

CADTH Health Technology Review

# Optimizing the Use of Iodinated Contrast Media for CT: Managing Shortages and Planning for a Sustainable and Secure Supply

ISSN: 2563-6596

**Disclaimer:** The information in this document is intended to help Canadian health care decision-makers, health care professionals, health systems leaders, and policy-makers make well-informed decisions and thereby improve the quality of health care services. While patients and others may access this document, the document is made available for informational purposes only and no representations or warranties are made with respect to its fitness for any particular purpose. The information in this document should not be used as a substitute for professional medical advice or as a substitute for the application of clinical judgment in respect of the care of a particular patient or other professional judgment in any decision-making process. The Canadian Agency for Drugs and Technologies in Health (CADTH) does not endorse any information, drugs, therapies, treatments, products, processes, or services.

While care has been taken to ensure that the information prepared by CADTH in this document is accurate, complete, and up-to-date as at the applicable date the material was first published by CADTH, CADTH does not make any guarantees to that effect. CADTH does not guarantee and is not responsible for the quality, currency, propriety, accuracy, or reasonableness of any statements, information, or conclusions contained in any third-party materials used in preparing this document. The views and opinions of third parties published in this document do not necessarily state or reflect those of CADTH.

CADTH is not responsible for any errors, omissions, injury, loss, or damage arising from or relating to the use (or misuse) of any information, statements, or conclusions contained in or implied by the contents of this document or any of the source materials.

This document may contain links to third-party websites. CADTH does not have control over the content of such sites. Use of third-party sites is governed by the third-party website owners' own terms and conditions set out for such sites. CADTH does not make any guarantee with respect to any information contained on such third-party sites and CADTH is not responsible for any injury, loss, or damage suffered as a result of using such third-party sites. CADTH has no responsibility for the collection, use, and disclosure of personal information by third-party sites.

Subject to the aforementioned limitations, the views expressed herein are those of CADTH and do not necessarily represent the views of Canada's federal, provincial, or territorial governments or any third-party supplier of information.

This document is prepared and intended for use in the context of the Canadian health care system. The use of this document outside of Canada is done so at the user's own risk.

This disclaimer and any questions or matters of any nature arising from or relating to the content or use (or misuse) of this document will be governed by and interpreted in accordance with the laws of the Province of Ontario and the laws of Canada applicable therein, and all proceedings shall be subject to the exclusive jurisdiction of the courts of the Province of Ontario, Canada.

The copyright and other intellectual property rights in this document are owned by CADTH and its licensors. These rights are protected by the Canadian *Copyright Act* and other national and international laws and agreements. Users are permitted to make copies of this document for non-commercial purposes only, provided it is not modified when reproduced and appropriate credit is given to CADTH and its licensors.

**About CADTH:** CADTH is an independent, not-for-profit organization responsible for providing Canada's health care decision-makers with objective evidence to help make informed decisions about the optimal use of drugs, medical devices, diagnostics, and procedures in our health care system.

**Funding:** CADTH receives funding from Canada's federal, provincial, and territorial governments, with the exception of Quebec.

Questions or requests for information about this report can be directed to [Requests@CADTH.ca](mailto:Requests@CADTH.ca)

## Table of Contents

---

<b>Abbreviations</b> .....	<b>5</b>
<b>Key Messages</b> .....	<b>6</b>
<b>Context</b> .....	<b>6</b>
<b>Objective</b> .....	<b>7</b>
<b>About This Document</b> .....	<b>7</b>
<b>Results</b> .....	<b>7</b>
<b>Strategies to Mitigate Shortages of ICM</b> .....	<b>8</b>
Substitution of Scans or Contrast Agents and Prioritization of Scans .....	8
Optimizing ICM Dose.....	9
Inventory Management .....	9
Optimizing Technical Parameters for Image Acquisition .....	10
Improve Communication via Command Centres .....	11
Regulatory Involvement.....	11
<b>Supply Chain Weaknesses</b> .....	<b>11</b>
Identified Supply Chain Weaknesses .....	11
Just-In-Time Inventories .....	12
Preferred Vendor and Sole Source .....	12
Decentralized Supply Chains .....	13
Other Factors .....	13
<b>Unanticipated Consequences of Conserving ICM</b> .....	<b>13</b>
Patient Impacts – Safety and Access to Care .....	13
Costs and Staff Impacts .....	14
Environmental Effects of Contrast Media.....	14
Image Quality Impacts .....	15
Clinical Trial Impacts.....	15
<b>Implications for Decision-Making</b> .....	<b>15</b>
<b>References</b> .....	<b>16</b>

# List of Tables

---

Table 1: Nonionic Iodinated Contrast Media Products and Manufacturers<sup>a51</sup> ..... 10

## Abbreviations

<b>ICM</b>	iodinated contrast media
<b>INESSS</b>	Institut national d'excellence en santé et en services sociaux

## Key Messages

- Shortages of iodinated contrast media (ICM) due to pandemic-related lockdowns and transportation disruptions have exposed vulnerabilities in supply chains for essential medical supplies.
- Radiology associations, government agencies, and clinicians have suggested various strategies to address ICM shortages and strengthen supply chains.
- A systems approach to managing ICM shortages could help ensure the involvement of health care providers from all relevant clinical specialties, administration and purchasing, as well as government and industry. Clear communication is key to managing a critical shortage of ICM.
- Use of contrast-enhanced CT has increased and the ICM shortages may provide an opportunity to assess optimal use of ICM and reduce unnecessary exams.
- ICM use carries environmental consequences that have not yet been fully managed. Strategies to reduce the use of ICM may also help mitigate the environmental impact.

## Context

Iodinated contrast media (ICM) is used to enhance visualization of images in diagnostic imaging and interventional procedures in medicine, including trauma and stroke diagnosis in the emergency department, cancer diagnosis, staging and follow-up, cardiovascular and peripheral vascular interventions, gastrointestinal, urological, and interventional pain procedures.<sup>1-4</sup>

Contrast-enhanced CT scans are the largest volume users of ICM.<sup>5-9</sup> The Canadian Medical Imaging Inventory (CMII) reports more than 5.4 million CT scans were conducted nationwide in 2019 – an increase of 31% over the previous decade.<sup>10</sup> Approximately 50% of CT scans in Canada use ICM.<sup>11,12</sup> Much of the ICM used in Canada is supplied by GE Healthcare from its main manufacturing plant in Shanghai, China.<sup>3,9,13</sup> This plant produces 80% of GE Healthcare's iohexol (Omnipaque) and iodixanol (Visipaque) contrast agents; the remaining 20% is produced in their smaller facility, in Cork, Ireland, but most of this product is intended for the European market.<sup>3,14</sup> There are a number of ICM brands and products available internationally (refer to [Table 1](#)).

