Impact of Patient Volume on Iodinated Contrast Material Waste with Multidose Contrast Injectors

Niloufar Rafiei Alavi, Julie Limfueco, Randall Yamamoto, James Shi, Roozbeh Houshyar, Vahid Yaghmai

Background: Multidose iodinated contrast media (ICM) injectors have shown promise in reducing ICM waste. This study aims to evaluate the impact of patient volume on ICM waste reduction in multidose injectors.

Methods: CT studies performed over one-year period with a multidose injector at our emergency CT unit. We recorded the ICM volume, time, and date for each injection and calculated total annual ICM use, accounting for the 500 mL ICM containers' 8-hour window usage limit. We then calculated the ICM waste for the same patient cohort assuming single-dose vials used with single-dose injectors were used instead, without the 8-hour window for usage. To assess the impact of patient volume, we evaluated six subgroups based on daily injected patient counts: Group 1 (< 10 patients/day), Group 2 (10–19 patients/day), Group 3 (20–29 patients/day), Group 4 (30–39 patients/day), Group 5 (40–49 patients/day), Group 6 (≥ 50 patients/day). Annual and mean per patient ICM waste was calculated for both injector types and compared among all subgroups.

Results: In total, across 12,290 scans, multidose injectors reduced annual ICM waste by 86.1% compared to single-use injectors. Annual ICM waste was zero on days with 50 or more patients and was minimal (253 mL) for days with 40–49 patients. A significant negative correlation between patient volume and ICM waste was observed ($r = -0.365$, $p < 0.0001$). Mean ICM waste per patient was 2.5 times higher in Group 1 and 71.4% higher in Group 2 with multidose injector compared to single-dose injector. Conversely, in groups with at least 20 patients per day, mean ICM waste per patient was lower with multidose injectors compared to single-dose injectors. Mean ICM waste per patient was reduced by 53.9% in Group 3, 88.9% in Group 4 and 100% in Group 6.

Conclusion: High patient throughput centers with over 40 patients per day can nearly eliminate ICM waste with multidose injectors. However, using multidose injectors in centers with lower patient volumes (< 20 patients per day) may lead to increased ICM waste compared to single-dose injectors, underscoring the importance of aligning injector choice with patient volume to optimize resource utilization and minimize waste.

Key Words: Contrast Media; Computed Tomography; Iodinated Contrast Media; Contrast Injector; Sustainability.

INTRODUCTION

Environmental awareness has become prominent in recent years, and its importance is being increasingly recognized in healthcare, including radiology (1). A significant sustainability concern in radiology is the waste and greenhouse gas emissions generated by the extensive use of single-use materials in imaging procedures (2,3).

Iodinated contrast material (ICM) is one of the most commonly used pharmaceuticals in radiology (4–6). The rising annual number of contrast-enhanced CT scans and the growing demand for ICM are contributing to significant pharmaceutical waste, posing significant environmental and economic challenges (7,8). Moreover, iodinated contrast media have been detected in sewage, surface water, and drinking water worldwide (9). Standard purification techniques are insufficient to remove these substances, leading to unresolved concerns regarding drinking water safety. To mitigate this impact, measures should focus on minimizing the use and waste of contrast media (10).

Iodinated intravenous contrast media (ICM) is typically supplied in single-use plastic vials of various sizes and administered to patients using a syringe-based power injector

Acad Radiol 2025; 32:2111–2120

From the Department of Radiological Sciences, University of California Irvine, Orange, CA 92868. Received September 29, 2024; revised December 6, 2024; accepted December 7, 2024. **Address correspondence to:** V.Y. e-mail: vyaghmai@uci.edu

https://doi.org/10.1016/j.acra.2024.12.013

(11). These vials are available in limited package sizes. Because contrast doses vary among individuals, especially with weight-based dosing, single-use packaging often results in significant contrast media waste (12).

Multidose ICM packaging was initially introduced for cost-saving purposes but has recently gained attention for its environmental benefits (13–15). The latest generation of syringeless multidose injectors, designed to minimize infection risk, limits the use of contrast containers to an 8-hour window after opening. This restriction ensures timely use of opened containers. However, this practice could also lead to potential contrast waste since the efficiency of these new syringeless multidose injectors depends on patient volume. In other words, if the majority of the loaded 500 mL contrast bottle is not used within the 8-hour limit, the ICM waste may be considerable. Several previous studies have reported minimal ICM waste from these devices; however, the effect of patient volume on contrast wastage by syringeless multidose injectors is not well studied (7,16,17).

Hence, we aimed to evaluate the ICM waste of these new syringeless multidose injectors relative to patient volume and compare it with that of conventional single-dose injectors, considering the time restrictions for administering ICM from the container.

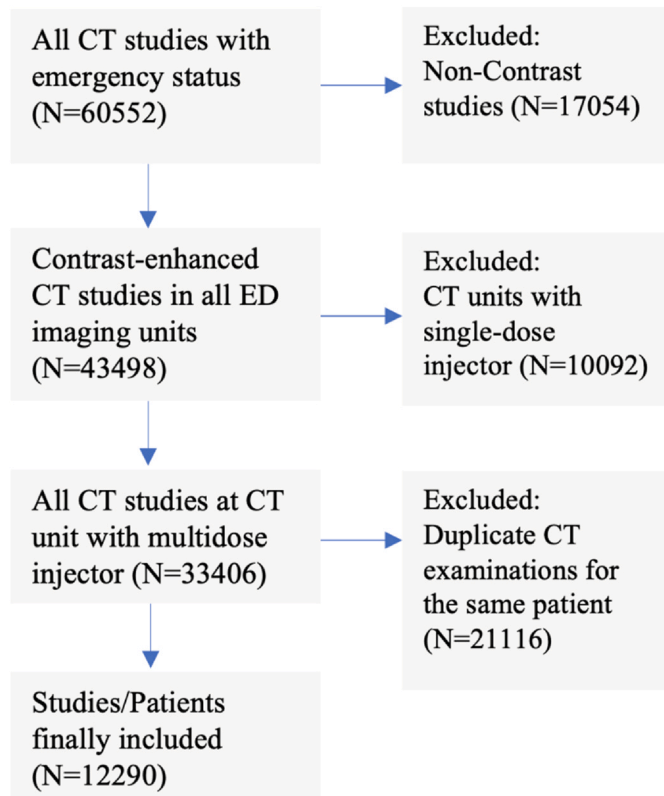

Figure 1. Study selection flowchart.

