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Iodinated contrast media shortage: Insights and guidance from two major public hospitals

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Summary

Global shortage of *iodinated contrast medium* (ICM) is the latest health care ripple-effect from the COVID-19 pandemic. Some public hospitals in Australia have less than a week's supply. Strategies are, therefore, urgently needed to conserve ICM for those diagnostic tests and interventions, which are time-critical, and without which patients would suffer death or significant morbidity. A plan is also required to continue providing best possible care to patients in the worst-case scenario of exhausted ICM supplies. This document, by representatives from two major public hospitals, will provide some guidance that is tailored to the Australian context.

Key words: contrast dose reduction; contrast-enhanced CT; iodinated contrast media.

Introduction

The recent COVID-19 lockdown in Shanghai, China, has led to an unanticipated severe global shortage of *iodinated contrast media* (ICM). General Electric (GE) Healthcare is the largest producer of ICM in the form of iohexol (Omnipaque), supplying >75% of the Australian market. GE's main ICM factory in Shanghai was temporarily shut-down, leading to reduced production of iohexol.[1] Production capacity at GE's other factory in Ireland is insufficient to meet the deficit, while supplies from other vendors (Bracco, Bayer and Guerbet) are being rapidly exhausted worldwide. Correspondence from GE indicates that the shortage is expected to persist until at least late June 2022. The uncertainty associated with the pandemic, disruption of supply chains and our small consumer market mean that the shortage may last longer in Australia.

Iodinated contrast media are widely used in *computed tomography* (CT) to produce angiographic and *contrast-enhanced CT* (CECT) images, which enable the diagnosis of pathologies ranging from tumours to pulmonary embolus and large-vessel occlusion stroke. It is also used for catheter angiography and to guide percutaneous interventions. Services outside radiology which are, therefore, reliant on ICM include cardiology, gastrointestinal and vascular surgery and urology.

Several major hospitals in Australia, including some trauma and comprehensive stroke centres, have ICM supplies which will last a few weeks or less under normal operating conditions. Strategies are, therefore, urgently needed to conserve ICM supplies for diagnostic tests and interventions, which are time-critical and necessary to prevent death or significant morbidity. These include catheter procedures to treat acute myocardial ischaemia, stroke and life-threatening haemorrhage.

The *American College of Radiology* (ACR) Committee on Drugs and Contrast Media has issued a statement providing guidance and recommendations on how to continue high-quality patient care in the face of this emergency.[2] The Royal Australian and New Zealand College of Radiologists has also issued a statement endorsing these recommendations to conserve ICM supplies. Authors from Yale have provided additional

Table 1. Examples of imaging stratified by necessity for ICM

Tier 1	Tier 2	Tier 3	Tier 4
Multimodal code stroke CT[1]	Diverticulitis	Occult Infection	Asymptomatic annual staging
Subarachnoid Haemorrhage[1]	Appendicitis	Pulmonary Embolism	Pulmonary nodules <8 mm
Suspected aortic dissection	Bowel Obstruction/perforation	Oncology Staging	Low-risk incidental findings workup
Level 1 Trauma	Fluid collections	Focal Liver lesions	Claudication
Oncology initial staging[2]	Chest Imaging	Cerebral venous sinus thrombosis	
Oncology restaging[3]	Selected oncology/haematology studies[5]	Biliary/renal obstruction	
Active lower GI bleed[4]	Trauma—clinically stable	TIA workup	
Acute Mesenteric Ischaemia			
Clinical Trial Patients (where CT is mandated by the trial)			

Modified from Cavallo et al, practice management strategies for imaging facilities facing an acute iodinated contrast media shortage, AJR 2022 preprint https://doi.org/10.2214/AJR.22.27969. Tier 1 – CT with contrast necessary. Tier 2 – unenhanced CT is feasible. Tier 3 – alternative modalities can be used, for example, NM, PET, US, CEUS and MRI. Tier 4 – study can be delayed. 1 – Contrast is necessary during phase 1 and 2. Once contrast supplies are critical, these can be replaced with MRI (with DWI and perfusion-weighted images for ischaemic stroke). 2 – where the patient is potentially curable, could be enrolled in a trial or to guide biopsy. 3 – following neoadjuvant therapy where the patient is a potential resection candidate. 4 – Upper GI bleed should have an endoscopy, and if that fails discussion with an IR consultant. 5 – patients with measurable disease without needing contrast, based upon prior studies and no clinical suspicion of recurrence/disease progression.

guidance on how to rationalize and optimize ICM consumption.[1]

In this review, we have synthesized these recommendations to provide guidance, tailored and nuanced to the Australian context, on how to maintain clinical care while reducing ICM utilization. Options to explore should the worst-case scenario of ICM exhaustion eventuate have been included. We also provide insights and data from early implementation in two major public hospitals, including Australia's largest radiology department.

Quantify ICM inventory and requirements to meet critical needs

Institutions should—if available, ideally by means of business intelligence tools –gauge the severity of the problem they face by determining how long the current stock of ICM will last (1) under normal operating conditions and (2) if consumption were limited to critical procedures and scans. ICM-requiring procedures, which we consider critical, include coronary interventions for acute myocardial syndromes, *endovascular clot retrieval* (ECR) and angioembolization for life-threatening haemorrhage. Time-critical indications for CECT, where there is no adequate alternative test, are listed in Table 1.

