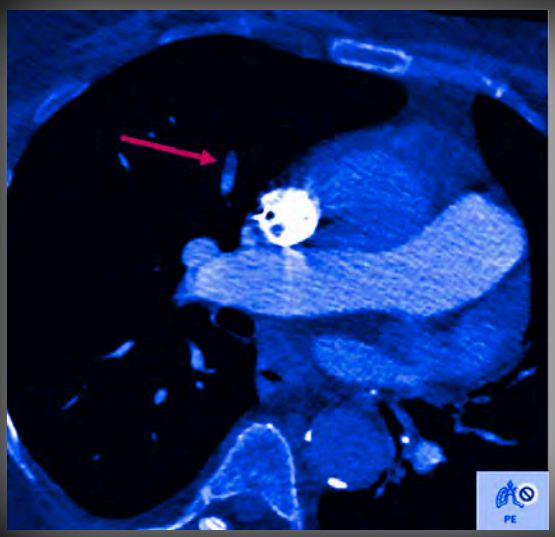
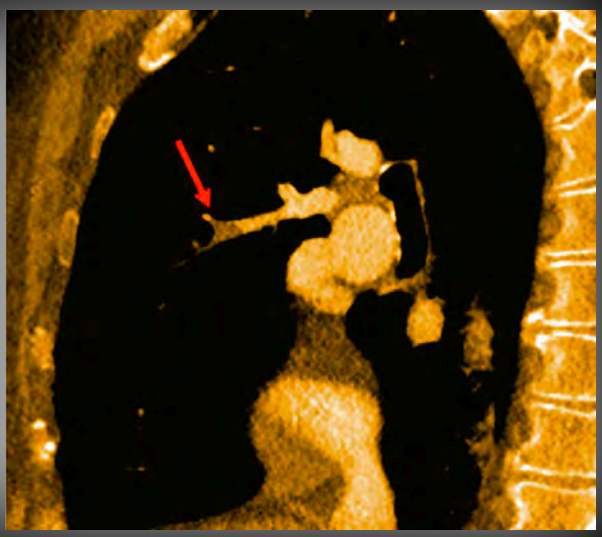
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CT for Pulmonary Embolism: Value of Artificial Intelligence Techniques

Charles S. White, MD; Allison Herring, MD

Artificial intelligence (AI) is increasingly being used to enhance the detection and assessment of pulmonary embolism on CT pulmonary angiography and other contrast-enhanced CT examinations. This review examines the evidence supporting AI applications in pulmonary embolism detection, risk stratification, study prioritization, and workflow efficiency, including their potential to reduce missed diagnoses and interpretation turnaround times.

Thyroid Artery Embolization for Thyroid Nodules, Goiter, and Graves Disease

Nicholas Prus, BS; Layth Alkhani, BS; Mikin V. Patel, MD; Juan Camacho, MD; Osman Ahmed, MD

Patients who are poor surgical candidates, or who wish to avoid surgery, may have thyroid artery embolization (TAE) as an option for treating symptomatic benign thyroid nodules, goiter, and selected cases of Graves disease. In this review, the authors discuss patient selection, procedural techniques, clinical outcomes, and complications, while highlighting evidence of substantial thyroid volume reduction and improved thyroid function in selected patients.

From Anatomy to Perfusion: Point-of-Care Contrast-Enhanced Ultrasound in Acute and Emergent Care

Tobias Kummer, MD; Jaydev K. Dave, PhD; Priscilla Machado, MD

Contrast-enhanced ultrasound (CEUS) offers a valuable tool for acute and emergency imaging by providing real-time, bedside assessment of tissue perfusion and vascular integrity. This review explores its applications in detecting ischemia, active hemorrhage, and inflammation, including solid-organ injuries, vascular complications, acute cholecystitis, and inflammatory bowel disease. With no ionizing radiation or nephrotoxic contrast agents, CEUS is particularly useful for serial monitoring, pediatric patients, and those with renal impairment, serving as an adjunct or, in selected cases, an alternative to CT.

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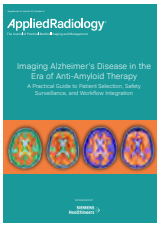
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On the cover: Image adapted from Figure 2 of 'CT for Pulmonary Embolism: Value of Artificial Intelligence Techniques,' by Charles S. White, MD; Allison Herring, MD. Cover design by *Applied Radiology.*

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EDITORIAL

Radiology's Place in Clinical Care

Nina S. Vincoff, MD



Nina S. Vincoff, MD, is the Editor-in-Chief of *Applied Radiology*. She is Executive Medical Director of the Radiology Care Division at Prisma Health and Clinical Associate Professor of Radiology at the University of South Carolina School of Medicine Greenville. She can be reached at nina@appliedradiology.com

It is November again, and many of us will soon be heading to Chicago for RSNA. This year's RSNA theme, "At the Center of Care," reflects the evolving role of radiology and radiologists in care delivery. It also captures some of my hopes as I consider the future of our specialty: not at the margins of a patient's journey, but increasingly at its center.

Imaging volumes are growing steadily, with no sign of slowing. A recent *JACR* study found a 31% increase in examinations read at participating facilities between the first quarters of 2018 and 2024, an average annual growth rate of 4.6%.[1]

As radiologists, we often discuss this growth in terms of staffing, worklists, turnaround times, and productivity. Those pressures are real. But the volumes also tell us something important about how the practice of medicine is changing and our place in the future of clinical care. In a world that relies increasingly on imaging for clinical decision-making, I believe that we have an opportunity, and an obligation, to play a more central role in patient care.

Traditionally, the radiologist's job has been to answer a clinical question. A patient develops a symptom, a clinician orders an examination, and we help explain what is wrong. That component of our work remains essential.

Increasingly, however, we enter the care pathway earlier, identifying risks and findings before anyone knows to ask about them. A CT performed for abdominal pain may reveal low bone density and lead to lifestyle changes or medication to reduce fracture risk. Coronary artery calcification on a chest CT or breast arterial calcification on a mammogram may be a patient's first sign of cardiovascular risk. These findings can open the door to prevention, even when they have little to do with the reason the examination was ordered. In such cases, imaging becomes more than an answer to a question; it becomes the starting point for a new conversation and a new care pathway.

Across the many examinations we interpret, these opportunities give radiology a growing role in population health. We can help identify patients who may benefit from further evaluation, surveillance, or preventive care.

To truly realize our potential, we will need to rethink our responsibilities. As our role shifts toward risk identification and early disease detection, our value cannot be defined by making an accurate diagnosis and issuing a report. Instead, it will be measured by whether our findings are understood, communicated, and translated into the right care. That does not mean radiologists must manage every subsequent step, but it does mean we should help create dependable pathways.

Consumer-driven imaging introduces another change to our place in care delivery. This issue's discussion of whole-body MRI explores patients' growing interest in understanding their health before symptoms develop. Some come to us without a specific clinical question, hoping imaging will reveal whether there is anything they should know. These encounters will change the relationship between radiologists and patients, making us visible clinical partners rather than unseen interpreters.

Rising imaging volumes and new care models present real challenges, but they also create an extraordinary opportunity for our specialty. If we respond only by reading faster, we may miss the larger transformation taking place. If, rather, we commit to clearer communication, stronger follow-up systems, and closer collaboration with patients and clinical colleagues, we can help shape care well beyond the reading room. By accepting that challenge, radiology and radiologists can truly be at the center of care.

Reference

1) US radiology imaging and workforce volumes 2017-2024: an analysis of 46.4 million imaging examinations from 167 radiology facilities. J Am Coll Radiol. 2026;23(6):1041-1048.

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CT for Pulmonary Embolism: Value of Artificial Intelligence Techniques

Charles S. White, MD; Allison Herring, MD

Abstract

Pulmonary embolism is a frequently occurring, often life-threatening condition. CT pulmonary angiography (CTPA) is the leading imaging technique used to establish its presence. Interpretation of CTPA requires assessment of a large volume of images, a process that can lead to overlooking the diagnosis as well as reader fatigue. Artificial intelligence (AI) tools can assist the radiologist by improving the performance of CTPA and are increasingly being applied in clinical practice. This review describes the case for several uses of AI algorithms for CTPA and their application to clinical practice at our institution.

Introduction

Pulmonary embolism (PE) remains a serious condition and is considered in some reports to be the third most common cause of death worldwide.[1] Although many cases are mild or subclinical, mortality in more severe instances can reach as high as 35%.[2] In the past 2 decades, CT pulmonary angiography (CTPA) has overtaken ventilation-perfusion scanning and invasive angiography as the favored imaging technique to establish the diagnosis of PE, accounting for approximately 90% of such examinations in the United States.[3] CT scanners have become widely available in emergent and nonemergent settings. CTPA can be performed rapidly with minimal discomfort to the patient. CTPA has a reported pooled sensitivity and specificity of 0.94 and 0.98, respectively.[4]

The diagnosis of PE on CTPA relies primarily on the identification of a filling defect within the intravenous contrast column. Ancillary findings include the presence of a wedge-shaped peripheral density in the lung indicating pulmonary hemorrhage or infarction.[5] Evidence of increased risk in patients with PE on CTPA includes findings of right ventricular (RV) dysfunction, such as RV enlargement relative to the left ventricle (LV), flattening of the interventricular septum, and reflux of contrast material into the inferior vena cava.[6,7]

Interpretation of CTPA for PE requires analysis of hundreds of thin-section CT images, as well as multiplanar reconstructions. The extent of PE varies widely, ranging from saddle emboli to isolated subsegmental emboli. A recently published classification system, PE-RADS, categorizes PE based on the centrality of embolus location and other findings on CTPA and MRI.[5]

Increasing imaging volumes amid a shortage of radiologists have created pressure to interpret studies more rapidly.[8,9] Additional challenges include the small size and subtle appearance of some pulmonary emboli and variability in CT technique, including intravenous contrast administration and image acquisition parameters.[5] These factors may increase the likelihood that pulmonary emboli will be overlooked by radiologists.

Artificial intelligence (AI) tools hold the prospect of assisting the radiologist at several levels. They may suggest the presence of PE that might otherwise remain undetected by the radiologist and assess PE severity. AI tools may also assist in prioritizing the reading order of CTPA studies such that those with findings suspicious for PE are evaluated immediately. More broadly, AI approaches may permit a reduction in reading time for CTPA studies that can lead to more efficiency and less radiologist burnout.

Here, we discuss the fundamentals of AI and its uses in the context of CTPA, including the basics of AI technology and research into its application of CTPA. We also describe its potential value in a clinical context (Table 1), based on our experience over a 4-year period.

Affiliation: University of Maryland School of Medicine, Baltimore, Maryland.
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Technical Aspects of AI on CTPA

AI tools have advanced rapidly across multiple areas of medical imaging. In PE detection, AI applications increasingly incorporate machine learning and deep learning methods trained on large CTPA datasets to improve diagnostic accuracy. Preprocessing may be performed to isolate the pulmonary vasculature. In one approach, Digital Imaging and Communications in Medicine data are used to generate a lung mask and a 3-dimensional (3D) bounding box encompassing the thorax. The resulting images are then resized and processed as a series of image slices.

A deep learning model based on a convolutional neural network (CNN), such as ResNet-50, is subsequently applied to extract imaging features associated with PE. The model undergoes training and validation using CTPA datasets to optimize its performance. Ultimately, the model generates a probability score indicating the likelihood of PE. Results may be displayed as probability values, heat maps, or notification icons triggered when a predefined threshold is exceeded.[9-11]

The stand-alone diagnostic accuracy of CNN-based AI algorithms for detecting PE on CTPA was evaluated in a systematic review and meta-analysis by Soffer et al.[12] Seven studies comprising 36,847 CTPA examinations met the inclusion criteria. The pooled sensitivity was 88% (95% CI 80.3-92.7%), and the pooled specificity was 86% (95% CI 75.6-92.4%). The analysis included studies published through 2020. A more recent meta-analysis of 6 studies comprising 9101 CTPA examinations reported higher pooled sensitivity and specificity of 93% (95% CI 88-95%) and 98% (95% CI 93-100%), respectively.[13]

Applications of AI for CTPA and Other CT Studies

AI as a Second or Concurrent Reader for CTPA with the Radiologist

Based on current FDA requirements, AI algorithms cannot act as a primary interpreter of CTPA studies. Several studies have assessed the performance of radiologists for reading CTPAs vis-à-vis AI techniques, showing benefit for the latter over traditional radiologist reads (Figures 1, 2). One study of 1202 patients who had a PE prevalence on CTPA of 15.8% compared AI tools with emergency radiologists. The AI algorithm had superior sensitivity and negative predictive values (92.6% vs 90%; 98.6% vs 98.1%, respectively), whereas radiologists had better specificity and positive predictive value (99.1% vs 95.8% and 95% vs 80.4%, respectively). However, poor-to-average CTPA image quality decreased the advantage for radiologists and artifacts can be an issue (Figures 3, 4). Nearly 70% of radiologists agreed that AI increased their diagnostic comfort, suggesting the value of AI as a safety net for radiologists.[14]

A recent study that used real-time adjudication between radiologists and an AI algorithm in 32,501 CTPA studies demonstrated 97.8% concordance between the 2. In instances of discordance, adjudication favored the radiologist in 88.7% of cases.[15] Another report of 3316 CTPA studies that involved either a radiologist or radiologist trainee showed significantly higher sensitivity and specificity for the AI tool (96.8% vs 91.6% and 99.9% vs 99.7%, respectively).[16] The percentage of radiology trainees in this study was not stated.

A 3rd study used a sequential approach in which CTPA studies were interpreted by radiologists alone and later by radiologists with the assistance of an AI tool, which demonstrated a nonsignificant increase in sensitivity for PE detection (97.6% to 98.6%) and decrease in PE miss rate (12.3% to 6.1%). However, differences in composition between the initial and follow-up radiologist groups that performed the study may have impacted the results.[17]

The benefit of AI may be greatest among radiology trainees. In a study of 207 patients with suspected acute PE evaluated on CTPA, the sensitivity of PE diagnosis improved from 81.7% to 93.5% after using an AI algorithm. The concordance in interpretation between residents also improved significantly.[18] A smaller study among junior trainees showed an increased sensitivity from 83% to 96% for diagnosis of PE on CTPA using AI.[19]

AI in the Detection of Incidental PE on CT

Incidental pulmonary embolism (IPE) is estimated to occur in 1.3-2.6% of patients undergoing contrast- enhanced chest CT, and AI may be of use in such instances (Figure 5).[20,21] In a retrospective study involving 3003 conventional contrast-enhanced CT scans in which AI was utilized, AI showed significantly lower positive predictive value and specificity compared with radiologist readers, 86.8% vs 97.3%, and 99.8% vs 100.0%, respectively, and nonsignificant differences in sensitivity and negative predictive value, 82.5% vs 90.0%, and 99.8% vs 99.9%, respectively. AI detected 4 instances of PE that were overlooked by radiologists based on their reports. In a look-back study involving 1892 enhanced chest CT or chest/abdomen CT scans in 1069 patients with underlying malignancy, IPE was detected in 4% after application of AI, of which only 0.8% were initially reported.[22]

A study that assessed the effect of interval implementation of AI tools in patients with IPE in over 4000 contrast-enhanced body CT examinations, the vast majority of which were chest CTs, showed that the addition of AI to the workflow significantly increased sensitivity from 80.0% vs 96.2% without a change in specificity (99.9% vs 99.9%).[23] Research has also demonstrated the value of AI techniques when applied to IPE on contrast-enhanced abdominal CT. In a study of 5515 contrast-enhanced abdominal CTs, AI tools identified 19 false-negative examinations (0.34%) overlooked on initial interpretation.[21]

IPE occurs in approximately 1.1% of patients undergoing cardiac CT angiography (CCTA).[24] In one study of 1534 CCTA scans, 22 (1.4%) were found to have IPE after analysis with AI. 45% of these IPEs were overlooked on initial

Figure 1. Extensive pulmonary embolism (PE) noted by the radiologist and deemed positive by the artificial intelligence (AI) tool. CT axial and coronal maximum intensity projection mediastinal images (A and B) demonstrate multifocal central PE (arrows) with a corresponding positive AI PE result (orange circle). CT axial image at the level of the heart (C) shows dilatation of left ventricle (LV), rendering assessment of the RV:LV ratio ineffective, but there is substantial leftward deviation of the atrial septum that was new from baseline suggesting right heart strain. Angiography (D) demonstrated a filling defect (dotted arrow) and elevated pressures that decreased following thrombectomy. RV, right ventricle.