METHODS

Data Collection

This retrospective study received approval from the Institutional Review Board, and the requirement for informed written consent was waived. We used an institutional imaging reports database (Nuance mPower, Microsoft, Redmond, WA) to retrospectively retrieve all contrast-enhanced computed tomography (CT) studies performed in our emergency department between January 1, 2023, and January 1, 2024. Only contrast-enhanced CT studies conducted in the CT suite equipped with the syringeless multidose injector device (CT Motion Contrast Media Injector, GE Healthcare, WI, USA) were included in the analysis. This injector features a closed-system mechanism with one-way valves that prevent backflow of fluids into the contrast container. This design ensures that once contrast media enters the tubing, it cannot re-enter the main container, thereby eliminating contamination risk and supporting safe use in high-throughput settings. The CT scanner was a 256-slice MDCT scanner (Brilliance iCT, Philips Healthcare, Cleveland, OH, USA). 12,290 studies were finally included, and the iodinated contrast media (ICM) dose usage for each study was recorded. Out of all studies in the CT suite with multidose injector (33,406 studies), 21,116 were duplicate examinations for the same patients. In these cases, which were primarily trauma patients, contrast was administered only once, but multiple serial imaging acquisitions were performed on different body parts depending on the patient's clinical history (e.g., abdomen and pelvis, chest, head, or extremities). To ensure accurate dose calculations and avoid double-counting, we identified and removed these duplicate studies. Finally, 12,290 unique studies were included in our final analysis (Fig 1).

Calculation of Contrast Usage for Multidose Injector

The multidose injector utilizes 500 mL ICM containers (Omnipaque 350; GE Healthcare, Boston, MA) which can be used for up to 8 h once opened.

To determine contrast waste in the multidose injector system, we developed a waste calculation model in Python that accurately accounts for contrast media waste by considering both volume and time constraints (8-hour window for use) of each container.

We developed a Python-based computational model to accurately quantify the waste of iodinated contrast media (ICM) generated by the multidose injector system. This system uses 500 mL containers of ICM (Omnipaque 350; GE Healthcare, Boston, MA), which must be discarded eight hours after opening, regardless of the remaining volume. The model considers both the volume and time constraints of each container to provide a detailed analysis of contrast media utilization in our clinical practice.

The model's input data consisted of the administered ICM dose, and the exact date and time (hour and minute) of each injection, as recorded in the imaging reports. Two variables were set up initially: “container start time,” to keep track of time passed since opening a new container, and “total ICM volume,” to keep track of cumulative consumed ICM volume. The model processed each record in chronological order. At the time of the first injection, a new 500 mL ICM container was considered "opened." For each subsequent injection, the model updated the total ICM volume, and time. The model then checks whether container start time exceeds 8 hours or if the total ICM volume exceeds 500 mL. If either condition was met, the model marked the current container as finished and updated the container volume to 500 mL for subsequent injections. It then calculated ICM waste volume by subtracting total ICM volume from 500 mL.

Comparison with Single-use Contrast Bottles

An intra-patient comparison was conducted to analyze ICM waste between multidose and single-use injectors across the 12,290 included studies. ICM waste was calculated as if single-use contrast bottles were used instead of the multidose injector. At our center, single-use vials are available in 50 mL, 100 mL, and 200 mL sizes. For each study, the most appropriate vial size was selected based on the required ICM volume, with any remaining volume in the vial after each injection recorded as waste.

Contrast Waste Calculation in Different Patient Workflows

To study the effect of patient volume on ICM waste in multidose injectors, First, daily patient counts were recorded over a one-year period, resulting in a dataset with patient volumes ranging from a minimum of 20 to a maximum of 54 patients per day. As this dataset did not include days with lower patient volumes (< 20 patients per day). A Python script was used to randomly remove 50% of patients from the original dataset, creating a simulated dataset to represent a setting in which a 24-hour injector is continuously reloaded, with daily patient volumes below 20. Using the previously described ICM waste calculation model, we calculated the daily ICM waste for this new dataset. From this dataset, we extracted days with patient volumes less than 20 and recorded their daily ICM waste. These data were then combined with the original dataset to form a comprehensive dataset encompassing a wider range of patient volumes.

The combined dataset was stratified into six subgroups based on daily patient volumes: Group 1 comprised days with fewer than 10 patients per day; Group 2 included days with 10–19 patients per day; Group 3 consisted of days with 20–29 patients per day; Group 4 included days with 30–39 patients per day; Group 5 consisted of days with 40–49 patients per day; and Group 6 included days with 50 or more patients per day. We then calculated the annual ICM waste and mean per patient ICM waste for all subgroups.

Statistical Analyses

Quantitative variables were reported as means and standard deviations when the data were normally distributed, and as medians with interquartile ranges when the data were skewed. Frequency counts and percentages were used to report categorical variables. Contrast savings were expressed as percentages in comparison to conventional single-dose injectors.

The Spearman correlation test was employed to assess the correlation between patient volume and ICM waste A p-value of ≤ 0.05 was considered to be statistically significant. Statistical analyses were conducted using IBM SPSS Statistics software, version 26.0 (IBM, Inc, Chicago, IL), and STATA software, version 4.2.1 (Stata Corp, LLC, College Station, TX).

