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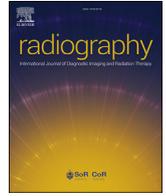
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Review article

More sustainable use of iodinated contrast media – Why?

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ABSTRACT

Objectives: Based on a narrative review of the literature to 1) assess the need for and 2) report methods to help deliver a sustainable approach to iodinated contrast media (ICM) administration.

Key findings: Acute ICM shortages have been noted in the literature. As demand for contrast-enhanced imaging continues to increase and access to raw materials becomes more limited, such events may increase. Evidence from the literature has documented a range of iodinated contrast reduction strategies. These include individualised contrast-media dosing, multi-dose bulk ICM vials, switching to alternative modalities or the increased use of non-contrast examinations. The optimisation of imaging parameters, the use of saline chasers, and alternative contrast agents should be further considered. Given the rising concerns regarding the presence and effects of ICMs in waste and drinking water, further consideration of strategies for managing waste and excreted ICMs are starting to emerge.

Conclusions: Sustainable ICM practices are needed to help avoid supply shortages and to help protect our environment. Such practices must be led and supported locally, nationally, and internationally. Sustainable ICM practices must be reflected within professional Standards of Proficiencies and be adopted by all members of the multidisciplinary team.

Implications for practice: Changes to working practices surrounding the sustainable use of ICMs will likely become commonplace. New methods to ensure optimised ICM dosage with minimal wastage will be more heavily featured in departmental practices. Correct disposal of waste and excreted ICMs will also form part of future changes to practice.

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Introduction

Iodinated contrast media (ICM) are commonly administered within radiology to more clearly differentiate anatomical structures and to detect and characterise pathologies.¹ Due to the rapid growth of medical imaging over the past few decades,² there has been a substantial increase in the demand for ICMs.³ This has largely been driven by greater availability of diagnostic imaging, for example more computed tomography (CT) scanners, and a greater number of medical treatments requiring radiology-based information.⁴ Contrast-enhanced CT examinations have been reported by many authors as the largest volume users of ICMs. Data from the Canadian Medical Imaging Inventory (CMII)⁵ reported that more than 5.4 million CT scans were conducted in 2019, an increase of

over 30% from the previous decade. Reports suggest that >40% of CT scans required ICMs.^{6,7}

Unsurprisingly, according to the U.S Geological Survey (Mineral Commodity Summaries)⁸ in 2020, the leading use of iodine was in the production of X-ray ICMs. Primary producers of iodine were Chile and Japan with 18 000 and 8000 metric tonnes being produced annually, respectively. Global iodine reserves of 6.3 million tonnes have been estimated and current consumption rates are in the region of 0.5% per annum. GE Healthcare recently highlighted that based on current trends the clinical demand for ICMs will eventually outstrip supply.⁹ Such trends are largely due to rising in chronic diseases with the demand for ICMs expected to double over the next decade.

Such rises in demand are a source of concern, again the importance of this has been stressed by the U.S Geological Survey⁸ in that 1) no comparable substitutes currently exist for iodine for many of its principle applications and 2) currently only small amounts of iodine are recycled. Unsurprisingly, ICM shortages have

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been reported in the literature^{10–13} (Fig. 1), the most noteworthy followed the temporary close of the GE Healthcare manufacturing facility in China. The closure resulted from local COVID-19 policies and placed further strain on the remaining manufacturing sites.¹⁴ Despite being more than four years on, concerns regarding the long-term supply of ICMs still exist⁹ and as such many ICM conservation strategies have been proposed.^{10,11,15}

From a sustainability perspective, supply issues when combined with the continuing rise in the use of ICMs, generate associated challenges. The first is how to generate a reliable supply of suitable ICMs to meet current and future global demands. The second is consideration of the environmental impact of using ICMs. Wastage from single-use items,¹⁶ leftover ICMs,¹⁵ and discharge into waste and drinking water¹⁷ have also been raised as key environmental themes.

The aim of this article is to discuss the challenges of ICM sustainability, both supply and conservation, and the relevant strategies available. A further aim of this narrative review is to consider the current situation regarding ICMs but also the future changes to opinions, behaviours and practices which encourage the environmentally sustainable supply of ICMs.

