kamihata, S. Tsujimoto et al., "A new protocol using sodium bicarbonate for the prevention of contrast-induced nephropathy in patients undergoing coronary angiography," *The American Journal of Cardiology*, vol. 107, no. 11, pp. 1604-1608, 2011.
- [52] M. Maioli, A. Toso, M. Leoncini, C. Micheletti, and F. Bellandi, "Effects of hydration in contrast-induced acute kidney injury after primary angioplasty: a randomized, controlled trial," *Circulation: Cardiovascular Interventions*, vol. 4, no. 5, pp. 456-462, 2011.
- [53] S.-W. Lee, W.-J. Kim, Y.-H. Kim et al., "Preventive strategies of renal insufficiency in patients with diabetes undergoing intervention or arteriography (the PREVENT Trial)," *The American Journal of Cardiology*, vol. 107, no. 10, pp. 1447-1452, 2011.
- [54] A. M. Hafiz, M. F. Jan, N. Mori et al., "Prevention of contrast-induced acute kidney injury in patients with stable chronic renal disease undergoing elective percutaneous coronary and peripheral interventions: randomized comparison of two preventive strategies," *Catheterization and Cardiovascular Interventions*, vol. 79, no. 6, pp. 929-937, 2012.
- [55] C. Briguori, G. Visconti, A. Focaccio et al., "Renal insufficiency after contrast media administration trial II (REMEDIAL II): RenalGuard system in high-risk patients for contrast-induced acute kidney injury," *Circulation*, vol. 124, no. 11, pp. 1260-1269, 2011.
- [56] W. Wróbel, W. Sinkiewicz, M. Gordon, and A. Woniak-Winiowska, "Oral versus intravenous hydration and renal function in diabetic patients undergoing percutaneous coronary interventions," *Kardiologia Polska*, vol. 68, pp. 1015-1020, 2010.
- [57] A. Vasheghani-Farahani, G. Sadigh, S. E. Kassaian et al., "Sodium bicarbonate in preventing contrast nephropathy in patients at risk for volume overload: a randomized controlled trial," *Journal of Nephrology*, vol. 23, pp. 216-223, 2010.
- [58] R. Cho, N. Javed, D. Traub, S. Kodali, F. Atem, and V. Srinivasan, "Oral hydration and alkalization is noninferior to intravenous therapy for prevention of contrast-induced nephropathy in patients with chronic kidney disease," *Journal of Interventional Cardiology*, vol. 23, no. 5, pp. 460-466, 2010.
- [59] A. Vasheghani-Farahani, G. Sadigh, S. E. Kassaian et al., "Sodium bicarbonate plus isotonic saline versus saline for prevention of contrast-induced nephropathy in patients undergoing coronary angiography: a randomized controlled trial," *American Journal of Kidney Diseases*, vol. 54, no. 4, pp. 610-618, 2009.
- [60] A. Tamura, Y. Goto, K. Miyamoto et al., "Efficacy of single-bolus administration of sodium bicarbonate to prevent contrast-induced nephropathy in patients with mild renal insufficiency undergoing an elective coronary procedure," *The American Journal of Cardiology*, vol. 104, no. 7, pp. 921-925, 2009.
- [61] M. Pakfetrat, M. H. Nikoo, L. Malekmakan et al., "A comparison of sodium bicarbonate infusion versus normal saline infusion and its combination with oral acetazolamide for prevention of contrast-induced nephropathy: a randomized, double-blind trial," *International Urology and Nephrology*, vol. 41, no. 3, pp. 629-634, 2009.
- [62] M. Haase, A. Haase-Fielitz, R. Bellomo et al., "Sodium bicarbonate to prevent increases in serum creatinine after cardiac surgery: a pilot double-blind, randomized controlled trial," *Critical Care Medicine*, vol. 37, no. 1, pp. 39-47, 2009.
- [63] P. Budhiraja, Z. Chen, and M. Popovtzer, "Sodium bicarbonate versus normal saline for protection against contrast nephropathy," *Renal Failure*, vol. 31, no. 2, pp. 118-123, 2009.
- [64] D. Angoulvant, M. Cucherat, G. Rioufol et al., "Preventing acute decrease in renal function induced by coronary angiography (PRECORD): a prospective randomized trial," *Archives of Cardiovascular Diseases*, vol. 102, no. 11, pp. 761-767, 2009.
- [65] M. Maioli, A. Toso, M. Leoncini et al., "Sodium bicarbonate versus saline for the prevention of contrast-induced nephropathy in patients with renal dysfunction undergoing coronary angiography or intervention," *Journal of the American College of Cardiology*, vol. 52, no. 8, pp. 599-604, 2008.
- [66] S. L. Chen, J. Zhang, F. Yei et al., "Clinical outcomes of contrast-induced nephropathy in patients undergoing percutaneous coronary intervention: a prospective, multicenter, randomized study to analyze the effect of hydration and acetylcysteine," *International Journal of Cardiology*, vol. 126, no. 3, pp. 407-413, 2008.

- [67] S. S. Brar, A. Y. Shen, M. B. Jorgensen et al., "Sodium bicarbonate vs sodium chloride for the prevention of contrast medium-induced nephropathy in patients undergoing coronary angiography: a randomized trial," *JAMA*, vol. 300, no. 9, pp. 1038–1046, 2008.