RESULTS

Patient Throughput Analysis

A total of 12,290 contrast-enhanced CT studies were performed using the multidose syringeless injector over the course of one year. The mean number of patients per day was 33.6 ± 6.8 (Table 2). Annual analyses revealed that the daily patient count ranged from 20–29 on 108 days (29.6%), and 30–39 patients, on 195 days (53.4%) of the year. Higher patient throughputs were less common: 40–49 patients on 52 days (14.5%) and more than 50 patients on 10 days (2.7%) of the year (Fig 2).

Monthly analyses showed that in all 12 months of the year, the majority of days had a patient count of 20–39 per day (Fig 2. November and December experienced busier workloads, with a high frequency of days having 40–49 patients (November: 10 days, 33.3%; December: 16 days, 51.6%) and 50–59 patients (November: 4 days, 13.3%; December: 4 days, 12.9%). In contrast, January and March were less busy months, with no days exceeding 39 patients (Fig 2).

Iodinated Contrast Medium Use Per Patient

The mean ICM dose per patient was 100.7 ± 2.2. The majority of patients (8522; 69.34%) received an ICM dosage of 100 mL per patient, with contrast-enhanced CT abdomen and pelvis being the most common procedure in this group. A dose of 50–90 mL was administered to 2530 patients (20.59%), most commonly for pulmonary CT angiography. Next, 150–199 mL was administered to 1028 patients (8.36%). The least common individual ICM dose groups were 100–149 mL in 163 patients (1.33%), 200–350 mL in 37 patients (0.30%), and < 50 mL in 10 patients (0.08%) (Fig 3).

Comparison of Annual ICM Waste

In total, the annual ICM waste was 115,700 mL using single-dose 100 mL contrast bottles and 16,020 mL for the

TABLE 1. Annual and Per Day ICM Waste in Single-Dose vs Multidose Injectors Overall and Across All Patient Volume Subgroups.

Patient number groups	Patient number per day (Mean ± SD)	Mean per day ICM waste Multidose (Median, 95%CI)	Mean per day ICM waste Single-dose (Median, 95%CI)	Annual ICM waste Multidose (mL)	Annual ICM waste Single-dose (mL)	Annual ICM Waste changes (%)
Group 1 < 10	8.6 ± 0.48	356.8, [200–525]	82.72, [50–125]	3925	910	+331.3
Group 2 10–19	15.3 ± 2.5	191.2, [82.5–280]	161.2, [100–200]	49,150	41,277	+16
Group 3 20–29	28.3 ± 2.42	43.2, [0–45]	256, [175–301.5]	9087	27,668	−67.2
Group 4 30–39	33.6 ± 2.6	32.7, [0–25.5]	329, [235–400]	6680	63,833	−89.5
Group 5 40–49	43.6 ± 2.7	4.9, [0]	373.8, [305–460]	253	19,439	−98.7
Group 6 ≥ 50	51.8 ± 2.68	0, [0]	476, [385–555]	0	4760	−100
All*	33.6 ± 6.8	43.2, [0–45]	317, [225–400]	16,020	115,700	−86.1

*This row includes only the groups from original dataset (Group 3 to 6).

syringeless multidose injector. This represents an 86.1% reduction in annual ICM waste (Fig 4). The mean ICM waste per day also decreased by 86.4%, from 317 mL [225–400 mL] per day with the single-dose injector to 43.2 mL [0–45 mL] per day with the multidose injector (Table 1). These findings are based on data from our high-volume emergency department and may differ in settings with lower patient volumes.

Comparison of Annual Waste in Different Patient Throughput

The number of patients per day, ICM waste per day, and annual ICM waste were calculated across patient throughput subgroups from the original dataset. The annual waste was considerably higher for Group 1 (3925 mL), Group 2 (49,150 mL), Group 3 (9087 mL) and the Group 4 (6680 mL) with less than 40 patients per day compared to Group 5 and 6 with more than 40 patients per day. In Group 5 (40–49 patients per day), the annual waste was only 253 mL, and in Group 6 (≥ 50 patients per day), the waste was zero, indicating that all loaded contrast in the containers was used before 8 h had passed, eliminating the need to discard any remaining contrast (Table 1, Fig 5).

Contrast savings compared to the single-dose injector were significantly higher in Group 4, 5 and 6, at 89.5%, 98.7%, and 100%, respectively, but relatively lower in the group 3 (67.2%). In contrast, in group 1 annual contrast was about three times higher than single-dose injector and increased by 16% in Group 2 (Table 1).

The Spearman correlation coefficient showed a significant negative correlation between ICM waste and the number of patients per day ($r = -0.365$, $p < 0.0001$) (Fig 6).

Comparison of ICM Waste Per Patient

ICM waste per patient was considerably higher in multidose injector compared to the single-dose injector in Groups with patient volume < 20. The mean ICM waste per patient was about two and a half times higher in the days with patient volumes of < 10 patients per day and increased by 71.4% in days with 10–19 patients scanned per day. Conversely, in groups with patient volumes ≥ 20 per day, waste was reduced compared to the single-dose packaging. In Group 3 with 20–29 patients per day, the ICM waste per patient was decreased by 53.9%, and it was decreased by 88.5% in Group 4. In Groups 5 and 6 (≥ 40 patients per day) multidose injector mean ICM waste per patient was near-zero (Fig 7, Table 2).