Key findings

Conservation of ICMs

Literature has reported strategies for promoting the conservation of ICMs during shortages (Fig. 2).

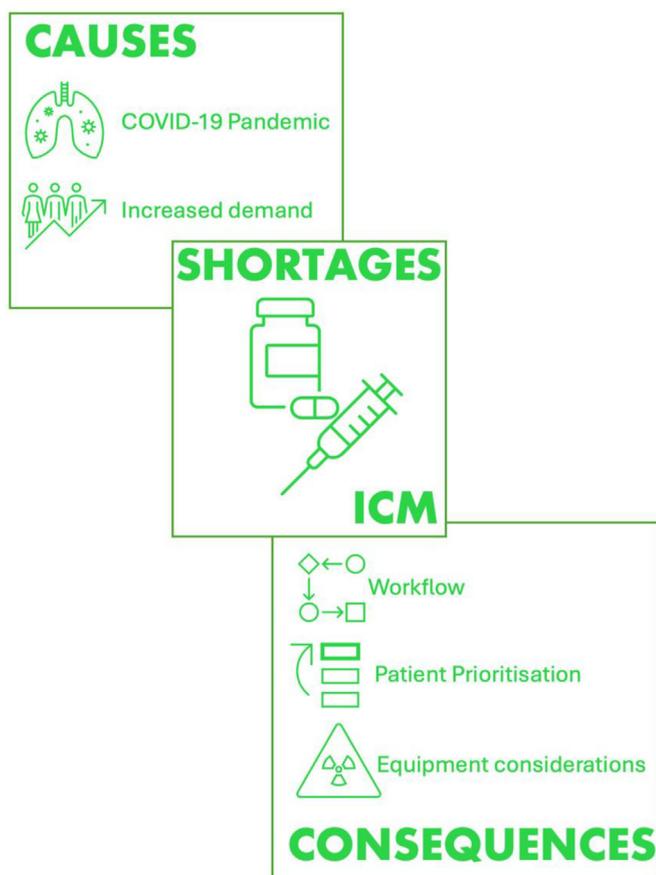


Figure 1. Infographic summarising the causes and consequences of ICM shortages.

Delayed examinations

Delaying imaging examinations is a possibility and has been identified as an option by Yu.¹⁸ Yu (2022) advocates that any delay would need to reflect the urgency and necessity of the examination. Examinations which might warrant a delay could include the follow-up of incidentalomas or annual surveillance scans without any documented change in clinical condition. In keeping with this, Amukotuwa et al.¹¹ and Cavallo et al.,¹⁰ argued, for example, that cases of suspected aortic dissection, major trauma, and initial oncological staging would need to be prioritised over the investigation of lower-risk conditions. Although this is an option for reducing ICM consumption, it should be noted that this often requires careful review of the radiology referral and discussion with the referrer, which will carry resource implications for radiology. More widely, any planned catch-up must be carefully managed when full ICM availability resumes. This can be problematic when combined with staff shortages and imaging modalities which are already at full capacity.

National guidelines

In response to previous ICM shortages, national guidelines have been developed, for example by the American College of Radiology,¹⁹ which recommend that iodinated contrast should only be administered where the study is 1) needed to change management, 2) there is no alternative imaging modality which can deliver similar levels of diagnostic accuracy or 3) where delays in contrast administration could increase the risk of mortality/morbidity for patient. Similar guidance documents have been published by the Royal Australian and New Zealand Association of Radiologists²⁰ and the Canadian Association of Radiologists,²¹ amongst others. Generally, the focus of these documents has been on radiological aspects of ICM utilization, however the UK Society & College of Radiographers, in conjunction with the UK Royal College of Radiologists, provided a joint position statement including recommendations for radiographers.

Individualised doses

Weight-based contrast dosing for CT has been advocated by some authors.^{22–24} George, Manghat and Hamilton compared fixed-dose and weight-based dosing protocols for abdominal CT.²² Within this relatively small study, both contrast-enhancement and contrast media doses were compared for patients who received the full-dose weight-based protocol and those who received a reduce-dose weight-based protocol because of renal impairment. Study findings indicated that depending on mean patient mass overall ICM doses can be reduced. Yap and colleagues compared fixed volume and weight-based ICM volumes for CT examinations of the chest, abdomen and pelvis.²³ A volume of 100 mL was used for the fixed protocol whereas the median volume for the weight-based was statistically lower, 57.5 (IQR: 50–60) mL. Concerns have been raised regarding weight-based protocols in that although beneficial to the patient, the ICM volume difference between fixed and weight-based could simply result in additional waste.²⁴ Such waste is more likely when single-use vials of 100 and 150 mL are available.