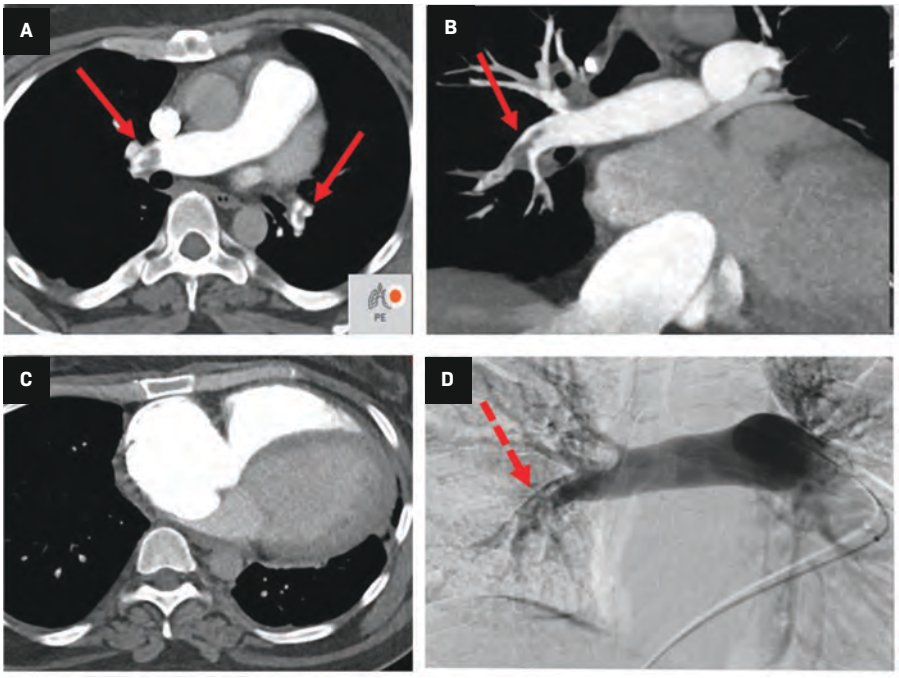
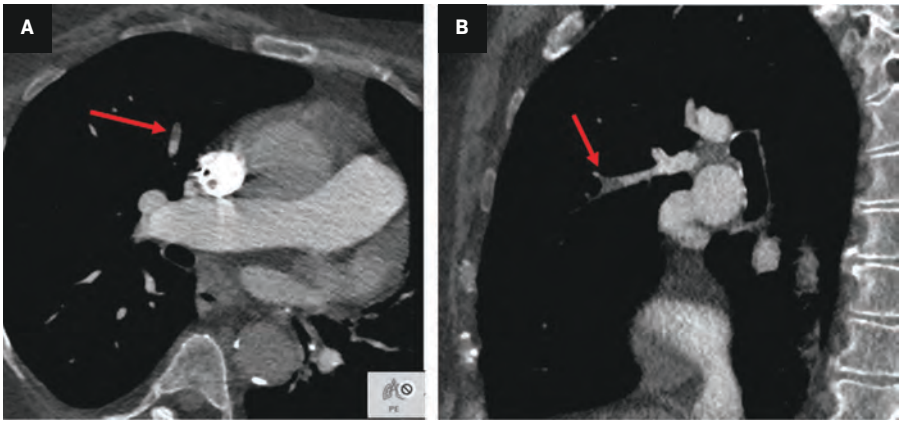


Figure 2. Subsegmental pulmonary embolism (PE) overlooked by the artificial intelligence PE tool (A). CT axial and sagittal mediastinal images (B) demonstrate a subsegmental filling defect (arrows) in the anterior segment of the right upper lobe. The interpreting radiologist correctly identified this small PE.



interpretation, all involving the segmental and subsegmental branches.[25]

It is important to note that even in areas where benefit for AI tools can be shown in the assessment of IPE, the downstream clinical value in terms of morbidity and mortality remains uncertain. For example, in the CCTA report described above, RV dysfunction portending an unfavorable prognosis was not found in any study in which IPE was missed. Graeve et al analyzed the impact of improved detection of IPE by AI techniques on 90-day mortality. In comparing cohorts before and after the implementation of AI, they found a decrease in missed IPE from 50% to 7.1%, without a significant change in 90-day mortality.[26]

Automation in the Assessment of PE Severity

Common CT-based approaches to assess the severity of PE are findings of RV dysfunction based on an increased RV/LV diameter ratio and thrombus burden based on vascular obstruction scores of which the Qanadli score is a widely used example.[27] Djahnine used a database of 1386 CTPA examinations with image- and pixel-level annotations. The RV/LV diameter ratio was based on an AI 3D cardiac segmentation model and computer distance maps (distance to nearest boundary). The efficacy of the vascular obstruction score was obtained by plotting the Qanadli scores against the total volume of blood clots. Both indices showed good results on regression analysis, with $R^2 = 0.723$ (95% CI 0.668-0.766) for RV/LV diameter and $R^2 = 0.717$ (95% CI 0.668-0.760) for the Qanadli score, respectively.[28]

In a recent clinical study, 408 patients had positive CTPAs, 266 (65%) of whom demonstrated an increased RV/LV ratio (>1) determined based on an AI algorithm.[29] In this enriched population, patients with an increased RV/LV ratio were significantly more likely to be admitted to the intensive care unit and had a higher rate of vascular intervention. However, the 30- and 90-day mortality was the same for patients with increased and normal RV/LV ratios.

Prioritization of CT Studies

With the increasing workload of radiologists, backlogs for certain types of studies are becoming more common. Included in this category are routine contrast studies that have the potential to demonstrate PE, particularly in oncology patients who are known to have an elevated risk of IPE. One pooled analysis identified IPE in 3.4% of patients.[30]

AI-triage techniques have the capability to analyze the enhanced CT scans in the queue for IPE and provide notification that allows the study to be prioritized for interpretation. One study that evaluated

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Figure 3. Patient with suspected pulmonary embolism (PE) and discrepancy between the radiologist and artificial intelligence (AI) PE tool. CT axial mediastinal window image (A) shows a possible filling defect (arrow) in a posterior segmental right lower lobe pulmonary artery interpreted by the radiologist as positive for PE. The AI PE tool identified no PE. CT axial lung image (B) shows substantial motion at the same level as the filling defect. Leg US study was negative for deep vein thrombosis and follow-up CT pulmonary angiography showed no PE. The original interpretation was deemed to be a false-positive read by the radiologist.

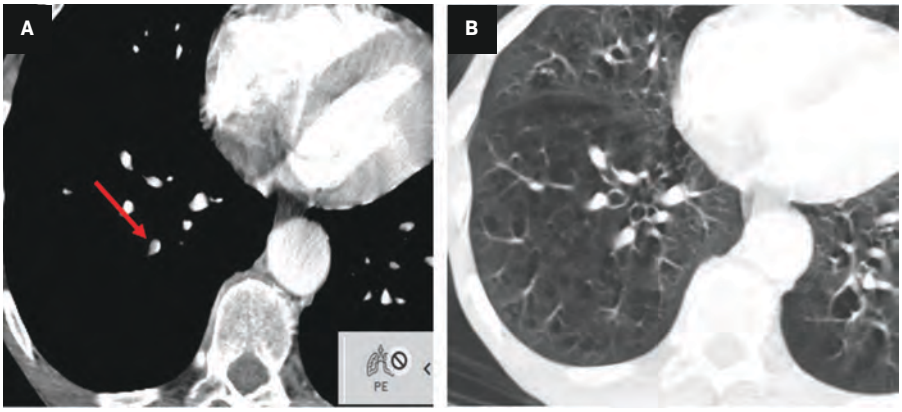


Figure 4. False-positive artificial intelligence (AI) pulmonary embolism (PE) result. CT axial mediastinal image (A) demonstrates apparent filling defects in the right lung (arrow) that the AI PE tool determined was positive. Coronal CT image (B) shows that the filling defects are caused by debris in a chest tube, mimicking PE. This error occurred early in our AI PE experience. Subsequent modifications of the AI PE algorithm make this error less likely.

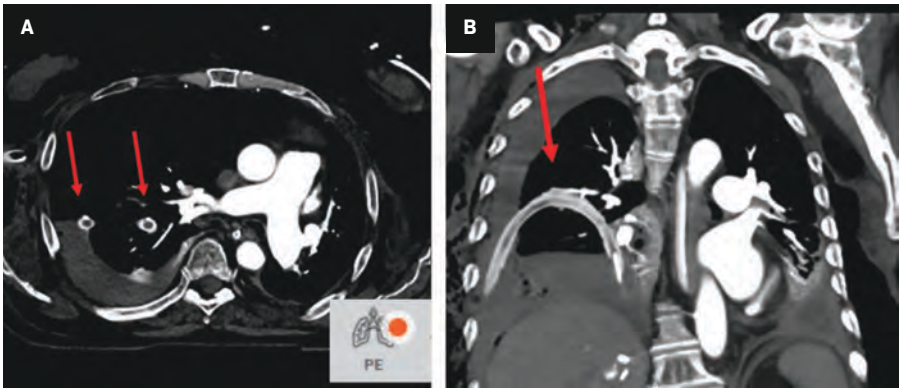
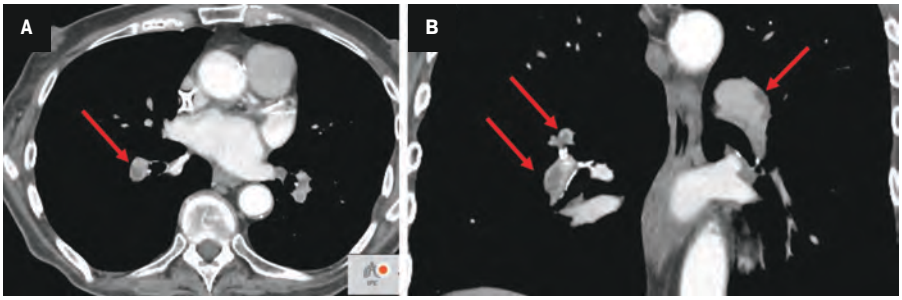


Figure 5. Patient with gastric cancer who was noted to have incidental pulmonary embolism (PE) with the artificial intelligence PE tool on a nondedicated CT study. CT axial and coronal mediastinal images (A, B) demonstrate filling defects within several pulmonary arteries (arrows). Note the contrast attenuation is much higher in the aortic circulation than the pulmonary circulation.



this potential application assessed 11,736 CT scans in 6447 oncology patients.[31] The AI algorithm facilitated a reduction in detection and notification time to a median of 87 minutes from 7714 minutes without the use of AI tools in the routine setting. The IPE miss rate of radiologists in the study decreased from 44.8% to 2.6% with AI assistance.

A second prioritization study performed in a clinical setting without a significant backlog involved 2501 examinations of 2197 patients.[20] Comparison of turnaround times before and after application of AI technology showed prioritization of 12.7% of studies in which AI detected PE. The mean report turnaround time decreased to 47.6 from 59.9 minutes, accounted for by a decrease in wait time rather than radiologist reading time. The effect was only noted for CT studies labeled as routine.

Reported Turnaround Time

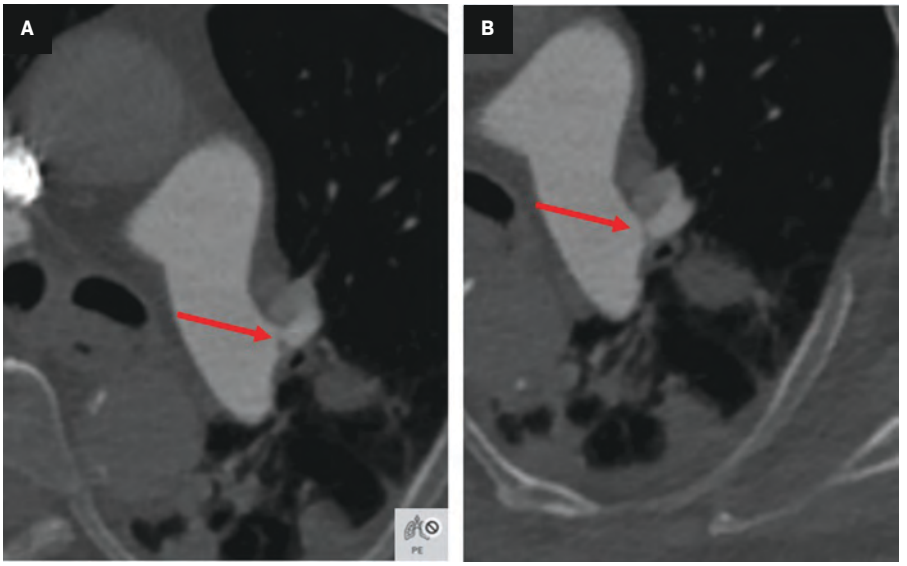
One study of 11,252 CT studies evaluated the pre- and post-AI implementation turnaround times for CTPA studies.[32] The PE-positive rate increased from 13.3% in the earlier cohort to 16.2% with the use of AI tools. During work hours, there was a significant decrease in turnaround time from 68.9 hours to 46.7 hours after AI implementation. However, the time-savings during off-hours were not significant (44.8 hours vs 42 hours).

Savage et al also evaluated report turnaround times before and after AI implementation in a setting without AI-based study prioritization.[23] Overall report turnaround time decreased slightly, from 66 to 64.3 hours, although the difference was not statistically significant. However, the wait-time component decreased significantly, from 39.9 to 28.8 hours.

Chronic Pulmonary Embolism

The literature on the use of AI for detecting chronic PE on CTPA remains limited (Figure 6). Abdulaal et al conducted a systematic review that identified 5 studies meeting the inclusion criteria.[33] These studies evaluated various manifestations of chronic PE, including vascular abnormalities such as webs, stenoses, and occlusions, as well as parenchymal findings such as mosaic attenuation and pulmonary infarction.

Figure 6. Thrombus at the origin of the left upper lobe pulmonary artery overlooked by the artificial intelligence (AI) pulmonary embolism (PE) tool. Thin-section axial mediastinal images demonstrate a filling defect (A, B, arrows) at the origin of the left upper lobe pulmonary artery not identified by the AI PE tool. The web-like appearance of this density suggests that it may reflect chronic PE. Most current AI PE tools are not trained to recognize chronic PE.



One study reported a sensitivity of 62% and specificity of 63% for detecting chronic PE, although the number of CTPA examinations evaluated was not reported.[34]

Commercial AI Tools

Four commercially available AI tools for PE detection include Aidoc, Viz.ai, Avicenna.AI, and RapidAI. These platforms offer varying capabilities and limitations. Depending on the platform, reported benefits include rapid triage of suspected PE, streamlined communication and care coordination, detection of incidental PE, and automated calculation of the RV-to-LV diameter ratio.

Limitations and Challenges

Drawbacks of AI PE include false-positive results due to structures that mimic PE, motion artifact, and suboptimal contrast. False-negative results are often due to small emboli in distal vessels that are not identified by the algorithm.

Chronic PE is also a cause of false-negative results because AI algorithms have not been optimized to detect the imaging manifestations such as webs and mural location.[33] Automation bias, the tendency to overly rely on a machine-generated output, can be an issue in stressful, work-heavy environments. AI has been tested in research settings and some clinical settings, but its generalizability to the broader clinical world has not been fully tested.

Use of AI for Pulmonary Embolism on CT in a Clinical Setting

The University of Maryland Medical System consists of 13 hospitals, 9 urgent care centers, and over 150 other care locations across Maryland. Most of the hospitals implemented AI tools for cross-sectional imaging on a routine basis beginning in November 2022. The studies are read by fellowship-trained cardiothoracic radiologists and general radiologists. Prior to that time, researchers at the University of Maryland had published several studies on the use of computer-aided detection algorithms to aid in the diagnosis of PE on cross-sectional imaging.[35-37] The following describes our institutional experience with AI PE.

The Aidoc AI tool is used at our institution to evaluate contrast-enhanced CT examinations of the chest and abdomen. The tool is integrated into the picture archiving and communication system and is accessible through a separate icon when a study is opened. A positive finding is indicated by a flashing, rounded orange icon that can be positioned within the workspace according to the interpreting radiologist's preference.

The general impression among radiologists in our practice is that the AI tool for PE detection is highly effective, particularly compared with other AI tools currently used in the department. In our experience, the tool demonstrates high accuracy, even for subsegmental pulmonary emboli, with relatively few false-positive and false-negative results. Most observed errors involve subtle findings.

Several radiologists use the AI tool concurrently with CTPA interpretation, reviewing the AI results while interpreting the examination. When using this approach, it remains important to review the multiplanar reformatted images. Concurrent use has not been associated with an apparent increase in reporting time in our practice. Some radiologists believe it reduces interpretation time, although this has not been formally evaluated.

Abdominal radiologists in our practice have also noted the value of the AI tool for detecting IPE at the lung bases on contrast-enhanced abdominal CT examinations. We have not implemented AI-based prioritization of studies with suspected IPE, in part because our practice does not currently experience a substantial interpretation backlog. However, this capability may be useful during off-hours, when elective CT examinations are typically interpreted the following morning.

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Table 1. AI Applications in Pulmonary Embolism Detection: Strength of Evidence and Clinical Utility

APPLICATION	EVIDENCE STRENGTH (1–4)	CLINICAL UTILITY
CTPA PE R/O	3	Detection/confirmation in a large volume of images
Incidental PE	3	Unexpected PE identification in lower IV contrast studies
Severity	2	Quantifies/standardizes RV/LV and clot burden scoring
Prioritization	2	Tags positive studies in a busy work environment — decrease turnaround
Report turnaround	2	More rapid delivery of results to the clinical team
Chronic PE	1	Earlier intervention to restore normal pulmonary artery pressures

Trainees are permitted to use the AI tool but are instructed to formulate their interpretations based on the CT images before reviewing the AI results. Many have elected not to use the tool during their initial interpretation.

Future Directions

The recent release of the PE-RADS classification presents an opportunity to more closely integrate AI PE, including severity scoring and detection of right heart strain with this new system, facilitating an automatically generated PE-RADS score and providing improved standardization for reporting, quality improvement, and research.[5] Current models have limited capability to detect chronic PE.[33] Because 1-5% of patients with acute PE ultimately develop chronic PE, often with significant clinical consequences, automated detection of chronic PE would be advantageous.[38] Another potential application to consider is the use of AI PE to determine the risk of recurrence. Finally, the use of multimodal AI modeling that allows integration of other data from the electronic health system, including clinical and other imaging data, may provide improved clinical risk stratification and workflow efficiency.

Conclusion

Substantial advances have been made in the application of AI to the detection and risk assessment of PE, as well as the prioritization of contrast-enhanced CT examinations. A growing body of research supports the utility of AI in several areas, including detection of acute and incidental PE, risk stratification, workflow optimization, and reduced interpretation turnaround times. Nevertheless, much of the evidence comes from single-center studies, relatively few studies are prospective, and randomized trials comparing outcomes with and without AI assistance present practical challenges. Consequently, although AI has demonstrated promise in improving PE detection and clinical workflows, whether these improvements translate into better patient outcomes remains uncertain. AI-assisted assessment of PE on contrast-enhanced CT is increasingly being integrated into clinical practice, although the extent of its future adoption remains to be determined.

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Addition of ^{68}Ga-PSMA-11-11 PET/CT to MRI in the Prostate Cancer Diagnostic Pathway: Addressing an Unmet Need

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Addition of ^{68}Ga-PSMA-11 PET/CT to MRI in the Prostate Cancer Diagnostic Pathway: Addressing an Unmet Need

Munir Ghesani[1], Joseph Osborne[2], Paul Yonover[3], J Travis Mendel[4], Sanoj Punnen[5]

The addition of prostate-specific membrane antigen (PSMA) PET/CT with ^{68}Ga-PSMA-11 to multiparametric MRI (mpMRI) has the potential to improve the diagnostic pathway for suspected prostate cancer by enhancing risk stratification, identifying clinically significant disease that MRI alone may miss, and reducing unnecessary biopsies in appropriately selected patients.

Unmet Need in the Current Diagnostic Pathway

mpMRI has improved the diagnostic pathway for suspected prostate cancer and is now widely used before biopsy. However, important gaps remain. MRI may miss clinically significant lesions, biopsy can cause patient anxiety and post-procedural complications, and negative or inconclusive biopsy results may still leave diagnostic uncertainty. There remains a need for improved patient stratification, particularly in men with persistent clinical suspicion despite negative, non-suspicious, or equivocal MRI findings.

