Thoughts on sustainability in the use of iodinated contrast media in CT: a practice-oriented review based on the example of a hospital and a private practice

Gedanken zur Nachhaltigkeit beim Umgang mit iodhaltigen Kontrastmitteln in der CT: eine Praxis-orientierte Übersicht am Beispiel von Klinik und Niederlassung

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ABSTRACT

Background Iodinated contrast media (CM) have become indispensable in computed tomography (CT), angiography, and cardiac cathlab as well as in other X-ray-based procedures, for example in urology. In this context, iodinated CM are released into the environment in particular via patient excretions along with other trace substances. At the same time, the use of iodinated CM also involves CM leftovers as well as packaging and consumables.

Method In order to reduce the discharge of iodinated CM into the environment and to promote efficient use of resources, awareness of the sustainable and responsible use of iodinated CM and associated consumables is essential. A number of effective measures can contribute to this in the short, medium, and long term. Based on the literature and quantitative data from our own routine, aspects of sustainability when dealing with CM in computed tomography are discussed in this review using the example of a hospital and a private practice.

Conclusion When planning and performing contrast-enhanced CT examinations, personalized CM protocols can make CM use more efficient. Some CM manufacturers offer recycling programs for CM leftovers. The collection of CM excretions after CM injections using urine bags might have a major impact on reducing the discharge of iodinated CM into the environment. In addition, responsible use of consumables and packaging material, in particular the use of multi-patient systems, can make a valuable contribution to waste avoidance and resource conservation. All of these measures can ultimately be fully effective in terms of protecting the environment and resources if they can be implemented on a broad basis. For this purpose, an even greater focus on the topic of sustainability among all parties involved is desirable.

Key Points
- Sustainable and responsible use of iodinated contrast media is desirable.
- Various measures can be taken today to reduce the environmental impact and conserve resources.
- CM use can be made more efficient by optimizing contrast-enhanced CT examinations.
- Recycling programs for CM leftovers enable their further use.
- Urine bags might have a major impact on reducing the environmental impact.

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ZUSAMMENFASSUNG

Hintergrund Iodhaltige Kontrastmittel (KM) sind aus der Computertomografie (CT), der Angiografie und dem Herzkatheter sowie weiteren Röntgen-basierten Verfahren z. B. in der Urologie nicht mehr wegzudenken. In diesem Kontext werden iodhaltige KM insbesondere über Patientenausscheidungen neben anderen Spurenstoffen in die Umwelt eingetragen. Gleichzeitig fallen beim Gebrauch iodhaltiger KM auch KM-Reste sowie Verpackungen und Verbrauchsmaterialien an.

Methode Um die Einbringung von iodhaltigen KM in die Umwelt zu reduzieren und einen effizienten Umgang mit den Ressourcen zu fördern, ist daher ein Bewusstsein für den nachhaltigen und verantwortungsvollen Umgang mit iodhaltigen KM und zugehörigen Materialien unerlässlich. Dabei kann durch eine Reihe wirkungsvoller Maßnahmen ein Beitrag geleistet werden. Anhand der Literatur und einer quantitativen Erhebung aus der eigenen Routine werden in dieser Übersichtsarbeit Aspekte der Nachhaltigkeit beim Umgang mit iodhaltigen KM in der CT am Beispiel von Klinik und Niederlassung diskutiert.

Schlussfolgerung Bei der Planung und Durchführung kontrastverstärkter CT-Untersuchungen kann durch personalisierte KM-Protokolle die KM-Nutzung effizienter gestaltet werden. Für die Weiterverwendung von KM-Resten bietet ein Teil der KM-Hersteller Rücknahmeprogramme an. Das Auffangen von KM-Ausscheidungen nach KM-Injektionen mittels Urinbeuteln könnte einen großen Einfluss auf die Reduktion des Umwelteintrags haben. Und nicht zuletzt kann durch einen verantwortungsvollen Umgang mit Verbrauchs- und Verpackungsmaterial, insbesondere die Nutzung von Multi-Patienten-Systemen, ein wertvoller Beitrag zur Abfallvermeidung und Ressourcenschonung geleistet werden. Alle diese Maßnahmen können ihre Wirksamkeit im Hinblick auf die Schonung von Umwelt und Ressourcen letztlich dann voll entfalten, wenn deren Umsetzung in der Breite realisiert werden kann. Hierfür ist ein noch größeres Augenmerk auf das Thema Nachhaltigkeit unter allen beteiligten Akteuren erstrebenswert.