Figure 1 shows an approach to (1) calculating basal daily ICM requirements to meet critical needs, (2) projecting the duration of critical supply and (3) determining the surplus ICM volume above this threshold for meeting critical needs until July (approximately 7 weeks). If ICM inventory will not last until July, ICM use must be more severely curtailed. ICM consumption with additional measures should be modelled based on existing data. The most critical indications that reduce patient morbidity and mortality should be prioritized. MRI should be considered for time-critical indications for which MRI is equally or more accurate, but CT is preferred because it is faster and easier to access in the emergent setting.

Strategies that we have already employed are given in Table 2. A stratified approach to further rationalization of ICM use, based on inventory, is given in Table S1.

Identify frequent flyers

An audit of the institution's 'frequent flyer' CECT and contrast-consuming procedures, and the typical volume of contrast required for each, will identify the main sources of ICM consumption to target. Figure 2 shows the most frequently performed CECT scans at Monash Health, and the volume of ICM consumed by each per day, on audit of data from 1/7/21 to 14/5/22. Reducing the number and contrast volume for these scans will have the greatest impact on ICM consumption.

Strategies to conserve ICM

Strategies to conserve ICM fall into two broad categories, a combination of which should be employed: (A) reducing the number of scans that require ICM through improved triage to CT, using alternative modalities and performing *non-enhanced CT* (NECT), and (B) reducing the dose of ICM used for scans and procedures leveraging modern CT technology. Deciding upon and implementing these measures should be a collaborative effort between radiology, its referring departments and other services which are operationally reliant upon ICM such as cardiology.

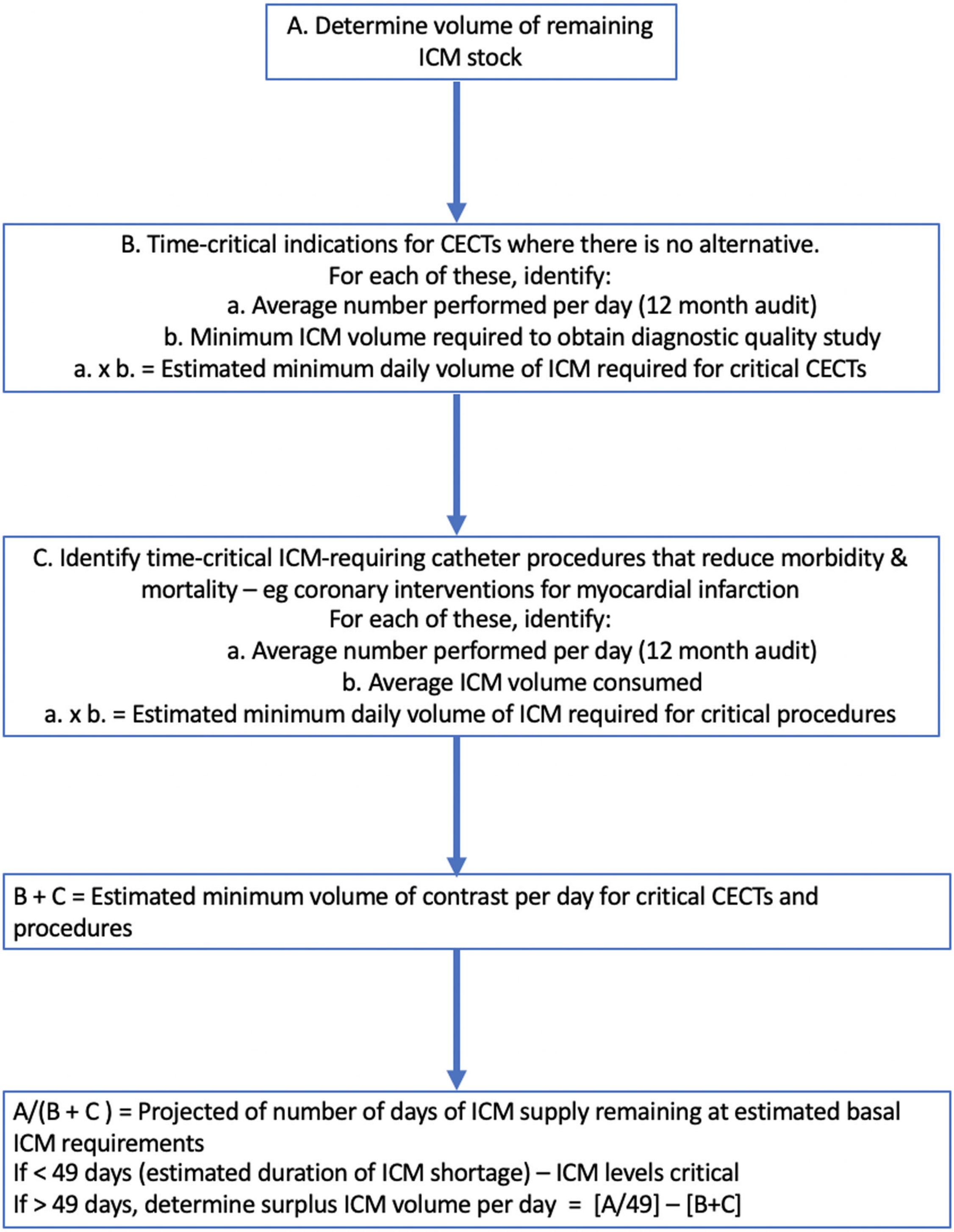


Fig. 1. Approach to determining how long ICM inventory will meet critical demand and calculating surplus.