More than 1 million prostate biopsies are performed annually, and a substantial proportion are negative or detect clinically insignificant disease.[1] Although mpMRI has improved detection of clinically significant prostate cancer and reduced unnecessary biopsies, its negative predictive value may decline in higher-risk populations.[2] Men with negative or indeterminate MRI findings may still harbor clinically significant disease, and variability in MRI quality, reader expertise, and reference standards can limit reproducibility outside expert centers. ^{68}Ga-PSMA-11 PET/CT has therefore emerged as a promising complementary modality in the pre-biopsy setting.[3-5]

Evidence Supporting ^{68}Ga-PSMA-11 PET/CT as a Complementary Modality

Evidence from systematic reviews, multimodality trials, and the PRIMARY and PRIMARY2 trials supports the role of ^{68}Ga-PSMA-11 PET/CT as a complementary modality to mpMRI in the pre-biopsy diagnostic pathway.[6] Together, PRIMARY and PRIMARY2 evaluated ^{68}Ga-PSMA-11 PET/CT in combination with MRI and used the PRIMARY score as a standardized framework for ^{68}Ga-PSMA-11 PET interpretation. These data suggest that adding ^{68}Ga-PSMA-11 PET/CT to MRI may improve detection of clinically significant prostate cancer, identify lesions missed by mpMRI, and support more risk-adapted biopsy decisions. However, prospective validation remains important to define optimal patient selection, cost-effectiveness, and the clinical significance of ^{68}Ga-PSMA-11-positive lesions, particularly when MRI findings are negative or equivocal.

PRIMARY and PRIMARY2: Foundation for a ^{68}Ga-PSMA-11-Guided Strategy

The PRIMARY study evaluated ^{68}Ga-PSMA-11 PET/CT in biopsy-naïve men with suspected prostate cancer and demonstrated that combining ^{68}Ga-PSMA-11 PET/CT with mpMRI improved sensitivity and negative predictive value for clinically significant prostate cancer compared with mpMRI alone.[6]

The PRIMARY score was developed from this evidence base as a five-point

Affiliation: [1]Chief Medical Officer, United Theranostics; Former President, Society of Nuclear Medicine and Molecular Imaging; Former System Chief of Nuclear Medicine, Mount Sinai Health; Associate Professor of Radiology, Icahn School of Medicine at Mount Sinai. [2]Chief of Molecular Imaging and Therapeutics and Professor of Radiology, Weill Cornell Medicine. [3]Chief Data Officer and Director of Clinical Navigation, UroPartners, Chicago; Clinical Assistant Professor of Urology, University of Illinois Chicago. [4]Medical Director, Rio Grande Cancer Specialists. [5]Sanoj Punnen, MD MAS MBA, Pap Corps Champions for Cancer Research Endowed Chair in Solid Tumor Research, Professor and Vice Chair of Research, Desai Sethi Urology Institute, Co-lead for Cancer Control Research Program and Assistant Director of Clinical Research, Sylvester Comprehensive Cancer Center, Miller School of Medicine, University of Miami.
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framework to standardize intraprostatic ^{68}Ga-PSMA-11 PET interpretation and improve risk stratification for clinically significant disease.[6,7]

PRIMARY2 extended this approach in a randomized Phase 3 setting, evaluating ^{68}Ga-PSMA-11 PET/CT in men with non-suspicious or equivocal mpMRI findings and persistent clinical risk. In the ^{68}Ga-PSMA-11 PET arm, men with negative scans avoided biopsy, while those with positive scans underwent targeted biopsy.[8]

PRIMARY2 showed that an imaging-first strategy avoided biopsy in nearly half of men without compromising detection of clinically significant prostate cancer and substantially reduced detection of clinically insignificant disease.[8] This work provides a seminal evidence base for BiPASS, which extends the same ^{68}Ga-PSMA-11 and PRIMARY score approach into a registration-enabling program.

BiPASS: Translating Evidence into a Registration-Enabling Program

Building on PRIMARY and PRIMARY2, Telix Pharmaceutical's registration-enabling Phase 3 BiPASS trial is designed to evaluate ^{68}Ga-PSMA-11 PET/CT combined with MRI in men with suspected prostate cancer in the pre-biopsy setting. BiPASS incorporates the PRIMARY score as a core component of its imaging assessment methodology and is intended to support a standardized ^{68}Ga-PSMA-11 PET/MRI-informed diagnostic pathway.

The trial is titled: "A Single-Arm, Multicenter, Prospective, Open-Label, Longitudinal Phase 3 Study of Prostate-Specific Membrane Antigen (^{68}Ga-PSMA-11) Positron Emission Tomography (PET) Combined With Magnetic Resonance Imaging (MRI) Compared With Standard of Care (SOC) for the Detection of Prostate Cancer."

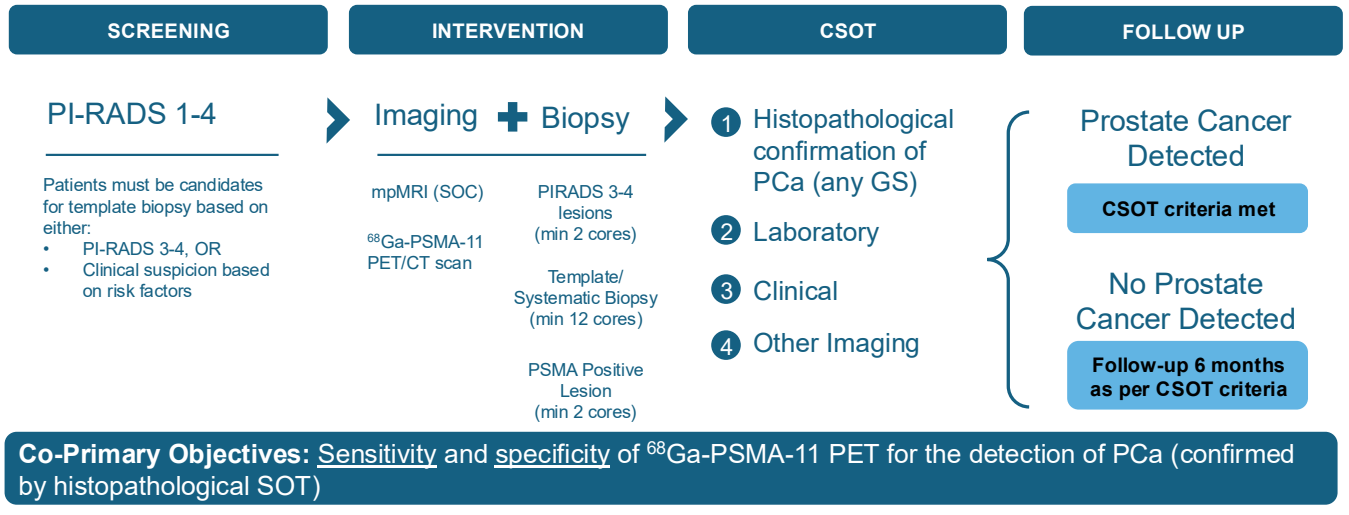
Key design elements include eligibility for men with PI-RADS 1–4 findings, exclusion of PI-RADS 5 disease, PET/CT plus biopsy assessment, template or systematic biopsy with at least 12 cores, targeted cores from MRI- and ^{68}Ga-PSMA-11-positive lesions, and 6-month follow-up using a composite standard of truth.

Within this registration-enabling framework, the use of ^{68}Ga-PSMA-11 is not simply a tracer selection but a key design feature that preserves continuity with the PRIMARY and PRIMARY2 evidence base. Because BiPASS is intended to evaluate whether ^{68}Ga-PSMA-11 PET combined with MRI can safely support biopsy deferral or more targeted biopsy in men with suspected prostate cancer, the imaging agent must maximize interpretive confidence and minimize avoidable sources of uncertainty. This is particularly important given published experience with certain ^{18}F-labeled ^{68}Ga-PSMA-11 agents, where higher rates of benign or indeterminate bone lesion (IBL) uptake have been reported and may increase the risk of false-positive interpretation.[9-11] False-positive interpretation of IBL detection can negatively impact treatment decisions and outcomes. By using the same ^{68}Ga-PSMA-11 platform and PRIMARY score framework evaluated in the foundational studies, BiPASS strengthens the clinical and regulatory rationale for testing a standardized, reproducible ^{68}Ga-PSMA-11 PET/MRI-informed pathway that can improve patient stratification, reduce unnecessary biopsies, and support broader adoption across academic and community practice settings.

Potential Clinical Impact

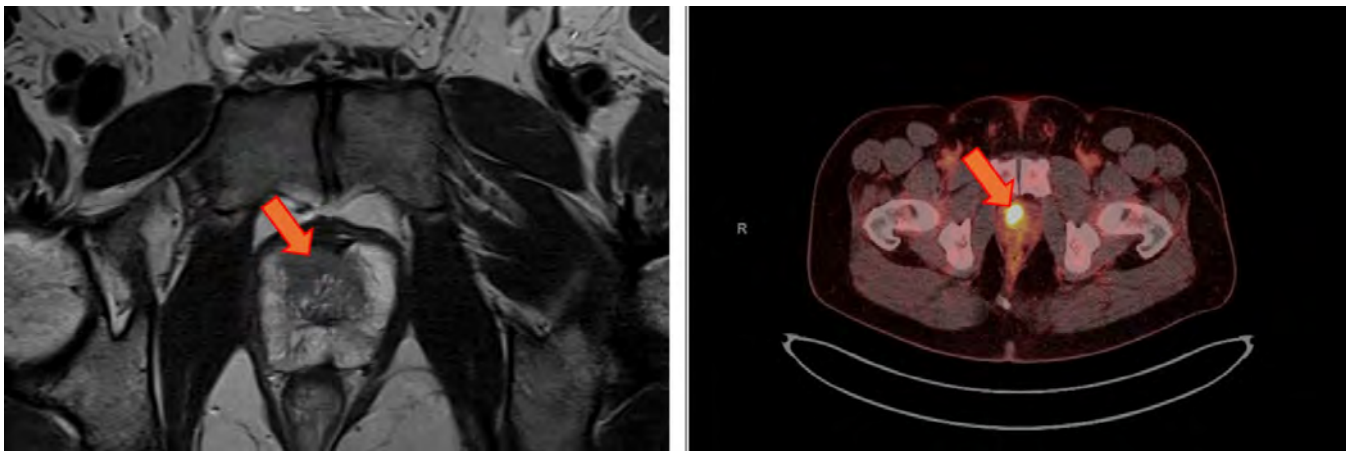
BiPASS could reshape the prostate cancer diagnostic pathway by positioning MRI and ^{68}Ga-PSMA-11 PET/CT as complementary tools. ^{68}Ga-PSMA-11 PET may identify lesions missed by MRI, including challenging anterior or MRI-occult lesions, while MRI may detect lesions that are PMSA-negative.[12]

BiPASS Trial Design



This study sponsored by Telix Pharmaceuticals. NCT07052214
CSOT, composite standard of truth; GS, Gleason Score

Case Study: 56-Year-Old Male with MRI (Left) and ^{68}Ga-PSMA-11 PET (Right)



Courtesy of Sanoj Punnen, MD

56-year-old male with elevated PSA came in for evaluation of a PSA that had increased from 2-3.5 over the year. An MRI showed a lesion in the right anterior peripheral zone. A biopsy was scheduled but ^{68}Ga-PSMA-11 was also requested by the patient and found an area of avidity in the right apex.

Biopsy showed a Gleason 8 high grade cancer in 2/2 cores from the target and Gleason 6 in 1/12 cores from the template biopsy.

Together, these modalities could support more precise biopsy targeting and reduce reliance on routine systematic sampling in appropriately selected patients.

The near-term clinical opportunity is a smarter biopsy strategy: using combined MRI and ^{68}Ga-PSMA-11 PET information to guide when biopsy is necessary, where biopsy should be targeted, and when biopsy may be safely deferred. This approach may improve patient experience, reduce unnecessary procedures, and provide more actionable anatomic and molecular information for treatment planning.

Clinical Adoption and Standardization Considerations

For BiPASS to translate from evidence generation into routine clinical practice, adoption will depend not only on diagnostic performance but also on whether the pathway can be implemented consistently across care settings. Academic centers may adopt earlier, particularly where ^{68}Ga-PSMA-11 PET infrastructure and multidisciplinary expertise are already established; however, broader community uptake will require clear reimbursement pathways, payer confidence, and eventual guideline incorporation, particularly within NCCN recommendations. Standardized ^{68}Ga-PSMA-11 PET interpretation, structured reporting templates, and reader training will be essential to ensure reproducibility across sites and to give clinicians confidence that biopsy deferral or more targeted biopsy decisions can be applied safely. In this context, the PRIMARY score provides a practical framework analogous to PI-RADS for MRI, supporting risk stratification and a common language for ^{68}Ga-PSMA-11-informed biopsy decision-making. The strongest adoption rationale is in men with persistent clinical suspicion and negative, non-suspicious, or equivocal MRI findings, where BiPASS could support a standardized, evidence-based shift from routine biopsy toward smarter, risk-adapted biopsy triage.

Evidence Thresholds for Clinical Confidence

Clinical adoption will require evidence that the pathway can safely support biopsy deferral without missing clinically significant cancer. A high negative predictive value will be essential, because missed clinically significant disease remains the central concern. Additional confidence may come from evidence of improved lesion localization, stronger alignment with pathology, and clinically meaningful impact on treatment planning, including radiation planning, focal boost strategies, nodal clinical target volume decisions, and salvage planning.

Discussion

Key risks and limitations include the possibility of missed clinically significant cancer if biopsy is deferred based on negative imaging; false-positive ^{68}Ga-PSMA-11-avid benign findings such as prostatitis, benign prostatic hyperplasia

nodules, or ganglia; uncertainty regarding the biology of ^{68}Ga-PSMA-11-positive, MRI-negative lesions; limited long-term oncologic outcomes for imaging-deferred cohorts; cost-effectiveness compared with mpMRI plus targeted biopsy; and operational constraints related to ^{68}Ga supply and PET capacity. Importantly, many of these risks are readily mitigated through protocol-defined eligibility criteria, standardized PRIMARY score interpretation, structured reporting, reader training, multidisciplinary review of discordant MRI and ^{68}Ga-PSMA-11 PET findings, and safety follow-up for patients in whom biopsy is deferred.

Medico-legal, reimbursement, and access concerns can be addressed through clear clinical algorithms, documented shared decision-making, payer evidence packages, phased implementation at experienced centers, and incorporation into clinical guidelines, which can strengthen payer confidence and support more consistent reimbursement as interpretation standards and operational workflows are established.

Standardized interpretation, structured reporting, and reader training will be necessary to reduce variability and ensure consistent performance in clinical practice.

From the community's urology perspective, BiPASS may shift biopsy practice from pattern-based sampling toward more targeted discovery of clinically significant disease. Combining ^{68}Ga-PSMA-11 PET with MRI could help avoid unnecessary biopsies while more precisely guiding biopsy in those who need them.

Balanced Interpretation

Overall, the evidence supports ^{68}Ga-PSMA-11 PET/CT as a promising complement to mpMRI rather than a replacement for careful clinical judgment. The most compelling near-term use case is selective biopsy avoidance or biopsy refinement in men with persistent suspicion of prostate cancer and negative, non-suspicious, or equivocal mpMRI findings. However, implementation should be guided by prospective validation, standardized interpretation, and confirmation that detected lesions represent clinically meaningful disease.

Conclusion

The addition of ^{68}Ga-PSMA-11 PET/CT to MRI has the potential to improve the prostate cancer diagnostic pathway by enhancing lesion detection, refining patient stratification, and reducing unnecessary biopsies in appropriately selected patients. PRIMARY and PRIMARY2 provide a strong evidentiary rationale, and BiPASS is positioned to test whether this approach can support broader clinical adoption in the pre-biopsy setting. Successful implementation will require prospective validation, standardized interpretation, reimbursement and access pathways, and evidence that detected lesions are clinically meaningful.

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REVIEW

Thyroid Artery Embolization for Thyroid Nodules, Goiter, and Graves' Disease

Nicholas Prus, BS; Layth Alkhani, BS; Mikin V. Patel, MD; Juan Camacho, MD; Osman Ahmed, MD

Abstract

Thyroid nodules, goiter, and Graves' disease currently lack a robust treatment algorithm, as traditional interventions, such as medical therapy and surgery, carry high relapse rates or risks of permanent complications. Thyroid artery embolization (TAE) has emerged as a minimally invasive, nonsurgical alternative for patients with select thyroid pathologies. It is primarily indicated for patients with large symptomatic benign nodules exceeding 30 mL, compressive goiters, hyperthyroidism refractory to medical therapy, or those who are poor surgical candidates or wish to avoid surgery. TAE targets feeding thyroid arteries with embolic spheres, aiming to diminish parenchymal blush. Published studies reported volume reductions between 53% and 69%, high rates of euthyroidism restoration, and decreases in thyrotropin receptor antibody levels for Graves' disease. While rare major complications exist, TAE maintains a favorable safety profile characterized primarily by transient postembolization syndrome. TAE provides a viable, tissue-sparing alternative for appropriately selected patients, though further prospective trials and standardized protocols are required to fully establish its long-term role within the treatment algorithm.