In April 2022, due to a COVID-19 outbreak and lockdown measures, the GE Healthcare factory in Shanghai was closed for several weeks, followed by a period of reduced production until full capacity resumed in June.<sup>13</sup> In addition to the factory lockdown, general labour shortages and worldwide shipping delays further disrupted the production and distribution of ICM to Canada and globally.<sup>5,7,13,15</sup>

Many hospitals stock limited supplies of ICM (1 to 2 weeks' worth).<sup>16</sup> The GE Healthcare factory closure resulted in a sudden, unanticipated shortage of ICM globally as other manufacturers were unable to rapidly scale up production to meet the demand.<sup>5,13,16-21</sup>

Shortages of ICM products were reported by the US FDA in May 2022.<sup>22</sup> In June 2022, iodixanol injection and iohexol injection were added to Health Canada's list of tier 3 drug shortages<sup>23</sup>: Tier 3 drug shortages are those likely to have the greatest potential impact on the health care system.<sup>5,13,21,23</sup>

It is important that health systems are equipped to handle the challenges that come with disruption to critical supplies needed for patient care.<sup>5</sup> There may be more supply chain disruptions in the future, and strategies to help manage these challenges may support better patient outcomes.

## Objective

This report summarizes information on strategies to conserve ICM supplies during the shortage. It also identifies ways to strengthen the supply chain for ICM, and other critical health care products to better prepare for, and manage, potential future shortages.

The key objectives are to:

1. identify strategies to mitigate shortages of ICM
2. outline supply chain weaknesses that can exacerbate such shortages
3. highlight unanticipated consequences of ICM shortages.

## About This Document

This report summarizes information identified through a limited literature search using PubMed and grey literature sources of information. This report may not provide an entirely comprehensive review of ICM shortages across Canada and internationally because the literature search used to inform the findings was limited to English-language documents.

## Results

Various medical societies, governments, and other agencies have suggested options or provided guidance to consider during times of ICM shortages:

- Canadian Association of Radiologists<sup>13</sup>
- Institut national d'excellence en santé et en services sociaux (INESSS) in Quebec<sup>24</sup>
- Ontario Health<sup>9</sup>
- American College of Radiology<sup>25</sup>
- American Society of Regional Anesthesia<sup>26,27</sup>
- American Society of Health-System Pharmacists<sup>21</sup>
- Society for Cardiovascular Angiography and Interventions in the US<sup>28</sup>
- Royal Australian and New Zealand College of Radiologists (RANZCR)<sup>8,29</sup>
- Royal College of Radiologists (RCR) in the UK.<sup>30</sup>

In addition to the strategies proposed by the previously stated agencies, clinicians at hospital systems globally have described their experiences and plans for managing ICM shortages, including those reported by institutions in Australia,<sup>4,20,31,32</sup> Germany,<sup>33</sup> and the US.<sup>1,5,7,16,17,19,34-38</sup>

## Strategies to Mitigate Shortages of ICM

A recent rapid review from INESSS, in Quebec,<sup>24</sup> organized ICM conservation strategies into 3 main action areas based on the recommendations of radiology associations from Canada,<sup>13</sup> Australia and New Zealand,<sup>8</sup> the UK,<sup>30</sup> and the US<sup>25</sup>: substitution and prioritization of scans, optimization of ICM doses, and inventory management to avoid waste.<sup>24</sup> The INESSS review includes a description of the action plan for dealing with ICM shortages adopted by the Centre Hospitalier de l'Université de Montréal (CHUM).<sup>24</sup> CHUM developed strategies based on 3 levels of ICM shortage: yellow (indicating insufficient supplies of ICM to carry out scans scheduled within the next 5 days), orange (insufficient ICM to carry out emergency department and hospitalized patient scans), and red (insufficient supplies of ICM to perform urgent angiograms).<sup>24</sup>

Ontario Health's technical guidance for the conservation of ICM focused on 5 main areas<sup>9,39</sup>: expanding use of non-contrast-enhanced CT scans, implementing ICM dose reduction when possible while ensuring diagnostic image quality, tailoring ICM dosages to patient body weight, reducing wastage of ICM, and optimizing technical parameters for image acquisition.<sup>9,39</sup>

The strategies presented by INESSS and Ontario Health were also cited in many of the guidance documents identified and reviewed for this report. Additional options for managing ICM during times of shortage were also captured in guidance documents (e.g., setting up "command centres" to monitor supplies of ICM and communicating information to clinical and administrative staff).<sup>9</sup>

Considering all the identified guidance together, the following 6 broad categories are believed to capture the main strategies to mitigate shortages of ICM:

### Substitution of Scans or Contrast Agents and Prioritization of Scans

Strategies aimed at substituting alternate imaging modalities and contrast agents as well as prioritizing ICM exams may be used to help mitigate ICM shortages. For example, using CT without contrast or alternative imaging modalities that do not require ICM, such as ultrasound, MRI, and nuclear medicine, may be appropriate in some circumstances.<sup>1,4,7-9,13,16,19,21,24-27,33,38-41</sup> If possible, alternative brands of contrast agents from other vendors could be purchased in some instances to help mitigate ICM shortages.<sup>13,17,25,33</sup>

Examples of alternate contrast agents may include oral contrast (such as barium sulphate or diatrizoate meglumine and diatrizoate sodium [Gastrografin, Cystografin, Sinografin]) or, if appropriate, carbon dioxide angiography for peripheral artery disease, MRI with gadolinium contrast, or ethiodized oil (Lipiodol, Guerbet).<sup>5,9,13,14,16,19,21,25,38,42</sup>

Procedures may be stratified based on risk to determine which may be safely deferred until normal ICM supplies resume (for example, routine follow-up exams).<sup>5,7,13,16,19,21,24,26-28,34</sup> At Monash Health in Australia, for example, a tier system identified conditions in which contrast-

enhanced CT was necessary (tier 1), CT without contrast was sufficient (tier 2), alternate types of imaging could be used (tier 3), and imaging could be postponed (tier 4).<sup>4</sup>

## Optimizing ICM Dose

In some circumstances, ICM doses may be reduced if image quality is still adequate.<sup>6,7,9,13,17,19,27,38,40</sup> Two examples include tailoring ICM doses to the patient's body weight<sup>1,5,9,16,17,24,25,33,43</sup> and updating dosing protocols for ICM (i.e., reduced) to reflect newer generations of CT scanners.<sup>4</sup>

Moreover, waste of ICM may be minimized by:<sup>1,7,9,13,16,17,21,24,25,33,37-39</sup>

- Repackaging larger vials of ICM into smaller quantities. To avoid contamination and risk to patients, this should be performed by a trained health care professional (i.e., pharmacist or under the supervision of a pharmacist), following established protocols for sterile procedures.<sup>5,13,21,25,26,44</sup> Of note, this strategy was also suggested by GE Healthcare (i.e., repackaging of larger vials into smaller, single-use preparations, if necessary).<sup>45</sup>
- Refrigerating (but not freezing) or keeping repackaged contrast in a cool place can extend the beyond-use date.<sup>21</sup>
- “Rounding down” ICM dosing slightly to match the vial size, if feasible.<sup>5,7</sup>
- Involving regulatory authorities to explore ways to create safe, multipuncture ICM vials<sup>5</sup> and to ensure ICM products are available in more appropriate vial sizes for most common procedures.<sup>46</sup>
- Checking ICM expiry timelines and coordinating scan scheduling to ensure optimal use.<sup>9</sup>

