Original Article

A prospective study of contrast preservation using ultra-low contrast delivery technique versus standard automated contrast injector system in coronary procedures

Adam Styse, Maheedhar Gedelaa,*, Udit Bhatnagarb, Marian Petraskoa, Hazem Dawoud, Tadeusz Malinskib, Tomasz Styse

a Sanford Heart Hospital, Sanford Cardiovascular Institute, University of South Dakota Sanford School of Medicine, Sioux Falls, SD, 57105, USA
b Nanomedical Research Laboratory, Ohio University, Athens, OH, 45701, USA

1. Introduction

Contrast-induced acute kidney injury (CI-AKI) is associated with short- and long-term consequences comprising worse in-hospital mortality, 1-year mortality, steady decline in renal function, need for renal replacement therapy, and increased health care costs.1–4 Most cases result from the intravascular contrast media (CM) exposure during cardiac catheterization and percutaneous coronary intervention (PCI).5 The currently recommended strategies to prevent CI-AKI in those who are at risk are holding nephrotic medications, adequate periprocedural intravenous hydration, use of iso-osmolar or low-osmolar contrast media, lowering the volume of contrast media administered, and short-term high-dose statin therapy.6 Among these, the intravenous hydration and minimizing contrast volume are considered most effective in decreasing the risk of CI-AKI.7

The contrast media volume (CMV) is a modifiable factor, and various strategies have been described with a goal to reduce the adverse renal outcomes by minimizing the CM exposure, including specific devices. These include automated contrast injector systems, CM modulating devices, and removal of contrast from the coronary sinus or by hemodialysis.8 With the growing aging population and potential for these patients to have baseline renal dysfunction when they present for the coronary procedures, the efforts to reduce CMV become even more important. We previously published an ultra-low contrast delivery (ULCD) technique with the use of automated contrast injector system (ACIS) and showed a significant reduction in CMV in patients undergoing coronary invasive procedures. Even in the standard ACIS arm, CMV was significantly lower than values reported in literature, possibly due to operators’ bias toward contrast preservation.

Our study showed a highly significant reduction in mean CMV with ULCD technique versus standard ACIS, respectively: angiogram 24.8 ± 15.8 mL (n = 194) vs 42.3 ± 25.1 mL (n = 200) (p < 0.0001); PCI 23.5 ± 19.7 mL (n = 52) vs 48.2 ± 30.8 mL (n = 16) (p < 0.0070); angiogram with ad hoc PCI 53.4 ± 32.1 mL (n = 23) vs 89.7 ± 56.6 mL (n = 16) (p < 0.0024); and overall angiogram and PCI 27.4 ± 20.5 mL (n = 204) vs 44.9 ± 28.0 mL (n = 181) (p < 0.0001).

Conclusion: Our study showed a highly significant reduction in CMV using ULCD technique compared to standard ACIS contrast delivery in coronary invasive procedures. Even in the standard ACIS arm, CMV was significantly lower than values reported in literature, possibly due to operators’ bias toward contrast preservation.

* Corresponding author. Sanford Heart Hospital University of South Dakota Sanford School of Medicine, 1301 West 18th Street, Sioux Falls, SD, 57105, USA
E-mail address: maheedhargedela@gmail.com (M. Gedela).

https://doi.org/10.1016/j.ihj.2019.09.001
0019-4832/© 2019 Cardiological Society of India. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
reported a nanomedical ex vivo study showing that the toxic effect of the CM on endothelial and renal cells decreased exponentially with a linear decrease of contrast media concentrations. Here, we sought to prospectively evaluate the CMV administered using ULCD technique with and without ACIS in “all-comers” who underwent invasive coronary procedures.