Keywords: thyroid artery embolization, thyroid nodule, thyroid goiter, Graves' disease, transarterial embolization

Introduction

The thyroid gland is a vascularized endocrine organ located below the thyroid cartilage and anterior to the trachea in the lower anterior neck, composed of 2 lobes connected by an isthmus.[1] The superior and inferior thyroid arteries provide the primary blood supply to the gland, with occasional contributions from a thyroidea ima artery originating from the aortic arch or brachiocephalic trunk.[2,3] The thyroid consists of follicles lined by follicular epithelial cells that synthesize and store thyroid hormones responsible for regulating the body's metabolic functions.[4]

Thyroid nodules are focal areas of abnormal growth within the thyroid parenchyma and represent one of the most common clinical findings in endocrinology.[5] Their global prevalence has increased from 22% between 2000 and 2011 to 29% between 2012 and 2022.[6] Thyroid nodules are largely asymptomatic, but may be accompanied by dysphagia, dyspnea, hoarseness, and neck pain. Additionally, the gland's anatomical location creates an aesthetic motivation for nodule removal. Risk factors for thyroid nodules include female sex, older age, higher body mass index, and iodine deficiency.[5] Approximately 10% of those who present with thyroid nodules, especially those who have undergone childhood irradiation, have a family history of thyroid cancer or hereditary syndromes, and rapid nodule growth, are at risk of malignancy.[7]

First-line management for benign, asymptomatic thyroid nodules typically consists of US monitoring to observe changes in gland size. For those with symptomatic, benign nodules, radioactive iodine (RAI) therapy achieves 40-50% volume reduction within 1 year, but it is limited by variable rates of response, high rates of subsequent hypothyroidism, and decreased efficacy in goiters.[8-10] More recently, other minimally invasive techniques such as radiofrequency ablation (RFA) have emerged. RFA has shown lower complication rates than

Affiliations: University of Illinois College of Medicine, Chicago, Illinois (Prus). Northwestern University Feinberg School of Medicine, Chicago, Illinois (Alkhani). Joint & Vascular Institute, Libertyville, Illinois (Patel, Ahmed). Department of Clinical Sciences, Florida State University, Sarasota, Florida (Camacho). University of Utah, Salt Lake City, Utah (Ahmed).
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surgery, with associated volume reduction rates (VRRs) of 73% at 6 months and 76% at 12 months.[11] However, RFA may require multiple sessions for large nodules, resulting in an extended treatment course.[12,13] For patients with large goiters or nodules refractory to the aforementioned therapies, current surgical interventions include thyroid lobectomy or total thyroidectomy. Despite their high efficacy, surgical procedures require general anesthesia and carry the risk of recurrent laryngeal nerve injury, permanent hypoparathyroidism, and postoperative hemorrhage.[14]

Graves' disease, another common thyroid pathology, is the most common cause of hyperthyroidism with an incidence of around 20-50 cases per 100,000 people.[15] Graves' is an autoimmune disorder in which thyrotropin receptor antibodies (TRAb) bind to and activate thyroid-stimulating hormone (TSH) receptors on thyroid follicular cells. This results in unregulated synthesis and release of thyroid hormones independent of the hypothalamic-pituitary axis, leading to palpitations, tremor, weight loss, anxiety, and diarrhea.[16] Graves' disease can also present with extrathyroidal manifestations, including orbitopathy and dermatopathy, which result from fibroblast activation and glycosaminoglycan deposition in the retro-orbital tissues and skin.[15]

Current treatment options for Graves' disease include antithyroid drugs (ATDs), RAI therapy, and thyroidectomy. ATDs are widely used and effective for short-term resolution of hyperthyroidism, but with relapse rates of around 50%, their long-term efficacy is compromised. ATDs also carry risk of agranulocytosis and hepatotoxicity, which may limit long-term use.[17] RAI therapy is also effective with resolution but carries the risk of hypothyroidism in 50-70% of patients after low-dose and 90-100% after high-dose regimens, with the potential of exacerbating or inducing Graves' orbitopathy.[18,19]

This review examines the potential role of thyroid artery embolization (TAE) in the treatment of thyroid nodules, goiter, and Graves' disease in patients who are not ideal candidates for surgery or prefer nonsurgical treatment.

Patient Selection

Patient selection plays a central role in optimizing outcomes in TAE. This procedure is most effective in patients with symptomatic benign thyroid nodules measuring greater than 30 mL or multinodular goiter producing compressive symptoms such as dysphagia or dyspnea, those with cosmetic concerns, or those with hyperthyroidism refractory to medical therapy.[20] Ideal candidates are those wishing to delay surgery or who are deemed unfit for surgery. TAE may also serve as an adjunct to thermal ablation in hypervascular nodules where the heatsink effect limits ablative efficacy.[21] In the setting of Graves' disease, TAE may be particularly advantageous for patients with active or high-risk Graves' orbitopathy, in whom RAI therapy is relatively contraindicated due to the risk of exacerbating eye disease.[22]

A thorough clinical evaluation is necessary during the initial consultation to assess suitability for the procedure. Thyroid ultrasonography is essential to characterize nodule features, location, relation to critical structures, and volume. Thyroid function tests, including TSH, free T4, and a complete blood count, are also recommended.[23] For patients being evaluated for Graves' disease, TRAb levels should be obtained to confirm autoimmune etiology and establish a baseline to monitor the severity of the disease.[24] The benign nature of the nodule can be confirmed via a US-guided fine-needle aspiration biopsy yielding a Bethesda II cytology result.[25] In addition to US, cross-sectional imaging with CT may be utilized in cases of suspected retrosternal extension to evaluate the extent of intrathoracic disease.

Given the catheter-based nature of the procedure, patients with hypersensitivity to iodinated contrast media or significant renal insufficiency represent relative contraindications for TAE. Patients with marked tracheal compression may not be well suited for the procedure as post-procedural edema may compromise the airway. Confirmed or suspected thyroid malignancy should be excluded as TAE is not yet indicated as a definitive treatment for thyroid cancer.

Procedural Technique

TAE aims to diminish blood flow to the thyroid parenchyma and its nodular components selectively targeting the feeding branches of the superior and/or inferior thyroid artery, thereby inducing ischemia-driven volume reduction.[26]

Access is typically gained through the radial artery, although femoral access may be used with US guidance while utilizing Seldinger's technique. Given the occurrence of vasospasm in the radial artery, a vasodilatory cocktail is often administered to prevent arterial damage or intraprocedural complications. After placement of a 5-French vascular sheath, a catheter is advanced over a hydrophilic guidewire to select the ipsilateral subclavian artery via a radial approach. Contrast is injected and a subclavian arteriogram is performed to confirm hypertrophied thyroid arteries and hyperemic staining of the thyroid nodule/goiter on the ipsilateral side. A 1.7-2.8-French microcatheter is then selectively advanced in either the ipsilateral thyrocervical trunk or external carotid artery to identify the inferior or superior arteries, respectively. Contrast is injected to delineate the arterial anatomy and confirm the feeding vessels to the thyroid parenchyma. A balloon occlusion or pressure-enabled microcatheter is often selected in these cases to prevent reflux of embolic particles.

Embolization can be performed with calibrated, permanent microspheres or polyvinyl alcohol (PVA) particles. Reported particle sizes range from 100 to 700 µm with microspheres and 350-500 µm with PVA particles.[21,27,28] Particles are injected under fluoroscopic guidance until decreased flow to the thyroid

gland is observed. TAE is routinely performed with particles as opposed to other embolic agents as they allow for more controlled delivery and are able to be lodged at the microvascular level, leading to devascularization and necrosis of the thyroid parenchyma. Embolization is typically performed with 300-500-µm-sized particles, but other particle sizes can be used for more proximal or distal occlusion.[20] In TAE, the endpoint is diminished parenchymal blush within the target nodule or gland rather than complete arterial stasis. There have been reports of occlusion of the proximal portion of feeding arteries with coils to ensure durable embolization.[21] Once embolization of one side of the thyroid is complete, the decision to embolize contralateral vessels depends on the extent of the disease and feeding arteries. If necessary, the procedural steps are repeated on the contralateral side beginning with radial access. In patients with bilateral thyroid nodules or goiter, traditional techniques called for preservation of at least one inferior thyroid artery to reduce the risk of hypoparathyroidism resulting from devascularization of the parathyroid glands, which are located on the posterior surface of the thyroid gland.[21] More recent techniques permit bilateral inferior TAE.

In a retrospective cohort study of 22 patients undergoing pressure-enabled TAE, 12 (55%) underwent bilateral embolization, with a 100% technical and clinical success rate, in addition to no neurovascular complications reported across the entire cohort.[29] This revised approach allows for more distal embolization using smaller particles through the utilization of a pressure gradient generated by a pressurized catheter.

Following embolization, the microcatheter is carefully withdrawn to prevent arterial spasm and completion angiography is performed to confirm occlusion of the target vessels and absence of residual nodular blush. A post-procedure thyroid ultrasonography is performed once the patient is stabilized and all catheters and wires are removed.

Patients are observed for 2-6 hours to monitor for potential complications. Neck pain is a common post-procedural discomfort that can be managed with nonsteroidal anti-inflammatory drugs. Follow-up evaluation is completed 1, 3, 6, and 12 months post-procedure to monitor progress.

Case Examples

An adult patient presented with a multinodular goiter with a history of compressive symptoms. Arteriograms of the right and left subclavian arteries were performed demonstrating hypertrophied right and left inferior thyroid arteries, respectively (Figure 1). Selective arteriograms of the right and left inferior thyroid arteries demonstrated hypervascular tumor blush (Figure 1). The right and left inferior thyroid arteries were embolized using a pressure-enabled technique with 3.5 cc of 100-300 µm microspheres and 3.2 cc of 100-300 µm microspheres, respectively. At a 3-month follow-up, the patient reported improved energy levels and denied throat pain, dysphagia, or dyspnea with a significantly reduced bilateral goiter size.

In another case, an adult patient presented with a large, solitary, nontoxic right thyroid nodule and globus sensation. An axial contrast-enhanced CT image of the neck demonstrated a large, expansile, heterogeneously enhancing right thyroid mass with central necrotic degeneration causing significant mass effect (Figure 2). Intraprocedural cone-beam CT and right inferior thyroid arteriogram supported microcatheter positioning (Figure 2). The right inferior thyroid artery was embolized with 3.7 cc of 100-300 µm microspheres (Figure 2). Post-procedural imaging demonstrated a marked reduction in gland volume (Figure 2).

Clinical Efficacy

A growing body of literature, including a meta-analysis of 10 studies encompassing 347 patients, describes the feasibility and efficacy of TAE for the treatment of thyroid nodules and multinodular goiters. Volume reduction is the primary measure of clinical efficacy, with a significant mean reduction in nodule volume of approximately 52 mL in the meta-analysis.[30] Individual studies have reported volume reduction ranging from 53% to 69% at 6-24 months.[27,28,31] In patients with non-Graves' hyperthyroidism, TAE has also demonstrated efficacy in restoring euthyroidism, with 86% of hyperthyroid patients becoming euthyroid after the procedure.[31]

Emerging data also support the use of TAE in Graves' disease. Although data are limited, preliminary studies have shown it to reduce thyroid volume, normalize thyroid function tests, and decrease TRAb levels in patients with Graves' hyperthyroidism.[32,33]

TAE Versus Alternative Treatment Modalities

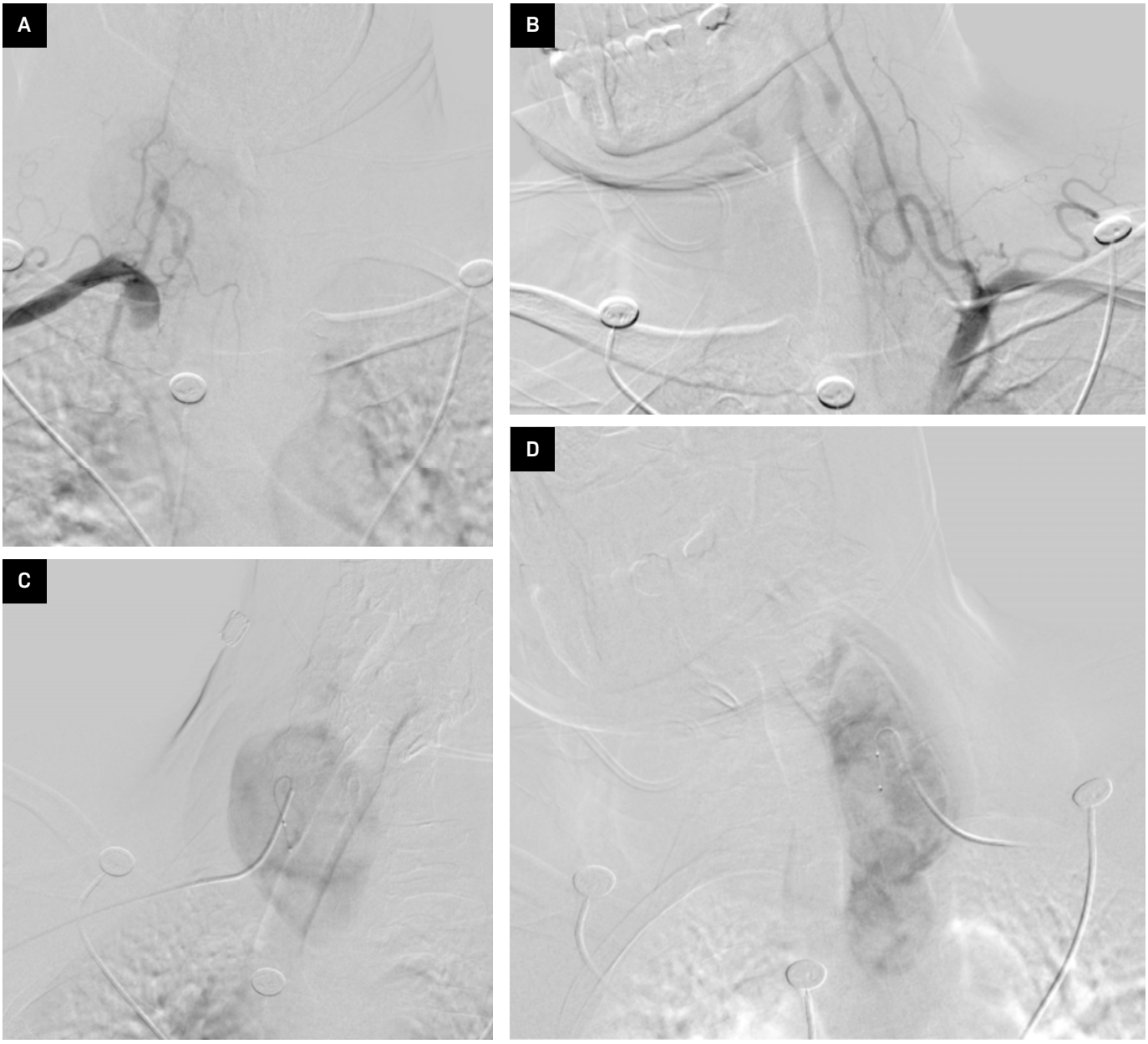
Early comparative data suggest that TAE may offer advantages over RFA for large thyroid nodules. At 6 months, TAE was associated with a significantly greater VRR than RFA for nodules larger than 100 mL.[34] The study also reported a higher complication rate with RFA than with TAE. Although not based on a direct comparison, another study reported a greater VRR with combined TAE and RFA than with 2 sessions of RFA alone.[21]

Although no direct comparisons between TAE and surgical treatment currently exist, early case series data suggest TAE has a favorable safety profile with predominantly minor, self-limited adverse events such as neck pain and transient fever.[33] Serious complications appear rare, though long-term recurrence data remain limited by small sample sizes and short follow-up periods.

A network meta-analysis of minimally invasive treatments for benign thyroid nodules found no significant differences among RFA, laser ablation, microwave ablation, high-intensity focused US, and

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Figure 1. (A) Right subclavian arteriogram demonstrating a hypertrophied right inferior thyroid artery feeding the large thyroid nodule. (B) Left subclavian arteriogram demonstrating a hypertrophied left inferior thyroid artery feeding the large thyroid nodule. (C) Right inferior thyroid arteriogram demonstrating prominent hypervascular tumor blush outlining the large thyroid nodule. (D) Left inferior thyroid arteriogram demonstrating prominent hypervascular tumor blush outlining the large thyroid nodule.



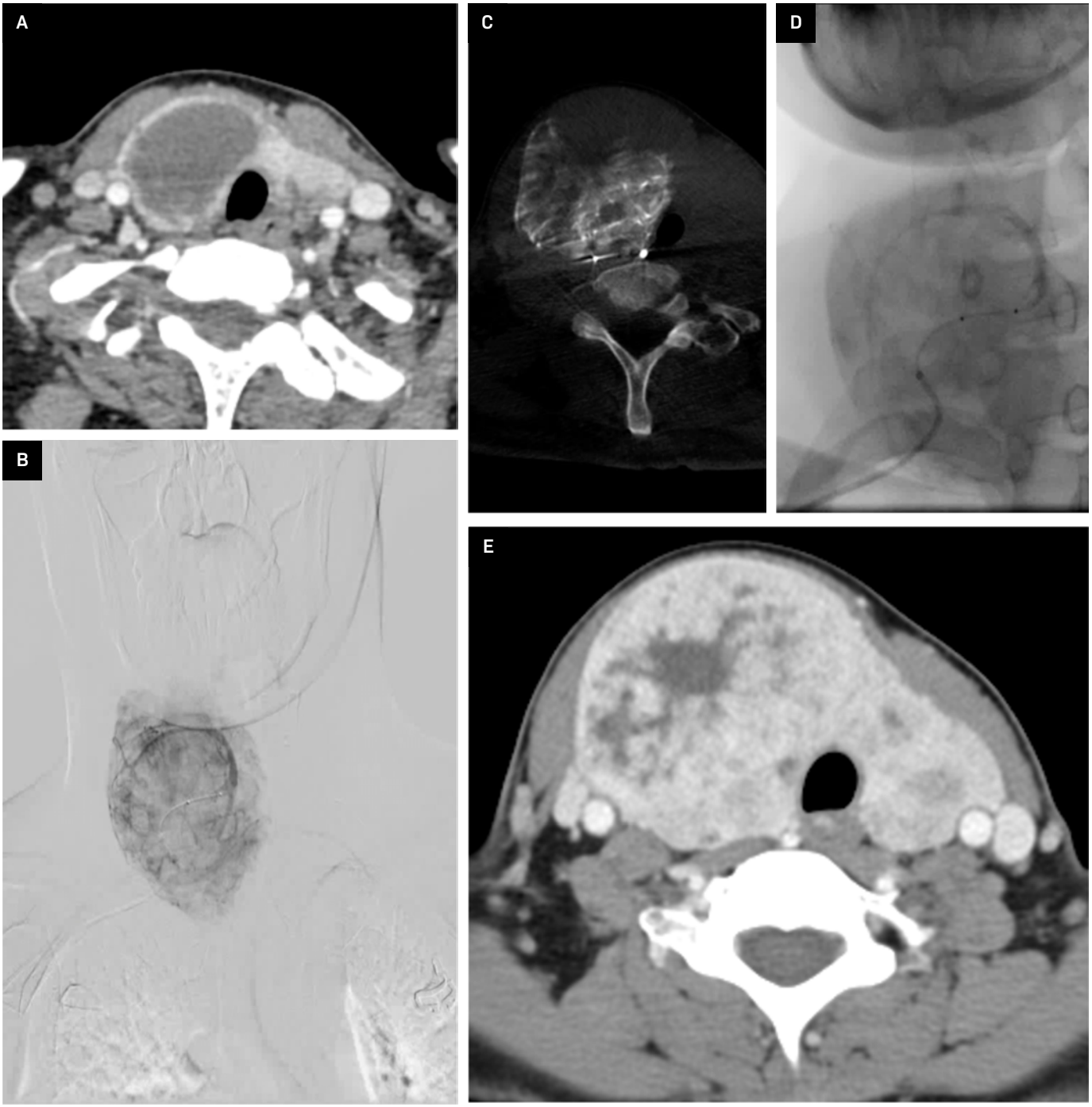
conventional surgery regarding VRR, symptomatic score, and cosmetic score improvement. One of these thermal ablation modalities, RFA, was associated with a reduced risk of vocal complications, hypothyroidism, and nodular regrowth compared to surgery.[35]

Safety

TAE maintains a generally favorable safety profile. The most common adverse events are minor and transient, consistent with postembolization syndrome, which typically includes neck pain, low-grade fever, and mild swelling that is usually self-resolving in a few days.[20,28,33]

Major complications, although rare, have been reported. In a single-center series of 40 patients, the major adverse event rate was 5%, comprising one cerebellar infarction from non-target embolization and one perithyroidal

Figure 2. (A) Pre-thyroid artery embolization (TAE) axial contrast-enhanced CT image demonstrating the size of the solitary large right thyroid nodule with compression of the trachea. (B) Right inferior thyroid arteriogram demonstrating prominent hypervascular tumor blush outlining the large right thyroid nodule. (C) Axial intraprocedural cone-beam CT image demonstrating selective microcatheter positioning and dense parenchymal contrast opacification throughout the targeted right thyroid nodule. (D) Intraprocedural inferior thyroid arteriogram demonstrating the final embolization endpoint, characterized by diminished parenchymal blush of the hypervascular right thyroid nodule. (E) Post-TAE axial contrast-enhanced CT image demonstrating extensive central hypoattenuation within the treated right thyroid nodule alongside marked reduction in solid enhancement and mass effect on the adjacent trachea.