DISCUSSION

The production of single-use medical supplies in radiology, especially iodinated contrast material (ICM) for CT imaging, significantly contributes to waste and greenhouse gas emissions (2,3). ICM, typically supplied in single-use plastic vials, results in substantial waste. Our study aimed to quantify the

TABLE 2. Comparison of ICM Waste Per Patient (mL) Across All Patient Volume Subgroups

Group name	Patient number (per day)	Per patient ICM Waste Multidose (Mean ± SD)	Per patient ICM Waste Single-dose (Mean ± SD)	ICM Waste changes (%)
Group 1	< 10	36.8 ± 4.8	9.8 ± 2.3	**+160.7**
Group 2	10–19	12.3 ± 2.8	10.2 ± 2.2	**+71.4**
Group 3	20–29	4.5 ± 2.5	9.7 ± 2.1	**–53.9**
Group 4	30–39	1.1 ± 0.6	9.6 ± 2.4	**–88.5**
Group 5	40–49	0 ± 0	8.6 ± 2.3	**–100**
Group 6	≥50	0 ± 0	9.2 ± 2.7	**–100**

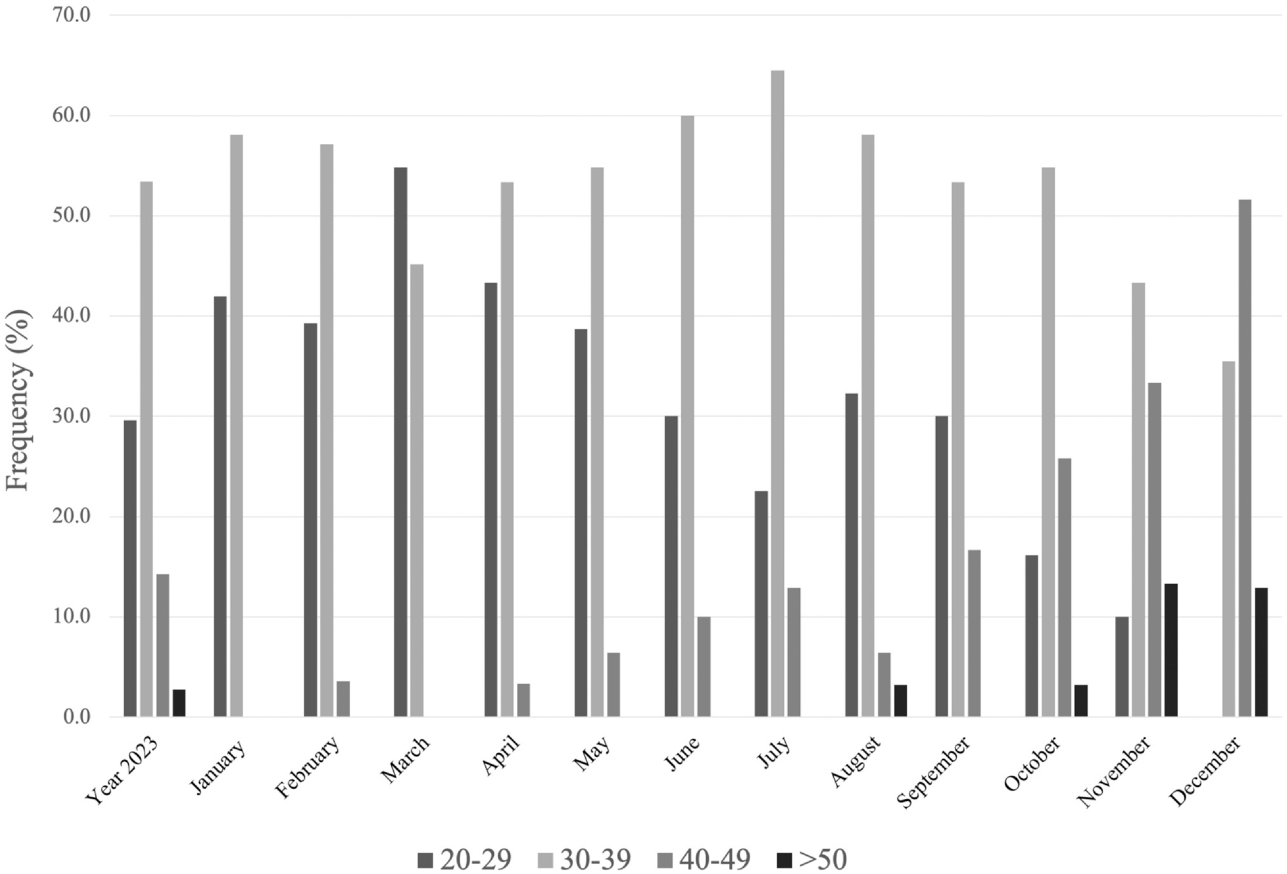

Figure 2. Monthly patient throughput (number of patients per day).

ICM waste from these syringeless multidose injectors compared to single-dose injectors and assess the impact of patient volume on waste savings.

Our study revealed a significant reduction in annual waste—86.1%—when using the multidose injector compared to single-use contrast bottles. This finding underscores the substantial ICM waste reduction achievable, even when the 8-hour limit on 500 mL contrast containers is applied.

We also examined the impact of patient throughput and found a strong correlation between waste and patient volume. Specifically, waste was nearly zero for CT suites handling over 40 patients per day, which equates to almost two patients per hour. This suggests that CT suites with high patient throughput, operating 24 h a day and scanning one to two patients per hour, would greatly benefit from adopting multidose injectors. These facilities can maximize the use of contrast media within the 8-hour limit, thereby minimizing waste and enhancing cost efficiency.

Our original data came from a tertiary academic care center with a high patient throughput in the ED CT suite. To assess the impact of lower patient volumes, we generated a new dataset by randomly excluding half of patients from the original data. This approach allowed us to explore the effects of varying patient volumes on waste reduction. We discovered that patient volumes of less than 20 per day—around one patient per hour—resulted in significant waste. This finding is particularly important for outpatient centers with lower patient volumes.