2. Materials and methods

2.1. Study population and design

We conducted a prospective, observational study at the Sanford University Medical Center, Sioux Falls, SD, USA. We enrolled all consecutive patients who were undergoing cardiac catheterization and/or PCI between May 2017 and July 2018. There were no exclusions for this study. Informed consent was obtained from all patients enrolled. The study protocol was approved by our institutional review board. All coronary procedures were performed using iodixanol (Visipaque), an iodine-containing nonionic isosmolar contrast agent. ACIST CV® (ACIST Medical Systems, Eden Prairie, Minnesota) ACIS was used in all cases. Patients were allocated to either ULCD technique arm (n = 204) or ACIS (n = 200) arm. The ULCD technique has been previously described in detail and is briefly outlined below. A total of 204 patients underwent diagnostic catheterization and/or PCI in the ULCD technique arm. A total of 200 patients underwent diagnostic catheterization, and 28 patients underwent PCI using standard ACIS programming (the ACIS arm). A total of 26 patients underwent PCI using ULCD technique in the ACIS arm. We then further divided the patients into subgroups consisting of those who underwent diagnostic catheterization only, PCI only, and those who underwent diagnostic catheterization followed by an ad hoc PCI. All cardiovascular specialists who conducted the procedure reported the amount of CMV delivered. The CMV administered was compared between these two arms who underwent coronary procedures. Total procedure time and fluoroscopy dose were also compared between the two groups. The quality of images was assessed and deemed adequate by an experienced interventional cardiologist as per usual practice. Baseline demographic, angiographic, and procedure-related information was obtained from the review of the electronic medical records. Patients who underwent elective procedures received 1–2 mL/kg/hour intravenous (IV) fluids for 2–4 h before and after procedure and those who underwent emergent/urgent procedures received 1–2 mL/kg/hour IV fluids for 4 h after procedure per our institutional protocol.

2.2. Ultra-low contrast delivery technique

The ULCD technique requires the automated contrast injectors such as ACIST device. The volume (mL), flow (mL/s), rise time (sec), and pressure (psi) are adjusted for left/right coronary artery based on the initial small volume of injection of 0.5 mL (spill-over). Based on the catheter filling, the size of the coronary artery and flow is determined. Then the ACIS programming is done, with, in general, 1–4 mL, 2–4 mL/s, 0.2–0.5 s rise time, and 300–450 psi depending on “spill-over” findings during catheter filling. The detailed description of the technique has been previously published (Figs. 1 and 2).

2.3. Statistical analysis

Continuous variables are displayed as mean ± standard deviation, and categorical variables are displayed as numbers and percentages. Continuous variables were analyzed using student t-test, and categorical variables were analyzed by a chi-square test. T-tests were used to compare mean contrast volumes between ULCD and ACIS groups (Table 2). Descriptive statistics were also compared between ULCD and ACIS groups (Table 1). The p-value is a result of the comparison between these two groups, and the significant difference was defined as p < 0.05.

3. Results

Of the consecutive 204 patients in the ULCD arm, 194 underwent diagnostic catheterization, 59 underwent PCI, and 24 underwent diagnostic coronary angiogram with ad hoc PCI. Two hundred patients underwent diagnostic catheterization, and 28 patients underwent diagnostic catheterization with ad hoc PCI in the ACIS arm. No separate PCI-only procedure was conducted in the ACIS group. The baseline characteristics did not differ significantly between these two groups (Table 1). Most patients underwent coronary procedures through the radial approach. Overall, patients with Stage 3 and 4 chronic kidney disease represent 70% of the study population.

The amount of CMV was significantly lower in the ULCD arm across all the subgroups (Fig. 3). For patients who underwent diagnostic catheterization only, the mean CMV was significantly lower in the ULCD arm compared to ACIS arm: 24.8 ± 15.8 mL (n = 194) vs 42.3 ± 25.1 mL (n = 200) (p < 0.0001). For patients who underwent PCI only, the mean CMV was significantly lower in the ULCD arm compared to ACIS arm: 23.5 ± 19.7 mL (n = 52) vs. 48.2 ± 30.8 mL (n = 16) (p < 0.0070). For patients who underwent diagnostic catheterization with ad hoc PCI, the mean CMV was significantly lower in the ULCD arm compared to ACIS arm: 53.4 ± 32.1 mL (n = 23) vs. 89.7 ± 35.6 mL (n = 16). When the total amount of CMV administered combining diagnostic catheterization and PCI in the ULCD arm compared to ACIS, the mean CMV was significantly lower: 27.4 ± 20.5 mL (n = 204) vs. 44.9 ± 28.0 mL (n = 181) (p < 0.0001). Besides, the total procedure time is significantly lower in the ULCD group compared to the ACIS group (18.0 ± 11.3 min vs. 29.3 ± 27.2 mL, p < 0.0001). We also observed a significant reduction in the total amount of radiation dose in ULCD arm compared to ACID arm (535.0 ± 500.4 mGy vs. 720.7 ± 674.8 mGy, p < 0.002).