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hematoma requiring percutaneous drainage.[27] Given the possibility of cerebral infarcts, it is imperative that an experienced interventional radiologist performs these with proper equipment and training.

In another single-center series of 56 patients, a mortality rate of 1.8% at 30 days was reported after a patient passed away from a myocardial infarction that was possibly procedure related.[31] Reflecting these safety concerns, a 2026 systematic review of 24 studies concluded that the potential for serious complications and the absence of a standardized protocol currently preclude routine use of TAE, which should be reserved for exceptional cases performed at specialized centers.[26] More recently, the 2026 North American Society for Interventional Thyroidology (NASIT) consensus statement took a more supportive position, concluding that TAE is a safe, effective, and durable option for selected patients with large symptomatic benign nodules and goiters while still emphasizing the need for further studies to standardize technique and define its role relative to other therapies.[20]

Given the catheter-based, minimally invasive nature of the procedure, TAE does not carry the risks of recurrent laryngeal nerve injury, permanent hypothyroidism, wound infection, or delayed healing that are associated with thyroidectomy.[23,36]

Conclusion

TAE is an emerging, minimally invasive treatment option for patients with symptomatic thyroid nodules or goiter who are poor surgical candidates or wish to avoid surgery. Preliminary evidence also suggests potential benefits for selected patients with Graves' disease. Reported reductions in thyroid volume, restoration of euthyroidism in some patients, and the 2026 NASIT consensus statement support further consideration of TAE in selected patients. However, serious complications have been reported, and a 2026 systematic review concluded that current evidence does not support its routine use. Although TAE shows promise, further prospective studies, standardized techniques, direct comparisons with surgery and thermal ablation, and long-term outcome data are needed to better define its safety, efficacy, and role in thyroid disease management.

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From Anatomy to Perfusion: Point-of-Care Contrast-Enhanced US in Acute and Emergent Care

Tobias Kummer, MD; Jaydev K. Dave, PhD; Priscilla Machado, MD

Abstract

Contrast-enhanced US (CEUS) is most commonly associated with focal liver lesion characterization, yet its applications in acute and emergency care are considerably broader and remain underrecognized. Using microbubbles as purely intravascular blood-pool agents, CEUS provides real-time assessment of tissue perfusion and vascular integrity, extending US evaluation beyond morphology alone. This review presents a practical perfusion-based framework for acute-care CEUS built on 3 recurring patterns: reduced perfusion in ischemia, infarction, and organ injury; extravascular contrast in active hemorrhage; and increased perfusion in inflammation and infection. Representative applications include detection and follow-up of solid-organ injuries, identification of active bleeding and pseudoaneurysms, assessment of complications of acute cholecystitis, and evaluation of inflammatory bowel disease activity. Because CEUS can be performed at the bedside and repeated as often as clinically necessary, without ionizing radiation or nephrotoxicity, it is particularly suited to serial surveillance, pediatric imaging, patients with renal impairment, and situations in which transport to CT is undesirable.

Keywords: contrast-enhanced US, CEUS, microbubbles, point-of-care US, perfusion imaging, emergency radiology, blunt abdominal trauma, contrast-enhanced FAST, acute cholecystitis, pseudoaneurysm

Introduction

Contrast-enhanced US (CEUS) has evolved from its early clinical use in echocardiography and focal liver lesion characterization into a broader technique for evaluating organ perfusion and vascular integrity. Nonhepatic applications now include trauma, vascular complications, renal and bowel imaging, and image-guided interventions. Contemporary reviews and guidelines recognize CEUS as a problem-solving modality in selected acute and point-of-care settings.[1-3]

US contrast agents consist of gas-filled microbubbles approximately the size of erythrocytes that remain confined to the intravascular space. When insonated, microbubbles oscillate nonlinearly, and contrast-specific pulse sequences suppress the predominantly linear tissue signal while preserving the nonlinear microbubble response. Imaging at a low mechanical index minimizes microbubble destruction and allows continuous observation of arterial arrival and parenchymal enhancement. Because the signal reflects circulating microbubbles independent of the insonation angle, CEUS

Affiliations: Department of Emergency Medicine, Mayo Clinic, Rochester, Minnesota (Kummer). Department of Radiology, Mayo Clinic, Rochester, Minnesota (Dave). Department of Radiology, Thomas Jefferson University, Philadelphia, Pennsylvania (Machado).

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Table 1. The 3 Perfusion Patterns in Acute Contrast-Enhanced US

PERFUSION PATTERN	CONTRAST-ENHANCED US SIGNATURE	REPRESENTATIVE EMERGENT DIAGNOSES	MANAGEMENT CONSEQUENCE
Reduced	Ischemia: slow/hypoenhancement Infarction: Well-demarcated, persistent nonenhancement across all phases	Splenic/renal/hepatic infarct; testicular torsion; pulmonary infarction	Confirms nonviability; drives urgent surgery (torsion) or supportive care
Misdirected	Microbubble pooling or pulsatile jet beyond vascular architecture; contained to-and-fro pattern (pseudoaneurysm)	Active solid-organ hemorrhage; pseudoaneurysm	Identifies need for embolization or operative control
Increased	Earlier or more intense enhancement than adjacent tissue	Complicated acute cholecystitis; active inflammatory bowel disease	Supports assessment of inflammatory activity and identifies progression toward ischemia, necrosis, or other complications

is sensitive to microvascular perfusion that may be inapparent on conventional color or power Doppler.[4-6] Unlike CT or MRI, CEUS depicts contrast transit in real time at the bedside and can be repeated without ionizing radiation or nephrotoxicity.

Point-of-care US has transformed acute and critical care through rapid anatomic and macrovascular assessment, but many time-sensitive questions are fundamentally physiologic: Is an organ perfused? Is blood escaping the vascular space? Has inflammation altered regional microvascular flow? CT remains the reference standard for many acute abnormalities, particularly when a comprehensive field of view is required, but CEUS can address selected perfusion questions in real time at the bedside without ionizing radiation or nephrotoxic contrast.[1,7,8] This review focuses on recurring perfusion patterns across organ systems and how these patterns apply to acute care cases.

Why Perfusion Matters at the Point of Care

Acute US imaging traditionally focuses on morphology, including mural thickening, focal lesions, and fluid collections. Many time-sensitive diagnoses, however, are fundamentally disorders of tissue perfusion. In the acute setting, CEUS findings can be organized into 3 recurring patterns that apply across organ systems and clinical scenarios (Table 1): reduced perfusion associated with ischemia, infarction, and devascularizing injury; misdirected perfusion, characterized by extravascular contrast accumulation associated with hemorrhage; and increased perfusion associated with inflammation and infection.

These patterns can also be demonstrated with CT and MRI. Unlike CT, which captures isolated phases of contrast enhancement, CEUS allows direct observation of evolving processes such as active hemorrhage, tissue ischemia, and inflammatory hyperemia. Compared with Doppler techniques, which depend on flow direction and insonation angle, CEUS is more sensitive to microvascular perfusion.[4-6] The examination can be performed in the emergency department, ICU, or other acute-care settings without transporting the patient.[1,7,8] This makes CEUS a monitoring tool as well as a diagnostic modality.

In practical terms, a nonenhancing region suggests infarction or traumatic devascularization, contrast outside the vascular compartment indicates hemorrhage, and focal hyperenhancement reflects inflammatory or infectious hyperemia.

Reduced Perfusion: Ischemia, Injury, and Infarction

Loss of tissue perfusion is one of the most recognizable CEUS findings in acute care. Viable parenchyma enhances promptly following microbubble arrival, whereas ischemic or devascularized tissue remains nonenhancing. On CEUS, this typically appears as a sharply demarcated perfusion defect that is often more obvious than on grayscale or Doppler imaging.[9-11]

When caused by occlusion of a segmental arterial branch, the defect is classically wedge-shaped, with its base at the organ capsule and apex directed toward the hilum. Similar findings occur in splenic, renal, hepatic, and testicular infarction (Figure 1).[2,3,11] In paired organs such as the kidney or testis, comparison with the contralateral side provides a useful internal control.

Conventional focused assessment with sonography in trauma (FAST) primarily detects free intraperitoneal fluid, which is an indirect sign of abdominal injury and may be absent despite parenchymal injury. Traumatic solid-organ injuries follow the same perfusion principle. Lacerations, hematomas, and devascularized segments appear as focal nonenhancing regions that may be occult on conventional B-mode imaging (Figure 2). In an early prospective series of CT-confirmed hepatic, splenic, and renal injuries, noncontrast sonography detected 50% of injuries compared with 91% using CEUS.[12] More recent prospective point-of-care data similarly showed sensitivity improving from 65% to 94%, and a meta-analysis found pooled sensitivity increasing from 56% to 93% when CEUS was added (Table 2).[13,14]

Follow-up of a known injury is when CEUS can be particularly useful. The examination can be repeated without ionizing radiation and enables

Figure 1. Wedge-shaped splenic infarct. (A) Reference B-mode image, in which the infarct is only subtly hypoechoic. (B) Contrast-enhanced US demonstrating a sharply demarcated, nonenhancing wedge with its base at the capsule (asterisk), persisting through all vascular phases.

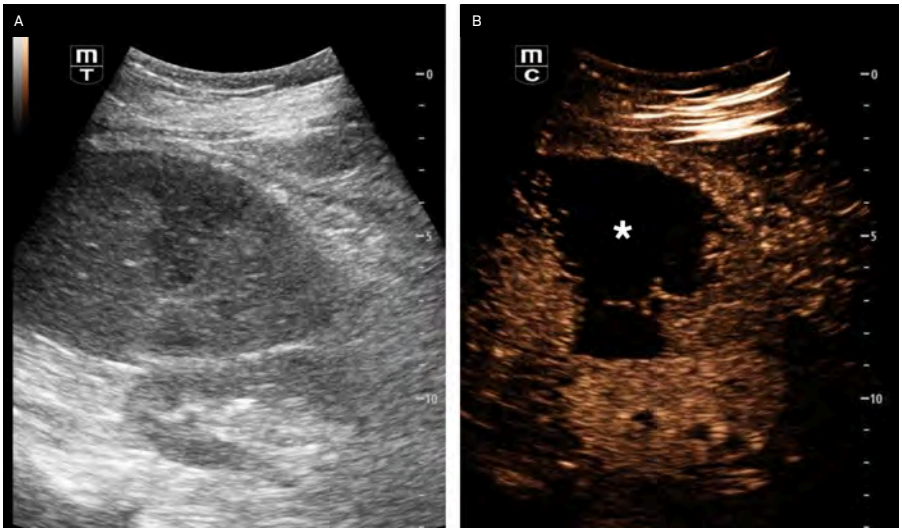
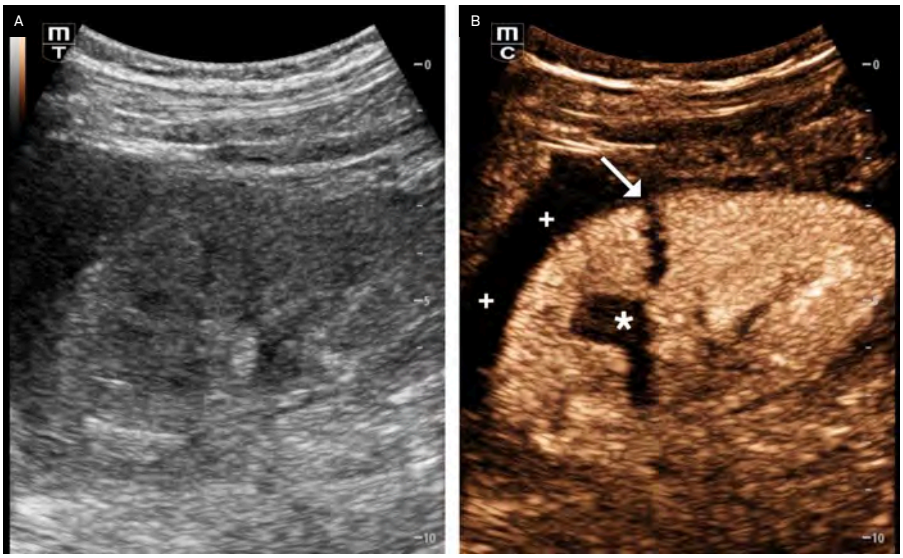


Figure 2. Right renal American Association for the Surgery of Trauma grade III laceration after a motorcycle crash. (A) Reference B-mode image. (B) Contrast-enhanced US showing the nonenhancing laceration (arrow) and blood in Morison pouch (plus signs) without contrast extravasation. The collecting system is unopacified (asterisk) because US contrast agents are not renally cleared.



bedside assessment of evolving perfusion abnormalities, making it well-suited to contemporary nonoperative management strategies, especially in children (Table 2). Current trauma guidelines recognize CEUS as an alternative to CT for follow-up, including surveillance after splenic injury.[15]

Misdirected Perfusion: Extravascular Contrast and Active Hemorrhage

Active hemorrhage appears on CEUS as focal microbubble extravasation with progressive pooling or dispersion outside the expected vascular boundaries (Figure 3). Because microbubbles remain strictly intravascular, contrast outside a vessel is always abnormal. CEUS allows direct real-time visualization of hemorrhage as it evolves, providing temporal information that cannot be obtained from discrete CT contrast-enhancement phases alone.[16] Potential applications include blunt or penetrating trauma, postprocedural bleeding, spontaneous hemorrhage, and vascular complications such as pseudoaneurysms.

Free Contrast in the Peritoneum

Microbubbles reaching the peritoneal cavity appear as free-floating echogenic foci within otherwise anechoic fluid, converting the nonspecific free fluid of the FAST exam into direct evidence of active bleeding (Figure 3). This principle underlies the contrast-enhanced FAST examination and substantially improves the detection of active hemorrhage compared with conventional US.[13,17]

Pooling within a Hematoma

Active bleeding within a hematoma appears as progressive contrast accumulation within the collection (Figure 3). CEUS demonstrates this process continuously following a single contrast injection and may help characterize a focal arterial source versus slower or indeterminate bleeding.[18-20] CEUS can also guide treatment by identifying the bleeding source, confirming hemostasis after compression, or assessing whether percutaneous thrombin injection was effective.[20]

Pseudoaneurysm

Pseudoaneurysms represent a distinct form of extravascular contrast. Rather than accumulating progressively, they demonstrate cyclical filling and emptying with the cardiac cycle (Figure 3).

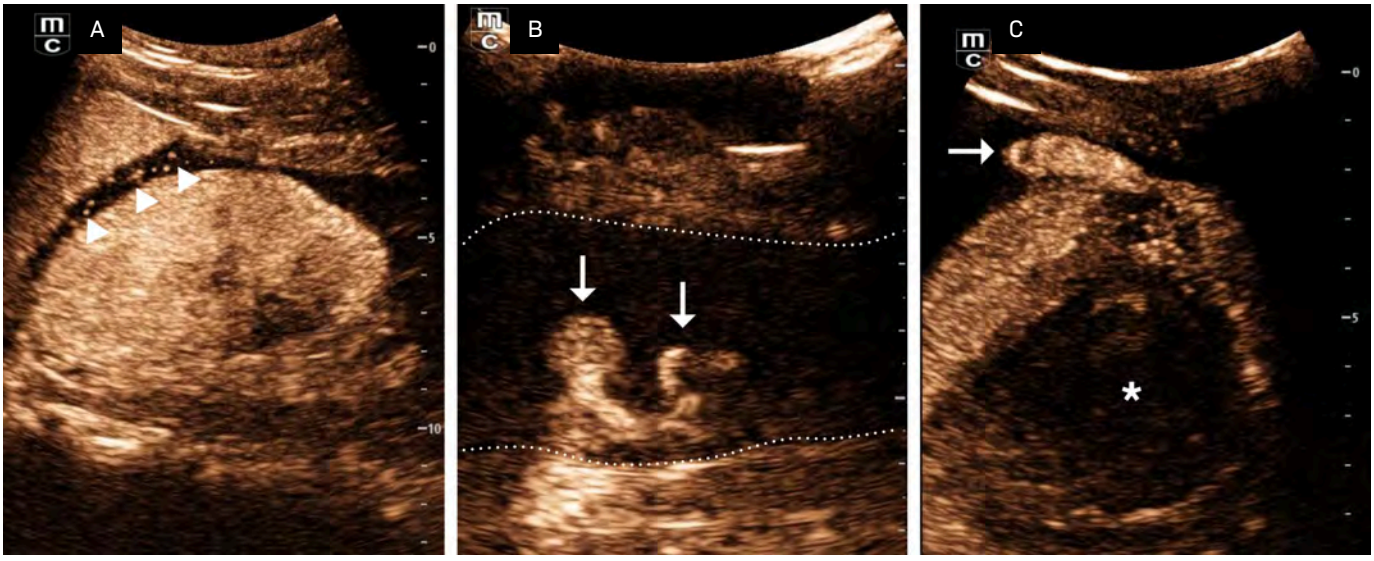
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Table 2. Diagnostic Performance and Surveillance Role in Blunt Abdominal Trauma

MODALITY	SENSITIVITY FOR SOLID-ORGAN INJURY	IONIZING RADIATION	NEPHROTOXICITY /CREATININE	SERIAL MONITORING	KEY TRAUMA LIMITATION
Conventional US/FAST	56% (pooled)[13]	None	No	Yes	Low sensitivity; free fluid as surrogate marker[13]
CEUS	93% (pooled)[13]	None	No	Yes	Hollow viscus and mesentery; pancreas and adrenal glands; renal collecting system
Contrast-enhanced CT	Reference standard[13]	Yes	Yes	Limited (cumulative dose)	Radiation; transport out of the resuscitation area

CEUS, contrast-enhanced US; FAST, focused assessment with sonography in trauma.

