Discharge of iodine-containing contrast media into the environment – problem analysis and implementation of measures to reduce discharge by means of separation toilets – experience from a pilot project

Herausforderung Eintrag jodhaltiger Röntgenkontrastmitteln in die Umwelt – Problemanalyse sowie Umsetzung erster Maßnahmen zur Reduktion des Eintrags mittels Trenntoiletten – Erfahrungen aus einem Pilotprojekt

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Key words

economics, CT, contrast agents, equipment, health policy and practice, occupational/environmental hazards

received 06.05.2023
accepted 19.08.2023
published online 04.10.2023

Bibliography

Fortschr Röntgenstr 2023; 195: 1122–1127
DOI 10.1055/a-2168-8346
ISSN 1438-9029

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

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Supplementary material is available under https://doi.org/10.1055/a-2168-8346

ABSTRACT

Purpose Environmental aspects and sustainability are becoming increasingly important. In addition to energy consumption, the consumption and environmental discharge of contrast agents pose a particular challenge. Because of their desired stability, X-ray contrast agents (XCAs) are deposited in surface water at a rate of up to 400 tons per year.

Materials and Methods In a pilot project, a set of measures (installation of specific separation toilets, the establishment of feedback systems, interviews, questionnaires, and observation) was implemented to sensitize patients and staff to the problem of XCAs during outpatient CT examinations and a retention and recovery system for XCAs was evaluated.

Results In the initial baseline phase, a separation toilet with an additional collection system and a feedback/button system was installed. The built-in feedback system indicated that the separation toilets were used by approx. 16 % of patients without measures. In two subsequent intervention phases, accompanying measures significantly ($p < 0.01$) increased the use of these separation toilets to 21 % and 25 %, respectively. The measures to reduce the discharge of XCAs were positively assessed by both staff and patients.

Conclusion Measures to reduce the discharge of XCAs into the environment have a high acceptance among staff and patients. The subsequent installation of separation toilets is one possibility to achieve on-site retention of XCAs. However, this measure is likely to be of high value only if patients stay on site for a correspondingly long time, as is the case in cardiology, for example.

Key points:

- The input of X-ray contrast agents into the environment is relevant in light of the quantity
- Measures to reduce the discharge of X-ray contrast agents into the environment have been investigated in pilot projects
- The (subsequent) installation of separation toilets is possible and allows retention of X-ray contrast agents
- This measure is considered useful by patients and staff
- The financing of these measures needs to be clarified

Citation Format

- Beer M, Schuler J, Kraus E et al. Discharge of iodine-containing contrast media into the environment – problem analysis and implementation of measures to reduce discharge by means of separation toilets – experience from a pilot project. Fortschr Röntgenstr 2023; 195: 1122–1127

ZUSAMMENFASSUNG

Ziel Umweltaspekte und Nachhaltigkeit spielen eine zunehmend größere Rolle. Neben dem Energieverbrauch stellt der Verbrauch und der damit verbundene Umwelteintrag von Kontrastmitteln eine besondere Herausforderung dar. Röntgenkontrastmittel (RKM) reichern sich angesichts ihrer gewünschten Stabilität mit bis zu 400 Tonnen pro Jahr vor allem im Oberflächenwasser an.

Material und Methoden In einem Pilotprojekt wurde ein Maßnahmenbündel (Einbau von spezifischen Trenntoiletten, die Einrichtung von Feedback-Systemen, Interviews, Fragebögen und Beobachtungen) zur Sensibilisierung von Patient:innen und Personal bei ambulanten CT-Untersuchungen für die RKM-Problematik evaluiert sowie ein Rückhalte- und Gewinnungssystem für RKM implementiert.

Ergebnisse In einer Basisphase wurde ein Trenntoilettensystem mit einem zusätzlichen Auffangsystem eingebaut. Das eingebaute Feedback-System zeigte an, dass die Trenntoiletten ohne Maßnahmen von ca. 16 % der Patient:innen genutzt wurde. In zwei darauffolgenden Interventionsphasen konnte mit flankierenden Maßnahmen die Verwendung dieser Trenntoiletten signifikant ($p < 0.01$) auf 21 % bzw. 25 % gesteigert werden. Die Maßnahmen zur Reduktion des Eintrags von RKM wurden sowohl von Personal als auch Patienten positiv beurteilt.