4. Discussion

Depending on the baseline renal function, risk factors, and clinical setting, the incidence of CI-AKI varies from 2% to as high as 50% in patients undergoing invasive coronary procedures and CI-AKI is considered a third leading cause of the hospital-acquired acute kidney injury.11,12 Aside from providing adequate periprocedural intravenous hydration and minimizing CMV, no other pharmacological preventive or treatment measures have proven to be efficacious in preventing CI-AKI. The CMV is a procedural variable that is modifiable by the operator in coronary procedures, and the degree of benefit in reducing CK-AKI is proportional to the amount of reduction in CMV.13 The recent National Cardiovascular Data Registry CathPCI reported a mean CMV of 197.7 mL for patients undergoing PCI.14 Although reducing the CMV has been shown to reduce the incidence of the CI-AKI during the coronary procedures, the safe limit of contrast dose is not well known. In 1989, Cigarroa et al. proposed maximal acceptable contrast dose derived by a formula 5 mL/kg body weight divided by baseline serum creatinine (mg/dl) to decrease CI-AKI.15 Although this formula has been tested in a large study of 16,952 PCIs in predicting the nephropathy requiring dialysis, it is not commonly used.16 Laskey et al. reported that the ratio of the volume of contrast media to the creatinine clearance
>3.7 was a predictor of CI-AKI in patients undergoing PCI and may be used to estimate the highest amount of contrast media that can be administered to decrease the risk of CI-AKI. Another study suggested a ratio of amount of contrast given to calculated creatinine clearance of more than 3 is associated with an increased risk of CI-AKI and dialysis in invasive coronary procedures. In addition, a computational model was developed to assess the degree of contrast media volume reduction and the occurrence of the AKI among patients receiving PCI. This modeling study showed a 12.8% and 8.8% reduction in AKI with 30% and 20% reduction in contrast media volume, respectively, and the benefit corresponded to the degree of contrast reduction.

The definition of low contrast volume differs from study to study but the basic principle for the contrast media volume administered for a coronary procedure is as low as reasonably achievable (ALARA) for at-risk patients, and this approach has found its way into the guidelines. Devices have been developed and studied to limit the CMV, including ACIST CVi® (ACIST Medical Systems, Eden Prairie, Minnesota), Avanta system (MEDRAD Inc., Warrendale, Pennsylvania) and AVERT system (Osprey Medical, Minnetonka, Minnesota). A meta-analysis comparing the administered CMV using the ACIS versus the manual injection in patients undergoing coronary procedures showed a significant reduction in contrast administered using ACIS. In this study, there was a 45 mL reduction in CMV per case and a 15% reduction in the incidence of CI-AKI in the ACIS cohort. However, the individual studies comparing ACIS use versus manual manifold system for the contrast delivery in coronary procedures showed conflicting results in reducing the CMV delivered and CI-AKI.

The DyeVert System, a next-generation AVERT System, has been tested for CMV reduction with and without assessing CI-AKI outcome. Sapontis et al. reported that overall attempted mean CMV injected was 172.9 ± 116.8 mL and actual mean CMV injected was 88.7 ± 56.9 mL with a saved volume of 84.1 ± 66.1 mL due to the device in all diagnostic angiograms and PCIs (n = 44). Small study of patients (n = 10) who underwent coronary and peripheral procedures reported an injected mean CMV of 79.9 ± 48.8 mL and absolute CMV of 55.8 ± 31.9 mL, with one case of asymptomatic CI-AKI. A prospective, single-center, open-label randomized controlled trial of 96 patients who underwent diagnostic coronary angiograms only using DyeVert system showed 36.9 ± 10.9 mL contrast utilization versus 62.5 ± 12.7 mL with no DyeVert system, reporting 41% contrast media volume reduction.