## Inventory Management

Inventory management principles have been adopted to help navigate ICM shortages and extend existing supplies. These principles often leverage information technology to coordinate, monitor, and share supplies, and predict the inventory requirements during the shortage.<sup>1,4,16,47</sup> Related inventory management principles may include:

- **Establishing an inventory and closely monitoring ICM supplies.**<sup>1,5,7,9,13,17,32</sup> In Ontario, Ontario Health established a provincial dashboard that was updated weekly to track regional supplies of ICM and daily use by all clinical programs and to identify sites with less than a 14-day supply.<sup>39</sup> In Australia, staff at Monash Health inventoried existing supplies of ICM and used business intelligence software to project how long supplies would meet demand under normal operating conditions and when restricted to only critical (e.g., lifesaving or emergency) procedures.<sup>4</sup> An audit of CT scan data from the previous year helped with projection models by identifying procedures that most often required contrast-enhanced imaging, the number of these procedures performed each day, and the minimum volume of ICM needed for diagnostic imaging quality.<sup>4</sup> In the US, purchasing and medical record data were used to determine current inventory and forecast how long ICM supplies would last, and to allow projections of how much ICM use could be reduced through conservation measures.<sup>1,16</sup> In addition, it was also mentioned that opportunities could be explored with regional health networks to coordinate and share supplies.<sup>9,13</sup>
- **Using electronic medical records and ordering systems to provide alerts and ensure awareness of ICM shortages, flag potentially redundant imaging, and provide clinical decision-support tools to guide users to alternate imaging options.**<sup>2,5,35</sup>

- Digital contrast media injection management systems may enable more consistent recording of all information on ICM type and dosage in patients' electronic medical records. This may allow more complete tracking of ICM usage and of any contrast-related adverse events.<sup>47</sup>
- Unnecessary or inappropriate imaging may be reduced by following evidence-based guidelines and recommendations, such as those from Choosing Wisely Canada and the Canadian Association of Radiologists.<sup>9,48</sup>
- Patient triage may be facilitated through the use of decision aids and laboratory tests to rule out clinical conditions before using diagnostic imaging.<sup>49</sup>
- Reviewing prior imaging and patient medical records before requesting new scans may help avoid unnecessary duplication and identify additional clinical information.<sup>9,28,50</sup>
- Where possible, a requirement for radiologist or senior clinician review of requests for contrast-enhanced imaging may help provide oversight and guidance on other available options.<sup>1,17,20,24</sup>
- Some "add-on" contrast-enhanced imaging may be deferred or performed using other types of imaging.<sup>28,40</sup>
- Bundling exams for which contrast is needed into 1 contrast-enhanced scan rather than individual scans for different areas of the body, which may reduce both ICM and CT scanner use.<sup>6</sup>

## Optimizing Technical Parameters for Image Acquisition

Technology may be used to enhance image quality, such as dual-energy CT and lower kilovoltage peak (kVp) imaging.<sup>1,4,5,7,9,13,17,18,25,33,39,40,43,50</sup> Other examples of how technology may be used to enhance image quality include adjusting imaging settings for different parts of the body to optimize visualization,<sup>50</sup> using artificial intelligence or machine-based learning for postprocessing to facilitate image enhancement,<sup>2</sup> using saline flush techniques to ensure complete delivery of ICM dose into the circulatory system, and the use of injector pump systems, particularly those with the ability to collect and analyze data on exam protocols

**Table 1: Nonionic Iodinated Contrast Media Products and Manufacturers<sup>a51</sup>**

Product name	Generic name	Company
Omnipaque	Iohexol	GE Healthcare
Visipaque	Iodixanol	GE Healthcare
Ultravist	Iopromide	Bayer Healthcare
Iomeron	Iomeprol injection	Bracco Diagnostics
Isovue	Iopamidol injection	Bracco Diagnostics
Ultraject/Optiject/Optiray	Ioversol	Guerbet
Oxilan	Ioxilan	Guerbet
Xenetix	Iobitridol	Guerbet
Iodixanol Injection USP	Iodixanol injection	Fresenius Kabi <sup>b</sup>

<sup>a</sup>There are 2 main types of iodinated contrast media: ionic and nonionic.<sup>52</sup> Nonionic contrast media have a lower osmolarity than ionic and do not dissociate into charged particles in a solution, making them safer for patients and more widely used than the older, ionic forms of contrast media.

<sup>b</sup>A generic iodinated contrast media (bioequivalent to Visipaque) recently received US Food and Drug Administration approval.<sup>53</sup>

and radiation dose.<sup>9,43</sup> Moreover, the use of automated contrast delivery systems may help to conserve contrast media; for example, the ACIST CVi (ACIST Medical Systems / Bracco) may reduce the use of contrast media<sup>54</sup> and allows contrast to be delivered from 1 reservoir for up to 5 patients, potentially reducing wastage.<sup>28</sup> Another contrast management system, Namic (Navilyst Medical) allows larger sizes of contrast vials to be safely used multiple times within the use by period.<sup>19</sup>

## Improve Communication via Command Centres

Establishing an institution-wide committee to develop a comprehensive communication strategy to ensure awareness and oversight of ICM conservation measures and promote shared decision-making.<sup>9,13,20</sup> Representatives from all clinical areas that use contrast media, and other departments, such as information technology and pharmacy, could be involved in the committee.<sup>9</sup> The committee may take responsibility for all communications about the shortage and consequent practice changes.<sup>1,5,7</sup> Related strategies may include:

- Tracking and sharing information on ICM usage and shortages, and reviewing protocols with all relevant departments to ensure the best use of available ICM supplies.<sup>4,9,13,20</sup>
- Using a collaborative approach and clear communication when determining which actions to take and how to implement them.<sup>4,20</sup>
- Targeting potential reductions in high volume areas. For example, clinicians in the US and Australia determined contrast-enhanced CT was commonly used for abdominopelvic indications, for which alternative options (including CT without contrast) are available.<sup>32,55</sup> The American College of Radiology's ACR appropriateness criteria provides guidance on alternative imaging modalities.<sup>56</sup>

## Regulatory Involvement

Involving government regulatory agencies may help to explore availability and possible exceptional importation of foreign-authorized ICM products not currently licensed for domestic use.<sup>29</sup> However, due to the lead time needed for production increases and organizing exceptional importations, this may not be possible in times of immediate global shortages.