Schlussfolgerung Maßnahmen zur Reduktion des Eintrags von RKM in die Umwelt haben bei Personal und PatientInnen eine hohe Akzeptanz. Der nachträgliche Einbau von Trenntoiletten ist eine Möglichkeit, ein Zurückhalten der RKMs vor Ort zu erreichen. Allerdings zeigt diese Maßnahme voraussichtlich nur bei entsprechend langer Verweildauer der PatientInnen vor Ort einen relevanten Effekt, wie dies z. B. in der Kardiologie gegeben ist.

Introduction

Sustainability is becoming increasingly important in radiology. Thus, the sustainability commission was recently established at the German Radiological Society. In March 2021, a 10-point sustainability plan in radiology was introduced [1]. In light of the current situation, the energy consumption of large systems in radiology has increasingly become a topic of interest. Numerous measures to reduce energy consumption are currently being discussed and some have already been implemented [2, 3].

In addition to energy consumption, the use of contrast agents in radiology and their discharge into the environment represent a second important pillar of the sustainability agenda. Contrast agents in MRI and CT are used to increase the sensitivity and specificity of radiological examinations. They are essential for many medical issues, particularly in oncological, neurological, and cardiological settings [4–6].

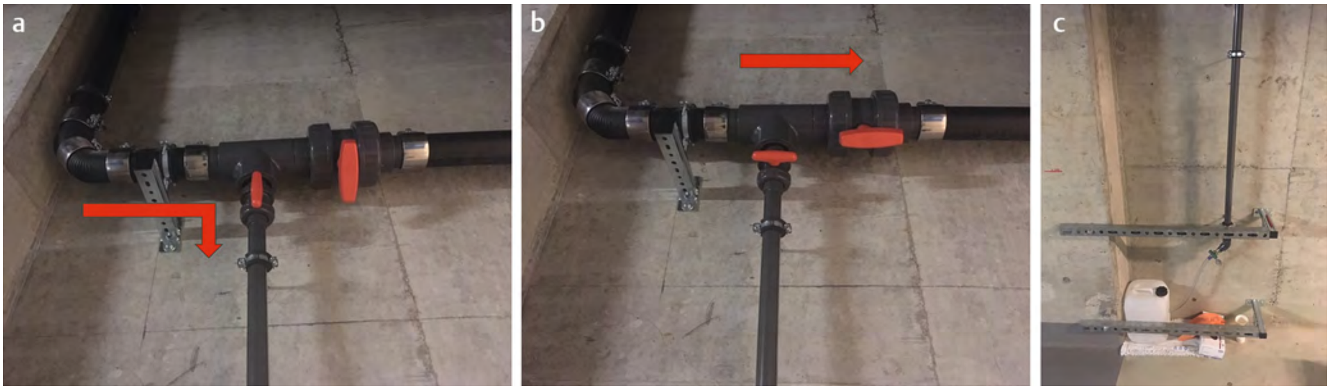
Especially iodine-based X-ray contrast agents (XCAs) are of particular importance with respect to the environment [7]. More than 400 tons of X-ray contrast agent are discharged into wastewater each year with approximately 40–50 % thereof then being released into the environment [8]. This amount is still substantial even when the total discharge of pharmaceuticals (approx. 30 000 tons per year) is taken into consideration. Almost half of the substances are harmless, e. g., electrolytes and vitamins [9, 10] The biggest contributors are the so-called "big 4": pain medication, anti-seizure medications, hormones, and antibiotics. Even in the case of the big 4, the maximum discharge per substance group is less than one hundred tons per year which is significantly less than the amount of X-ray contrast agent discharged into the environment. A further complication is that XCAs are highly stable and only slowly break down so that they accumulate in the environment for a long time.