Lately, a prospective, multicenter AVERT (AVERT Clinical Trial for Contrast Media Volume Reduction and Incidence of CIN) randomized trial (n = 578) compared the AVERT system plus periprocedural hydration versus procedural hydration in reducing the contrast media volume and preventing CI-AKI events in at-risk individuals undergoing coronary angiogram with or without PCI. Using the first-generation AVERT system, this trial reported a...
Table 1
Clinical and procedural characteristics.

| Clinical variable                  | ULCD N = 204 | ACIS N = 200 | p value |
|-----------------------------------|--------------|--------------|---------|
| Age in years (mean ± SD)          | 67.75 ± 11.21| 68.56 ± 11.91| 0.482   |
| Male                              | 121 (59.3%)  | 113 (56.5%)  | 0.567   |
| Female                            | 83 (40.7%)   | 87 (43.5%)   |         |
| Weight in kg (mean ± SD)          | 94.41 ± 24.08| 93.84 ± 24.28| 0.814   |
| Height in cm (mean ± SD)          | 171.51 ± 11.57| 171.37 ± 11.36| 0.905   |
| Body surface area in m²           | 2.05 ± 0.30  | 2.04 ± 0.28  | 0.828   |
| Creatinine clearance              |              |              |         |
| eGFR <30%                         | 9 (4.4%)     | 7 (3.5%)     | 0.638   |
| eGFR 30–59%                       | 40 (19.6%)   | 40 (20.0%)   | 0.921   |
| eGFR 60–89%                       | 97 (47.5%)   | 99 (49.5%)   | 0.695   |
| eGFR >90%                         | 57 (27.9%)   | 53 (26.5%)   | 0.745   |
| History of CABG                   | 28 (13.7%)   | 19 (9.5%)    | 0.185   |
| No. of diagnostic coronary angiogram | 194       | 200          | N/A     |
| No. of percutaneous intervention  | 59           | 28           | N/A     |
| No. of diagnostic coronary angiogram and ad hoc percutaneous intervention | 24 | 28 | N/A |
| Indication for the procedure      |              |              |         |
| Elective                          | 181 (88.7%)  | 185 (92.5%)  | 0.194   |
| Urgent                            | 23 (11.3%)   | 14 (7.0%)    | 0.136   |
| Emergent                          | 2 (1.0%)     | 0 (0.0%)     | 0.159   |
| No. of biplane used               | 116 (58.0%)  | 118 (59.3%)  | 0.793   |
| No. of single plane used          | 84 (42.0%)   | 80 (40.2%)   | 0.715   |
| Radial access                     | 173 (84.8%)  | 183 (91.5%)  | 0.038   |
| Ulnar access                      | 2 (1.0%)     | 0 (0.0%)     | 0.160   |
| Femoral access                    | 32 (15.7%)   | 31 (15.5%)   | 0.959   |
| Total fluoro dose in mGy          | 535.04 ± 500.37 | 720.67 ± 674.82 | 0.002 |
| Total procedure time in min       | 18.02 ± 11.27| 29.35 ± 27.20| <0.001  |

ULCD, ultra-low contrast delivery; ACIS, automated contrast injector system; eGFR, estimated glomerular filtration rate; CABG, coronary artery bypass graft surgery.