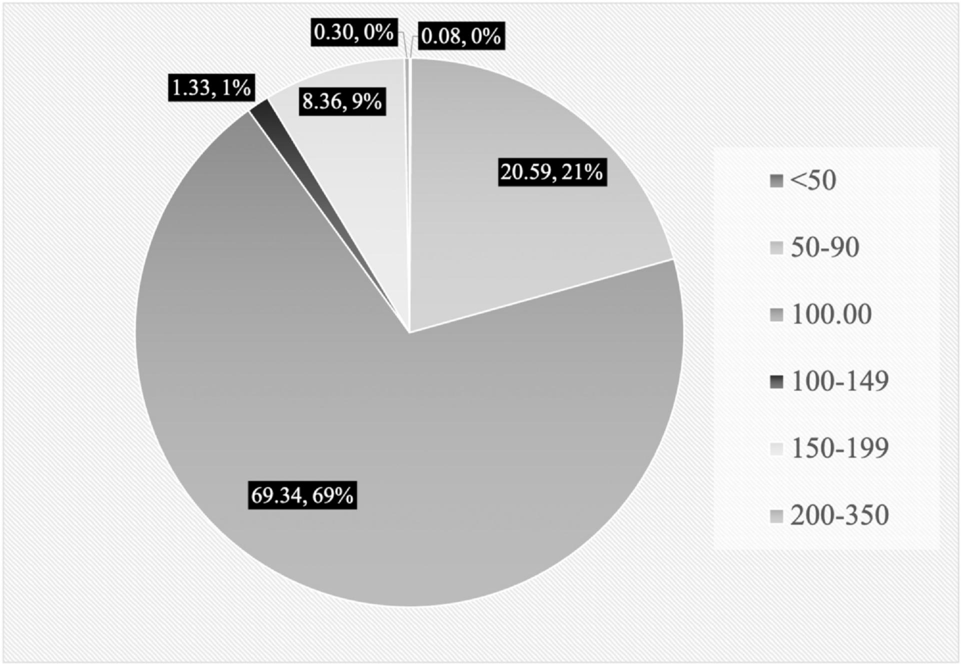

Figure 3. The most common ICM dose per patient across all patient volume subgroups with relative frequencies (%).

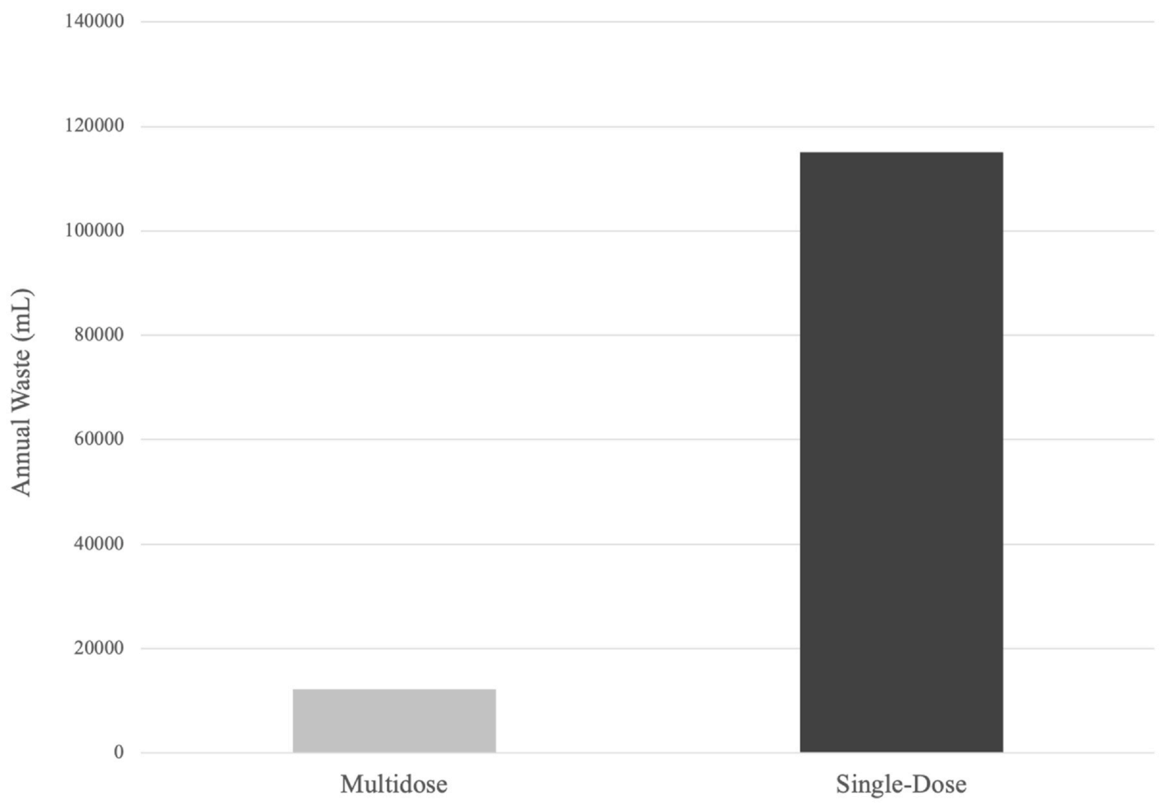

Figure 4. Annual ICM waste (mL) in multidose vs single-dose injectors.

By understanding the limitations and advantages of multidose injectors in different settings, radiology departments can make informed choices that align with their operational needs and sustainability goals.

Other studies have demonstrated the waste reduction benefits of employing multidose ICM injectors. Three studies reported near-zero ICM waste (16–18), while one study observed a 73% reduction (7) with multidose injectors.