Studies have shown increasing evidence of X-ray contrast agents in surface waters [11, 12]. Efforts to eliminate XCAs at wastewater treatment plants have only been minimally successful since even the most modern 4-step treatment plants equipped with carbon filtration can only remove a relatively small amount [13].

Damaging cytotoxic and genotoxic effects of iodine-containing XCAs have not been proven. To date, behavioral changes in animals as seen, for example, due to oxazepam residues [14] have not been able to be proven with regard to XCAs. However, in light of transformation products with potentially negative effects resulting from the accumulation of X-ray contrast agents in the environment [13], it is essential to reduce the discharge of XCAs.

Several studies with the goal of reducing the discharge of XCAs into the environment have already been conducted [15, 16]. Various pilot projects using urine collection systems or special toilets have been conducted in clinical areas [16]. A stakeholder process was also established in the last 5 years. This resulted in the establishment of the X-ray contrast agent round table at the end of 2019. This process has since been completed [17]. Consequently, different measures to reduce the discharge of XCAs into the environment are to be evaluated in lighthouse projects.

A pilot project regarding the retrofitting of separation toilets for the retention of XCAs was conducted at our hospital. This was a scientific project with the following goals: 1. Is it possible to subsequently install separation toilets at an existing major medical facility (university hospital)? 2. To what extent are these separation toilets accepted by the affected patients in the outpatient setting? 3. To what extent can acceptance of this measure be increased and usage of the toilets be maximized? 4. How effective is the use of such separation toilets in an outpatient setting?



▶ **Fig. 1** **a** Discharge system “sampling”. Discharging pipe system in “sampling” mode, the arrow shows the direction of flow when the discharge of urine into the wastewater system is blocked. **b** Drainage system “wastewater”. Discharging pipe system in “discharge to wastewater system” mode, the arrow shows the flow direction when the urine is discharged into the wastewater system. **c** Pipe system at the sampling point. The points are set in the “sample collection” mode. In the lower part of the figure, the collection canister with discharging tube is shown.

Methods

Participants, study design, and measures

All data were prospectively collected in a period of 6 months (with the approval of the local ethic committee). The patients that participated in the interviews as well as the participating medical personnel provided their consent. A separation toilet and a collection system with a drainage system to allow analysis of the urine were installed. The number of patients using the separation toilet without instruction was recorded. The toilet was located close to the CT examination site. This phase was followed by an intervention phase. Measures to increase awareness of the environmental effects of X-ray contrast agent (in the form of a flyer) and accompanying measures (urine bags, drinking water, signs clearly marking the way to the separation toilet system) were introduced. Data was collected by means of buttons as the feedback system (a device with 3 buttons: a negative, neutral, and positive smiley face) installed in the room with the separation toilet and based on observation by personnel and the analysis of urine samples. The number of outpatient CT patients (receiving contrast agent) and the amount of contrast agent used daily in CT examinations were used for comparison.

Subsequent installation of separation toilets

Toilets that do not require water for rinsing are needed for efficient collection. Toilets already installed near the CT examination rooms were retrofitted with a urinal system (Urimat ceramic; Urimat; Hundsanger, Germany). A urinal costs between 1000 and 1500 euros depending on the manufacturer. Since a corresponding urinal for women was lacking at the time of the study, normal toilets in the ladies' room were designated for study participation. In this way, women were able to participate in the study and give their opinion without any significant disadvantage for them. The only difference was that the urine could not be collected.

For the study, a diverter valve with outlet into the drain pipe of the urinal was able to be installed in the basement under the sanitary facilities so that samples could be collected in a canister as needed. The urine was transferred to test tubes for analysis (▶ **Fig. 1a–c**).

Permanent installation of such a system would result in additional costs due to the installation of separate pipes and a collection system. These costs are dependent on the basic conditions. Operating costs are largely the result of the need for the collected urine to be picked up and properly disposed of or recycled.