Table 2
Mean amount of contrast media volume delivered per patient using ACIST device with and without ULCD technique.

| Type of procedure                  | ULCD No. of patients | Contrast volume (mL) | ACIS No. of patients | Contrast volume (mL) | Mean percent contrast reduction (%) | p value |
|-----------------------------------|----------------------|----------------------|----------------------|----------------------|-------------------------------------|---------|
| Diagnostic angiogram              | 194                  | 24.8 ± 15.8          | 200                  | 42.3 ± 25.1          | 41.5                                | <0.0001 |
| PCI                               | 52                   | 23.5 ± 19.7          | 16                   | 48.2 ± 30.8          | 51.2                                | 0.0070  |
| Diagnostic angiogram + ad hoc PCI | 23                   | 33.4 ± 32.1          | 16                   | 89.7 ± 35.6          | 40.4                                | 0.0024  |
| Combined diagnostic angiogram and PCI | 204                     | 27.4 ± 20.5          | 181                  | 44.9 ± 28.0          | 45.7                                | <0.0001 |

ULCD, ultra-low contrast delivery; ACIS, automated contrast injector system; PCI, percutaneous coronary intervention.

Fig. 3. Bar-graph representation of contrast media volume administration using ULCD technique vs. ACIS across all coronary procedures. ULCD, ultra-low contrast delivery; ACIS, automated contrast injector system.
A statistically significant reduction from 101.3 ± 71.1 mL to 85.6 ± 50.5 mL CMV in all coronary procedures and from 147 ± 81 mL to 114 ± 55 mL CMV in PCIs. However, no significant reduction in CI-AKI was observed in the two study arms, and attributable reasons to this finding were multifactorial etiology of the CI-AKI, relatively lower CMV reduction in patients who underwent diagnostic coronary angiograms, and inadequate power to detect CI-AKI events in the PCI-only group. A recent multicenter, prospective, observational study by Gurm et al. reported that a mean CMV delivered in patients undergoing coronary angiogram and/or PCI was 67 ± 5 mL using DyeVert Plus System in patients with CKD and noted an AKI incidence rate of 9.6%.

Our previous study with ULCD technique demonstrated a remarkable lowering of CMV administered with a mean CMV of 17.9 mL (n = 123) in Stage 3 and 4 CKD patients who underwent diagnostic coronary angiogram and/or PCI. Only 7.3% (n = 9/123) patients developed CIN at 30-day follow-up period. In the present study, we aimed to assess the role of our ULCD technique with ACIS in reducing the contrast media volume compared to ACIS alone in “all comers” series of consecutive patients undergoing invasive coronary procedures.

Regardless of the type of the coronary procedure, diagnostic catheterization, PCI, or diagnostic catheterization with ad hoc PCI, the mean CMV administered was significantly lower in the ULCD group compared to ACIS group. Across all groups, there was a 40–50% reduction in CMV administered with ULCD technique compared to ACIS only. The procedure time was also significantly lower in the ULCD group compared to ACIS. This could be due to higher procedural efficiency of interventionalists vs. invasive cardiologists in performing angiograms, but also time-saving advantage of the ULCD technique is a possibility. In addition, the ULCD technique is associated with lower radiation compared to standard ACIS for possibly similar reason(s). We did not assess the incidence of CI-AKI in our study. Overall, our ULCD technique with the use of ACIS significantly lowers the CMV administration and compared to the contemporary studies; the ULCD technique delivers lowest CMV in the literature (Table 3). Another very pertinent in our opinion observation is the relatively low CMV in our control arm compared to other studies. We think that this is due to the experience gained by the cath lab technicians from the ULCD arm operators and application of some of the reduced volumes programmed in the ACIS arm by the operators. Simple awareness of contrast preservation efforts by operators and staff alone could have contributed to this finding.

In parallel to the clinical study presented here, we performed a separate study using nanomedical sensors to monitor in vitro the interaction of contrast media molecules and their toxicity on human endothelial and renal cells. The preliminary results already indicate the toxic effect can be significantly reduced at low concentration of contrast media 2.5 mgI/mL (equivalent to 39 mL of infused contrast). At a concentration of 6 mgI/mL (equivalent to 94 mL of infused contrast), a dramatic increase in cytotoxic peroxynitrite (ONOO−), the main component of oxidative stress, and a decrease in cytoprotective nitric oxide (NO) were observed. This can lead to endothelial dysfunction and CI-AKI. These data provide molecular basis justifying reduction of CMV administered to a patient, as means of reducing CI-AKI.