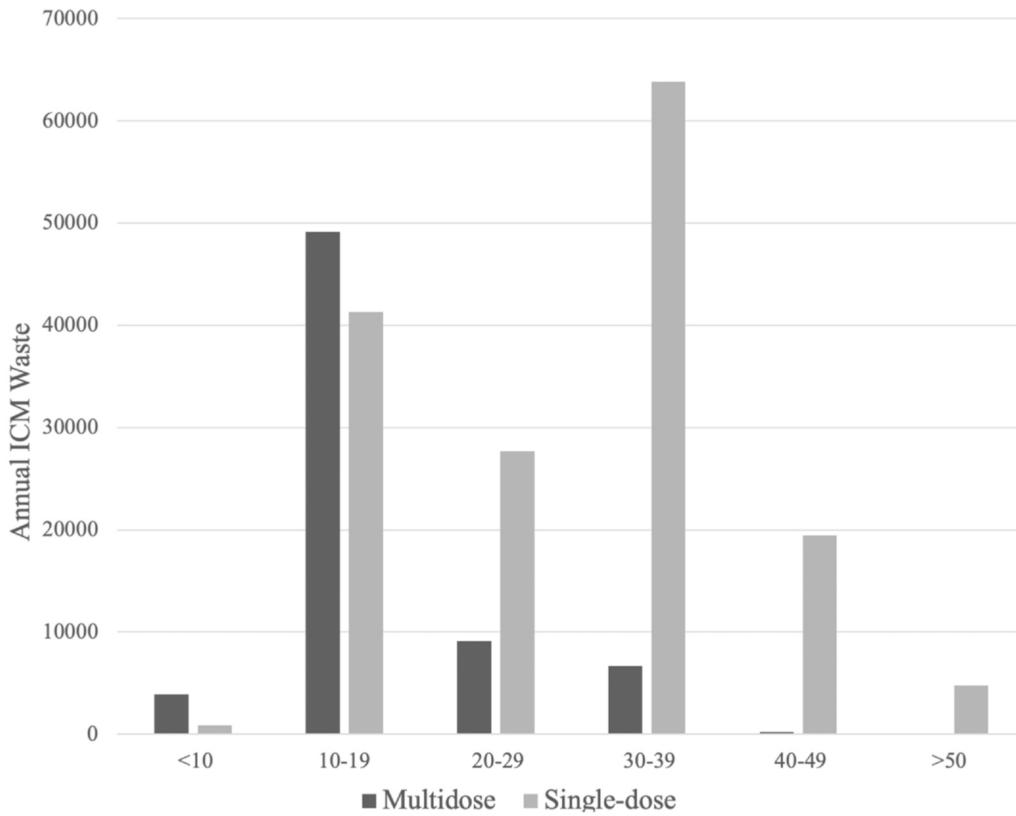

Figure 5. Annual ICM waste (mL) in multidose vs single-dose injectors across all patient volume subgroups.

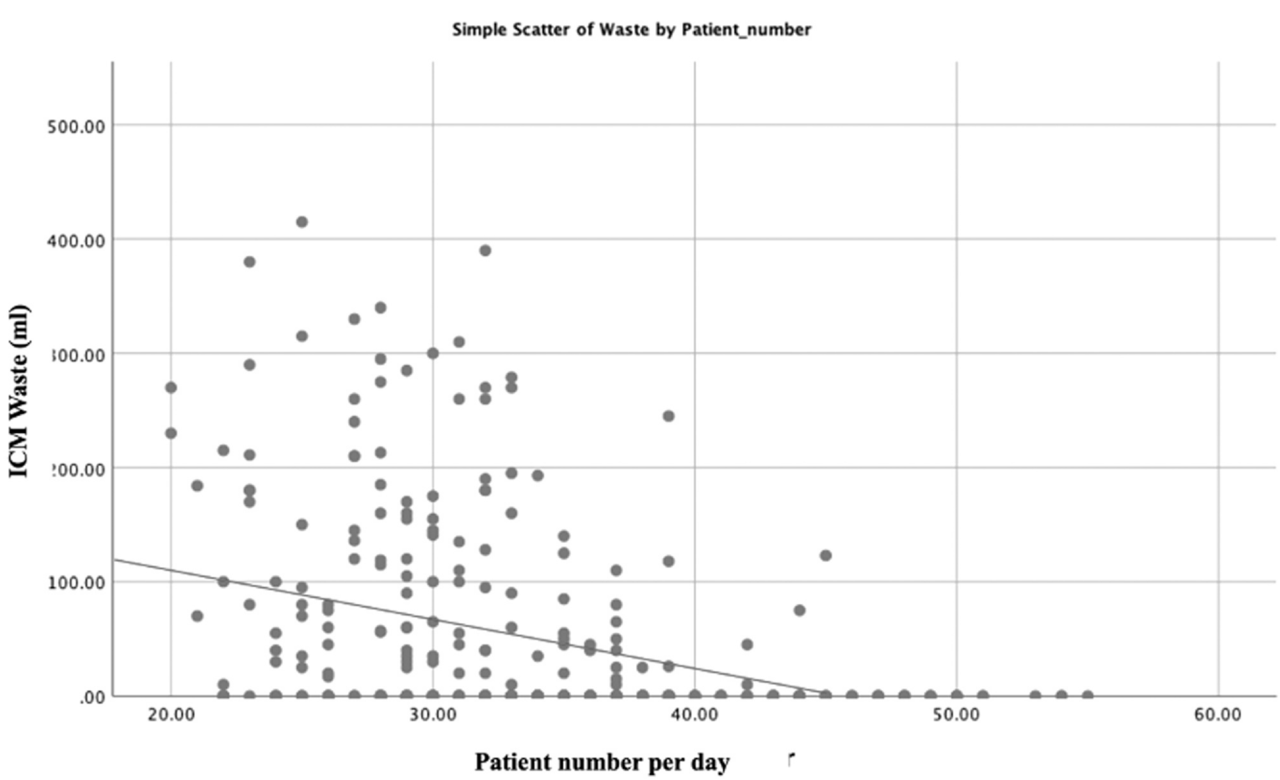

Figure 6. The scatter plot shows the correlation of ICM waste (mL) per day to the patient number per day. The plot also highlights the linear fit for the correlation. Spearman correlation coefficient was r = −0.365 with a p-value of < 0.0001.