Acceptance by patients and personnel in the outpatient setting

Acceptance and participation on the part of patients was evaluated in three different ways: First using the button-based feedback system, second by means of questionnaires and interviews, and third with covert observation. Acceptance on the part of personnel was evaluated by interviews. Buttons were installed in the rooms with the designated XCA toilets to be able to directly measure the number of times patients used the toilet. All feedback from the system (positive, neutral, or negative) was counted as use of the toilet. A 2-second system lock after each feedback submission was used to prevent one patient from being counted twice. The feedback was transferred digitally directly to the evaluation software. Evaluation was performed purely quantitatively. Feedback was processed separately for the men's room and the ladies' room. At six randomly selected time points lasting 1.5 hours each in the intervention phase in the period from 4/10/2019 to 6/4/2019, covert observation was performed by a research assistant who was not introduced to patients in order to reduce the risk of social pressure influencing patient behavior. For all outpatient CT patients who were present during this time and received contrast agent, it was recorded whether they read the information material, drank water as recommended during the waiting period, and used the XCA toilet as instructed. This information was used to calculate among other things which percentage of those using the toilet actually used the button-based feedback system. As a result, the reported number of uses of the toilet could be adjusted accordingly by a correction factor.

Evaluation via questionnaires, interviews, and observation

During the intervention phase, questionnaires were distributed to the participating patients. The questionnaires included a separate section for free text. This text was evaluated qualitatively in the present study to identify possible motivations of the patients (see **Appendix**).

In addition to the questionnaires, 20 individual interviews with randomly selected patients and medical personnel were conducted in the two phases. During the baseline phase, ten patients and three employees were interviewed. In the intervention phase, another four outpatient CT patients and three employees participating in the process were interviewed. The interview included questions about the time point and type of examination, any use of the toilet, and the route to the XCA toilet. Personnel were questioned in order to estimate the percentage of patients who used the XCA toilet.

Effectiveness of separation toilets in the outpatient setting

The goal of urinalysis was to determine how much iodine can be separated in a defined (4-week) collection period and thus can potentially be recycled. The samples were collected with the help of the described pipe system in a 10-liter canister. 10 µl of urine needed to be diluted with 10 ml of distilled water (Ampuwa rinsing solution Plastipur, Fresenius Kabi, Bad Homburg, Germany) to obtain meaningful results with the analysis method that was used. In total, usable samples on 5 analysis days over a period of two weeks were collected and analyzed. Iodine was identified using inductively coupled plasma mass spectrometry (ICP-MS) in the MVZ Laboratory of Dr. Limbach in Heidelberg.

Statistics

All personal data was stored anonymously. All analyses were performed using Excel 2019 (Microsoft, Redmond/WA, USA) or SPSS Version 28 (IBM, Armonk/NY, USA). The evaluations were limited to descriptive analyses and t-tests for testing significance. In all cases, a significance level of 5 % (significant) or 1 % (highly significant) was used.

Results

Subsequent installation of separation toilets

Since the market for waterless separation toilets is relatively small, it did not take long to select a suitable separation system. The selection was made in collaboration with the administration of the medical facility. The toilet and the collection system in the basement beneath the toilet system were installed within several days.

Results of the covert observation

In total, 35 outpatient CT patients were observed. 69 % (25) of them read the flyer, 53 % (19) drank water during the waiting period, and 42 % (15) used the designated XCA toilet. 7 of the 15 people who used the separation toilet provided feedback via the button system. This results in a correction coefficient of 46.7 % for feedback via the button system.

Acceptance by patients and personnel in the outpatient setting

Buttons, questionnaires, interviews

In the baseline phase between 9 and 23 uses of the feedback system were evaluated per week. On average, 15.6 % of included patients used the separation toilets and evaluated the toilets by means of the feedback system. Adjusting by the error quotient of toilet users who did not push any button yields a value of 33.4 % (e. g., 358 of 1072 patients). In the intervention phase, the number of uses of the feedback system fluctuated between 6 and 26 per week. This corresponds to a percentage of 21.7 % and 46.5 % with error correction (585 of 1258 patients). This increase of approximately 13 percentage points is already statistically significant (χ^2 (1,$N = 2330$) = 41.3, $p < 0.01$). In addition, not all patients in the intervention phase could be supplied with informational materials. The rate was approximately 72 %. If only patients who received the informational material in the intervention phase are taken into consideration, a corrected use rate of 65 % can be assumed (585 of 901). This corresponds to a highly significant (χ^2 (1,$N = 1973$) = 195.1, $p < 0.01$) increase in use of approx. 31 percentage points.