Figure 3. The 3 patterns of extravascular contrast. (A) Free-floating microbubbles (triangles) within hemoperitoneum in blunt abdominal trauma, indicating ongoing intraperitoneal bleeding. (B) "Bleeding mushroom": progressive pooling of contrast (arrows) within an actively bleeding hematoma (dotted outline). (C) Pseudoaneurysm of the posterolateral spleen demonstrating to-and-fro filling (arrow) in a patient with a large splenic hematoma (*).



Distinguishing pseudoaneurysm from active extravasation is clinically important because management can differ substantially.[21] In children with blunt liver or splenic injuries, CEUS identified pseudoaneurysms with 83% sensitivity and 92% specificity.[22] Post-traumatic pseudoaneurysms are an important target of follow-up imaging after nonoperative liver or splenic injury.[15,22]

Increased Perfusion: Infection and Inflammation

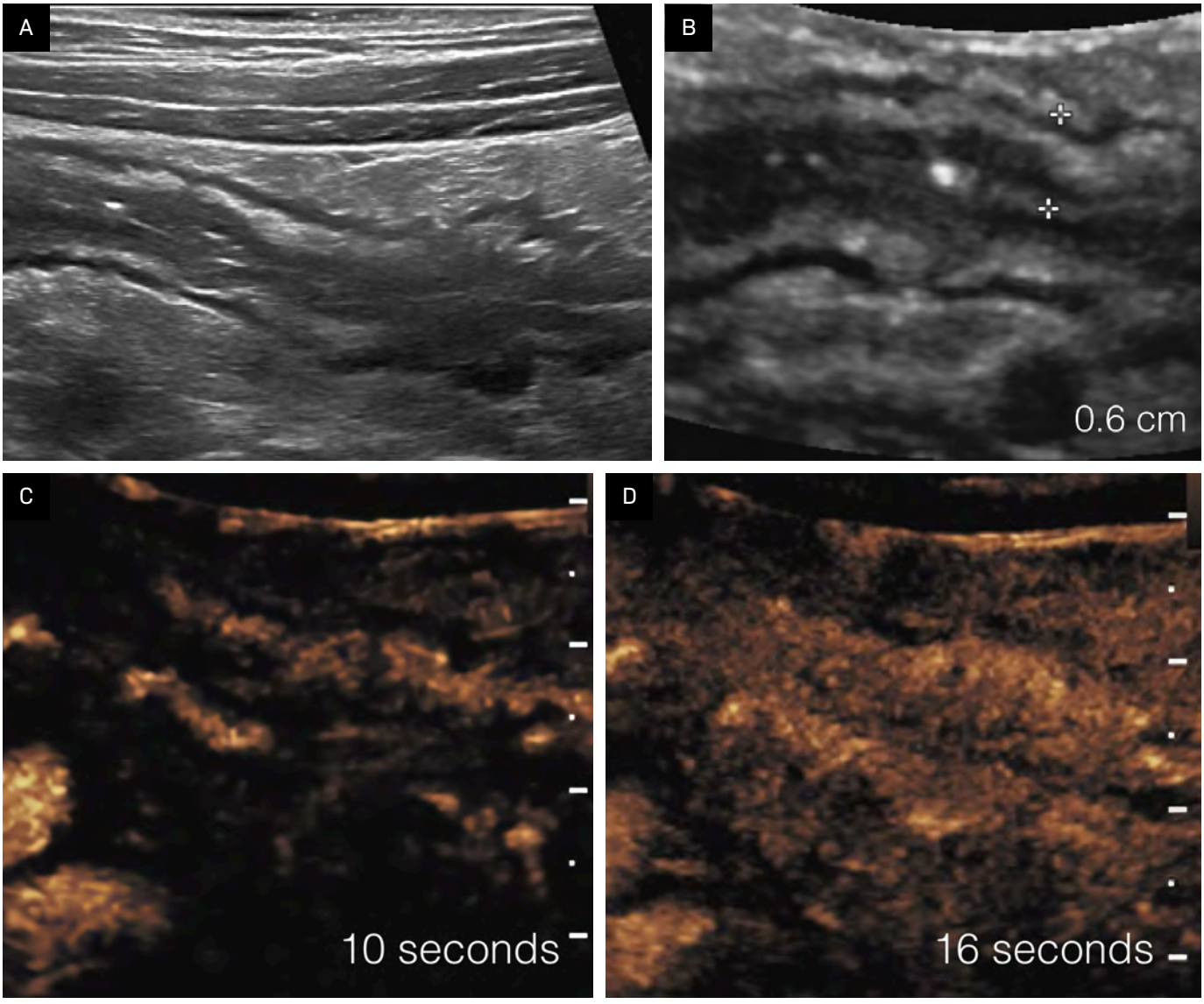
Inflamed tissue enhances earlier, more intensely, and for longer than surrounding parenchyma, reflecting vasodilation, capillary recruitment, and increased microvascular flow. Unlike ischemia, where the key finding is absent enhancement, inflammatory processes are characterized by relative hyperenhancement that can be assessed qualitatively or quantified using time-intensity curves.

Infection

Conventional US remains the first-line imaging modality for suspected acute cholecystitis; established findings include gallstones, wall thickening, pericholecystic fluid, and a sonographic Murphy sign. Currently, CEUS should not be positioned as a replacement for these criteria in routine uncomplicated disease. Its better-supported role is characterization of mural perfusion when complicated or gangrenous cholecystitis is suspected. In a prospective study of 150 surgically treated patients, focal or diffuse defects in gallbladder wall enhancement were associated with gangrenous cholecystitis, with reported sensitivity ranging from 85% to 91% and specificity ranging from 67.5% to 84.8%.[23,24]

Inflammation can produce early, intense mural enhancement,

Figure 4. Active inflammatory Crohn disease of the terminal ileum in a 28-year-old man with a long-segment stricture. (A) B-mode image demonstrating a long-segment thickening of the terminal ileum. (B) Magnified view of the wall measuring 0.6 cm. (C, D) Contrast-enhanced US at 10 and 16 seconds after contrast administration showing progressive, near-transmural hyperenhancement with minimal sparing of the muscularis propria, indicating active inflammation rather than a purely fibrotic stricture. Images courtesy of Shuchi K. Rodgers, MD.



whereas progressive ischemia and necrosis produce focal or diffuse nonenhancement.[23,24] The illustrative case below of acute acalculous cholecystitis demonstrates how inflammatory hyperemia and focal hypoperfusion can coexist within the same gallbladder wall as disease evolves.

Inflammation

In inflammatory bowel disease, CEUS allows direct assessment of bowel wall vascularity and disease activity.[2] Active inflammation appears as early, intense mural enhancement, and enhancement measures correlate with endoscopic and clinical activity.[25,26]

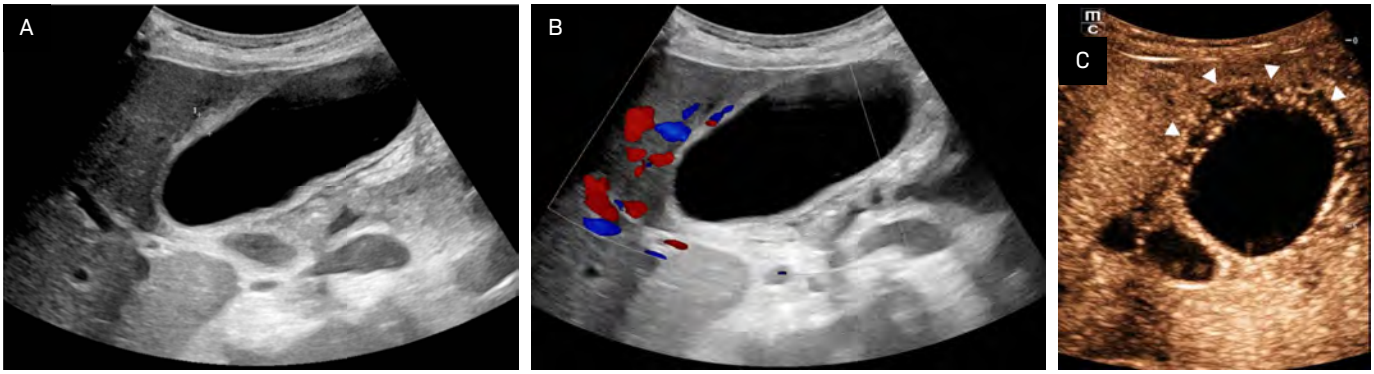
At the point of care, its clearest role is assessment of known disease activity and complications rather than replacement of CT for an undifferentiated acute abdomen. In the terminal ileal stricture shown in Figure 4, near-transmural hyperenhancement supports persistent inflammatory activity despite chronic luminal narrowing. Because patients with inflammatory bowel disease often undergo repeated imaging over many years, CEUS also offers a radiation-free option for longitudinal assessment.[26]

Illustrative Case: Acute Acalculous Cholecystitis

A patient in her 80s receiving chemotherapy for locally advanced duodenal adenocarcinoma presented after

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Figure 5. Acute acalculous cholecystitis in a woman in her 80s. (A) B-mode image showing a distended gallbladder with 7 mm wall thickening and trace pericholecystic fluid, without gallstones and with an absent sonographic Murphy sign. (B) Color Doppler image of part of the gallbladder wall and adjacent liver parenchyma. (C) Contrast-enhanced US demonstrating intense mucosal hyperenhancement alongside focal areas of mural hypoperfusion (arrowheads). Coexisting mucosal hyperemia and focal mural hypoperfusion raise concern for evolving ischemic complication.



a fall with weakness, confusion, nausea, and new right upper quadrant pain. Leukocyte count and liver biochemical test results were normal. Cross-sectional imaging showed gallbladder wall thickening and pericholecystic fluid without gallstones. Conventional US remained equivocal, showing a distended gallbladder with a 7 mm wall, trace pericholecystic fluid, no cholelithiasis, and an absent sonographic Murphy sign (Figure 5).

CEUS demonstrated intense mucosal hyperenhancement with focal nonenhancing regions within the thickened gallbladder wall (Figure 5), indicating inflammatory hyperemia with superimposed mural hypoperfusion. The wall remained intact, with no imaging evidence of perforation. In the clinical context, the findings supported acute acalculous cholecystitis and raised concern for evolving ischemic injury rather than uncomplicated inflammation.

This case illustrates that the 3 perfusion patterns described in this review are not fixed diagnostic categories. As acute disease evolves, inflammatory hyperemia, ischemia, and tissue injury may coexist within the same organ. By offering real-time assessment of tissue vascularity, CEUS can depict this transition directly and identify patients progressing from inflammation toward ischemia and necrosis.

Beyond the Abdomen: Additional Point-of-Care Applications

The perfusion principles described above extend beyond the abdominal organs and have been incorporated into emergency and critical care CEUS guidelines.[27] In echocardiography, microbubble contrast improves endocardial border definition and left ventricular opacification in technically limited studies, particularly in critically ill patients. At the same time, myocardial perfusion imaging may provide additional information in patients with suspected ischemia.[28,29]

The same perfusion framework is applicable to vascular and thoracic imaging. In the aorta, CEUS can demonstrate contrast extravasation and is commonly used to detect endoleaks following endovascular aneurysm repair.[2] In the lung, homogeneous enhancement of a peripheral consolidation favors infection, whereas absent or heterogeneous enhancement suggests pulmonary infarction from pulmonary embolism.[30,31]

Although these applications remain less established than abdominal CEUS, each reflects the same underlying approach: assessment of tissue perfusion and vascular integrity at the bedside.

CEUS also has a practical role in interventional radiology. It can improve visualization of targets that are inconspicuous on B-mode imaging, direct biopsy toward viable enhancing tissue and away from necrosis, guide and immediately assess ablation, identify postprocedural bleeding, and, with intracavitary administration, confirm catheter position or delineate cavities and fistulous tracts.[32,33]

Which Patients Benefit Most?

The advantages of CEUS are most apparent in clinical situations where repeated imaging, radiation, or iodinated contrast become important considerations. US contrast agents (UCAs) have an excellent safety profile, with severe adverse reactions reported in only 0.006% of adults and 0.016% of children.[34] These rates are comparable to or lower than those associated with iodinated CT contrast and gadolinium-based MRI contrast agents.[4]

The potential advantages of CEUS are particularly relevant in several patient populations. Children often require serial imaging and are more vulnerable to cumulative radiation exposure. Patients with renal impairment or a history of adverse reactions to iodinated contrast may benefit from a perfusion study that does not require nephrotoxic contrast agents. Early experience in pregnancy has also been reassuring, although use remains off-label in the United States.[8,35]

The choice of imaging modality ultimately depends on the clinical question, target organ, acoustic window, and local expertise. However, the combination of real-time perfusion imaging, ready repeatability, lack of ionizing radiation, and bedside availability can make CEUS a preferred imaging strategy rather than merely an alternative to CT.

Integration into Acute and Point-of-Care Imaging Practice

Adding CEUS to an existing point-of-care practice is a logistical rather than a technical problem. The essential requirements are a US system with contrast-specific imaging capability, access to an approved UCA, IV access, and personnel familiar with contrast administration and image acquisition.[7,36] Contrast-specific imaging is now available on many portable and mid-range US platforms, making implementation increasingly feasible in emergency departments and intensive care units.[1,7,27,36]

Clinical adoption is increasing but remains uneven, and robust national utilization data that permit direct comparison between the United States and other countries are limited. In a 2017 Society for Pediatric Radiology survey, 44 of 325 respondents (13.5%) reported performing pediatric CEUS. Of the respondents, 72% reported barriers, most commonly a lack of expertise, a lack of trained sonographers, time constraints, and uncertainty regarding reimbursement.[37] A 2024 international survey of 454 younger radiologists from 48 countries found that 65.4% were aware of CEUS benefits, but 54.8% did not perform CEUS.[38] The 2026 European Federation of Societies for Ultrasound in Medicine and Biology nonhepatic guideline update describes nonhepatic CEUS applications as steadily growing, with bowel imaging among active research areas and renal/urologic applications increasingly established in routine practice.[39] These data are not directly comparable by country but emphasize recurring barriers: training, workflow, regulatory indications, access to contrast-specific software and agents, and reimbursement.

In the United States, however, most acute-care CEUS applications remain off-label because the commercially available UCAs are approved only for left ventricular opacification (Definity, Lumason, Optison), characterization of focal liver lesions (Lumason), and pediatric vesicoureteral reflux imaging (Lumason).[8] Although this does not preclude clinical use, it should be reflected in institutional protocols and local consent practices.

Training for acute-care CEUS builds on existing US training and experience and does not require an entirely new skill set. Operators should already be proficient in the corresponding conventional examination and understand the enhancement characteristics associated with ischemia, hemorrhage, and inflammation.[17] Structured reporting and archiving of cine clips are essential because interpretation depends on dynamic enhancement patterns, not isolated still images.

The principal limitations of CEUS are sonographic rather than pharmacologic. Body habitus, dressings, bowel gas, and limited acoustic windows may restrict image quality. CEUS also remains unreliable for hollow viscus and mesenteric injury and cannot evaluate structures that are not accessible sonographically.[17]

Whether CEUS is an adjunct to CT or the definitive study depends on the clinical question. CT remains the preferred imaging modality when injuries involve multiple organ systems or structures that cannot be adequately assessed with US. In contrast, CEUS may be the primary study for a defined set of indications: minor to moderate blunt abdominal trauma in stable children, follow-up of solid-organ injuries, active bleeding within accessible hematomas, and focused perfusion questions such as renal infarction or suspected complications of acute cholecystitis.[3,13,17,18] In these settings, real-time bedside perfusion assessment can provide information that directly influences management.

Conclusion

Although modern imaging evaluates both structure and function, many acute-care questions are ultimately questions of tissue perfusion. CEUS provides real-time assessment of tissue perfusion at the bedside, a physiologic parameter that is often central to acute clinical decision-making. Across a broad range of acute and emergency conditions, CEUS findings can be interpreted using 3 recurring patterns: reduced perfusion associated with ischemia and infarction, extravascular contrast associated with active hemorrhage, and increased perfusion associated with inflammation and infection.

The evidence base is not uniform across indications. Trauma, solid-organ injury surveillance, active bleeding, and selected vascular complications are among the most mature acute-care applications, while inflammatory applications are more indication-specific and should be interpreted within conventional diagnostic pathways. The gallbladder case illustrates why the 3 perfusion patterns should not be viewed as fixed categories —inflammatory hyperemia and ischemic injury may coexist as a disease evolves.

For radiologists and acute-care clinicians, CEUS extends the diagnostic capabilities of conventional US without sacrificing portability or increasing radiation exposure. Although CT continues to be essential for comprehensive evaluation and pathology beyond the sonographic field of view, CEUS may serve as a complementary or, in selected settings, alternative imaging modality for pediatric trauma, follow-up of solid-organ injury, and assessment of accessible hemorrhagic, ischemic, and inflammatory processes.

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CEUS provides direct assessment of tissue perfusion at the bedside, offering a practical way to answer important diagnostic questions in acute and emergent care.

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Put People at the Center of Your AI Implementation

Vickie Bedel

Successful implementation of artificial intelligence (AI) in radiology requires more than choosing the right technology. It requires a commitment to the people whose work will be affected by it.

That may seem counterintuitive. As AI systems become increasingly sophisticated and autonomous, it can be tempting to focus primarily on technical capabilities. But in my experience of overseeing the implementation of AI-powered technologies across hundreds of imaging centers, the human side of adoption is often what determines whether a promising technology delivers meaningful results and sustainable impact.

Several lessons have emerged from that experience.

Establish Your Desired Purpose and Outcome

What problem are you trying to solve? Address that question from the outset of discussions on whether to integrate AI into your radiology practice. Make sure your answer is specific and holistic enough to support the investment of money, time, research, training, and other change-management resources associated with adopting an AI product.

A plan with the best chance of success will include solutions rooted in a full understanding of real-world clinical practice. That will require working with a vendor that has extensive knowledge of radiology's staffing challenges, workflow pain points, and the greatest opportunities to increase diagnostic accuracy while improving the patient experience.