Saline chasers

Reports documenting the use of saline chaser/flush techniques to reduce ICM volumes are not new.^{25,26} Haage and colleagues,²⁵ in 2000, reported a 20% reduction in ICM doses (60 mL) when incorporating a 30 ml saline flush for chest CT scans. There are, however, contrasting reports for example, Yoon et al.²⁷ undertook a

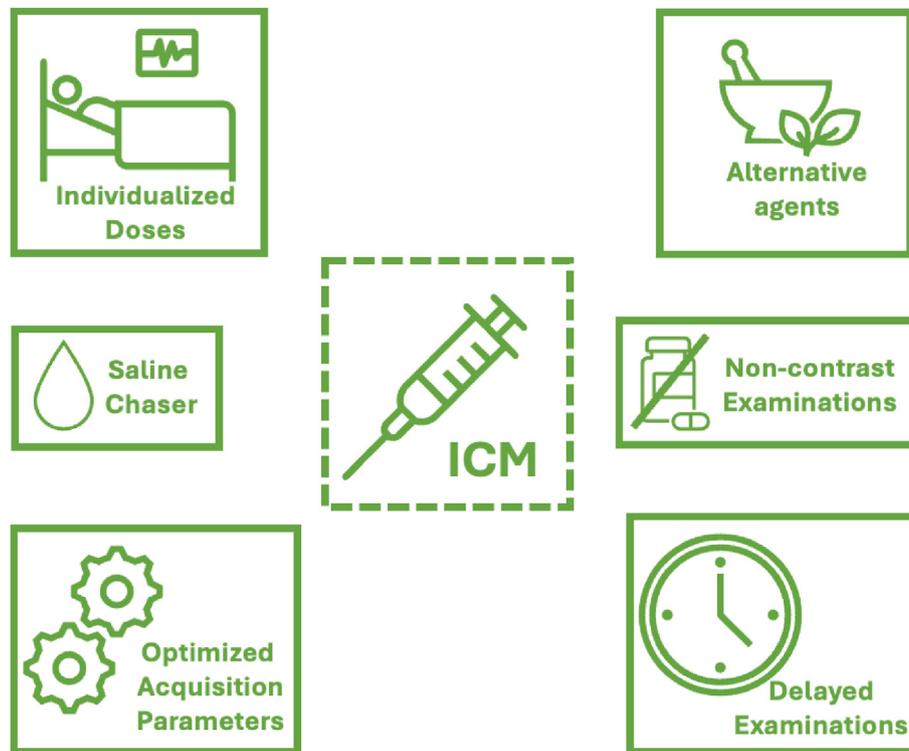


Figure 2. Schematic illustrating options for reducing ICM consumption.

randomised trial of different ICM regimens during head and neck CT. They concluded that that reduction in ICM volumes from 80 to 60 mL resulted in insufficient enhancement of the neck vessels and that the benefits of saline chasers were not obvious. Coursey and colleagues²⁶ evaluated aortic enhancement during CT angiography using a phantom. They argued that reducing the ICM volume from 125 to 75 mL, increasing the flow rate to 8 mL/s and when using a saline bolus can result in acceptable aortic enhancement profiles. Often the incorporation of saline chasers within contrast administration protocols is undertaken alongside reductions in contrast volume and changes in flow rates. Horehledova and colleagues²⁸ evaluated an ultra-low ICM protocol for assessing peripheral artery disease (PAD). PAD imaging was undertaken using 30 mL ICM bolus (5 mL/s) followed by a 40 mL saline bolus. Mean attenuation values typically exceeded 250HU from the aorta down to the anterior tibial artery. Reduced attenuation was experienced in the left and right dorsalis pedis arteries (165 and 199 HU, respectively). Subjective image quality scores were excellent above the popliteal segment and good below the knee. Bammer and Amukotuma²⁹ advocates increasing the saline chaser (60 mL) for CT perfusion studies of the brain, within their protocol they suggest that when combined with a wide-detector array CT scanner, 80 kVp tube potential that the ICM volume can be reduced to 30–40 mL. Nowadays, for modern wide detector array CT systems, the incorporate of saline chasers is likely to be standard of care.