## Supply Chain Weaknesses

### Identified Supply Chain Weaknesses

The COVID-19 pandemic disrupted supplies of many health care products, exposing vulnerabilities in current supply chain methods, characterized by the reliance on a single ICM supplier and inventory management practices focused on the delivery of products when they are needed.<sup>5,16,20,32,57-60</sup>

A position paper from the US Pharmacopeia stressed the need for a more “resilient” supply chain.<sup>61</sup> Similarly, a 2022 Emergency Care Research Institute (ECRI) White Paper, *Lessons of COVID-19: Three Actions for a More Resilient Supply Chain*, noted that: “The pandemic fueled a ‘perfect storm’: a crisis of international scale with multiple product lines affected and high demand for those products, all supported by a supply chain designed around lean inventory

models...” (p. 3)<sup>62</sup> The ECRI report focuses on supply chain issues with personal protective equipment during the early days of the pandemic, but many of the recommendations can be applied to the ICM shortage as well. In particular, ECRI recommends mapping the supply chain down to the level of sources of raw materials, and the locations, stock on hand, and capacities of manufacturing facilities.<sup>62</sup> This is consistent with other guidance documents that recommend identifying sources of raw materials to identify areas of risk and improve the strength of supply chains.<sup>57,61</sup>

## Just-In-Time Inventories

With just-in-time inventory practices, minimal supplies are stocked and supplies are reordered as needed, helping to ensure minimal waste and reducing storage requirements.<sup>59</sup> Just-in-time inventory management systems have been widely adopted in health care settings; however, they are known to work best under normal conditions.<sup>59</sup> For example, just-in-time inventory management relies on rapid, frequent transport and delivery of supplies — and the transportation sector likewise experienced pandemic-related disruptions.<sup>59</sup> Thus, just-in-time inventory can result in a limited ability to manage a surge in demand, product shortages, and worker absenteeism.<sup>63</sup> Addressing vulnerabilities in the supply chain requires stockpiling of critical medical supplies to ensure they are available in times of shortages.<sup>5,59,61</sup> One author suggested maintaining a 6 month, rather than a 1 week’s supply of ICM, given the relatively long shelf life of contrast media. Despite the extra storage costs, this would ensure a “safety net.”<sup>5</sup> Stockpiling was suggested at both the national and the health system levels.<sup>5,61</sup> Because all types of medical equipment could be affected by supply chain disruptions, it is also important to ensure that adequate stocks of ancillary equipment needed for ICM administration are maintained (for example, IV needles and injection tubing).<sup>5</sup>

## Preferred Vendor and Sole Source

Reliance on a single supplier can make it difficult to source alternative products (and may also indicate an absence of domestic manufacturing capacity).<sup>63</sup> ECRI also recommends reviewing preferred vendor and sole source agreements and considering expanding to multiple supply sources.<sup>62</sup> Currently, an estimated 80% of active pharmaceutical ingredients used in the US drug supply are sourced from China and India.<sup>64</sup> Increasing domestic production of critical medical products may be another option to help improve the strength of supply chains.<sup>5,18</sup> At least 1 guidance document proposed the requirement for vendors to use production facilities at more than 1 location.<sup>65</sup>

Rather than supply chain *resilience*, a recent analysis by Ivanov refers to supply chain *viability*.<sup>66</sup> Viability is defined as the “...ability of a supply chain to maintain itself and survive in a changing environment through a redesign of structures and replanning of performance with long-term impacts...”<sup>66</sup> Key aspects of viability to better manage supply chain disruptions are production capacity *scalability*; *intertwined* supply networks; *substitution* of alternative products through developing relationships with other suppliers and manufacturers; and *repurposing* manufacturing facilities, when needed (such as the example of the Ford manufacturing plant retooling to produce personal protection face shields in the early days of the pandemic).<sup>66</sup> Additional guidance documents offer the suggestion of increasing transparency of the supply chain and reporting requirements for manufacturers and suppliers; stipulating that manufacturers develop contingency or backup plans to address production problems, and using advanced manufacturing processes, such as “continuous manufacturing,” in a single production line.<sup>61,65</sup>

When expansions to GE Healthcare’s facility in Ireland are completed in 2025, production at this facility is expected to increase by more than 50%.<sup>67</sup> GE Healthcare also recently signed an agreement with a Chilean mining company, the Sociedad Química y Minera de Chile, to increase their production of iodine.<sup>68</sup> The recent introduction of a generic ICM, from Fresenius Kabi, may also increase supply options.<sup>53</sup>

## Decentralized Supply Chains

A recent review of pandemic-related supply chain issues in Canada highlighted decentralization as a contributing factor in supply chain “fragilities.”<sup>63</sup> It was noted in the review that decentralized supply chain management may result in increased competition for products.<sup>63</sup> As well, a lack of collaboration between decentralized jurisdictions can make it challenging to redistribute products where they are most needed.<sup>63</sup>

Specifically, Ontario and Quebec were described as provincial examples of decentralized supply chains, often with individual hospitals or hospital systems managing their own supply orders and with no province-wide system or coordinating network.<sup>63</sup> The Ontario Health guidance also noted the paucity of comprehensive, province-wide information on ICM usage and inventories in the province.<sup>9</sup> Elsewhere, provinces such as British Columbia, Alberta, Nova Scotia, and Newfoundland and Labrador, have centralized, province-wide supply chain systems that provide data on utilization and inventories across their jurisdictions.<sup>63,69-71</sup>

Internationally, New Zealand was not affected by the global ICM shortage, which is largely believed to be a result of their national government drug sourcing, centralized through Pharmac, requiring 2 month’s supply be held in the country at all times.<sup>72</sup> Further assessment of this type of centralized practice would be needed, including determination of who should be responsible for maintaining stockpiles of critical drugs and equipment.

## Other Factors

In addition, the lack of transparent, automated supply inventories (i.e., reliance on manual systems) can make it difficult to readily assess utilization data and identify supply risks.<sup>63</sup> An additional fragility is a “reactive” response strategy versus a proactive approach that anticipates or plans for supply disruptions.<sup>63</sup>

## Unanticipated Consequences of Conserving ICM

Within this context, and depending on local circumstances and resources, there may be opportunities and benefits to implementing ICM conservation measures on an ongoing basis. As previously mentioned, some CT protocols are based on practices with older CT units with slower image acquisition times.<sup>4,32</sup> With newer CT units that have much faster acquisition times, there may be an opportunity to revisit protocols and adjust ICM doses accordingly.<sup>4,32</sup>

## Patient Impacts – Safety and Access to Care

The use of contrast-enhanced CT is not risk-free because patients are exposed to both ionizing radiation and iodine.<sup>16,20</sup> From a patient safety perspective, reducing ICM can also reduce the overall radiation dose, which is an implication for patient care.<sup>73</sup> Iodinated contrast media is associated with a small risk for allergic reactions and acute kidney injury.<sup>11,74</sup> Using

safer imaging alternatives, when appropriate, and reducing ICM doses, may benefit patients by minimizing the risks of adverse events and reducing the time required to administer the scan (i.e., ICM CT scan versus non-ICM CT scan).<sup>6,16,20,34,54,75,76</sup> Of note, clinicians in Melbourne, Australia, found that diversion of some patients from contrast-enhanced to nonenhanced CT or to other types of imaging reduced the turnaround time for those patients who needed CT with contrast. As well, some authors have noted that longer-term patient follow-up may be needed to determine whether ICM conservation measures have negatively affected patients through missed diagnoses or delays in treatment.<sup>4,18,20,38</sup>