Evaluation via questionnaires and interviews

The patient interviews showed that in the baseline phase six of ten patients did not need to use the toilet in the 30-minute waiting period until the IV needle was removed. This corresponded to the observations of personnel during the baseline phase in which approximately half of the patients used the designated XCA toilets. During the intervention phase, four of four surveyed patients stated that they used the toilet. A desire for water dispensers in the waiting area was expressed. The questionnaires yielded an XCA toilet use rate during the intervention phase of 76 %. The relatively low rate of XCA toilet users during the baseline phase illustrates the need for providing information and drinks and motivating patients to drink so that they use the bathroom for the first time after imaging while they are still on site.

On the whole, the intervention phase was evaluated positively by personnel. There was good agreement between the interviews and the observations regarding the number of patients who read the flyer. Patients were largely aware of the purpose of the use of contrast agents in imaging but were unaware of the environmental effects of X-ray contrast agents.

Effectiveness of separation toilets in the outpatient setting

Based on the amount of contrast agent that was used and the urine samples that were collected, the amount of potentially recoverable iodine was able to be calculated. Due to a concentration that was too high, only 5 samples (after the introduction of 1:1000 dilution and with the availability of data processing data) were able to be quantitatively evaluated. A significant variation in the measured iodine concentrations ranging from 780 µg/L to 10 055 µg/L was seen.

Evaluation of the free text from the patient interviews showed that the majority of patients wanted greater availability of water and a quiet and pleasant waiting area. On the whole, the measures that were implemented were evaluated as good and useful.

Discussion

In summary, separation toilets can be installed retroactively even in a medical care context at a maximum care hospital. The resulting costs are minimal. The measure is well accepted by patients. However, the actual use is far below the stated use based on our own internal evaluations. Therefore, acceptance of these measures requires more information regarding sustainability. The effectiveness in the outpatient setting is easy to asses. In light of the kinetics of contrast excretion, this was expected. Thus, this measure is certainly more effective in the case of a longer length of stay after an examination, e. g. in cardiology after cardiac catheterization. It should be considered whether such measures should be installed decentrally outside of radiology within medical facilities.

History of the creation of round tables

As described at the beginning, the first round table was established at the end of 2019. The X-ray contrast agent round table was one of many. The others addressed, for example, diclofenac and benzotriazole. All relevant stakeholders from manufacturers and users to water management and hospital federations were included. Different aspects were discussed. These ranged from the need for and scope of XCA administration to disposal and the raising of awareness among users. The German Radiological Society and the Professional Association of German Radiologists held numerous informational events including at the German Radiology Congress. However, the financing of this process still needs to be clarified. With respect to feasibility, 2 measures were essentially taken into consideration: The use of urine bags that are handed out to patients immediately after an examination was investigated [8]. Based on excretion dynamics, the peak of XCA excretion is approximately 4–8 hours after administration. Therefore, patients should be provided with 2–3 urine bags. These are then disposed of in regular household garbage. However, in light of the sheer number of urine bags involved in this measure (based on 365 tons of X-ray contrast agent per year), the high environmental burden in terms of additional waste must be taken into consideration. Moreover, measures regarding financing of the costs incurred by the additional workload for personnel and the additional garbage for the individual health care facilities are lacking. Policymakers as well as health insurers and XCA manufacturers are primary contacts here.