Optimised acquisition parameters

Further ICM dose reductions steps may include biplanar imaging during angiography,³⁰ using smaller catheters,³⁰ reducing the tube potential during CT examinations³¹ and removing contrast prior to medication delivery or catheter removal.^{30,32} Mariani et al., demonstrated contrast reductions in the field of 50% when utilising intravascular ultrasound (IVUS) guided procedures.³³ Additionally,

other authors have suggested that IVUS can have application outside of the coronary arteries but uptake has been generally poor.³⁴

Within CT lower tube potential protocols have been associated with reductions in ICM volumes.^{35,36} Wang and colleagues³⁵ compared 120 and 100 kV scanning protocols for cardiovascular CT. They concluded that a 100 kV cardiothoracic CT protocol can be accompanied by a 44% reduction in ICM volume whilst maintaining satisfactory aortic blood-pool attenuation. Ippolito et al.³⁶ reported on a 100 kV CT angiography protocol combined with 30 mL ICM volume. Similarly, Cao and co-workers³⁷ reported on both contrast and radiation dose reductions when using 80 kV tube potential for coronary CT angiography. Study conclusions did note that evaluations were confined to patients with a low BMI (<23.0 kg m²). Other authors have advocated a BMI below 30 kg m² as an eligibility criterion when using reduced tube potentials in coronary CT angiography.^{38,39} A study has, however, evaluated the reduced tube potentials in patients with BMIs >30 kg m² but only with a limited sample size.⁴⁰

Several authors have advocated that the most significant contrast reductions can be achieved when using a multi-parameter approach.^{41,42} For example, Yin and colleagues reported on the REALISE trial, that evaluated the effects of reduced tube potential, lower iodine concentrations and iterative reconstruction (IR) techniques during coronary CT angiography.⁴¹ Within the trial patients were randomised either into Group 1 (120-kVp with 370mgI/mL iopromide or iopamidol) or Group 2 (100-kVp with 270mgI/mL iodixanol). Image reconstruction was performed with filtered back projection and IR. Study findings documented a 26.5% reduction in iodine dose ($p < 0.001$) for the combined 100-kVp/IR protocol but still maintained image quality. Similarly, Zhang and colleagues compared 100-kVp, IR and standard contrast doses (Group A) against a 70-kVp, lower contrast volumes and deep learning image reconstruction (Group B) in 100 patients undergoing head and neck CT angiography.⁴³ The mean contrast volume in Group A was 45.0 mL which was statistically higher than 28.8 mL in Group B ($p < 0.001$). It

should be noted that the mean BMI for both groups was 21.8 and thus the impact of such protocol modifications on larger body mass patients would need evaluation.

Dual-energy CT, where available, can lower the amount of ICM required for examinations.¹⁴ Noise-optimising reconstruction algorithms in dual-energy CT can lower the energy level to 40–50 keV.⁴⁴ Such an approach can decrease the volume of ICMs required. Other reports have indicated that further ICM usage can be optimised by tailoring flow rate and volume to specific monoenergetic levels and to the automatically selected tube potential for single-energy acquisitions.⁴⁵

Alternative agents

Reports suggest that CO₂ can be effectively used as a contrast agent for infradiaphragmatic arteriography and central venography above the diaphragm.⁴⁶ CO₂ can, however, have operational challenges including a lack of availability and also a reluctance to its use amongst clinicians.⁴⁷ CO₂ is also potentially neurotoxic and thus has limited/restricted use near or within the cerebral circulation.⁴⁸ Alternative agents have also been considered for CT. A more common alternative contrast agent proposed is the use of gadolinium, as within magnetic resonance imaging.^{49,50} Remy-Jardin and colleagues⁴⁹ described the use of gadolinium to support CT angiography in 37 patients who had contraindications to iodine. Outside of CT, Lardiere et al., described the potential for gadolinium to support image guidance during urological procedures.⁵¹