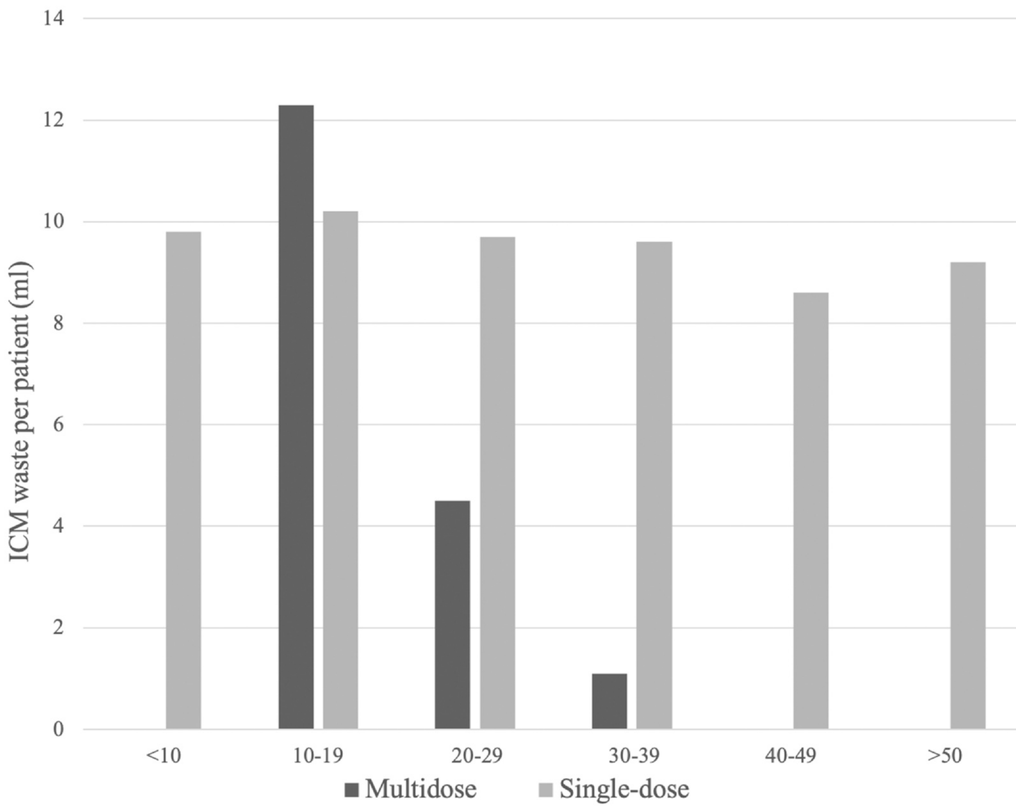

Figure 7. Comparison of mean ICM waste per patient (mL) across all patient volume subgroups.

However, none of these studies accounted for the 8-hour limit on the use of contrast containers, which could lead to significant waste in settings with low patient volumes. One study assumed that technologists would avoid spiking a large volume of multi-use contrast agent for a single patient at the end of the workday, which could reduce waste to some extent (16). However, this strategy is practical only in centers that do not operate around the clock. In 24-hour facilities, where patient flow is unpredictable, it is difficult for technologists to accurately foresee when no additional patients will arrive and stop loading a new container.

The environmental benefits of multidose injectors extend beyond reducing ICM waste. Studies have shown that multidose contrast media bottles are a more environmentally friendly option for ICM packaging. These bottles generate 42% less plastic waste per unit of ICM compared to single-dose bottles. Additionally, the multidose delivery system can precisely titrate doses using a roller pump and eliminates the need for single-use administration syringes, which constitute a significant portion of discarded plastic (7). Overall, the total weight of plastic waste is estimated to decrease by 84.6% to 92.6% (7,16).

Previous studies have shown that the adoption of multidose injectors significantly enhances the efficiency of CT image acquisition as it has a high capacity for contrast media (CM) and saline loads (1000 mL), which supports 8 to 15 contrast-enhanced CT examinations depending on the type and body part being scanned. As a result, the room equipped with the syringeless injectors can accommodate more patients, averaging an additional 2.6 patients per day (19). Additionally, operational efficiency is improved with multidose injector compared to single-dose injectors. With the multidose injector, the ICM container, pump tubing, and plastic spike only need to be set up once every 8 h. For each individual patient, the only preparation step required is replacing the patient tubing, a quick process that takes less than a minute. In contrast, the single-use syringe-based injector requires a more involved setup for each patient. For each injection, the appropriate contrast bottle must be selected, plastic syringes must be inserted, and contrast and saline loaded manually. This setup process for the single-use injector takes a couple of minutes per patient. A study found that CT technologists spend an average of 40.5 s less per exam with multidose injectors compared to single-dose injectors, and they subjectively rate the multidose injectors higher in work efficiency, user-friendliness, and overall satisfaction. Equipment preparation and release times per examination are also reduced (16–18). This efficiency is accompanied with considerable cost savings (11–17). The adoption of multidose injectors at an institutional level can yield impressive annual savings, estimated to be between \$31,800 and \$494,000 (7,19). Patient costs per examination are reduced by up to \$12.84 to \$14.66 (11). Additionally, the syringeless power injector (PI) system saves about €6.18 per patient, attributed to the lower cost of devices and enhanced performance (17).

Several strategies can be used to maximize ICM savings with multidose injectors. Adaptive weight-based dosing minimizes excess contrast by ensuring that the administered ICM volume is precisely aligned with each patient's body weight. Additionally, analyzing departmental patient volume data can identify predictable low-volume intervals, such as post-midnight hours. Forecasting these periods enables technologists to make informed contrast-loading decisions, thereby reducing waste. During these low-volume periods, rather than loading a full 500 mL container, a smaller volume (e.g., half of the container) can be loaded to minimize ICM waste during these intervals.

Our study had limitations. In this study, we analyzed ICM volume and scan timing data from a continuously operating, 24-hour emergency department setting, where patients are seen on an as-needed basis rather than by appointment. This unscheduled workflow results in varying levels of ICM waste depending on daily patient volume, with minimal waste observed when patient volume exceeds 40 per day. Our findings suggest that the more frequently a multidose injector is used, the greater the ICM savings compared to single-dose injectors. Thus, multidose injectors may also be suitable for outpatient settings with lower daily patient volumes, provided that contrast-enhanced CTs are scheduled consecutively within the ICM container 8-hour usage window. Future multicenter studies, including both outpatient and inpatient settings in elective and emergency contexts, are recommended to validate these findings and enhance the generalizability of our results.