Kernaussagen
- Ein nachhaltiger und verantwortungsvoller Umgang mit iodhaltigen KM ist erstrebenswert.
- Durch heute umsetzbare Maßnahmen können der Umwelteintrag reduziert und Ressourcen geschont werden.
- Die KM-Nutzung kann durch Optimierung kontrastverstärkter CT-Untersuchungen effizienter gestaltet werden.
- Rücknahmeprogramme für KM-Reste ermöglichen deren Weiterverwendung.
- Urinbeutel könnten einen großen Einfluss auf die Reduktion des Umwelteintrags haben.

Introduction

Contrast media (CM) have become indispensable in medicine. Iodinated CM are used in particular for computed tomography (CT), angiography, and cardiac cathlab, as well as in other X-ray-based procedures, e. g., in urology. The use of iodinated CM is steadily increasing globally due to the growing need for contrast-enhanced procedures. Consequently, iodinated CM as well as other trace substances that can be found in waters [1]. The use of iodinated CM also involves packaging and consumables.

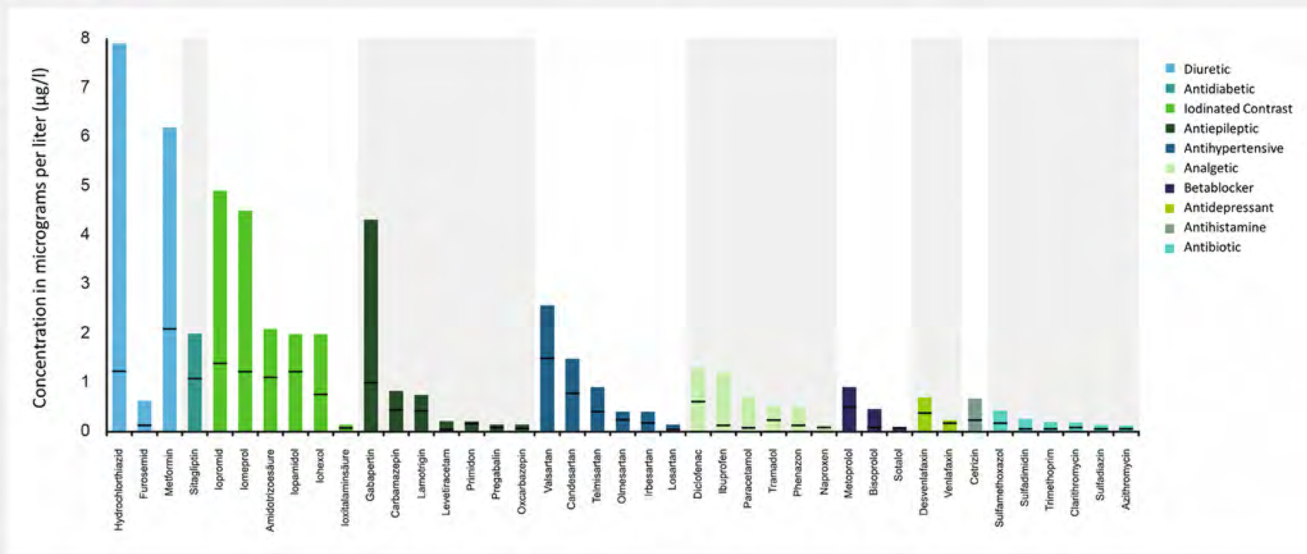
In order to reduce the impact of iodinated CM on the environment and to promote efficient use of resources, sustainable and responsible use of iodinated CM and associated materials is essential. The areas that could help achieve this goal include:
- Planning and performing of contrast-enhanced CT examinations
- Disposal and reuse of contrast leftovers
- Collection and handling of contrast excretions
- Handling of consumables and packaging

Our review article discusses these aspects practically with regards to CT, using examples from both a hospital and a private practice.