Plan for the Tech's Beneficiaries

The AI product on your radar may seem attractive based on cost, features, and technical support, but it could very well be incompatible with your end users.

For example, a technology that boosts detection of breast abnormalities in a specific patient population could actually underperform in other diverse populations, thus leaving out the full community served by your practice. An AI solution for brain imaging that spotlights every possible abnormality could be a mismatch for a practice where the neuro subspecialists prefer more targeted sensitivity. Or maybe your radiology group purchased an AI solution for MRI remote scanning, only to realize afterward that technologists assigned to this new set-up struggled with the expected workflows.

To avoid such challenges, thoroughly engage your end users for input and feedback from the outset and adjust the plan as your project moves forward.

Make Integration as Seamless as Possible

Create a framework that accounts for every person who will use, interact with, or otherwise be affected by the technology you will bring onboard. Whenever possible, include those colleagues in the development and implementation plan.

You will maximize enthusiasm by showcasing the product's benefits from the beginning. Forecast operational changes while providing ample training, answering questions, and making clear the intended purpose of the technology.

Then follow up with continued support following deployment, adjusting as needed for even the simplest factors. Take, for instance, an AI self-registration system that functions well in lab testing but freezes up in an imaging center with spotty Wi-Fi. Success will depend on the willingness to identify and respond to discrepancies between pre- and post-deployment phases.

Define Success—Then Measure It

You have pinpointed your AI project's purpose and targeted outcome, then built your master plan for engaging colleagues. Now you must set agreed-upon metrics—and benchmark performance against them.

In my experience, AI implementations succeed when

- leaders actively encourage honest assessments about what has gone well and what has underwhelmed, as well as about unexpected twists that have arisen and opportunities to enhance the product;
- anecdotal evidence is combined with data-driven insights to evaluate how the AI solution is faring; and
- the organization takes appropriate actions based on its continued learnings.

Ultimately, an inclusive, thorough, and human-centered approach will maximize the odds of achieving the pinnacle goal of any AI implementation: helping radiologists, rad techs, front-desk liaisons, and other members of the imaging team better concentrate on the needs of patients.

Vickie Bedel is Chief Digital Operations Officer and Senior Vice President of Northeast Operations, RadNet.

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CT Contrast Delivery: Managing Injection Pressure Through Warming

Sponsored by GE HealthCare

Executive Summary

Advances in CT acquisition speed, detector coverage, and high-flow injection protocols have increased contrast delivery demands. Successfully achieving the prescribed contrast flow rate depends on multiple factors, including IV access and placement, contrast concentration and viscosity, injection volume and duration, patient size and characteristics, and scan time and characteristics. Because contrast viscosity increases resistance to flow, it can contribute to higher injection pressures and difficulty maintaining the prescribed flow rate.

Contrast temperature is a modifiable factor that directly affects viscosity. Warming iodinated contrast media to 37°C, human body temperature, reduces viscosity and the resistance to flow. The American College of Radiology recognizes that warming can reduce the viscosity of iodinated contrast media, and may be considered in certain circumstances, particularly with higher-viscosity agents.

Despite previous success with contrast media warming, some CT departments discontinued the practice after weighing operational and quality assurance (QA) demands associated with Joint Commission expectations. However, as CT protocols and contrast-delivery practices have evolved, attention has returned to the potential value of contrast warming and maintaining consistent contrast temperatures throughout the delivery pathway.

Achieving that consistency involves more than warming contrast to a specified temperature; maintaining it through injection requires a consistent approach to monitoring, storage, and workflow. Associated QA requirements also must be met, including documentation of contrast stock rotation and usage in accordance with the prescribing information for each contrast bottle.

Technologies that integrate warming and temperature management into the contrast delivery system—such as CT syringeless injector systems with integrated warming and temperature-management features—offer a practical approach to streamlining these processes. For multidose contrast, the location of the warming mechanism can also affect temperature consistency across doses. Systems that position temperature management components directly at the bulk contrast bottles, for example, can maintain contrast temperature as the containers are drawn down, helping to keep the contrast warm until delivery. Importantly, warming is only one component of a broader strategy to promote consistency across the contrast delivery pathway and standardize protocols throughout a network of CT departments.



"When injection pressures become a limiting factor, it's important to look at the entire delivery apparatus, and warming contrast can be one way to reduce resistance and help maintain the prescribed flow rate."

–Corey Jensen, MD

ACR Guidance for Warming Contrast

Warming contrast lowers viscosity and reduces injection resistance, but more specific clinical advantages including patient comfort and diagnostic enhancement are less clearly demonstrated in research amid anecdotal reports of benefits.[1] The American College of Radiology, in its *Manual on Contrast Media*,[1] notes:

> **"Patients injected with more viscous contrast material may be more likely to have extravasations than patients injected with less viscous contrast material. This effect may be mitigated for viscous media by extrinsic warming to human body temperature prior to injection."**

Viscosity of iodinated contrast may vary and is affected by the amount of iodine in the select vial/bottle, known as the agent's concentration. The higher the concentration, the higher the viscosity (e.g. 370 mg (I)/mL).

The ACR manual cites a lack of supportive evidence for "routine warming of low-osmolality, lower-viscosity iodinated contrast agents," noting "some evidence that the warming of low-osmolality, higher-viscosity iodinated contrast agents may decrease the rate of contrast extravasations." It also notes that data are "inconsistent and insufficient to recommend its routine practice when considering the logistics involved."

The ACR suggests considering iodine-based contrast media warming to reduce viscosity in certain circumstances, noting that this may indirectly "reduce the risk of extravasation by decreasing resistance during intravascular injections in certain high-risk patients to improve iodine-based contrast flow and reduce injection pressure."[1]

Contrast Warming in CT

Contrast temperature is a modifiable factor that influences contrast viscosity, injection pressure, and iodine delivery. As CT protocols increasingly require higher injection rates, managing viscosity becomes important in consistently achieving prescribed flow rates, iodine delivery, and consistent imaging protocols across a network of scanners. Warming contrast media to 37°C reduces viscosity and injection pressure,[1] which may be relevant when using higher-flow injections.

CT technology continues to advance with faster acquisition speeds and wider detector coverage to capture more anatomy in less time, which places greater demands on timed contrast delivery. Many factors can impact the complete contrast delivery pathway and the ability to achieve prescribed flow rates including patient body size and cardiac output; IV access catheter size and location; contrast concentration and viscosity; injection volume and duration; and scan speed and timing. Of these, contrast viscosity can be managed before the injection begins.

"Higher viscosity agents have been shown to increase the risk of extravasation at ambient/room temperature, an effect which is reduced by contrast warming," says Nakul Gupta, MD, Vice-chair of Technology and Translational Imaging at Houston Methodist Hospital System. "Regrettably, high iodine content agents that are best suited for specific imaging protocols such as coronary angiography are more viscous agents. We view contrast warming as a modifiable risk factor that improves coronary enhancement and minimizes patient harm."

Although the advantages of warming contrast to lower its viscosity and reduce resistance during injection are well documented,[1] evidence that recommends warming to support specific clinical advantages is less clear, according to the American College of Radiology *Manual on Contrast Media*.[1] Over the years, as some practices weighed operational demands, like meeting stringent Joint Commission requirements against uncertain clinical benefits, many reconsidered or eliminated their contrast warming practices. Today, increasingly demanding CT protocols have renewed attention on the importance of consistent injector performance and maintaining contrast temperature throughout the injection pathway.

Lower Viscosity Supports More Consistent Contrast Delivery

High-flow rate protocols that depend on delivering a precise contrast bolus within a narrow acquisition window, especially for cardiac applications and perfusion, make low viscosity, consistent injection pressure, and contrast temperature critical, according to Pam Mager, RT(R)(CT), Enterprise Manager of Clinical CT Imaging Physics at Houston Methodist.

"There's a demand to deliver the contrast as effectively, efficiently, and consistently as possible," Mager notes of increasingly complex technology and faster speeds.

Computed tomography angiography (CTA) and contrast-enhanced cardiac CT imaging depend heavily on carefully controlled contrast timing, injection rate, concentration, and temperature to achieve consistent vascular enhancement. Warming contrast to reduce its

viscosity allows the contrast to flow more smoothly through the IV catheter with less injection pressure. While the ACR guidelines do not note evidence to support improved patient tolerance through warming, Carrie Bartels, RT(R) CT, Senior CT Technologist on the CT Protocol Team at UW Health, Radiology, in Madison, WI, describes her department's challenges associated with higher-viscosity contrast media.

"Higher-viscosity contrast media require greater injection pressure, which can make administration more challenging, particularly in patients with smaller or fragile veins. This may increase risk of injection-related complications, such as contrast extravasation, and can affect patient comfort," Bartels says.

During contrast administration, factors that increase injection resistance—including high contrast viscosity, small-gauge IV catheters, longer tubing, and other sources of flow restriction—can limit achievable flow rates, alter contrast bolus delivery, and potentially compromise image enhancement.[2] Patient-related factors, including cardiac output, also influence contrast circulation and image enhancement.[3] As CT power injectors approach preset pressure limits designed to prevent excessive pressure, safety features engage to reduce flow rate or activate a pause feature, creating workflow interruptions. In applications at UW Health, properly warmed contrast yielded lower viscosity to improve injection efficiency, reduced injector pressure alarms, and minimized delays caused by troubleshooting IV access or common injection issues to facilitate efficient patient throughput and reduce repeat scans.

"By warming contrast, we had fewer injector pressure alerts, more consistent achievement of programmed flow rates, smoother contrast bolus delivery, and improved reliability of high-flow injections," Bartels reports, noting that the changes were especially noticeable when using larger contrast volumes and higher iodine delivery rates where viscosity has a greater impact on injection dynamics.

The practical benefits of contrast viscosity reduction became apparent in another case example at UT MD Anderson in Houston. After transitioning to a higher concentration iodinated contrast agent, the department observed more frequent pressure-limit injections, particularly through implanted ports. An evaluation found that improving the injection pathway—including larger-bore needles and tubing, along with the administration of warmed contrast—substantially reduced pressure peaks and restored intended injection rates.[4]

"When injection pressures become a limiting factor, it's important to look at the entire delivery apparatus, and warming contrast can be one way to reduce resistance and help maintain the prescribed flow rate," according to Corey Jensen, MD,

Viscosity and Contrast Warming

Viscosity varies among iodinated contrast media and decreases substantially when the contrast is warmed to body temperature.

Warming reduces viscosity: Across the contrast agents evaluated, dynamic viscosity decreases by about half when warmed from room temperature (20-25°C) to body temperature (37°C).

Higher concentration generally means higher viscosity: Contrast media with higher iodine concentrations, such as 370-400 mg(I)/mL, generally have higher viscosity than lower-concentration agents at both room and body temperature.

Dynamic viscosity is measured in centipoise (cP), a unit of resistance to flow. As temperature increases, viscosity decreases.

Source: American College of Radiology. *Manual on Contrast Media. Appendix A: Contrast Media Specifications. 2026.*

QA Considerations

Because iodinated contrast media is considered a medication, warmed contrast may be subject to Joint Commission considerations related to medication handling, patient safety, and equipment management. Departments may therefore consider adopting site-specific procedures that address the following:

- **Temperature monitoring:** Verify that the warmer reaches and maintains the manufacturer-recommended temperature, commonly 37°C.
- **Storage duration:** Monitor how long contrast remains in the warmer and ensure it's used within manufacturer guidelines.
- **Documentation:** Maintain temperature logs and/or document the "time in" and "time out" schedule for each contrast media bottle in the warmer.
- **Equipment maintenance:** Complete and document preventive maintenance, calibration, and recommended performance checks for warming equipment.
- **Policies and procedures:** Establish clear, site-specific protocols for warming, storing, and administering contrast.
- **Staff training:** Provide training on the operational protocol of the warming equipment and institutional warming procedures, with documentation of competency/education.

Having clear protocols, maintenance records, and staff education documentation demonstrates compliance with Joint Commission expectations and safe care regulations.

Syringe-Based Injection Vs. Syringeless Technology

Syringe injector systems	Syringeless injector systems
Manual prep: Technologists must transfer contrast into an empty syringe before each imaging exam.	**Simplified prep:** Multi-dose contrast containers connect directly to the injector, reducing manual steps and contrast and consumables waste.
Repeated loading: Contrast and saline syringes are loaded, changed, and prepared between patients.	**Fewer manual steps:** The system does not require repeated loading and replacing of syringes.
Manual warming and maintenance: Contrast bottles are warmed separately, with temperature reduction occurring during transfer.	**Integrated heat maintainers:** Contrast must first be independently warmed, and is maintained to 37°C by the injector.
Temperature monitoring: Temperature checks and documentation are manual processes.	**Automated monitoring:** The injector system monitors the contrast temperature and captures documentation.
Workflow variability: Preparation and warming practices, including the use of contrast warmers and warming sleeves, vary by technologists and departments.	**Greater consistency:** Contrast preparation, heat maintenance, and delivery is standardized across scans via system automation features.
QA burden: Temperature logs, warming equipment, and other functions require staff oversight with consistent documentation.	**Streamlined QA:** Integration of heat maintainers and monitoring processes reduces manual documentation and demands of QA tasks.
Waste considerations: Contrast left in a prepared syringe is usually discarded after the exam.	**Single-use delivery:** Contrast is delivered right from the container, minimizing waste and the need for disposable syringes.

Director of Abdominal CT Imaging at UT MD Anderson.

As noted, warming contrast should be viewed as one component of an overall strategy to optimize safe contrast administration during high-flow injections.

Compliance and Comfort Without Compromise

Quality assurance plays a critical role in contrast warming to ensure patient safety, maintain regulatory compliance, and support consistent contrast delivery. Although processes vary according to established institutional guidelines and the warming technology used, departments must account for storage requirements, monitoring contrast stock rotation, equipment maintenance—including temperature monitoring—and ensuring that staff education includes written QA protocols with observations and documentation.

While QA considerations are manageable, they add workflow steps that can become burdensome in departments where contrast use is intermittent or where exams are subject to delays. Like many institutions, these considerations eventually led UW Health, which had been warming contrast for decades, to discontinue its warming programs. As a result, the department experienced a "small uptick in IV infiltrations," or contrast extravasations, according to Bartels.

Similarly, requirements such as maintaining a temperature log, "were actually deterring some of our community hospitals from warming," Mager says of Houston Methodist satellite locations. From an injection-performance perspective, however, unwarmed contrast presents a trade-off: room-temperature contrast has higher viscosity, which increases resistance to flow and may require higher injection pressures.

Today, both Houston and UW Health warm contrast to 37°C. Operationally, maintaining the temperature until the administration of the contrast presents the greatest challenge, because it gradually cools after removing from the warmer,

Workflow Savings of a Syringeless System

GE HealthCare's CT motion syringeless injector, manufactured by ulrich medical, outperformed a single-use syringe injector in terms of workflow efficiency, ease of use, and overall performance, with technologists spending 63.6 seconds less per patient in the scan room.*

**Toia G, et al. Consumable material waste and workflow efficiency comparison between multi-use syringeless and single-use syringe-based injectors in computed tomography.* Acad Radiol. *2023;30(10):2340-2349. doi:10.1016/j.acra.2023.05.038*

with the greatest loss occurring during the first 15 to 30 minutes. Injector-mounted warming sleeves may help maintain prewarmed contrast, but their effectiveness can vary based on positioning and operator use.

These challenges have prompted a shift toward more integrated approaches that reduce the number of manual steps required to maintain contrast temperature and support consistent iodine delivery. CT departments can more readily incorporate contrast warming into the injection workflow by using a syringeless injector system with built-in heat maintainers. This advanced injector technology reduces manual preparation and streamlines contrast delivery management. The technology can also address some of the storage, temperature maintenance, and handling challenges associated with conventional warming practices.

Integrating Contrast Warming Into CT Workflow

Syringeless injector systems consider the entire contrast delivery pathway for better preservation of temperature until the administration of the contrast injection, which, in turn, supports smoother, consistent contrast delivery and lower injection pressures. While the amount of temperature maintenance varies by injector system and departmental workflow, in general, syringeless systems present fewer opportunities for temperature loss, thus simplifying the warming process.

With multidose contrast delivery, where the warming mechanism is located impacts how consistently contrast temperature is maintained across doses. Maintaining the contrast temperature at the bulk vial helps ensure that it remains warmed between doses, supporting consistent temperature across the full dosing sequence.

"Modern injector systems maintain the contrast temperature even after it's been removed from the warmer and loaded into the injector, which can be a huge difference-maker if there's a lag between when the injector is loaded and when the patient is ultimately scanned. Being able to control as many variables as possible certainly aids in getting consistent results," Gupta says.

Advances in injector technology allow systems to respond to increasing injection pressure by incrementally reducing the flow rate rather than stopping the injection. This approach can help maintain contrast delivery when pressure limits are reached and support consistent imaging.

"Pressure limited injections result in marked drop-off of injection rate and poor opacification, with the degree of impairment depending on how soon the injection was cut off," explains Gupta.

Conclusion

As contrast injection protocols become more demanding, maintaining contrast temperature is an important component of consistent, reliable contrast delivery. An integrated approach that combines temperature maintenance, pressure management, quality assurance, and standardized workflow can help reduce variability across CT examinations and departments. By automating temperature monitoring and other aspects of contrast delivery, syringeless injector systems may further reduce manual steps and support greater consistency throughout the injection pathway.

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Key Takeaways

- Advanced CT requires faster, more precise contrast delivery.
- Higher-viscosity contrast increases injection resistance and pressure.
- Warming iodine-based contrast media to 37°C reduces viscosity to help facilitate high-flow rate injections.
- Warming isn't the whole equation: IV access, catheter size, contrast concentration, and patient factors also affect injection performance.
- Pressure-limited injections can reduce or interrupt contrast bolus.
- Traditional warming workflows require separate QA and manual processes; integrated technologies can streamline temperature maintenance and delivery.
- Syringeless technology can automate functions of contrast heat maintenance, monitoring, and delivery to reduce operator variability.



Scan to learn more about the CT motion syringeless injector

Whole-Body MRI Screening: Radiology's Evolving Role

Kerri Reeves

Whole-body MRI (WB-MRI) screening has gained visibility in recent years as for-profit enterprises market preventive imaging to healthy, asymptomatic individuals. Although research has not demonstrated a mortality benefit, consumers are increasingly seeking peace of mind—or, alternatively, detection of disease before symptoms arise—at imaging centers and a growing number of dedicated WB-MRI screening clinics. Paying out of pocket for WB-MRIs reflects a broader trend toward greater consumer involvement in health decisions.