Given the substantial amount of the contrast media reduction, we think that the ULCD technique is very useful clinically. We believe that at present, ALARA CMV for the coronary procedures is most efficiently obtained with our ULCD technique without sacrificing image quality.

### 4.1. Study limitations

First, this is an observational study conducted at a single center. Second, we did not study the incidence of the CI-AKI in our study as we did not check the renal function after procedure routinely. Third, our operators are relatively experienced; thus, application of this technique by invasive cardiologists elsewhere might involve some learning curve. However, our second-year fellows in the catheterization laboratory have been already quite handy with this technique; thus, we do not anticipate a steep learning curve in practicing cardiologists. In fact, the standard algorithm and use of ACIS makes it easier to teach than teaching manual injections, where it is difficult to exactly explain parameters like pressure applied and rate of rise.

### 5. Conclusion

We report that the ULCD technique with the use of ACIS during the coronary procedures can be applied in all patients with a very significant reduction in the contrast media volume delivered without compromising the angiographic image quality. This
technique is a relatively simple and inexpensive, yet it may translate into the meaningful reduction in CI-AKI events in a broad patient population.

Conflicts of interest

All authors have none to declare.

Financial disclosure statement

The authors have no financial disclosures to report.

References

1. McCullough PA, Wolyn R, Rocher LL, Levin RN, O’Neill WW. Acute renal failure after coronary intervention: incidence, risk factors, and relationship to mortality. Am J Med. 1997;103(5):368–375.
2. Gruberg L, Mintz GS, Mehran R, et al. The prognostic implications of further renal function deterioration within 48 h of interventional coronary procedures in patients with pre-existent chronic renal insufficiency. J Am Coll Cardiol. 2000;36(3):1542–1548.
3. Maiohi M, Toso A, Leocenici M, Gallopin M, Musini N, Bellandi F. Persistent renal damage after contrast-induced acute kidney injury: incidence, evolution, risk factors, and prognosis. Circulation. 2012;125(25):3099–3107.
4. Subramanian S, Tulmin J, Bapat B, Zycynski T. Economic burden of contrast-induced nephropathy: implications for prevention strategies. J Med Econ. 2007;10(2):119–134.
5. Nash K, Hafeez A, Hou S. Hospital-acquired renal insufficiency. Am J Kidney Dis. 2002;39(5):930–936.
6. Windecker S, Kolh P, Alfonso F, et al. 2014 ESC/EACTS guidelines on myocardial revascularization: the task force on myocardial revascularization of the European society of cardiology (ESC) and the European association for cardiothoracic surgery (EACTS) developed with the special contribution of the European association of percutaneous cardiovascular interventions (EAPCI). Eur Heart J. 2014;35(7):2541–2619.
7. Rear R, Bell RM, Hausenloy DJ. Contrast-induced nephropathy following angiography and cardiac interventions. Heart. 2016;102(8):638–648.
8. Stub D, Duffy SJ, Kaye DM. Device-based therapy in the prevention of contrast-induced nephropathy. Interv Cardiol Clin. 2014;3(3):421–428.
9. Kelly SC, Li S, Stys TP, Thompson PA, Stys AT. Reduction in contrast nephropathy from coronary angiography and percutaneous coronary intervention with ultra-low contrast delivery using an automated contrast injector system. J Invasive Cardiol. 2016;28(11):446–450.
10. Malinski T, Dawoud H, Levin RN, O’Neill WW. Acute renal failure after percutaneous coronary intervention: definition, risk factors, and relationship to mortality. Am J Med. 1997;103(5):368–375.
11. Gurm HS, Dixon SR, Smith DE, et al. Renal function-based contrast dosing to define safe limits of radiographic contrast media in patients undergoing percutaneous coronary interventions. J Am Coll Cardiol. 2011;58(9):907–914.