Overview of environmental aspects and the strategy for trace substances in Germany

The global supply of iodine comes primarily from three regions: the nitrate mines in Chile, oil and gas fields in Japan, and iodine-rich brine wells in the USA [2]. There were 6,300,000 tons of this resource globally in 2019. Global production exceeded 30,000 tons [2]. Iodine and its compounds are used most frequently in iodinated CM, pharmaceuticals, liquid crystal displays (LCDs), and iodophors, listed in decreasing order of usage [2]. In Germany, the purchased amount of iodinated CM (approximately 600–630 tons) corresponding to approximately 295–310 tons of iodine in the years 2017–2019 is relatively constant [3].

Iodinated contrast media are among the trace substances that can be detected in water at low concentrations. In addition to



▶ **Fig. 1** Active pharmaceutical ingredients found in surface waters in concentrations above 0.1 µg/l in 2019 (data from [43]). Columns represent the maximum concentration measured, and lines illustrate the highest annual mean value of all measuring points.

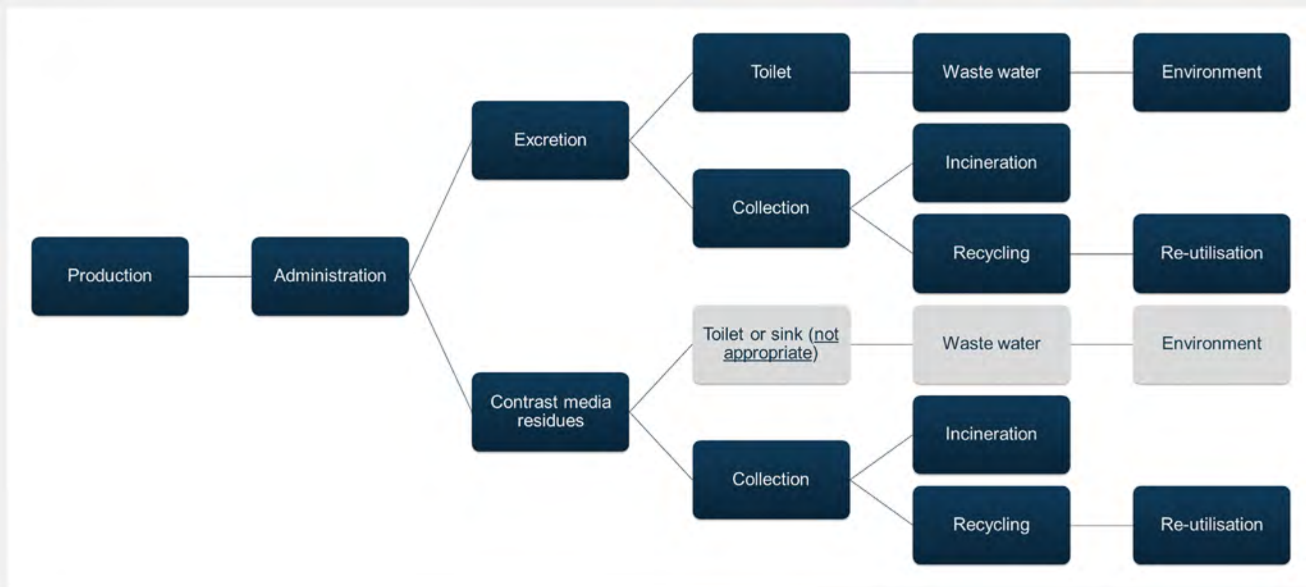
other pharmaceutical residues, these trace substances include body care products, industrial chemicals, and household chemicals. The concentration of iodinated CM as well as diuretics, antidiabetic drugs, antiepileptic medications, and antihypertensive medications in surface waters is greater than that of other pharmaceutical residues (▶ **Fig. 1**).