Table 2. Strategies that we have already employed to reduce ICM consumption

Strategy	Examples
Reduce CECT use through improved triage	Consultant or specialist registrar referrals Use of risk stratification algorithms (e.g. CXR, d-dimer and Wells score for triage to CTPA)
Reduce ICM dose by leveraging CT technology where it does not compromise image quality	CTA head and neck with 50 mL Omnipaque on modern fast multi-detector CT scanners using 80 kVp CTPA with 50–60 mL, reduced further with dual-energy CT
Perform NECT when it is sufficient to address the clinical question	NECT abdomen for suspected appendicitis, diverticulitis and hernia NECT chest for lung nodules, fluid collections

Strategies to reduce CECT scans

Ensure appropriate ordering practices—only scans that will progress patient care are done

The threshold for performing CT has decreased in recent years due to easy access. Most hospitals typically have a CT scanner within, or in close proximity to, the *emergency department* (ED). As EDs grow busier, clinicians have less time for a thorough assessment, and there is increased pressure to discharge patients home. These factors lead to increased reliance on CT instead of clinical assessment to screen and triage patients.

Figure 3 shows the increase in CECT scans ordered by ED. For example, the number of multimodal 'code stroke' CTs performed has increased by 40% in the 12 months to April 2022, without concomitant increase in ECR procedures. The growth has been driven by reliance on CT perfusion to make decisions regarding patient discharge, treatment and further workup.

Improving clinical assessment and triage to CT can reduce the number of unnecessary scans, which squander ICM. Strategies to achieve this include (1) mandating experienced and specialist medical staff oversight of CECT ordering, especially 'frequent flyer' scans, and (2) use of risk stratification and clinical decision support tools to identify low-risk patients in whom CECT can be avoided.

We have mandated:

1. Stroke neurologist consultation for all multimodal code stroke CTs, consisting of NECT brain, brain and neck *CT angiography* (CTA) and brain *CT perfusion* (CTP) brain. These consumed 11% of ICM used for CT between 1/7/21 and 14/522.
2. Surgical registrar or ED physician review to obtain abdominal CECTs, which consumed 26% of ICM between 1/7/21 and 14/522.
3. ED consultant (8 am to 12 am) or senior ED registrar (after 12 am) approval for all CECTs ordered by ED.
4. Triage to *CT pulmonary angiography* (CTPA) based on *chest x-ray* (CXR) and pre-test probability determined using the Wells score in conjunction with d-dimer. Patients with a clear CXR were diverted to a ventilation-perfusion (VQ) nuclear medicine scan (our risk stratification and decision support pathway is shown in Fig. 4).
5. All CECT scans are require radiologist or radiology registrar approval and triage.To ensure buy-in, it is important that these changes be made in collaboration with referring units. Any mandates should also take into consideration the current staff shortages facing