Roessler et al.⁵² evaluated hafnium and tungsten as alternative high atomic number contrast media for CT using quasi-anthropomorphic phantoms. Jost and colleagues⁵³ also suggests that there may be a role for tungsten as an alternative agent, especially with photon-counting CT technologies. Such studies regarding alternative high atomic number 'newer' agents are extremely limited and that a substantial evaluation period is likely before any such incorporation into routine clinical practice. Such studies have also not necessarily considered the availability of these elements, but having multiple options available are likely to reduce iodine demands. Data on the use of tungsten and hafnium are confined to phantom or animal-based pre-clinical studies.^{54,55} It should be noted that whilst newer agents may be of help, such elements could also be subject to the same supply challenges as iodine.

Schöckel and colleagues,⁷ in 2020, reviewed the potential developments in X-ray contrast media for CT. Within their work they suggested that new detector technologies and artificial intelligence (AI) will further improve CT image reconstruction and thus enable further reductions in ICM volumes. Jost and colleagues⁵³ support the concept of newer contrast media, they advocate that with the rollout of photon-counting CT there is a potential for newer contrast agents.

Although not technically an alternative contrast agent there is increasing interest within the scientific community on the potential for synthetic post-contrast imaging using AI.^{56,57} The idea behind such applications is that computational AI modelling could generate 'virtual contrast' images from non-contrast acquisitions or improvement enhancement when using low-post post-contrast images (augmented contrast).⁵⁶ Early work by Chandrashekar and colleagues⁵⁷ suggested that it may be possible, using non-contrast to contrast transformation tasks and significant refinements to methodologies, to potentially develop examinations without the need for ICMs. Similarly, early work by Lui et al. have proven the concept of generating virtual contrast CT images directly for non-contrast CT scans of the abdomen.⁵⁸

Alternative modalities

Greater utilisation of non-contrast CT scanning is also a valid option. In support, Yu¹⁸ stated that assessing pulmonary parenchymal, interstitial spaces, airways, pleura, and infective respiratory conditions does not necessarily require the administration of ICMs. Layer,⁵⁹ in 2019, supported this, arguing that there are more reasons to employ non-contrast enhanced scanning options than are currently used within clinical practice. Layer⁵⁹ also highlighted a dearth of literature comparing contrast-enhanced and non-contrast-enhanced radiological examinations. Such approaches could be an area for future work and could be supported by funding streams dedicated to evaluating radiology's environmental impact, particularly ICM sustainability.

In times of ICM shortage, alternative imaging modalities could be considered.⁶⁰ For example, nuclear medicine is used to investigate pulmonary embolism⁶¹ and contrast-enhanced ultrasound is used to assess hepatic lesions.⁶² Such an approach would again require adequate capacity within the alternative modalities and acceptance from those reporting the examinations. At times of ICM shortage, it is unlikely that all patients referred for a specific indication would undergo an alternative form of imaging. Such changes to practice should be managed on a patient-by-patient basis, and other relevant co-variables, such as patient condition and BMI, should be considered. If an imaging examination using ICM is warranted, then dose reduction methods should be considered.

Multi-dose systems

Historically, CT ICMs have been administered via 'single-dose' vials that preclude re-use and re-packaging.⁶³ Aligned with this, regulatory agencies, such as the Center for Disease Control and Prevention (CDC) in the United States, recommend discarding any unused ICM from a single-dose vial. Given the rise in CT examinations and greater demands on ICM consumption, using single-dose vials represents a significant source of pharmaceutical waste with both environmental and financial implications.¹⁶ Pepin et al. reported that when carefully considering vial sizes against contrast administration protocols, there could be between 50 and 59% reduction in contrast wastage.⁶⁴ Recently, switching to multi-dose bulk intravenous ICM delivery systems have received attention.^{65,66} In one US institution, such systems were estimated to reduce ICM expenditure by approximately \$30,000.⁶⁵ It should be acknowledged that limitations exist with the use of large volume vials in that manufacturers typically may recommend that the ICM is discarded after a certain amount of time has elapsed i.e. 12 h.