After intravascular administration, iodinated CM are excreted in patients with normal renal function via glomerular filtration and the urinary tract. Within approximately 2 hours, 50 % of the contrast medium has already been excreted [4–7]. CM are excreted almost unchanged in the urine and can then enter the environment and waters. Data from the year 2020 show between 10.3 and 175 kg/day for individual CM in the Rhine near Lobith (border between Germany and the Netherlands) [8]. Approximately 70 tons of iodinated CM crossed from Germany to the Netherlands via the Rhine in the year 2020 [8, 9].

In contrast to therapeutic pharmaceuticals, iodinated CM are biologically inactive substances. Therefore, their ecotoxicity is considered low [10]. Under certain conditions, conversion processes can occur in the environment, during wastewater treatment, or during drinking water treatment, resulting in byproducts that could pose a risk to the environment and potentially to drinking water [9].

In light of this, a dialog was initiated in Germany in 2016 by the Federal Ministry for the Environment and the German Federal Environmental Agency to develop a national strategy for trace substances. This process was led by the Fraunhofer Institute for System and Innovation Research (ISI) and moderated by IKU GmbH. The goal was to identify and develop recommendations for measures at various points in the life cycle of selected substance groups. Associations and parties involved in production, application, wastewater treatment, and disposal were included in the discussions (▶ **Fig. 2**) [11]. As part of this process, the *Round Table on X-Ray Contrast Media* was initiated and the following prevention and reduction measures were identified, discussed, evaluated, and published in 2021 [10]:

- Replacing contrast-enhanced examinations with examinations without iodinated CM only seems possible on a very limited basis. An attempt is being made at events and by other means to raise awareness among medical personnel regarding environmental aspects, particularly proper disposal of CM leftovers.
- From an environmental standpoint, there is no preferred iodinated contrast medium.
- For the implementation of urine collection systems to reduce the amount of iodinated contrast media in waters, a concept study for the "expansion of pilot studies with collection systems in hospitals/private practices" corresponding to the results of the dialog on trace substances was commissioned [10].
- At wastewater treatment plants, CM concentrations can be reduced with the help of activated charcoal or ozone. However, the effectiveness of these methods is limited and comprehensive implementation of these special procedures at wastewater treatment plants is not planned. Therefore, such a measure can be considered as a local but not a comprehensive method of reducing iodinated CM in waters.
- During production and processing, the discharge of wastewater is reduced to a minimum using a combination of various methods.
- In principle, recovery of the iodine could contribute both to resource security as well as to a reduction of the environmental impact. Recovery would be technically possible with urine separation and urine bags. Recovery from communal waters is not considered economical due to the high material and energy expenditure.



▶ **Fig. 2** Life cycle of iodine in contrast agents, simplified scheme, see text for explanation.

Planning and performing of contrast-enhanced CT examinations

Based on well-founded estimates, approximately 300 million CT examinations are performed globally each year [12] including 40 % contrast-enhanced CT examinations with an average of approximately 100 ml iodinated CM per examination.

More careful handling during use, particularly during the planning and performing of contrast-enhanced CT examinations, could help to reduce the consumption of iodinated CM and thus also limit the introduction of iodine into subsequent systems (▶ **Fig. 2**). Of course, this should not affect the diagnostic quality of images. Possible measures are discussed in the following.

Personalized contrast protocols

The new guidelines of the German Medical Association regarding quality assurance in CT from the year 2022 recommend an adaptation to body weight for many contrast protocols [13]. For example, the guidelines specify a weight-adapted iodine dose of 0.3–0.6 iodine/kg body weight for contrast-enhanced abdominal CT or a weight-adapted iodine dose of 0.2–0.4 iodine/kg body weight for CT angiography of the aorta (▶ **Table 1**). Moreover, the guidelines recommend taking the tube voltage in particular into consideration for CT angiography.

By personalizing contrast protocols according to body weight and tube voltage not only consistent image quality can be achieved but also the amount of CM can be reduced by up to 56 % for various examinations like coronary CT angiography, CT angiography of the aorta, and abdominal CT [14–22]. In relation to adaptation based on tube voltage in monoenergetic CT examinations, an established parameter is that compared to a reference of 120 kVp the CM dose can be lowered by 10 % with every 10 kVp reduction of the tube voltage while maintaining the image contrast [23]. Therefore, when using a tube voltage of 70 kVp (if possible given the scanner and patient habitus), a CM dose reduction of approximately 50 % can be achieved simply by taking the tube voltage into consideration. The introduction of the dual-energy scanner in 2005 and the photon counting scanner in 2022 made possible virtual monoenergetic reconstructions, which also have the potential for CM dose reductions [23].