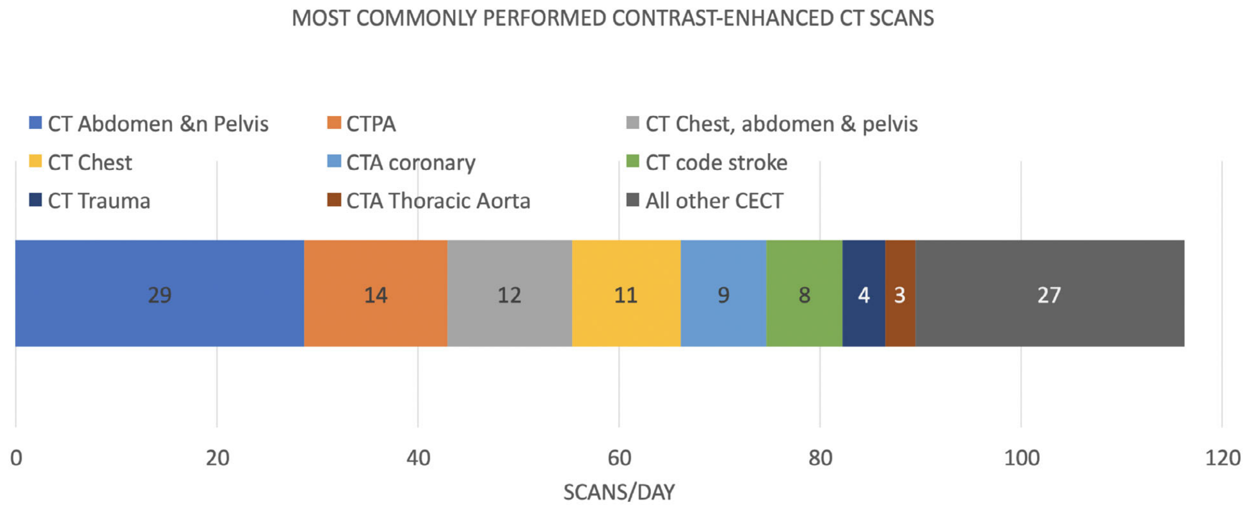
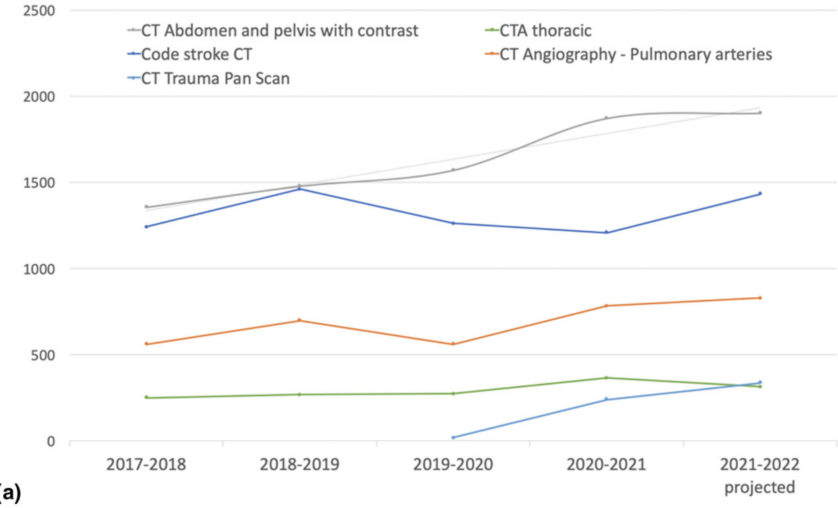
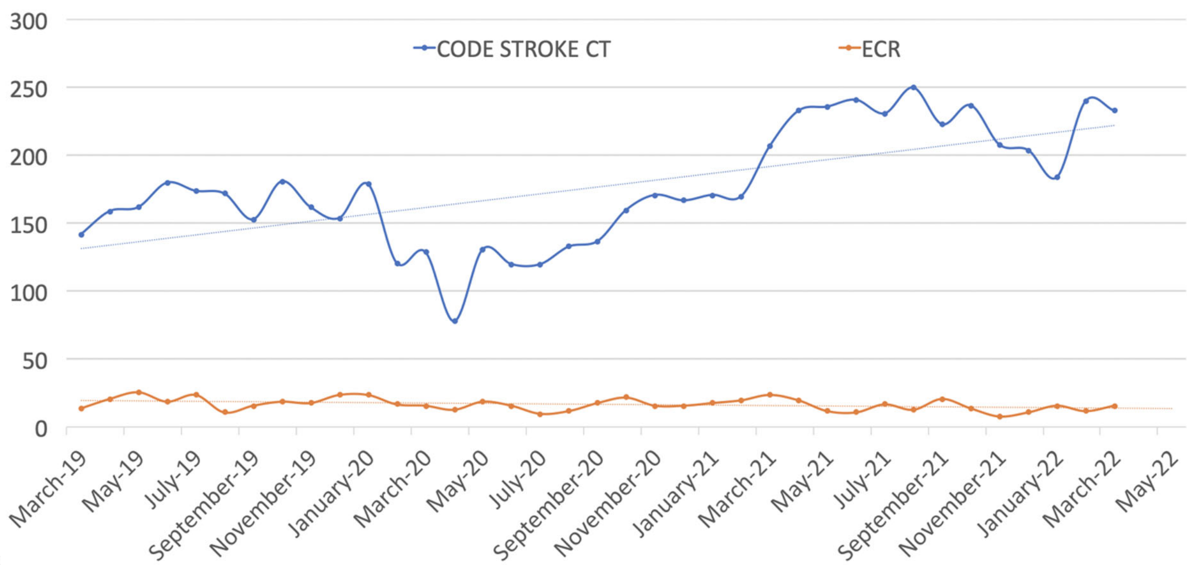


Fig. 2. Most frequently performed CECTs at Monash Health in the period from 1/7/22 to 13/5/22.



(a)



(b)

Fig. 3. Growth in ED CT numbers. (a) Emergency department-referred frequent-flyer CECTs performed per year. The dip in 2020/21 was related to reduced ED presentations during the COVID-19 lockdowns. (b) Number of multimodal code stroke CTs (NECT brain, CTA brain and neck, and brain CTP) and ECR procedures performed per month. While 'code stroke' CTs have increased since the COVID-19-related dip in April 2020, ECR procedures have decreased. The primary purpose of 'code stroke' CT is to identify stroke patients with large-vessel occlusions who may benefit from ECR.

emergency departments and inpatient units. Education and identification of champions amongst referrers will aid successful implementation.

Perform NECT where possible

It is important to ask: does a non-contrast CT (NCCT) answer the clinical question with sufficient accuracy? As shown in Figure 2, abdominal scans are the most frequent CECT. Many of the clinical indications (e.g. bowel obstruction, acute appendicitis, diverticulitis and hollow viscus perforation) for an abdominal CT can be addressed with sufficiently high accuracy on NCCT.[3,4] We have also opted to perform abdominal and chest CTs for minor trauma without ICM. Patient habitus should, however, be considered since a paucity of intra-abdominal fat makes interpretation of NECT challenging. Note that CECT should be performed in trauma patients with level 1 trauma, especially if they are hemodynamically unstable, to detect active bleeding which necessitates life-saving surgery or