Separation toilets as an alternative on-site measure without subsequent ecological problems

The installation or retrofitting of separation toilets is an alternative to the use of urine bags, which results in additional new problems as described. The goal is to collect contrast agents and their components directly on site, thus making it possible to reuse them after corresponding processing in terms of recycling management. Analogously to the established use of separation toilets in nuclear medicine, the idea to use separation toilets to collect XCAs was developed. However, in nuclear medicine, these considerations were based on a very different problem, namely how to deal with radioactive substances. Separation toilets are dry toilets equipped with a small filling. Immediate implementation in the workflow as close to existing patient areas as possible is challenging. Moreover, tanks and corresponding drainage systems need to be installed. However, in our experience, this can be achieved easily and quickly.

The retention value of 5 % determined in our study corresponds to expectations since the time of collection was limited to a window of approximately 30 minutes after contrast administration due to the local conditions. Regarding the excretion amount, Asberg et al. [18] examined iohexol clearance compared to the glomerular filtration rate (GFR). They saw a half-life time of 2 to maximum 2.5 hours. By applying the expected half-life of 2 hours to the relevant time periods in our study of 15 minutes and 30 minutes, excretion of 6.25 % and 12.5 %, respectively, can be extrapolated. However, in the subpopulations of this study with data at the early excretion time points (n = 42/176 at 10 minutes and n = 35/176 at 30 minutes; no data at 15 minutes), significantly greater excretion was seen at the earlier time points (▶ **Fig. 1**). However, neither this publication nor other studies (Larusso et al. [19]) on the topic of individual values (see page 2 of the **supplementary material**) include information about the early stages of excretion. Further research is needed for final evaluation of this important aspect.

Another important aspect is the dependence of the excretion rate of iomeprol on the GFR as studied by Larusso et al. [19]. A significantly reduced excretion rate was seen with decreasing renal function. In patients with healthy kidneys, 50 % was excreted after two hours. Patients with severe renal dysfunction required longer for elimination. Approximately 50 % remained in the urine 16 to 84 hours after injection. This is a relevant factor.

Therefore, it would be much more effective to install or retrofit separation toilets in locations in which patients spend a longer period of time after X-ray examinations.

This will vary and should be designed based on patient flow. In the case of cardiology, a toilet can be installed directly in the cardiology department because patients remain in this area for up to 4 hours, e. g. after cardiac catheterization. In contrast, for radiological examinations, decentralized collection sites and service systems can be used since outpatient patients can spend several hours in various oncological departments, for example after a staging CT scan in the radiology department. The optimal installation site will vary from facility to facility.

Moreover, such separation toilets installed in the various departments could also capture other medications excreted by patients.

Potential to recycle and reuse excreted contrast agent

Pilot studies regarding the recycling and reuse of excreted contrast agent are currently being conducted. Niederste-Hollenberg et al. published an overview [16] of current activities (page 33/126 ibidem). Multiple contrast agent manufacturers have started initiatives in the last 4 years for the return of unused contrast agent. The goal is also recycling with subsequent use in the medical field (manufacturer 1) and a non-medical field (manufacturer 2). The authors assume that an amount of recycled XCA equaling half a patient dose in CT can be achieved per institution/health care facility (requires a 100 % recycling rate). In reality, the rate is lower. Exact data is expected in the coming years.

Additional workload, expenditure, and refinancing

The additional work time, particularly for medical personnel, determined in our study corresponds to the workloads measured in earlier studies [15]. The measured times of 5–7 minutes initially don't seem particularly relevant. However, multiplied by the number of patients and the number of not only medical but also administrative personnel involved, significant costs and a need for additional personnel must be assumed. An added expenditure of 1.5 million euros per year was calculated for Berlin [15]. This is a significant additional expenditure. It is unclear who would be responsible for these additional costs. The planned lighthouse studies in the second process of the XCA round table will certainly contribute to this.

Clinical relevance

Sustainability is becoming increasingly important in radiology. Radiology is a leader in pilot projects regarding the analysis of the discharge of XCAs into the environment and the development of measures for reducing this discharge. The retrofitting or installation of separation toilets for XCA retention at the site of their use seems to be a possible and very attractive measure. The benefit depends on the site and time of collection and will vary between the disciplines using XCAs outside of radiology.

Funding

Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg

Conflict of Interest

The authors declare that they have no conflict of interest.

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