With these measures, not only the environmental impact of iodine excreted in urine can be reduced but costs can also be lowered. For the practical implementation of such personalized contrast protocols, there are already software solutions from various manufacturers allowing automatic calculation of patient-specific contrast protocol parameters [24, 25]. Moreover, various manufacturers offer a clinical application service that can serve as a competent on-site contact for optimization efforts [26, 27].

Saline bolus

A saline bolus, i. e., the injection of a saline solution immediately after CM injection, is a standard part of every CM protocol [13]. The primary purpose of the saline bolus is to push the CM out of the injection tube and the arm veins into the central veins. As a result, depending on the viscosity of the CM, all or most of the CM bolus can enter the target region of the CT examination and thus contribute to contrast enhancement. At the same time, the saline bolus results in a more compact CM bolus resulting in a faster increase in contrast enhancement in the target region and greater contrast enhancement due to the correspondingly lower dilution effect of the blood. The saline bolus thus represents an important aspect of the efficient use of contrast media.

Both CM and saline injections in CT examinations are typically performed with the help of automatic power injectors [28]. 30–50 ml of a saline solution are typically administered with the same injection rate as the previous CM injection [13].

▶ **Table 1** Two examples of personalised examination technique according to the guidelines of the German Medical Association for quality assurance in computed tomography [13].

	CTA of the aorta	Abdominal CT
Target enhancement	Blood pool ≥ 250 HU In TAVI ≥ 150 HU is sufficient	Not defined
Contrast medium timing	Bolus track or test bolus	Bolus track in multi-phase protocols
Position and size of the ROI for tracking the contrast bolus	Ascending aorta ROI ≥ 1 cm^2, approx. half of the inner diameter of the vessel	Descending aorta ROI ≥ 1 cm^2, approx. half of the inner diameter of the vessel
Delay/threshold value	120–180 HU, scan delay approx. 5 s	Standard abdomen: 70–85 s Multi-phase protocols: ≥ 100 HU, scan delay approx. 10 s
Adapted for weight	0.2–0.4 g iodine/kg body weight ≤ 45 g iodine total amount	0.3–0.6 g iodine/kg body weight ≤ 45 g iodine total amount
Consideration of the tube voltage	Recommended	Optional
Iodine delivery rate*	1.1–1.9 g iodine/s	1.1–1.9 g iodine/s
Example of contrast medium with 300 mg iodine/ml	Approx. 50–100 ml with 3.7–6.3 ml/s	Approx. 50–100 ml with 3.7–6.3 ml/s
Saline flush	Approx. 30–50 ml with identical flow rate	Approx. 30–50 ml with identical flow rate

* The iodine delivery rate is defined as the product of the iodine concentration of the contrast medium and the injection rate.

Disposal and reuse of contrast leftovers

The proper disposal, collection, and reuse of CM leftovers in CT can have a significant effect even though the quantities of CM leftovers in the interventional fields of various disciplines like vascular medicine, cardiology, and radiology are typically greater than in CT and the amount of CM in urinary excretion after contrast injection is significantly greater than the amount of CM leftovers in CT [13]

Service programs like that of Bayer AG and GE HealthCare for the recycling of CM leftovers and recovery of iodine allow reuse of the iodine and thus an extension of the iodine life cycle [29, 30]. For the collection of CM leftovers, a container is provided to the user at no cost, which is then collected and processed at production sites of Bayer AG in Germany and GE HealthCare in Norway. Such programs make it possible not only to reduce the impact of iodine on the environment and waters but also to protect iodine as a raw material.