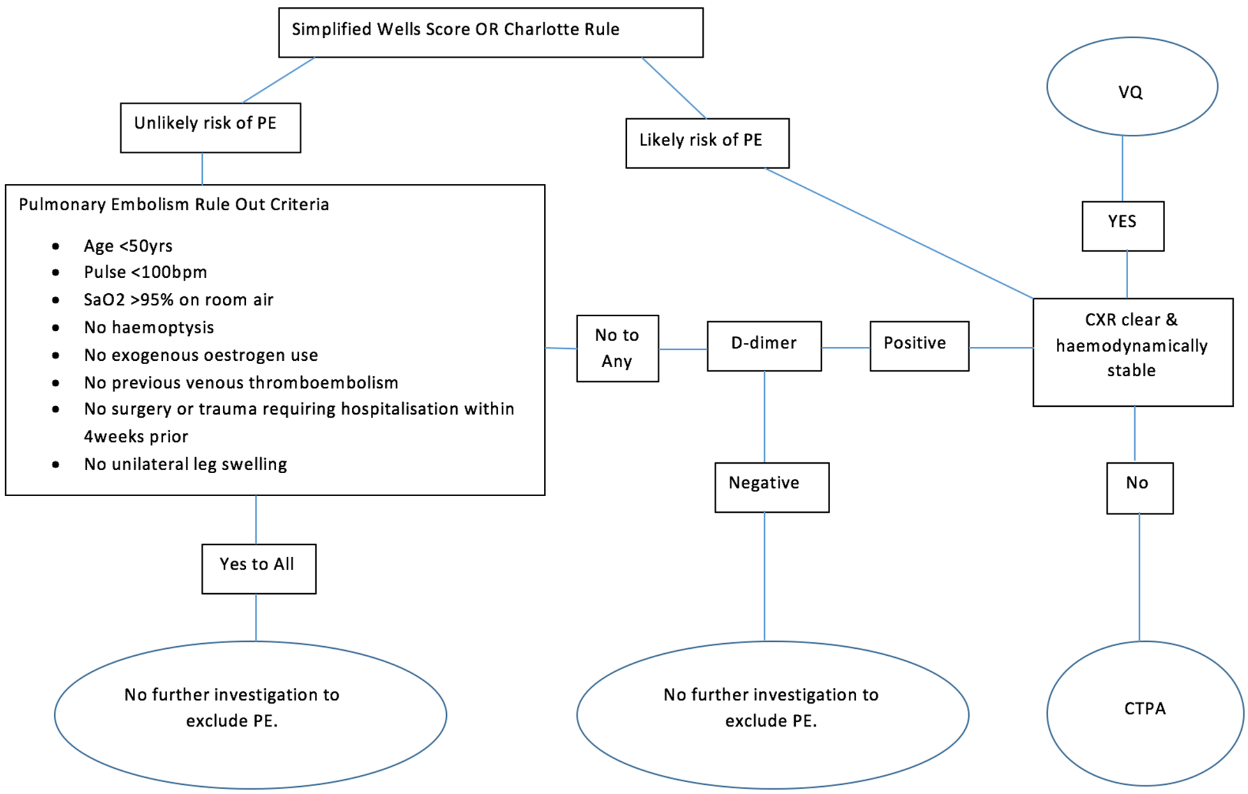


Fig. 4. Risk stratification and decision support pathway for suspected pulmonary embolus.

angioembolization. Many institutions have reduced the usage of positive oral contrast in recent years,[5] however, given the ICM shortage, we have increased oral contrast usage to aid unenhanced abdominal CT interpretation.

Most chest pathologies can be assessed with NECT, for example, lung nodules, interstitial lung disease and mediastinal lymphadenopathy. Oncological diagnostic and staging CTs can also be done without ICM when the probability of liver disease is either low (e.g. lymphoma) or the patient has known metastases at other sites. For example, tracking lung, bone or nodal metastases does not require ICM. However, CECTs should still be performed on all patients who are on clinical trials and require CECT, since performing NECT or delaying the scan may compromise their continued enrolment in the trial (and therefore ongoing treatment).

It is important that radiologists report the limitations of any NECTs which are performed in place of CECT, so that referrers are made aware of reduced sensitivity, for example, for detecting liver lesions and lacerations. In this setting, we have introduced a disclaimer to reports which reads 'This study has been performed during the global iv contrast shortage. Ideally contrast would have been administered but this was not possible due to supply issues. If clinical concerns persists, the study can be repeated once contrast is in stock. If this is time critical, please call a radiologist'.

Divert to alternative modalities

This will depend on access, which will vary depending on each institution's staffing, equipment, expertise and time of day. The ACR provides guidance on appropriate alternatives in their appropriateness criteria.[6]

MRI. Most questions that are answered with a CECT can be equally well or better addressed using MRI due to its superior soft tissue resolution and ability to interrogate tissue physiology. MRI is the superior test for almost all neuroimaging indications. MRI with *diffusion-weighted imaging* (DWI) is the imaging gold standard for detecting stroke, and MR *perfusion-weighted imaging* (PWI) was validated for delineating ischaemic penumbra well before CT. Brain, neck, thoracic, abdominal and limb angiography can be performed using a variety of contrast mechanisms to image flow and vessel lumen: time-of-flight, black blood, contrast opacification, arterial spin label and phase contrast.[7] It is the most sensitive and accurate test for identifying and characterizing liver and pancreatic lesions and can also be used to characterize renal masses and stage bladder tumours.[8–10]

Despite its diagnostic capabilities, MRI is less readily available in the emergent setting, image acquisition is slower than CT, and there is a requirement for safety screening. Multimodal CT, which is faster and easier to access, is therefore more widely used than MRI as first-line imaging for acute ischaemic stroke. MRI with DWI and PWI is, however, feasible in the emergent setting and used to triage stroke patients to ECR at some stroke centres in Europe and the United States.[11,12] We have set up a 6-min stroke protocol and are trialling acute MRI as the first-line imaging modality to screen some stroke patients who are eligible for clot retrieval. Since access to MRI is limited, and acute stroke is a time-critical emergency, this should be a late phase intervention that is considered when ICM supplies are critical. Strategies to overcome the logistical barriers to obtaining a fast MRI should be put in place in advance to minimize door-scan time, including a clear protocol for safety screening and early notification of the MRI team by emergency services. Clear communication of the new workflow, stroke team and MRI *medical imaging technologists* (MIT) engagement, and creation of MRI capacity will be critical to successful implementation of acute stroke MRI.