### Costs and Staff Impacts

The use of alternatives to CT was generally recommended, and shifting procedures to other areas of health care delivery would have impacts (e.g., wait lists, staffing, costs).<sup>4,6,9,24</sup> For example, if MRI was substituted for CT imaging in stroke diagnosis, because it is less available and more time consuming to perform, patient treatment could potentially be delayed.<sup>16,20</sup> Other effects of substituting MRI for contrast-enhanced CT may include the need to extend operating hours for MRI scanners to ensure availability, lease portable MRI units from vendors, use research MRI units for clinical exams, ensure MRI safety shielding is in place, and cross-train medical imaging technologists to work with both CT and MRI as needed.<sup>4</sup> Protocols for MRI for stroke may also need to be revised to reduce the time required for imaging acquisition.<sup>4,5,19,41</sup>

In this scenario, trained staff and the necessary supplies (e.g., MRI contrast agents or radiopharmaceuticals for nuclear medicine) for alternative imaging technologies would also need to be readily available,<sup>4</sup> and clinicians may need refresher training on interpreting images from non-contrast-enhanced CT scans.<sup>50</sup>

Assessments of the effects associated with strategies to reduce use of ICM would help inform future planning. Reductions in ICM usage may not necessarily result in overall cost savings when staff time and the costs of alternative imaging services are included.<sup>20,32</sup> However, reducing the use of contrast-enhanced CT may have a positive impact on some areas of workflow, such as reducing the staff time needed to place IV lines for contrast administration.<sup>65</sup>

### Environmental Effects of Contrast Media

More efficient use of ICM has environmental benefits as well.<sup>43</sup> The iodine used in ICM is a nonrenewable mineral resource.<sup>77</sup> According to a GE Healthcare news release, on average, 5% of purchased ICM supplies are not used.<sup>77</sup> GE Healthcare recently introduced a Canadian and US recycling program to collect unused ICM, similar to a longer-running program in Europe.<sup>77</sup> As of March, 2022, 15 sites in Canada were participating in the recycling program, and it is expanding across the country.<sup>77</sup> The iodine collected can be used to produce new contrast agents.<sup>43</sup> Other European manufacturers (Bracco Diagnostics and Bayer Healthcare) have also introduced iodine recycling processes.<sup>43</sup>

Contrast media is a known contaminant in water supplies — including in drinking water.<sup>43</sup> This is a growing problem as use of contrast-enhanced CT increases and the current methods of water purification do not adequately remove ICM and its breakdown by-products.<sup>78</sup> Water quality monitoring in Europe identified an increase in various ICM products over a 10-year period. Optimizing use of ICM and reducing product waste are 2 ways to help mitigate this

problem, in addition to urine collection technologies to prevent used ICM from entering the sewage system.<sup>43</sup>

### Image Quality Impacts

Ontario Health's guidance recommended that imaging centres aim to reduce their ICM consumption by 50% from baseline levels, regardless of vendor.<sup>9</sup> The Ontario guidance noted that some centres achieved a 30% to 60% reduction in ICM usage in the early days of the shortage, without compromising imaging quality.<sup>9</sup> Although not assessed through controlled studies, experiences at imaging facilities across the globe suggest that reducing ICM dosing in CT scans may not affect image quality or diagnostic accuracy.<sup>6</sup>

### Clinical Trial Impacts

Contrast media shortages have also had an effect on ongoing clinical trials.<sup>6</sup> The US National Cancer Institute outlined options for clinical trials during ICM shortages, including the use of alternative imaging modalities.<sup>6</sup>

## Implications for Decision-Making

The INESSS rapid review mentions that strategies for addressing the ICM shortage have not yet been evaluated and their applicability will vary depending on local context. A US review of the literature on ICM shortages relevant to trauma and emergency department care concluded that further studies are needed to obtain better evidence on how best to optimize ICM use without jeopardizing patient outcomes.

Regardless of local ICM inventories, ensuring equitable patient access to necessary contrast-enhanced imaging across jurisdictions is important. Reducing unnecessary use of contrast-enhanced CT scans could help improve access for patients for whom this type of imaging is critically needed, particularly during times of shortages.

Several factors have contributed to increasing use of contrast-enhanced CT scans, including increased demand and easier access to CT. Increased demand for CT in the context of recent shortages of ICM have highlighted a need to evaluate overall ICM use. Assessing ICM conservation strategies in the period of shortage could provide insight to help support appropriate use, including identifying potential overuse or "low-value" imaging. Measures to conserve ICM may also reduce its environmental impact. The Ontario guidance notes that, in addition to addressing ICM shortages, their recommendations are intended to ensure "sustainable, effective use of contrast media."

The recent shortage has also shed light on how procurement practices for critical supplies, which tend to be based on just-in-time inventory management, and often rely on a single supplier with limited local capacity, may have contributed to the shortage. Exploring alternative procurement practices, such as placing larger orders requiring less frequent delivery of critical medical supplies with long shelf lives, may enhance supply chain viability. These practices may also have some environmental benefits worthy of exploration when considering the fossil fuels required for their transcontinental delivery.