The availability of larger (500 mL) multiple use vials should provide further opportunities for ICM savings. Robinson, Mitsumori and Linnau, compared single or multiple-dose ICM vials for this purpose.²⁴ They reviewed data from 1341 CT examinations and evaluated three ICM models. Model 1 required 368 500 mL vials, Model 2 required 353 vials of 500 mL and Model 3 required 863 and 478 of 100/150 mL vials, respectively. In all scenarios, total ICM volume requirements were less when 500 mL vials were utilised.

Inter-professional communication

One method suggested by Eibschutz and Gholamrezaezhad¹⁴ to help manage ICM shortage is the role of inter-professional communication. Cavallo and Pahade argue that ICM stock levels should be frequently reported at an institutional level.¹⁰ Within their work on *Strategies and Recommendations to Combat Iodinated Contrast Shortage* Eibschutz and Gholamrezaezhad¹⁴ advocate the need for an institution-wide committee comprised of

radiologists, institutional leadership, and representatives that rely heavily on ICMs, for example cardiology, vascular surgery, urology and radiation oncology. Disappointingly, Eibschutz and Gholamrezanezhad¹⁴ failed to recommend the inclusion of radiographers within this committee; in most instances radiographers would be best placed to provide information on imaging trends and ICM availability. Eibschutz and Gholamrezanezhad¹⁴ did suggest that such a committee could define which studies could be paused during severe shortages and also that information on ICM availability and the importance of ICMs should be communicated to patients. Other authors have also recommended strategies for imaging deferment,^{19,67,68} agreement on such practices is likely to be difficult but Cavallo and Pahade¹⁰ suggested that follow-up examinations for incidental findings and asymptomatic staging CT scans for recurrence could be deferred.

Responsible disposal of ICM products

By nature, ICMs are designed to be inert and have high hydrophilicity, thus challenging treatment with conventional wastewater techniques.⁶⁹ Similar to other pharmaceuticals, the occurrence of ICMs within environmental waters has been documented on every continent.⁷⁰ Wastewater treatment plants (WWTPs) have not traditionally been designed to remove pharmaceuticals effectively.⁷¹ According to many authors, ICM can continuously be detected in WWTP effluent.⁴ Depending on the treatment technique, removal efficiency has been shown to vary. In 2021, Sengar and Vijayanandan summarised the efficiency of WWTP worldwide and demonstrated that removal efficiency depended on the type of ICM and treatment technique and ranged from 5% to 97%.⁷¹ ICMs themselves are not lethal, levels of iodine can be naturally present in sea and drinking water.⁷² Problems do arise when ICMs react with common disinfectants utilised in WWTP and can generate harmful by-products that have toxic and mutagenic effects on drinking water.⁷³

Service programs initiatives, for example provided by Bayer AG, Bracco⁷⁴ and GE HealthCare, facilitate the recycling of ICM residuals¹⁵ and the extraction of iodine, thereby effectively extending the iodine's life cycle. Users are furnished with complimentary receptacles to collect CM remnants, which undergo processing at production sites. These programs seek to address environmental and water pollution concerns associated with iodine while concurrently preserving it as a valuable natural resource. Limited research evidence is available on contrast media recycling programmes, despite this Gunasekaran and colleagues highlighted potential in their review of Cardiovascular Imaging, Climate Change, and Environmental Sustainability.⁷⁵

Zanardo and colleagues have proposed a study for reducing ICM residuals in hospital wastewater (GREENWATER study).⁷⁶ Within this work researchers aim to assess the effective quantities of ICMs that are retrievable from patients' urine collected following CT examinations. Study endpoints include per-patient urinary excretion and patients' acceptance. It is hypothesised that prolonging hospital stays may allow ICMs to be retrieved from patients' urine and this study is on-going.

Whilst correct ICM disposal and recycling is a key issue, there are also concerns regarding the usage and disposal of other single-use items used within ICM administration. One option to reduce associated waste from ICM administration is the use of syringeless power injections. Toia and colleagues⁷⁷ compared a multi-use syringeless injector (MUSI) versus a single-use syringe-based injection (SUSI). In their evaluation, they reported that over a period of three days plastic waste was 467.7 kg and 71.9 kg for SUSI and MUSI, respectively and equated to being 84.6% lower.