Paucity of scanners and slow image acquisition are likely to limit the number of MRIs, which can be substituted for CT for non-emergent indications. Diverting patients from CT to MRI will result in an increased workload on already stretched MRI services. Scans will need to be 'squeezed in' at short notice for emergency indications; hence, it is important to prepare for the logistical challenges ahead and create capacity. Strategies to expand MRI scanner capacity include leasing portable MRI units from vendors, utilizing research MRI scanners for clinical work, and running extended hours (even 24/7 utilization). To create staff capacity, institutions with cross-trained *medical imaging technologists* (MIT) can divert these staff from CT to MRI if oncology work is shifted. Targeted education and upskilling of MITs may be required for sites, which have not previously done much body MRI.

Institutions should also pre-emptively order more stock of *gadolinium-based contrast agent* (GBCA) to accommodate the increased demand for contrast-enhanced MRI, including hepatocyte-specific agents to address demand for oncology staging.

An obstacle to appropriate utilization of MRI in Australia is our licensing system, where Medicare rebates can only be claimed for certain indications and on licensed MRI scanners. A consequence is that patients do not get the right test at the right time. This has been the main reason that MRI is not the first-line modality for diagnosing and following up liver lesions in Australia, despite its superiority to CT. The volume of liver work diverted from CT will likely exceed licensed MRI capacity; therefore, either institutions or patients will have to bear the cost, exposing a major fault line in Australian health care.

Nuclear medicine and PET. Nuclear medicine scans can substitute for CECT for suspected pulmonary embolus and myocardial ischaemia. We still advise multiphase CECT (including CTA) for lower gastrointestinal bleeding since it provides anatomical detail, which is necessary for selective arterial cannulation and embolization to treat the bleed. Upper gastrointestinal bleeds should initially be evaluated endoscopically, and if this fails to control bleeding, it is usually possible to proceed directly to catheter angiography without CECT evaluation.

CTPA is the preferred imaging modality for most patients with suspected pulmonary embolus (PE) because of its high accuracy, ability to detect alternative pathologies and lower rate of non-diagnostic or inconclusive studies compared with a VQ scan.[13,14] However, VQ scans are preferred in young and pregnant women because of the lower radiation exposure. Given the shortage of ICM, we have improved access to VQ scans and encouraged its use in patients with suspected PE who are haemodynamically stable and have a clear chest XR. The average daily number of VQ scans that we performed at Monash increased from 3 to 7 (133% increase) in the first 48 h after we started diverting suitable patients from CTPA.

FDG-PET can be used for staging avid tumours and restaging and follow-up post-treatment but spatial resolution and anatomical delineation are poorer than that of CECT, and the requirement for FDG means only a limited number of centres offer this test.

As with MRI, access is a major limitation of nuclear medicine studies, which are typically offered during business hours. Departments may, therefore, need to increase capacity by offering extended operating hours during the ICM shortage. Suppliers of nuclear medicine tracers should also be contacted to shore up inventory to meet the increased demand. Many centres have significant staff shortages amongst nuclear medicine technologists, which may impact the ability to provide an after-hours service.

Ultrasound. Ultrasound is an alternative to CT and MRI for liver and kidney lesion characterization and imaging of neck, abdominal and limb vessels. Contrast-enhanced ultrasound is a valuable first-line investigation for characterizing incidental focal liver lesions detected on ultrasound. By establishing benign characteristics, it can obviate the need for CECT or MRI.[15] Advantages of this technique over both CECT and MRI include that the contrast agent is purely intravascular, and real-time dynamic imaging is used, allowing accurate detection of enhancement and washout.[16] Important limitations are that it is much more time-consuming and labour-intense for radiologists than CT and is highly operator-dependent. A sonographer shortage in Australia also means that access is reduced. Again, the poor Medicare funding of ultrasound and contrast-enhanced ultrasound has limited the growth of this alternate imaging modality, compounding our reliance on CECT.

Deferred imaging

Deferral of imaging should be considered as a last resort and should be limited to low-risk CECTs, such as follow-up CTA on treated aneurysms and long-term follow-up of known benign and long-standing lesions. We have currently deferred outpatient coronary CT angiograms. It is recommended that the decision to defer patient scans is made in consultation with referrers.

Use of alternative contrast agents

Once ICM supplies are critically short, the use of GBCAs can be considered for CT and fluoroscopic and angiographic procedures.[17,18] 3–4 times larger volumes of GBCA are required for CT than MRI due to dilution of available GBCA formulations.[1] Use of GBCA for CT is also not approved by the *Therapeutic Goods Association* (TGA); therefore, any use will be off-label. Consulting your institution's legal department and obtaining informed consent from patients is, therefore, suggested if GBCAs are to be used for CT. Despite recent relaxation of the contraindication to GBCA in patients with renal impairment when 'stable' (macrocyclic ionic) agents are used, caution is advised when using these higher doses for CECT.[19] 1-molar GBCA is preferred over ½-molar agents due to the significantly stronger opacification. Given the larger volumes needed for CECT, costs of GBCA need to be consider. It would be also prudent to review current injection protocols. We found that a lot of injection volumes have been grandfathered in from periods where scanners were slower; hence, a longer bolus was required to ensure that the bolus did not outrun the scanner. Nowadays, the opposite is true; hence, a shorter bolus can be used—provided that the timing is done well, which requires more vigilance by the CT operator.