## References

- Allen LM, Shechtel J, Frederick-Dyer K, et al. Rapid Response to the Acute Iodinated Contrast Shortage During the COVID-19 Pandemic: Single-Institution Experience. *J Am Coll Radiol*. 2022;19(7):836-840. [PubMed](#)
- Tu LH, Miller JE, Forman HP. The Critical Shortage of Iodinated Contrast Material - Will Value Prevail? *N Engl J Med*. 2022;387(6):491-493. [PubMed](#)
- Canadian Neurological Sciences Federation. Urgent communication: [contrast media shortage]. 2022; [https://www.cnsf.org/media/lihqsgfge/contrast-shortage\\_2022-07-06.pdf](https://www.cnsf.org/media/lihqsgfge/contrast-shortage_2022-07-06.pdf). Accessed 2022 Oct 27.
- Amukotuwa SA, Bammer R, Jackson DM, Sutherland T. Iodinated contrast media shortage: Insights and guidance from two major public hospitals. *J Med Imaging Radiat Oncol*. 2022;66(7):946-956. <https://onlinelibrary.wiley.com/doi/10.1111/1754-9485.13444>. Accessed May 30.
- Grist TM, Canon CL, Fishman EK, Kohi MP, Mossa-Basha M. Short-, Mid-, and Long-term Strategies to Manage the Shortage of Iohexol. *Radiology*. 2022;304(2):289-293. [PubMed](#)
- Luker GD. Iodinated Contrast Material Shortage: Perspectives from the Cancer Imaging Community. *Radiol Imaging Cancer*. 2022;4(4):e220077. [PubMed](#)
- Ananthkrishnan L, Kay FU, Zeikus EA, et al. What the Baby Formula and Medical Contrast Material Shortages Have in Common: Insights and Recommendations for Managing the Iodinated Contrast Media Shortage. *Radiol Cardiothorac Imaging*. 2022;4(3):e220101. [PubMed](#)
- Royal Australian and New Zealand College of Radiologists. RANZCR statement on iodinated contrast media shortage. 2022; [https://www.ranzcr.com/doclink/ranzcr-statement-on-iodinated-contrast-media-shortage/eyJ0eXAiOiJKV1QiLCJhbGciOiJIUzI1NiJ9.eyJzdWIiOiJyYW56Y3ltc3RhZGVtZW50LW9uLWlvZGluYXRlZC1jb250cmFzdC1tZWVpYS1zaG9ydGFnZSIsImhhdCI6MTY1Mjc2NTM4MywiZXhwIjoxNjUyODUxNzgzfQ.yblkoD4\\_pP9OVNCvxmZ44jOfp-Uu1W2ejWEAskIqyB8](https://www.ranzcr.com/doclink/ranzcr-statement-on-iodinated-contrast-media-shortage/eyJ0eXAiOiJKV1QiLCJhbGciOiJIUzI1NiJ9.eyJzdWIiOiJyYW56Y3ltc3RhZGVtZW50LW9uLWlvZGluYXRlZC1jb250cmFzdC1tZWVpYS1zaG9ydGFnZSIsImhhdCI6MTY1Mjc2NTM4MywiZXhwIjoxNjUyODUxNzgzfQ.yblkoD4_pP9OVNCvxmZ44jOfp-Uu1W2ejWEAskIqyB8). Accessed 2022 Oct 27.
- Ontario Health. Ontario Health clinical guidance for the conservation of iodinated contrast media (ICM). 2022 Jun 3; <https://radiology.mcmaster.ca/app/uploads/2022/06/Clinical-Guidance-for-the-Conservation-of-Iodinated-Contrast-Media-FINAL.pdf>. Accessed 2022 Oct 27.
- Chao Y-S, Sinclair A, Morrison A, Hafizi D, Pyke L. The Canadian Medical Imaging Inventory 2019–2020. Ottawa: CADTH; 2021; <https://www.cadth.ca/canadian-medical-imaging-inventory-2019-2020>. Accessed 2022 Nov 4.
- Macdonald DB, Hurrell C, Costa AF, et al. Canadian Association of Radiologists Guidance on Contrast Associated Acute Kidney Injury. *Canadian Association of Radiologists Journal*. 2022;73(3):499-514. [PubMed](#)
- Alberta Health Services. Global shortage of contrast dye results in postponement of some imaging procedures. 2022; <https://www.albertahealthservices.ca/news/releases/2022/Page16614.aspx>. Accessed 2022 Nov 30.
- Canadian Association of Radiologists. Statement on iodinated contrast media shortage. 2022; <https://car.ca/news/statement-on-iodinated-contrast-media-shortage/>. Accessed 2022 Sep 30.
- Keefe NA, Desai KR, Kohi MP, Salazar GM. Mitigation Strategies for Interventional Radiology During a Global Contrast Media Shortage. *J Vasc Interv Radiol*. 2022;33(9):1021-1024. [PubMed](#)
- Pearson D. CT contrast shortage seen as amplification, continuation of deep-set dynamics. *Radiology Business*; 2022; <https://radiologybusiness.com/topics/healthcare-management/business-intelligence/ct-contrast-shortage-seen-amplification>. Accessed 2022 Nov 30.
- Cavallo JJ, Pahade JK. Practice Management Strategies for Imaging Facilities Facing an Acute Iodinated Contrast Media Shortage. *AJR Am J Roentgenol*. 2022;219(4):666-670. [PubMed](#)
- Barreto IL, Grajo JR, Brock DE, Magnelli L, Patel P, Hochhegger B. A Health System's Response to the Ongoing Global Shortage of Iodinated Contrast Media. *AJR Am J Roentgenol*. 2022:1-6. [PubMed](#)
- Eibschutz LS, Gholamrezaezhad A. How low can we go? Strategies and recommendations to combat the iodinated contrast shortage. *Emerg Radiol*. 2022;29(5):925-928. [PubMed](#)
- Salazar G, Mossa-Basha M, Kohi MP, Burke LM. Short-Term Mitigation Steps During the Iohexol Contrast Shortage: A Single Institution's Approach. *J Am Coll Radiol*. 2022;19(7):841-845. [PubMed](#)
- Amukotuwa SA, Jackson D, Bammer R. Impact of iodinated contrast media conserving interventions and lessons for the future. *J Med Imaging Radiat Oncol*. 2022 Jul 20. <https://onlinelibrary.wiley.com/doi/10.1111/1754-9485.13458>. Accessed 2022 Jul 20.
- American Society of Health-System Pharmacists. Considerations for imaging contrast shortage management and conservation. 2022 May 13; [https://www.ashp.org/drug-shortages/shortage-resources/considerations-for-imaging-contrast-shortage-management?utm\\_term=&utm\\_campaign=Performance%20Max-Recruitment-1-00-4801-60000&utm\\_source=adwords&utm\\_medium=ppc&hsa\\_acc=3985934627&hsa\\_cam=17288510113&hsa\\_grp=&hsa\\_ad=&hsa\\_src=x&hsa\\_tgt=&hsa\\_kw=&hsa\\_mt=&hsa\\_net=adwords&hsa\\_ver=3&gclid=EAlalQobChMI8pG\\_sK-L-wlV4gB9Ch3t0QLoEAAAYASAAEgK\\_8vD\\_BwE&loginreturnUrl=SSOCheckOnly](https://www.ashp.org/drug-shortages/shortage-resources/considerations-for-imaging-contrast-shortage-management?utm_term=&utm_campaign=Performance%20Max-Recruitment-1-00-4801-60000&utm_source=adwords&utm_medium=ppc&hsa_acc=3985934627&hsa_cam=17288510113&hsa_grp=&hsa_ad=&hsa_src=x&hsa_tgt=&hsa_kw=&hsa_mt=&hsa_net=adwords&hsa_ver=3&gclid=EAlalQobChMI8pG_sK-L-wlV4gB9Ch3t0QLoEAAAYASAAEgK_8vD_BwE&loginreturnUrl=SSOCheckOnly). Accessed 2022 Oct 31.
- U.S. Food & Drug Administration. FDA drug shortages. 2022; [https://www.accessdata.fda.gov/scripts/drugshortages/dsp\\_SearchResults.cfm](https://www.accessdata.fda.gov/scripts/drugshortages/dsp_SearchResults.cfm). Accessed 2022 Oct 27.
- Health Canada. Tier 3 drug shortages. 2022; <https://www.canada.ca/en/health-canada/services/drugs-health-products/drug-products/drug-shortages/tier-3-shortages.html#wb-auto-4>. Accessed 28-Oct-2022.