Promoting sustainability

Sustainability is high on the agenda of many countries and is continually discussed at leading transnational meetings, such as COP24.⁷⁸ It is also encouraging that this is also a key feature of leading radiology congress, for example, the European Congress of Radiology 2025 'Planet Radiology'.⁷⁹ Furthermore, to promote sustainability in radiography, particularly concerning the use of ICM, it is crucial to establish comprehensive educational and training programs. These initiatives should focus on raising environmental awareness among student radiographers and experienced practitioners. Providing thorough instruction on properly handling environmentally hazardous substances is essential for all stakeholders. Furthermore, it is of utmost importance to improve the dissemination of public information regarding the environmental impact of ICMs. By increasing access to data on environmental risks, radiography professionals will be better equipped to stay updated on emerging environmental concerns and make informed decisions within their practice.

Conclusion

As the demand for medical imaging continues to rise and raw materials become more challenging to source, the issue of shortages will likely remain a frequent topic of debate. Together with measures to reduce ICM consumption and wastage, there must be further methods to mitigate the broader environmental impact. Reducing ICMs in waste and drinking water should also be a priority, as should reducing the waste from consumables associated with ICM delivery. Developments in the safe disposal of waste ICM, established in training programs, and when combined with improvements in water treatment are likely to help. The effectiveness of such initiatives should be evaluated and routinely reported. It should be acknowledged that many ICM conservation strategies advocated were introduced in response to acute shortages. Many commentators note that ICM shortages are likely to arise again in the future and such strategies will need to remain in place. Other practices and initiatives are likely to be required, early work in areas such as generating virtual and augmented contrast images is one possibility but thorough evaluations are necessary.

Conflict of interest statement

None.

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QUESTIONNAIRE

A9(25) Part 1 of 2

More sustainable use of iodinated contrast media - Why?

INSTRUCTIONS

- Read through the article and answer the multiple-choice questions provided below.
- **Some questions may have more than one correct answer;** in which case you must mark **all** the correct answers.

Introduction

Question 1: What is driving the increased demand for iodinated contrast media (ICM) according to the article?

- A:** Reduced cost of contrast media
- B:** Greater number of medical treatments requiring radiology-based information
- C:** Rapid growth in medical imaging, particularly with the increase in CT scans

Question 2: TRUE or FALSE:

Is it **TRUE** that GE Healthcare manufacturing recently highlighted that based on current trends the clinical demand for ICMs will eventually outstrip supply?

- A:** YES
- B:** NO

Question 3: What are the two primary environmental concerns associated with ICM use?

- A:** Emissions from manufacturing plants
- B:** Presence in waste and drinking water
- C:** Wastage from single-use items
- D:** Leftover ICMs

Key findings

National guidelines

Question 4: National guidelines have been developed, for example by the American College of Radiology, which recommend that iodinated contrast should only be administered where the study is?

- A:** Needed to change management
- B:** There is no alternative imaging modality which can deliver similar levels of diagnostic accuracy
- C:** Where delays in contrast administration could increase the risk of mortality/morbidity for patients.

Individualised doses

Question 5: Regarding weight-based dosing, which of the following statements are **TRUE**?

- A:** A study by George, Manghat and Hamilton indicated that depending on mean patient mass overall ICM doses cannot be reduced
- B:** Yap and colleagues compared fixed volume and weight-based ICM volumes for CT examinations of the chest, abdomen and pelvis
- C:** Concerns have been raised regarding weight-based protocols in that although beneficial to the patient, the ICM volume difference between fixed and weight-based could simply result in additional waste

Saline Chasers

Question 6: What percentage reduction in ICM dose was achieved using a 30ml saline flush for chest CT scans?

- A:** 10%
- B:** 15%
- C:** 20%
- D:** 30%

Question 7: Which of the following statements are **TRUE**?

- A:** *Yoon et al.* concluded that that reduction in ICM volumes from 80 to 60 ml resulted in insufficient enhancement of the neck vessels and that the benefits of saline chasers were not obvious
- B:** Coursey and colleagues evaluated aortic enhancement during CT angiography and argued that reducing ICM volume from 125 to 75ml, increasing the flow rate to 8ml/s and when using a saline bolus can result in acceptable aortic enhancement profiles
- C:** Bammer and Amukotuma advocate increasing the saline chaser (60 mL) for CT perfusion studies of the brain

Optimised acquisition parameters

Question 8: Is the following statement **TRUE** or **FALSE**?