Direct ICM dose reduction

The ACR has emphasized that we should not sacrifice image quality by using insufficient doses of contrast. That said, we should ask: can the clinical question still be answered with a reduced contrast-load? Modern CT technology can be leveraged to optimize these low-ICM dose studies to identify pathology.

Many CT scan protocols have been transposed to new-generation multi-detector scanners from older scanners without reducing ICM dose to accompany increased speed of acquisition. For example, we have reduced the ICM dose 50%, from 75 mL to 50 mL for both CTPA and brain and neck CTA, and 33%, from 60 to 40 mL, for brain CTP without compromising diagnostic image quality. These ICM dose reductions were also facilitated by reducing the kVp to 80, which is closer to the k-edge of iodine and, therefore, enhances the conspicuity of iodinated contrast. We routinely performed brain CTP at 80 kVp (or even 70 kVp when available) prior to this crisis, but transitioned to also performing CTA with 80 kVp. Reducing kVp can allow ICM to be reduced by up to 50% without compromising diagnostic image quality.[1] This can be done automatically on scanners with automated exposure control. A caveat is that skin radiation dose is increased, and tissue penetration reduced, especially at the shoulder level where more streaks may occur due to photon starvation, particularly if tube current modulation is not available. Dual-energy CT can also be leveraged to generate material-specific iodine maps that further enhance the conspicuity of contrast enhancement and opacification, allowing lower ICM volumes to be used. ICM volume reductions of 50% have been reported with weight-based dosing on dual-energy scanners.[20] The ACR recommends weight-based dosing for CT scans to avoid waste.

A major limitation of these ICM dose reduction strategies is access to dual-energy capable scanners, which consist of <5% of the install base in Australia. Further, the dose reduction which can be achieved while maintaining sufficient image quality depends on CT scanner hardware and software as well as patient weight and habitus. To ensure that diagnostic image quality is maintained, the same approach that has been applied to radiation dose reduction should be employed for ICM volume reduction—namely systematic image review to determine the lowest achievable ICM dose which does not compromise diagnostic capability.

The ACR has also suggested asking the hospital pharmacy department for assistance with repackaging higher volume single-use vials of ICM into smaller aliquots, to facilitate lower dose studies. This is important, since GE has advised that it will manufacture 100 mL vials when production recommences. It explicitly discourages using single-use vials for more than one patient unless proper infection control guidance has been followed, to minimize the risk of iatrogenic infection.

Interim audit of dose reduction strategies

The interventions that we have implemented thus far are (1) improved clinical triage to CECT by mandating consultant or speciality registrar referral, (2) ICM dose reduction for 'code stroke' CT and CTPA, (3) performing NECT for a number of indications that previously required CECT and (4) diversion of suspected PE patients with a normal CXR to VQ scan.

These interventions alone have led to a substantial reduction in CECT numbers within the first 72 h they were implemented, when compared against data from 2022 prior to these interventions. The average daily number of inpatient and ED CECTs performed decreased from 107.9 to 16 (85% reduction). Code stroke CTs decreased from 7.5 per day to 2 and CTPAs decreased from 14.1 per day to 2.3. More data over time are required to determine whether these decreases are significant and sustained. Contrast consumption decreased to 0.71 L/day (vs >10 L/day). The decrease in contrast used for emergency and inpatient scans on the first weekday following is shown in Figure 5.

Unintended consequences

Missed and delayed diagnosis

Major risks of deferring non-critical outpatient CECTs are delayed diagnosis and loss to follow-up. In some cases, the window of opportunity for treatment may be lost. These risks of deferred investigation have already been observed following the early phase of the COVID-19 pandemic during which non-urgent outpatient scans were postponed. We are, therefore, seeing more patients with late presentations of advanced disease. More patients are now presenting to our *emergency departments* (EDs), and they are sicker than ever. The capacity of EDs and hospital wards is exceeded, and elective surgical lists are saturated.

It is also important to note that we have implemented a number of changes, some of which are drastic, including mandating consultant-level referrals, substituting non-enhanced CT for CECT for many abdominal pathologies and reducing contrast dose. Under normal conditions, such interventions are assessed and implemented gradually using evidence-based principles. Instead, rapid adoption was necessitated by the sudden nature of the crisis. The impact of these interventions must, therefore, be closely monitored, and 'course corrections' may at times be warranted to ensure good clinical care.

It remains to be seen whether performing non-contrast CT will lead to missed diagnoses, delayed clinical presentation and patient harm. It is important that radiologists comment on the reduced sensitivity of NECT to avoid falsely reassuring referrers that such diagnoses as liver metastases have been confidently excluded.

Delays in performing alternative tests

Diverting patients from CECT to MRI is likely to lead to an increase in inpatient MRI scan numbers and turnaround times, given that MR scan acquisition is slower and slots are limited. There will be flow-on effects to outpatients with non-time-critical conditions (e.g. lumbar back pain), whose scans may have to be deferred accommodate time-sensitive oncology work, potentially leading to delayed pain management and prolonged impairment of quality of life for such patients. MRI waitlists, which are already lengthy due to COVID-related decreases in workflow efficiency and increased demand, are likely to become even longer.