24. Parent M. Stratégies de mitigation pour la pénurie d'agents de contraste iodés. *Réponse rapide*. Montreal, QC: INESSS; 2022: <https://www.inesss.qc.ca/publications/repertoire-des-publications/publication/strategies-de-mitigation-pour-la-penurie-dagents-de-contraste-iodes.html>. Accessed 2022 Nov 7.
25. Wang CL, Asch D, Cavallo J, et al. Statement from the ACR Committee on Drugs and Contrast Media on the Intravenous Iodinated Contrast Media Shortage. *J Am Coll Radiol*. 2022;19(7):834-835. [PubMed](#)
26. Kohan L, Pellis Z, Provenzano DA, Pearson AC, Narouze S, Benzon HT. American Society of Regional Anesthesia and Pain Medicine contrast shortage position statement. *Regional Anesthesia & Pain Medicine*. 2022;47(9):511-518. [PubMed](#)
27. Kohan L, Pellis Z, Provenzano D, Pearson A, Narouze S, Benzon H. ASRA pain medicine recommendations for interventional pain procedures during contrast shortage. 2022: <https://www.asra.com/guidelines-articles/original-articles/article-item/guidelines/2022/05/23/asra-pain-medicine-recommendations-for-interventional-pain-procedures-during-contrast-shortage>. Accessed 2022 Oct 28.
28. Athar SA, Tam, Truong, H.T., Doll, J.A., Lotfi, A., Potluri, S. Navigating the contrast media shortage. 2022; <https://scai.org/navigating-contrast-media-shortage>. Accessed 2022 Oct 27.
29. Australian Government. Therapeutics Goods A. Shortage of iodinated contrast media (contrast) diagnostic agents. [Canberra]: Australian Government. Department of Health and Aged Care. Therapeutic Goods Administration; 2022: <https://www.tga.gov.au/safety/shortages/medicine-shortage-alerts/shortage-iodinated-contrast-media-contrast-diagnostic-agents>. Accessed 2022 Nov 14.
30. Royal College of Radiologists. RCR/SoR position statement on iodinated contrast media supply issues. 2022; <https://www.rcr.ac.uk/posts/rcrsor-position-statement-iodinated-contrast-media-supply-issues>. Accessed 2022 Oct 27.
31. Amukotuwa SA, Jackson D, Bammer R. Iodinated Contrast Media Conservation Measures During a Global Shortage: Effect on Contrast Media Use at a Large Health System. *AJR Am J Roentgenol*. 2022:1-2. [PubMed](#)
32. Bammer R, Amukotuwa SA. Navigating Supply Chain Disruptions of Iodinated Contrast Agent for Neuroimaging and How Business Intelligence Can Help the Decision Process. *AJNR Am J Neuroradiol*. 2022;43(7):944-950. [PubMed](#)
33. Kaiser DPO, Abdalkader M, Berberich A, Sporns PB, Nguyen TN. Acute shortage of iodinated contrast media: implications and guidance for neurovascular imaging and intervention. *Neuroradiology*. 2022;64(9):1715-1718. [PubMed](#)
34. Forouzandeh F, Al-Kindi SG, Rana M, Lowry C, Simon DI, Shishebor MH. Navigating Through Contrast Media Shortage: Feasible Without Delaying Patient Care. *JACC Cardiovasc Interv*. 2022;15(13):1393-1394. [PubMed](#)
35. Glazer DI, Lucier DJ, Sisodia RC, et al. Electronic Health Record Order Entry-Based Interventions in Response to a Global Iodinated Contrast Media Shortage: Impact on Contrast-Enhanced CT Utilization. *AJR Am J Roentgenol*. 2022:1-7. [PubMed](#)
36. Almallouhi E, Sattur M, Lajthia O, et al. Contrast conservation measures during the global iohexol contrast shortage crisis did not affect stroke thrombectomy outcomes. *J Neurointerv Surg*. 2022. [PubMed](#)
37. Davenport MS, Chu P, Szykutowicz TP, Smith-Bindman R. Comparison of Strategies to Conserve Iodinated Intravascular Contrast Media for Computed Tomography During a Shortage. *Jama*. 2022;328(5):476-478. [PubMed](#)
38. Rosander A, Andrade R, Concepcion J, Woodley L, Havron W, Elkbuli A. Institutional response to the 2022 iodinated contrast shortage: A narrative review. *Am J Emerg Med*. 2022;64:62-66. [PubMed](#)
39. Dobranowski J, Langer D. Iodinated contrast media (ICM) shortage [presentation slides]. *Canadian Association of Radiologists, June 24, 2022*. Toronto: Ontario Health; 2022.
40. Kern MJ, Hirshfeld, J., Kaki, A., Rosenfeld, K., Ramee, S., Pelican, P., Pinto, D., Teirstein, P. Contrast media shortage: what should we do about it? *Cath Lab Digest*. 2022(June):6-8.
41. Reeder SB, Hess CP, Zaharchuk G, Moy L. Magnetic Resonance Imaging as an Alternative to Contrast-Enhanced Computed Tomography to Mitigate Iodinated Contrast Shortages in the United States: Recommendations From the International Society for Magnetic Resonance in Medicine. *J Magn Reson Imaging*. 2022;56(3):655-656. [PubMed](#)
42. Kern MJ, Hirshfeld J, Kaki A, et al. Contrast media shortage: what should we do about it? *Cath Lab Digest*. 2022(June):6-8. <https://www.hmpglobelearningnetwork.com/site/cathlab/clinical-editors-corner/contrast-media-shortage-what-should-we-do-about-it-0>. Accessed 2022 Dec 8.
43. Dekker HM, Stroomberg GJ, Prokop M. Tackling the increasing contamination of the water supply by iodinated contrast media. *Insights Imaging*. 2022;13(1):30. [PubMed](#)
44. Schuster NM, Ahadian FM, Zhao Z, et al. Best practices for interventional pain procedures in the setting of an iodinated contrast media shortage: A multisociety practice advisory. *Interventional Pain Medicine*. 2022;1(3):100122.
45. GE Healthcare. *Considerations for use of Omnipaque and Visipaque*. [n.d.]: GE Healthcare; [2022].
46. Moura T. Contrast media shortage reveals cracks in supply chain. *OR Manager*; 2022 Jun 28: <https://www.ormanager.com/contrast-media-shortage-reveals-cracks-in-supply-chain/>. Accessed 2022 Oct 28.
47. Fornell D. Strategies to lower CT contrast dose and track usage. *Imaging Technology News*. 2019. <https://www.itnonline.com/article/strategies-lower-ct-contrast-dose-and-track-usage>. Accessed 2022 Nov 24.