Direct reuse of CM leftovers on-site is possible, for example, by using them for ex vivo or experimental animal studies. At the University Medical Center Rostock, some CM leftovers from radiology are given, for example, to central facilities for small animal imaging and the keeping of laboratory animals. There are detailed disposal regulations and recommendations for the disposal of CM leftovers, particularly statement 18 of the Regional Working Group on Waste (LAGA) entitled “Guidelines for the disposal of waste from health care facilities” [31]: “*Pharmaceuticals including unused X-ray contrast media are to be collected separately. It is possible to dispose of this waste together with waste as defined by Waste Code 18 01 04 [comment: waste with no special requirements regarding collection and disposal with respect to infection prevention] or with mixed municipal waste. Improper access by third parties and any associated risk must be ruled out and subsequent thermal treatment must be ensured.*” [see Waste Code 18 01 09 from [31]]. Thermal treatment (incineration) destroys the chemical composition of contrast media and breaks them down into molecular iodine (I_2) and iodine salts, which are already naturally present in the environment [32]. Therefore, disposal of CM leftovers via a drain or toilet into the wastewater is not appropriate.

Collection and handling of contrast excretions

After intravascular injection, iodinated CM are quickly excreted primarily via the urinary tract in patients with normal renal function. Within approximately 2 hours, about 50 % has already been eliminated [4–7]. Therefore, the first urinary excretions after CM injection are of particular interest with respect to collection in order to reduce the excretion of CM into wastewater and thus the environmental impact. Urinary excretions can be collected either with urine collection containers or by using separate toilets with their own plumbing. Outpatient patients can be provided with suitable urine collection containers, e. g., in the form of urine bags with an absorbent material that holds the urine.

This concept has been examined in pilot studies in Germany and the Netherlands including several thousand patients. Patients were each given four urine bags and were asked to voluntarily use these bags for the first four urinary excretions after a contrast-enhanced CT examination [9, 33]. The large majority of patients stated that they used the urine bags. This resulted in a 45 % reduction of the CM concentration in wastewater [9, 33].

While a recovery of iodine from communal wastewater would be technically possible but would not be economical due to the high material and energy costs, the use of urine collection containers or urine separation to recover iodine could be technically possible and potentially economical depending on the price of iodine [13]. Iodine recovery could also contribute both to resource security and a reduction of the environmental impact. Proper disposal of used urine collection containers in hospital waste or private waste analogous to the disposal of CM leftovers (see above) with subsequent incineration is possible.

Broad ideally national implementation of urine collection systems depends not only on the practical implementation but also on the costs or financing. Multiple studies have examined the costs for the use of urine collection containers in this context. The costs for materials, personnel, and/or disposal were analyzed or estimated depending on the study. Material costs varied between 1.90 and 6.69 euros per patient [34–37]. The additional time requirement for personnel was estimated to be approximately 16 minutes per patient in the inpatient setting and approximately 6 minutes in the outpatient setting [34, 37]. The disposal costs were 0.15 to 0.39 euros per patient in the inpatient setting and 0.05 euros in the outpatient setting [34, 37, 38]. The Berlin study 2004–2006 conducted a complete cost estimate for future use in the inpatient setting and calculated costs in the amount of 10.03 euros per patient corresponding to approximately 380 euros per kg iodine [34]. A projection based on this for all hospitals in Berlin yielded annual costs of over 1.3 million euros [34]. A linear projection of this cost estimate from the year 2006 for the entire population of Germany would result in costs of over 30 million euros per year for inpatient use alone. The manner in which such sums could be recuperated is still completely open [3].

Another comprehensive approach to pharmaceutical leftovers in hospital wastewater could be dedicated on-site medical waste treatment. An example of this is the Pharmafilter concept with the goal of treating both solid waste and liquid waste in special fermentation systems in the vicinity of the hospital. Such systems produce biogas while removing a broad spectrum of pharmaceuticals including antibiotics from hospital wastewater. A pilot study in the Netherlands showed complete removal of iodinated CM from hospital wastewater using these filter systems [39].

Handling of consumables and packaging

Amount of consumables and disposal

Consumables and packaging include protective covers, tubes, peripheral intravenous catheters, syringes for saline, disposable gloves, kidney basins, disinfectants for skin and surfaces, swabs, adhesive bandages, and the corresponding packaging. With respect to carbon emissions, the entire cycle of consumables from production and supply chains to consumption and disposal must be considered in addition to the emissions from the production, supply chains, power consumption, and disposal of the equipment [40, 41]. In light of this, there are possibilities for optimization at various points in this cycle.