12. Kane GC, DoyleBJ, Lerman A, Barsness GW, Best RJ, Rihal CS. Ultra-low contrast volumes reduce rates of contrast-induced nephropathy in patients with chronic kidney disease undergoing coronary angiography. J Am Coll Cardiol. 2008;51(1):89–90.
13. Gurm HS, Seth M, Dixon SR, et al. Contemporary use of and outcomes associated with ultra-low contrast volume in patients undergoing percutaneous coronary interventions. Cathet Cardiovasc Interv. 2019 Feb 1;93(2):222–230.
14. McCullough PA, Choi JP, Feghali GA, et al. Contrast-induced acute kidney injury. J Am Coll Cardiol. 2010;58(13):1465–1473.
15. Nallamothu BK, Tommaso CT, Anderson HV, et al. ACC/AHA/SCAI/AMA-Convened PCPI/NCQA 2013 performance measures for adults undergoing percutaneous coronary intervention: a report of the American college of cardiology/American heart association task force on performance measures, the society for cardiovascular angiography and interventions, the American medical association-convened physician consortium for performance improvement, and the national committee for quality assurance. J Am Coll Cardiol. 2014;63(7):722–745.
16. Naik SS, Aronow HD, Box LC, et al. SCAI expert consensus statement: 2016 best practices in the cardiac catheterization laboratory: (Endorsed by the cardiological society of India, and sociedad Latino Americana de Cardiologia intervinenciista; Affirmation of value by the Canadian Association of interventional cardiology-Association canadienne de cardiologie d’intervention). Cathet Cardiovasc Interv. 2016;88(3):407–423.
17. Messenger JC, Casserly IP. Advances in contrast media and contrast injectors. Cardiol Clin. 2009;27(3):407–415.
18. Winsinger KD, Kassis HM, Block CA, Siddhu M, Brown JR. Meta-analysis of the effect of automated contrast injection devices versus manual injection and contrast volume on risk of contrast-induced nephropathy. Am J Cardiol. 2014;113(1):49–53.
19. Anne G, Gruberg L, Huber A, et al. Traditional versus automated injection contrast system in diagnostic and percutaneous coronary interventional procedures: comparison of the contrast volume delivered. J Invasive Cardiol. 2004;16(7):360–362.
20. Call J, Sacinty M, Applegate R, et al. Automated contrast injection in contemporary practice during cardiac catheterization and PCI: effects on contrast-induced nephropathy. J Invasive Cardiol. 2006;18(10):469–474.
21. Godley 2nd RW, Joshi K, Breall JA. A comparison of the use of traditional hand injection versus automated contrast injectors during cardiac catheterization. J Invasive Cardiol. 2012;24(12):628–630.
22. Hwang JR, D’Alonzo S, Kostuk WJ, et al. Contrast volume use in manual vs automated contrast injection systems for diagnostic coronary angiography and percutaneous coronary interventions. Can J Cardiol. 2013;29(3):372–376.
23. Gurm HS, Smith D, Share D, et al. Impact of automated contrast injector systems on contrast use and contrast-associated complications in patients undergoing percutaneous coronary interventions. JACC Cardiovasc Interv. 2013;6(4):399–405.
24. Saposnik J, Barron G, Seneviratne S, et al. A first in human evaluation of a novel contrast media saving device. Cathet Cardiovasc Interv. 2017;90(6):928–934.
25. Cornerone N, Blondi-Zoccai G, Ferraro P, et al. Contrast minimization with the next-generation DyeVert plus system for contrast reduction and real-time monitoring during coronary and peripheral procedures: first experience. J Invasive Cardiol. 2017;29(8):259–262.
26. Desch S, Fueran G, Poss J, et al. Impact of a novel contrast reduction system on contrast savings in coronary angiography – the DyeVert randomised controlled trial. Int J Cardiol. 2018;257:50–53.
27. Mehran R, Faggioni M, Chandrasekhar J, et al. Effect of a contrast modulation system on contrast media use and the rate of acute kidney injury after coronary angiography. JACC Cardiovasc Interv. 2018;11(16):1601–1610.
28. Gurm HS, Mavromatis K, Bertolet B, et al. Minimizing radiographic contrast administration during coronary angiography using a novel contrast reduction system: a multicenter observational study of the DyeVert plus contrast reduction system. Cathet Cardiovasc Interv. 2019 Jun 1;93(7):1228–1235.