Positive outcomes

The ICM shortage has galvanized the radiology community to action on introducing ICM-saving measures, providing an opportunity to review and modernize CT protocols. We are also more fully utilizing dual-energy CT, leveraging its ability to produce iodine-selective images to reduce ICM dose. Finally, this crisis has forced us to prioritize those scans, which are truly needed for the progression of patient care. Early data indicate that

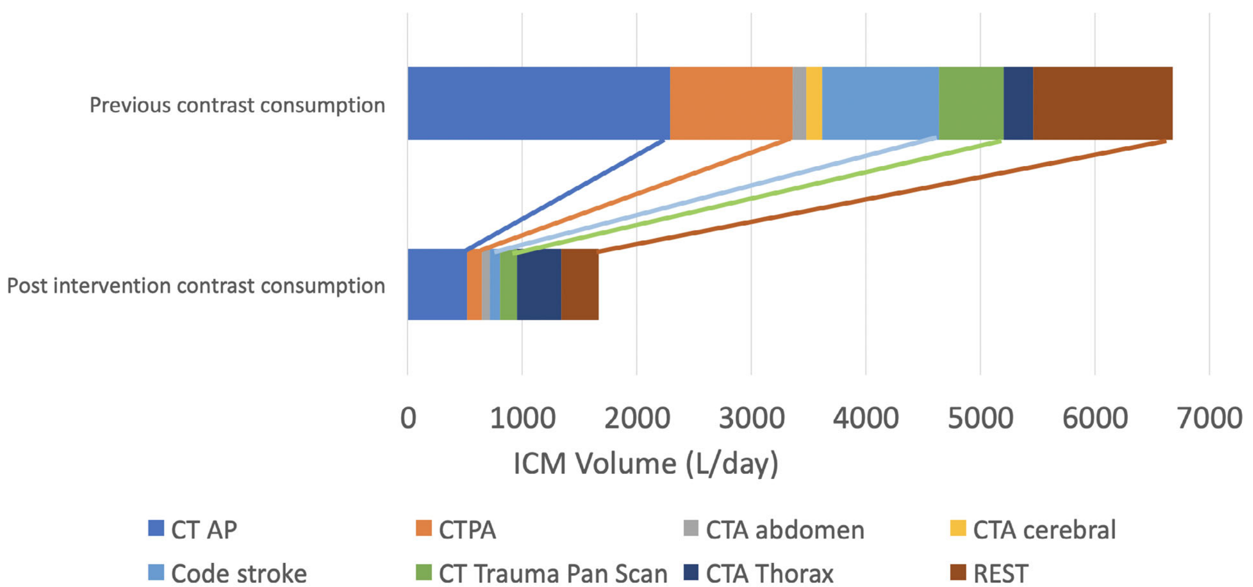


Fig. 5. Reduction in ICM volume used for ED CECTs on the first weekday after the introduction of the following interventions: ED consultant-level referrals to CECT, risk stratification for CTPA (including diversion to VQ scan for patients with normal CXR), non-contrast CT for several abdominal indications and minor trauma, ED consultant or surgical registrar assessment prior to abdominal CECT and ICM dose reduction for 'code stroke' CT and CTPA.

increasing the threshold for performing CECT by insisting on consultant or specialist registrar-level assessment and referral has not only decreased the number of scans performed, it has also increased diagnostic yield. We performed 12 'code stroke CTs' for 3 clot retrievals (4:1 ratio) in the past 5 days, while in the preceding 12 months, the ratio was 12.3:1. This may, therefore, be the hand-brake that was much needed to slow the inexorable growth in CT.

Communication

This crisis has necessitated many changes, some of which are drastic, over a very short period. We have found that this can cause confusion and lead to incorrect implementation of changes. Clear and consistent communication of changes, clearly defined roles and responsibilities (including points of contact for making protocol changes) and engagement of MITs and radiologists are all key to the successful implementation of ICM conserving strategies.

Conclusion

We have provided guidance on how to quantify ICM requirements and strategies to rationalize its use that are tailored to the Australian radiology context. Key messages are that (1) frequently ordered CECTs should be targeted for rationalization, (2) triage to CECT should be improved by ensuring consultant or specialist registrar referrals, and (3) the use of risk stratification algorithms, and non-contrast CT should be used whenever it is possible to address the clinical question. Alternative modalities, in particular nuclear medicine and MRI, should be considered if access allows it and diagnostic sensitivity is not compromised. Institutions must plan for the worst-case scenario of a lengthy scarcity of ICM, create capacity in alternative modalities and ensure adequate supplies of MRI contrast and nuclear medicine tracers to address increased demand. We hope that these suggestions will help your department weather this crisis and maintain good patient care in these challenging times.

Acknowledgement

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Ethical approval

Collection and dissemination of data provided in this review was approved by the local institutional review board, which granted a waiver of written consent based on the retrospective study design and anonymization of all data.

Data availability statement

The authors are happy to share their data, as well as CT and MRI protocols upon reasonable request.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table S1 Stratified approach to ICM conservation based on surplus of ICM inventory relative to difference between normal daily operational needs and basal daily requirements to meet critical needs until July.