Multi-patient systems

When using disposable systems, every use of CM can result in leftovers that need to be disposed of. At the same time, disposable syringes must be disposed every time CM is administered.

Multi-patient systems prevent the back flow of contrast medium, saline, and blood and thus prevent cross-contamination between patients. They are permitted for use in multiple patients over a defined time period. By using multi-patient systems, not only CM leftovers but also the amount of consumables can be reduced. Multi-patient systems allow flexible and situation-dependent use of containers ranging in size from 50 to 500 ml. 500-ml containers can typically be used at the start of the day and the size can then be adapted to the expected need over the course of the day [42]. The maximum permissible use periods for multi-patient systems and contrast bottles must be taken into consideration. This time varies between 10 and 24 hours and is limited to avoid the risk of inter-individual contamination.

Reflection of the own routine in the hospital and private practice

Finally, the sustainability aspects mentioned above regarding the use of iodinated CM in CT are discussed based on quantitative data collected in our own routine in our hospital University Medical Center Rostock and our private practice DIE RADIOLOGIE Munich. Data was collected over a 24-hour period on one weekday for 2 systems in the hospital and over 15 consecutive weekdays for 1 unit in the private practice. The percentage of contrast-enhanced CT examinations (approximately 40 %) and the average CM volume used (approximately 100 ml) according to the global estimations listed above [12] accurately reflected the values seen in our own routine.

Planning and performing of contrast-enhanced CT examinations

In the clinical routine of our hospital and practice, contrast protocols were not adapted to body weight with the exception of obese patients up to 2022. Based on the new guidelines from the German Medical Association on quality assurance in CT from the year 2022, the specifications regarding the personalization of contrast protocols began being gradually implemented in the routine at our hospital and practice in 2023.

Disposal and reuse of contrast leftovers

In the clinical routine of our hospital and practice, average amounts of 12 ml and 9.3 ml, respectively, were left over per 70–150 ml of CM injected for each contrast-enhanced CT examination. The ratio of CM leftovers to CM amount in urinary excretions was thus approximately 1:10. At the time this manuscript was written in June 2023, all CM leftovers – with the exception of a portion for reuse in ex vivo and experimental animal studies at the University Medical Center Rostock – were disposed of in the contrast bottle in the hospital waste or residual waste. Participation in a service program for the recycling of CM leftovers for the recovery of iodine will now be reviewed in both facilities.

Handling of consumables and packaging

In the clinical routine of our hospital and practice, an average of 120 liters of waste was created for every 12–18 patients. For example, on average, 44 peripheral intravenous catheters, 59 swabs, 60 adhesive bandages, 74 disposable gloves, 24 kidney basins, 37 saline syringes, and the corresponding packaging were used per 100 patients. In the hospital, all consumables and packaging except for large boxes were disposed of in the same trash bag. The introduction of waste separation for packaging materials would be desirable in this context. In the practice, boxes and packaging materials were already separated from the rest of the waste.

Conclusion

Sustainability is becoming increasingly important in health care. Both hospitals and private practices are attempting to reduce their ecological footprint, to act in a more sustainable manner, and to reduce costs.

In CT, iodinated CM and consumables as well as the power consumption of the equipment contribute to carbon emissions. Sustainable and responsible use of iodinated CM is also desirable from the standpoint of the environmental impact of CM and the protection of resources. A series of effective measures can help here in the short, medium, and long term.

When planning and performing contrast-enhanced CT examinations, personalized CM protocols and the use of a saline bolus for all CM protocols can make CM use more efficient. CM manufacturers offer recycling programs for the reuse of CM leftovers. The collection of CM excretions after CM injection by means of urine bags or separate toilets could help to significantly reduce the environmental impact in the future. Finally, responsible handling of consumables and packaging, particularly by using multi-patient systems, could help to reduce waste and protect resources.

Conflict of Interest

Fabian Rengier is an employee of Bayer Vital GmbH and holds stocks of Bayer AG. The other authors declare that they have no conflict of interest.

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