- [68] E. Adolph, B. Holdt-Lehmann, T. Chatterjee et al., "Renal Insufficiency Following Radiocontrast Exposure Trial (REINFORCE): a randomized comparison of sodium bicarbonate versus sodium chloride hydration for the prevention of contrast-induced nephropathy," *Coronary Artery Disease*, vol. 19, no. 19, pp. 413–419, 2008.
- [69] P. Schmidt, D. Pang, D. Nykamp, G. Knowlton, and H. Jia, "N-acetylcysteine and sodium bicarbonate versus N-acetylcysteine and standard hydration for the prevention of radiocontrast-induced nephropathy following coronary angiography," *Annals of Pharmacotherapy*, vol. 41, no. 1, pp. 46–50, 2007.
- [70] E. E. Ozcan, S. Guneri, B. Akdeniz et al., "Sodium bicarbonate, N-acetylcysteine, and saline for prevention of radiocontrast-induced nephropathy. A comparison of 3 regimens for protecting contrast-induced nephropathy in patients undergoing coronary procedures. A single-center prospective controlled trial," *American Heart Journal*, vol. 154, no. 3, pp. 539–544, 2007.
- [71] M. Masuda, T. Yamada, T. Mine et al., "Comparison of usefulness of sodium bicarbonate versus sodium chloride to prevent contrast-induced nephropathy in patients undergoing an emergent coronary procedure," *The American Journal of Cardiology*, vol. 100, no. 5, pp. 781–786, 2007.
- [72] B. Dussol, S. Morange, A. Loundoun, P. Auquier, and Y. Berland, "A randomized trial of saline hydration to prevent contrast nephropathy in chronic renal failure patients," *Nephrology Dialysis Transplantation*, vol. 21, no. 8, pp. 2120–2126, 2006.
- [73] C. Mueller, P. Seidensticker, H. J. Buettner et al., "Incidence of contrast nephropathy in patients receiving comprehensive intravenous and oral hydration," *Swiss Medical Weekly*, vol. 135, no. 135, pp. 286–290, 2005.
- [74] G. J. Merten, W. P. Burgess, L. V. Gray et al., "Prevention of contrast-induced nephropathy with sodium bicarbonate: a randomized controlled trial," *JAMA*, vol. 291, no. 19, pp. 2328–2334, 2004.
- [75] H. S. Trivedi, H. Moore, S. Nasr et al., "A randomized prospective trial to assess the role of saline hydration on the development of contrast nephrotoxicity," *Nephron Clinical Practice*, vol. 93, no. 93, pp. C29–C34, 2003.
- [76] C. Mueller, G. Buerkle, H. J. Buettner et al., "Prevention of contrast media-associated nephropathy: randomized comparison of 2 hydration regimens in 1620 patients undergoing coronary angioplasty," *Archives of Internal Medicine*, vol. 162, no. 3, pp. 329–336, 2002.
- [77] Task Force on Myocardial Revascularization of the European Society of C, the European Association for Cardio-Thoracic S, European Association for Percutaneous Cardiovascular I, "Guidelines on myocardial revascularization," *European Journal of Cardio-Thoracic Surgery: Official Journal of the European Association for Cardio-Thoracic Surgery*, vol. 38, pp. S1–S52, 2010.
- [78] H. S. Thomsen, "European Society of Urogenital Radiology (ESUR) guidelines on the safe use of iodinated contrast media," *European Journal of Radiology*, vol. 60, no. 3, pp. 307–313, 2006.
- [79] J. R. Brown, D. M. Pearlman, E. J. Marshall et al., "Meta-analysis of individual patient data of sodium bicarbonate and sodium chloride for all-cause mortality after coronary angiography," *The American Journal of Cardiology*, vol. 118, no. 10, pp. 1473–1479, 2016.
- [80] B. Zhang, L. Liang, W. Chen, C. Liang, and S. Zhang, "The efficacy of sodium bicarbonate in preventing contrast-induced nephropathy in patients with pre-existing renal insufficiency: a meta-analysis," *BMJ Open*, vol. 5, Article ID e006989, 2015.
- [81] S. Ali-Hassan-Sayegh, S. J. Mirhosseini, E. Rahimizadeh et al., "Current status of sodium bicarbonate in coronary angiography: an updated comprehensive meta-analysis and systematic review," *Cardiology Research and Practice*, vol. 2015, Article ID 690308, 16 pages, 2015.
- [82] J.-S. Jang, H.-Y. Jin, J.-S. Seo et al., "Sodium bicarbonate therapy for the prevention of contrast-induced acute kidney injury—a systematic review and meta-analysis," *Circulation Journal*, vol. 76, no. 9, pp. 2255–2265, 2012.
- [83] V. Kunadian, A. Zaman, I. Spyridopoulos, and W. Qiu, "Sodium bicarbonate for the prevention of contrast induced nephropathy: a meta-analysis of published clinical trials," *European Journal of Radiology*, vol. 79, no. 1, pp. 48–55, 2011.
- [84] S. N. Heyman, S. Rosen, M. Khamaisi, J.-M. Idée, and C. Rosenberger, "Reactive oxygen species and the pathogenesis of radiocontrast-induced nephropathy," *Investigative Radiology*, vol. 45, no. 4, pp. 188–195, 2010.