48. Canadian Association of Radiologists. Radiology: five tests and treatments to question. 2022; <https://choosingwiselycanada.org/recommendation/radiology/#related-rec>. Accessed 2022 Oct 27.
49. Castro-Dominguez Y, Li J, Sharma A. SVM Communications: Contrast media shortage and Society updates. *Vascular Medicine*. 2022;27(5):525-527. [PubMed](#)
50. Abdellatif W, Vasan V, Kay FU, Kohli A, Abbara S, Brewington C. Know your way around acute unenhanced CT during global iodinated contrast crisis: a refresher to ED radiologists. *Emerg Radiol*. 2022;1-13. [PubMed](#)
51. American College of Radiology. ACR manual on contrast media. [Reston, VA]: American College of Radiology (ACR); 2022: [https://www.acr.org/-/media/acr/files/clinical-resources/contrast\\_media.pdf](https://www.acr.org/-/media/acr/files/clinical-resources/contrast_media.pdf). Accessed 2022 Nov 14.
52. Baerlocher MO, Asch M, Myers A. The use of contrast media. *CMAJ*. 2010;182(7):697. [PubMed](#)
53. Fresenius Kabi introduces generic Iodixanol contrast media agent. Lake Zurich, IL: Fresenius Kabi; 2022: <https://www.fresenius-kabi.com/us/news/fresenius-kabi-introduces-generic-iodixanol-contrast-media#:~:text=Fresenius%20Kabi%20Iodixanol%20Injection%2C%20USP%20is%20an%20option%20for%20hospitals.kidneys%2C%20and%20other%20internal%20organs.&text=It%20is%20free%20of%20preservatives,made%20with%20natural%20rubber%20latex>. Accessed 2022 Jul 18.
54. Minsinger KD, Kassiss HM, Block CA, Sidhu M, Brown JR. Meta-analysis of the effect of automated contrast injection devices versus manual injection and contrast volume on risk of contrast-induced nephropathy. *Am J Cardiol*. 2014;113(1):49-53. [PubMed](#)
55. Horný M, Saindane AM, Duszak R, Jr. Clinical Characteristics of Most Frequent Use of Iodinated Contrast Media for CT. *AJR Am J Roentgenol*. 2022;1-2. [PubMed](#)
56. American College of Radiology. ACR appropriateness criteria. 2022; <https://www.acr.org/Clinical-Resources/ACR-Appropriateness-Criteria>. Accessed 2022 Oct 27.
57. Okeagu CN, Reed DS, Sun L, et al. Principles of supply chain management in the time of crisis. *Best Pract Res Clin Anaesthesiol*. 2021;35(3):369-376. [PubMed](#)
58. Burry LD, Barletta JF, Williamson D, et al. It Takes a Village...: Contending With Drug Shortages During Disasters. *Chest*. 2020;158(6):2414-2424. [PubMed](#)
59. Balkhi B, Alshahrani A, Khan A. Just-in-time approach in healthcare inventory management: Does it really work? *Saudi Pharmaceutical Journal*. 2022;30(12):1830-1835. [PubMed](#)
60. Rowland C. Covid shutdowns in China are delaying medical scans in the U.S. *The Washington Post*. 2022 May 11. <https://www.washingtonpost.com/business/2022/05/11/medical-scans-dye-shortage/>. Accessed 2022 Dec 4.
61. United States Pharmacopeia. Key elements to building a more resilient supply chain. 2020; <https://www.usp.org/sites/default/files/usp/document/our-impact/covid-19/global-policy-supply-chain.pdf>. Accessed 2022 Nov 11.
62. Browne T. Lessons of COVID-19: three actions for a more resilient supply chain. Plymouth Meeting (PA): ECRI; 2022: <https://www.ecri.org/covid-19-lessons-three-actions-resilient-supply-chain>. Accessed 2022 Nov 18.
63. Snowdon AW, Saunders M, Wright A. Key Characteristics of a Fragile Healthcare Supply Chain: Learning from a Pandemic. *Healthc Q*. 2021;24(1):36-43. [PubMed](#)
64. Huang Y. The coronavirus outbreak could disrupt the U.S. drug supply. 2020; <https://www.jstor.org/stable/resrep29852>. Accessed 2022 Nov 8.
65. Brook OR. Editorial Comment: Lessons Learned From the Iodinated Contrast Material Shortage. *AJR American journal of roentgenology*. 2022;219(4):670. [PubMed](#)
66. Ivanov D. Supply Chain Viability and the COVID-19 pandemic: a conceptual and formal generalisation of four major adaptation strategies. *International Journal of Production Research*. 2021;59(12):3535-3552.
67. GE Healthcare announces moves to bolster supply of iodinated contrast media for medical imaging. *HealthCare Africa*. 2022 Oct 16. <https://www.healthcareafrica.info/ge-healthcare-announces-moves-to-bolster-supply-of-iodinated-contrast-media-for-medical-imaging/>. Accessed 27 October 2022.
68. Hall J. GE Healthcare announces moves to bolster supply of iodinated contrast media for CT and x-ray imaging. *Diagn Imaging*. 2022 Oct 14. <https://www.diagnosticimaging.com/view/ge-healthcare-bolster-supply-of-iodinated-contrast-media-for-ct-and-x-ray-imaging>. Accessed 27 October 2022.
69. Snowdon AW, Saunders MJ. Supply chain integration as a strategy to strengthen pandemic responsiveness in Nova Scotia. *Healthc Manage Forum*. 2022;35(2):62-70. [PubMed](#)
70. Snowdon A, Wright A. Digitally enabled supply chain as a strategic asset for the COVID-19 response in Alberta. *Healthc Manage Forum*. 2022;35(2):90-98. [PubMed](#)
71. Snowdon AW, Saunders MJ. Supply chain capacity to respond to COVID-19 in Newfoundland and Labrador: An integrated leadership strategy. *Healthc Manage Forum*. 2022;35(2):71-79. [PubMed](#)
72. Pharmac. Aotearoa less affected by medicine supply issues than other countries. [Wellington, NZ]: Government of New Zealand. Pharmac / Te Pataka Whaioranga; 2022: <https://pharmac.govt.nz/news-and-resources/news/2022-07-22-media-release-aotearoa-less-affected-by-medicine-supply-issues-than-other-countries/>. Accessed 2022 Nov 14.
73. Sahbaee P, Abadi E, Segars WP, Marin D, Nelson RC, Samei E. The Effect of Contrast Material on Radiation Dose at CT: Part II. A Systematic Evaluation across 58 Patient Models. *Radiology*. 2017;283(3):749-757. [PubMed](#)
74. Kang HR, Jeong J, Brockow K. Diagnosis and Prevention of Hypersensitivity Reactions to Iodinated Contrast Media. *Allergy Asthma Immunol Res*. 2022;14(4):348-360. [PubMed](#)
75. Böhm IB. Lower dose and lower injection speed of iodinated contrast media: a new strategy to reduce the incidence rate of immediate hypersensitivity reactions. *Quant Imaging Med Surg*. 2020;10(4):883-885. [PubMed](#)

76. Total Health. AI to replace contrast dye injections in CT heart scans. 2021 Dec 14; <https://www.totalhealth.co.uk/blog/ai-replace-contrast-dye-injections-ct-heart-scans>. Accessed 2023 Mar 1.
77. Recycling iodine: how hospitals are keeping contrast media in the circular economy. 2022; <https://www.gehealthcare.com/insights/article/recycling-iodine-how-hospitals-are-keeping-contrast-media-in-the-circular-economy>. Accessed 2022 Oct 27.
78. Nowak A, Pacek G, Mrozik A. Transformation and ecotoxicological effects of iodinated X-ray contrast media. *Reviews in Environmental Science and Bio/Technology*. 2020;19(2):337-354.