“Further ICM dose reductions steps may include biplanar imaging during angiography, using smaller catheters, reducing the tube potential during CT examinations and removing contrast prior to medication delivery or catheter removal”.

- A:** TRUE
- B:** FALSE

Question 9: Is it **TRUE** that

- A:** Within CT lower tube potential protocols have NOT been associated with reductions in ICM volumes
- B:** *Ippolito et al.* reported on a 100 kV CT angiography protocol combined with 30 mL ICM volume
- C:** Cao and co-workers reported on both contrast and radiation dose reductions when using 80 kV tube potential for coronary CT angiography

Question 10: On which of the following did the REALISE trial report?

- A:** The effects of reduced tube potential
- B:** Lower iodine concentrations
- C:** Iterative reconstruction (IR) techniques

THE END

QUESTIONNAIRE

A9(25) Part 2 of 2

More sustainable use of iodinated contrast media - Why?

INSTRUCTIONS

- Read through the article and answer the multiple-choice questions provided below.
- **Some questions may have more than one correct answer;** in which case you must mark **all** the correct answers.

Alternative Agents

Question 1: Which limitation applies to CO₂ as an alternative contrast agent for infradiaphragmatic arteriography and central venography above the diaphragm?

- A. High cost
- B. Limited availability
- C. Poor image quality
- D. Potentially neurotoxic

Question 2: Which more common alternative contrast agent is proposed for CT angiography when iodine cannot be used?

- A. Gadolinium
- B. Barium
- C. Silver
- D. Gold

Question 3: Is it **TRUE** that studies regarding alternative high atomic number 'newer' agents are extremely limited and that a substantial evaluation period is likely before any such incorporation into routine clinical practice?

- A. YES
- B. NO

Alternative modalities

Question 4: Which of the following statements are **TRUE**?

- A. Greater utilization of non-contrast CT scanning is also a valid option
- B. However, Yu stated that assessing pulmonary parenchymal, interstitial spaces, airways, pleura, and infective respiratory conditions necessarily requires the administration of ICMs
- C. Layer also highlighted a dearth of literature comparing contrast-enhanced and noncontrast-enhanced radiological examinations

Multi-dose systems

Question 5: *Pepin et al.* reported that when carefully considering vial sizes against contrast administration protocols, there could be a reduction of in contrast wastage?

- A. 25 – 30%
- B. 50 – 59%
- C. 35 – 45%

Question 6: Robinson, Mitsumori and Linnau, compared single or multiple-dose ICM vials and found?

- A. Total ICM volume requirements were less when 150 ml. vials were used
- B. Total ICM volume requirements were less when 500 ml. vials were used
- C. Total ICM volume requirements were less when 100 ml. vials were used

Responsible Disposal of ICM Products

Question 7: Is it **TRUE** that within the context of the GREENWATER study, researchers aim to assess the effective quantities of ICMs that are retrievable from patients' urine collected following CT examinations?

- A. YES
- B. NO

Question 8: Which of the following companies have initiated service programs for ICM recycling?

- A. Bayer AG
- B. Bracco
- C. GE Healthcare
- D. Siemens

Promoting Sustainability

Question 9: What is recommended to promote sustainable ICM practices? Choose **TWO** correct answers.

- A. Comprehensive educational programs
- B. Training programs on sustainable practices
- C. By decreasing access to data on environmental risk
- D. Reduced imaging procedures

Conclusion

Question 10: What are the key components for addressing future medical imaging contrast material (ICM) challenges?

- A.** Measures to reduce ICM consumption and wastage
- B.** Generating virtual and augmented contrast
- C.** Reducing ICMs in waste and drinking water
- D.** Temporary protocols

THE END



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ANSWER SHEET

A9(25)

More sustainable use of iodinated contrast media - Why?

*Time spent on activity						hour	min				
PART 1						PART 2					
	A	B	C	D	E		A	B	C	D	E
1						1					
2						2					
3						3					
4						4					
5						5					
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9						9					
10						10					

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Not at all	Somewhat	Mostly	Extremely

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