The mean per patient ICM dose is also an important consideration for the generalizability of our findings. In our study we concluded that daily patient volume > 50 would result in zero ICM waste. On these high-volume days, patient volume is more than 50 patients over 24 h, or at least 2 patients per hour, with a mean per patient injected ICM dose of approximately 100 mL. This results in a total injected volume of at least 200 mL of ICM per hour (2 patients/hour × 100 mL/patient). Each 500 mL container is therefore fully consumed in approximately less than 2.5 h (500 mL ÷ 200 mL/hour ≈ 2.5 h), well within the 8-hour usage window, ensuring no residual contrast is wasted.

We recognize, however, that variability in the mean ICM dose may affect generalizability of our findings as these calculations are based on the fact that the dataset used in our study has a mean per patient ICM volume≈ 100. If the mean dose were lower, such as 50 mL, total injected volume would decrease to 100 mL per hour, with each 500 mL container used in about 5 h, still within the 8-hour window, resulting in zero waste. Likewise, if the mean dose was higher, hypothetically at 200 mL per patient, total injected volume would increase to 400 mL per hour, with each container used in 1.25 h. Thus, even with variation in mean per patient ICM dose, zero waste is achievable with daily patient volumes higher than 50. This shows that in high-volume settings, where contrast is injected at a rate that allows each container to be fully used within the allowed 8-hour time window, multidose injectors can effectively eliminate ICM waste. Future studies are needed to validate these findings.

CONCLUSION

Our study demonstrates that multidose injectors in CT suite reduce annual waste by 86.1% compared to single-use contrast bottles, even with the 8-hour usage window for using a 500 mL container. High patient throughput centers managing over 40 patients per day can nearly eliminate waste, maximizing contrast media efficiency and cost-effectiveness. However, facilities with low patient volumes may experience significant waste due to limited utilization within the 8-hour timeframe. Thus, while multidose injectors offer substantial benefits for high-volume centers, careful planning may be needed to ensure their effective use in lower-volume settings, optimizing sustainability and cost savings.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Sumner C, Ikuta I, Garg T, et al. Approaches to greening radiology. Acad Radiol 2023; 30(3):528–535.
2. Brown M, Schoen JH, Gross J, et al. Climate change and radiology: impetus for change and a toolkit for action. Radiology 2023; 307(4):e230229.
3. Sherman JD, Thiel C, MacNeill A, et al. The green print: advancement of environmental sustainability in healthcare. Resour Conserv Recycl 2020; 161:104882.
4. Pola A, Corbella D, Righini A, et al. Computed tomography use in a large Italian region: trend analysis 2004-2014 of emergency and outpatient CT examinations in children and adults. Eur Radiol 2018; 28:2308–2318.
5. Smith-Bindman R, Miglioretti DL, Johnson E, et al. Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010. JAMA 2012; 307(22):2400–2409.
6. GE Healthcare. Recycling Iodine: how hospitals are keeping contrast media in the circular economy. Available at: ⟨https://www⟩. gehealthcare.com/article/recycling-iodinehow-hospitals-are-keeping-contrast-mediain-the-circular-economy. Published 2022. Accessed May 6, 2022.
7. Lindsey JS, Frederick-Dyer K, Carr JJ, et al. Modeling the environmental and financial impact of multi-dose vs. single-dose iodinated contrast media packaging and delivery systems. Acad Radiol 2023; 30(6):1017–1023.
8. Smith-Bindman R, Kwan ML, Marlow EC, et al. Trends in use of medical imaging in US health care systems and in Ontario, Canada, 2000-2016. JAMA 2019; 322(9):843–856.
9. Dekker HM, Stroomberg GJ, Prokop M. Tackling the increasing contamination of the water supply by iodinated contrast media. Insights Imaging 2022; 13(1):30.
10. Woolen SA, Kim CJ, Hernandez AM, et al. Radiology environmental impact: what is known and how can we improve? Acad Radiol 2023; 30(4):625–630.
11. Chaya A, Jost G, Endrikat J. Piston-based vs peristaltic pump-based CT injector systems. Radiol Technol 2019; 90(4):344–352.
12. Wei Y, He Z, Zhang C, et al. Cost-minimization analysis of multidose and single-dose packaging of contrast media for contrast-enhanced CT:

results from real-world data in China. Am J Roentgenol 2020; 215(1):5–14.
13. Robinson JD, Mitsumori LM, Linnau KF. Evaluating contrast agent waste and costs of weight-based CT contrast bolus protocols using single-or multiple-dose packaging. Am J Roentgenol 2013; 200(6):W617–W620.
14. Buerke B, Mellmann A, Stehling C, et al. Microbiologic contamination of automatic injectors at MDCT: experimental and clinical investigations. Am J Roentgenol 2008; 191(6):W283–W287.
15. Grissinger M. Inappropriate use of pharmacy bulk packages of IV contrast media increases the risk of infections. Pharm Ther 2015; 40(5):306.
16. Toia GV, Rose SD, Brown Z, et al. Consumable material waste and workflow efficiency comparison between multi-use syringeless and single-use syringe-based injectors in computed tomography. Acad Radiol 2023; 30(10):2340–2349.
17. Colombo GL, Andreis IAB, Di Matteo S, et al. Syringeless power injector versus dual-syringe power injector: economic evaluation of user performance, the impact on contrast enhanced computed tomography (CECT) workflow exams, and hospital costs. Med Devices Evid Res 2013; 6:169–174.
18. Ma X, Singh A, Fay J, et al. Comparison of dual-syringe and syringeless power injectors in outpatient MDCT practice: impact on the operator's performance, CT workflow, and operation cost. J Am Coll Radiol 2012; 9(8):578–582.
19. Routhier J, Piazzo K, Sodickson A. Contrast and cost savings by implementation of a multidose bulk IV contrast delivery system. J Am Coll Radiol 2011; 8(4):265–270.