While they have the potential to catch disease that may otherwise go undetected, WB-MRI exams often identify lesions that ultimately are deemed benign. A 2020 review of 12 studies covering 6,214 WB-MRI screenings found that, of 17,961 abnormal findings reported, 91% were deemed benign, while 9 % were considered to be oncologically relevant and requiring further investigation. Only 0.5% of lesions were found to be suspicious for cancer.[1]

WB-MRI is commonly used for surveillance in patients with certain inherited cancer-predisposition syndromes like Li-Fraumeni and for management of genetic conditions such as neurofibromatosis and tuberous sclerosis complex. However, WB-MRI screening is not routinely recommended for average-risk individuals, and most insurance plans don't pay for it.

Evidence Review for Routine Screenings

The American College of Radiology states, "there is no documented evidence that total body screening is cost-efficient or effective in prolonging life" in asymptomatic patients.[2]

"The way you confirm whether a screening test creates health value—that it improves the quality or quantity of your life—is with a randomized trial," agrees Matthew Davenport, MD, professor of radiology and urology, vice chair and service chief of radiology, and associate chief of staff of the academic medical center at the University of Michigan. No such studies, however, have been done for WB-MRI, Dr. Davenport notes.

Established screening recommendations for cancers of the colon, breast, prostate, and cervix are supported by evidence of clinical benefit. Brian Dontchos, MD, associate professor of radiology, University of Washington (UW) School of Medicine, and physician, Fred Hutchinson Cancer Center in Seattle, says screening recommendations must demonstrate a disease-specific survival benefit, and be broadly applicable to a large population, reasonably cost-effective, and minimally invasive.

"Whole-body MRI does not fulfill these [criteria]," Dr. Dontchos says. "We need a lot more time to study this before we can make the important conclusion [about a disease-specific outcome]."

The consequences of implementing widespread screening without evidence of improved patient outcomes are illustrated by the trend of thyroid cancer screening in South Korea, where diagnoses increased 15-fold over 18 years while mortality remained stable, largely because of overdiagnosis associated with widespread ultrasound screening."[3]

"Thyroid ultrasound screening generated surgeries, cost, and anxiety from findings that patients likely would have died *with* rather than died *from*," Dr. Dontchos says.

Dr. Davenport adds that routine ovarian cancer screening—not recommended for asymptomatic, average-risk women—offers a similar lesson.

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Although a randomized trial of over 200,000 women found more early-stage diagnoses and fewer advanced-stage cases with ultrasound screening, mortality from ovarian or tubal cancer was identical in the screened and non-screened groups after a median follow-up of 16.3 years.[4]

"The authors highlighted the importance of focusing on cancer mortality as the primary outcome in screening trials, because detection alone does not necessarily translate into improved health," he says.

Routine WB-MRI does have advocates. Sean Raj, MD, MBA, chief medical officer and chief innovation officer at SimonMed, believes the benefits of earlier detection outweigh the potential harms of false positives in WB-MRI. Dr. Raj notes that his clinics regularly demonstrate unsuspected abnormalities, including cancers and aneurysms, in "otherwise perfectly healthy people."

"The bottom line is that we can now see clinically significant, previously unsuspected disease before there are even symptoms," he says.

"I'm encouraged about what whole-body MRI could potentially tell us about health before symptoms appear," agrees Zahi A. Fayad, PhD, director of the Biomedical Engineering and Imaging Institute and professor of diagnostic, molecular and interventional radiology at the Icahn School of Medicine at Mount Sinai in New York City.

The value of WB-MRI may be realized by its role in possibly preventing the need for aggressive treatments following early detection. Dr. Fayad says that to establish clinical value, prospective studies comparing WB-MRI plus usual preventive care with usual care alone are needed to assess impact on disease development, quality of life, benefits, harms, and costs.

"In the meantime, commercial programs should be clear about what the scans can miss, the uncertainty surrounding benefits, and the possibility of unnecessary follow-up. [WB-MRI] should complement recommended screening, and a normal scan should never be a reason to dismiss symptoms," he says.

Downstream Effects of WB-MRI Screening

While additional testing and treatment may lead to patient burdens and demands on healthcare resources, the significance of WB-MRI findings depends on clinical context and the outcome of follow-up care.

Manjiri Dighe, MD, UW professor of radiology, medical director of ultrasound and vice chair of quality and safety at UW Medical Center, explains that WB-MRI screens often start a "cascade" of medical tests that contribute to long wait times, high costs, and patient stress. With "some thyroid nodules" found in 50% of the population, according to Dr. Dighe, MRI leads to ultrasound and then frequently to a biopsy.

"Less than 5 % of any nodules seen turn out to be cancer," she explains, adding that liver lesions create a similar testing demand, with benign cysts or hemangiomas as typical outcomes.

"We're using these imaging slots that [patients] don't really need … and [that] would never have been investigated further and in most cases not be a significant finding that needs treatment," Dr. Dighe says. "Current oncology patients may not get appointments in time because we're trying to solve questions related to something seen incidentally on full-body MRI."

Dr. Davenport says incidental findings on WB-MRI are common. "Advanced imaging of a single part of the body like the abdomen detects findings of uncertain significance in approximately 20-40% of average-risk people," he says. "When images are taken of the entire body, that rate is higher."

Follow-up testing is not unique to WB-MRI. Man well-established screening programs consider additional testing inevitable. Nina Vincoff, MD, chair of the ACR Patient and Family Centered Care Commission, executive medical director of Prisma Health Radiology Care Division, and editor-in-chief of *Applied Radiology,* notes that about 10% of screening mammograms result in a callback, while approximately five cancers are detected per 1,000 women screened.[5]

"We accept the tradeoff because of the potential value of detecting disease earlier," she says.

Dr. Raj explains that SimonMed utilizes advanced 3T magnets with detailed resolution, and employs fellowship-trained radiologists supported by AI to characterize findings accurately. This, he says, greatly reduces the number of "indeterminate findings." His providers also consult with WB-MRI patients on recommendations through their full-service imaging clinics. "We really hold their hand through the process."

Not all WB-MRI providers uphold high standards for protocols, reporting, and management. Unlike targeted diagnostic exams that can draw on frameworks like BI-RADS, LI-RADS, and TI-RADS, WB-MRI screening presents challenges in maintaining consistency across organ systems. This presents an opportunity for radiology to guide responsible use, developing standardized protocols, reporting frameworks, outcomes research, and evidence-based pathways for follow-up care, says Dr. Dighe.

Protocols must also be evaluated in the context of their intended use. WB-MRI protocols, for example, usually differ from those of dedicated breast MRI, which calls for tailored acquisition techniques like prone positioning and contrast-enhanced sequences to address specific diagnostic questions. A challenge with WB-MRI protocol design remains balancing exam scope and duration with the clarity required to detect abnormalities.

"There are limitations on whether the magnet can get images from head to toe within a reasonable amount of time. There's a balance to strike between the resolution you're trying to achieve to see lesions and the amount of time you spend in getting those images," Dr. Dighe says.

Radiology's Role in a Consumer-Driven Future

Routine WB-MRI screening is part of a larger trend toward consumer-directed, fee-for-service health testing. Demand for diagnostic medical information outside traditional clinical pathways is growing amid uncertainties around its clinical utility, appropriate use, and downstream effects. According to Dr. Raj, radiologists can support the growing practice by setting clear expectations with patients prior to the screening about what the exams could show, and afterwards by contextualizing findings, ensuring that the scans don't "cause more panic than good."

"In preventive imaging, knowing when *not* to do more [is vital]" he says. "If we identify a benign finding, we need the confidence to [say] it doesn't need additional testing. When we identify one that's potentially serious, we need a clear pathway to act. That's how we turn more information into better medicine, rather than simply more healthcare."

With appropriate oversight from radiology, consumer-driven imaging may yield more meaningful results.

"Radiology departments have an opportunity to lead the work of building evidence and guiding responsible use. We should help define protocols, how findings are reported, and when further investigation is warranted," concludes Dr. Fayad, adding that the examinations could contribute to research that follows people over time and establishes which measurements actually help guide care.

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Rasmussen Aneurysm

Molly Lieux Furrow, MD; Kyler Shin, MD; Craig Kym, MD; Milan Maheshwari, BS; David Wynne, MD; Mukul Maheshwari, MD

Abstract

Tuberculosis (TB) is a major cause of mortality and morbidity worldwide, with provisional data suggesting a recent increase in case counts in the United States. Complications from pulmonary TB (PTB), including cavitation, bronchiectasis, pleural disease, and vascular abnormalities, can occur despite treatment and are associated with high mortality. A rare vascular complication is aneurysmal dilatation of the pulmonary artery, known as a Rasmussen aneurysm. Massive hemoptysis is a common manifestation with a high mortality rate that exceeds 5-25%. While most cases of PTB-associated hemoptysis arise from the bronchial circulation, hemoptysis due to a Rasmussen aneurysm stems from an affected pulmonary artery. Initial diagnosis relies on CT pulmonary angiography. Pulmonary artery angiography and embolization are required for treatment.

Keywords: rasmussen, tuberculosis, pseudoaneurysm, hemoptysis

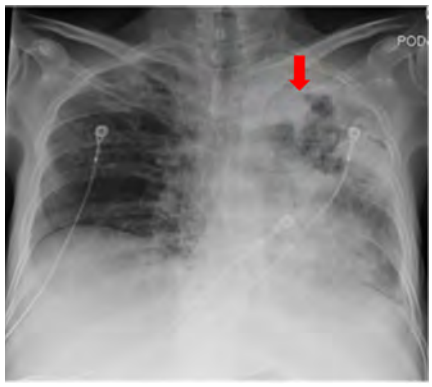
Case Summary

An adult with a history of decompensated alcoholic cirrhosis complicated by hepatic encephalopathy and ascites, small esophageal varices, and recent admission for newly diagnosed active pulmonary tuberculosis (PTB) presented with multiple tablespoons of hemoptysis. The patient's symptoms were accompanied by worsening abdominal distension. The patient reported coughing up a larger volume of blood than when initially diagnosed with TB. Laboratory evaluation revealed a hemoglobin of 8.4 g/dL, a prothrombin time (PT) of 25.5 seconds, an activated partial thromboplastin time of 37.6 seconds, and platelets of 103,000/µL.

Imaging Findings

Chest radiography on admission (Figure 1) demonstrated diffuse multifocal airspace opacities throughout the left lung with an associated left apical cavitary lesion. Subsequent chest CTA performed in the pulmonary arterial phase (Figure 2) demonstrated a 0.6 × 0.5 cm saccular focal outpouching from the anterior segmental branch of the left upper lobe pulmonary artery adjacent to the left apical cavitary lesion, suspicious for a Rasmussen aneurysm. Follow-up CTA performed in the systemic arterial phase ruled out active arterial extravasation and excluded aneurysmal involvement of the surrounding bronchial arteries. The patient was referred for pulmonary angiography with coil embolization of the anterior segmental branch of the left upper lobe pulmonary artery just distal and proximal to the aneurysm (Figure 3), with subsequent resolution of hemoptysis.

Figure 1. Initial chest radiograph. Diffuse multifocal airspace opacities throughout the left lung with an associated left apical cavitary lesion (red arrow).



Diagnosis

Rasmussen aneurysm.

Affiliations: Department of Radiology, Baylor College of Medicine, Houston, Texas (Lieux Furrow, Shin, Kym, M Maheshwari); Texas Tech University, Health Sciences Center, Lubbock, Texas (M Maheshwari).
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Figure 2. CT pulmonary angiography. Axial soft tissue window (A), axial lung window (B), and coronal soft tissue window (C) images demonstrating a focal saccular aneurysmal outpouching (red arrow) along the anterior segmental branch of the left upper lobe pulmonary artery, consistent with a Rasmussen aneurysm adjacent to the left apical cavitary lesion.

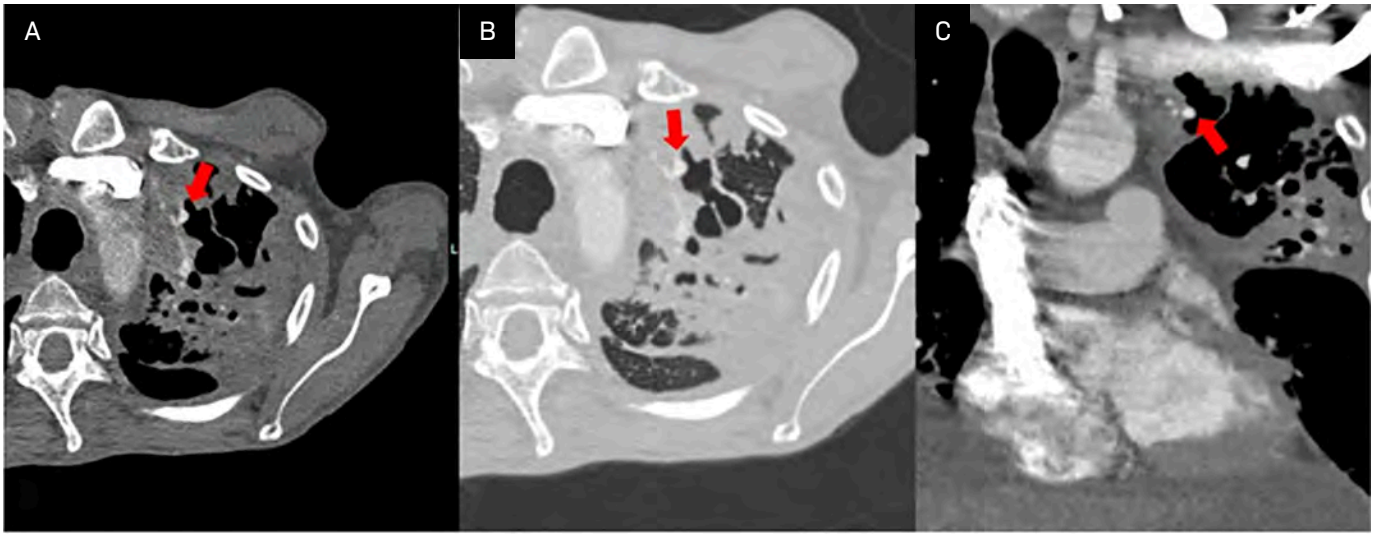
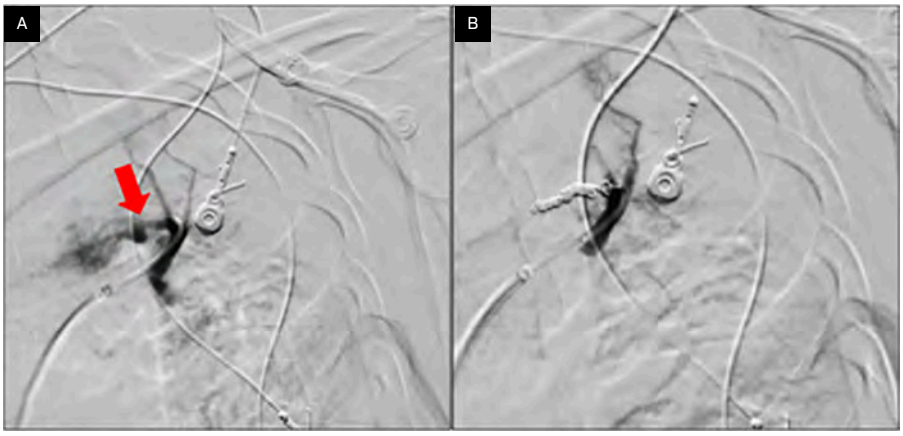


Figure 3. Pulmonary angiography with coil embolization. Digital subtraction angiography of the left pulmonary artery (A) demonstrating a Rasmussen aneurysm (red arrow) involving the anterior segmental branch of the left upper lobe pulmonary artery. Following coil embolization just distal and proximal to the aneurysm (B), no residual contrast filling of the aneurysm sac was noted.



Differential diagnosis in a patient with PTB and hemoptysis includes pulmonary embolism, bronchial artery hypertrophy/bronchiectasis, aspergilloma, and lung cancer.

Discussion

Rasmussen aneurysm is a rare but potentially life-threatening complication of PTB. Granulomatous inflammation from a cavitary tuberculous lesion results in caseous necrosis and mural thinning of the adjacent pulmonary arterial wall, leading to pseudoaneurysm formation.[1-4] Rasmussen aneurysm formation has been described in approximately 5% of cases of PTB,[4] with mortality rates as high as 50% in untreated patients due to rupture into the airway resulting in massive hemoptysis.[5] Early diagnosis and treatment are essential to avoid morbidity and mortality.

Contrast-enhanced CT pulmonary angiography (CTPA) plays a crucial role in differentiating Rasmussen aneurysm from bronchial arterial hemorrhage as the source of hemoptysis, thus guiding further management. Typical CTA findings include an eccentric, nodular outpouching arising from a pulmonary artery with contrast opacification in the pulmonary arterial phase.[4] Rakesh et al report that the source of hemorrhage was actually Rasmussen aneurysm in approximately 38% of patients with persistent hemoptysis following bronchial artery embolization.[6]

Treatment of a Rasmussen aneurysm is centered on endovascular embolization of the affected pulmonary artery.[1] Coils, vascular plugs, n-butyl cyanoacrylate glue, and ethylene-vinyl alcohol copolymers are all effective in achieving hemostasis while preserving lung parenchyma.[7,8] Surgery is rarely required and is reserved for patients with recurrent large-volume hemoptysis who have failed endovascular therapy. Effective management of hemoptysis in the setting of Rasmussen aneurysm relies on early detection with CTPA and consultation with diagnostic radiology, interventional radiology, and pulmonology to reduce morbidity and mortality.

Conclusion

Rasmussen aneurysm is a rare, life-threatening complication of PTB.

Granulomatous inflammation from an adjacent tuberculous lesion results in thinning of the pulmonary arterial wall and pseudoaneurysm formation, with rupture leading to often-fatal, large-volume hemoptysis. Prompt diagnosis with CTPA and endovascular treatment are crucial in reducing morbidity and mortality.

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Erdheim-Chester Disease with Isolated Central Nervous System Involvement: A Case Report

Cory Pierson, MD; Ethan H. Willbrand, BA; John-Paul J. Yu, MD, PhD

Case Summary

A previously healthy, middle-aged patient presented to the emergency department due to multiple falls stemming from acutely worsening ataxia and lower extremity weakness. Before presentation, the patient reportedly had several months of declining cognitive function, including slower processing speed, difficulties with long-term planning, and a suspected new left-hand tremor. There was no reported headache, nausea, or vomiting, and no reported history of smoking, alcohol, or drug use, or known malignancy.

Head CT demonstrated a hyperdense mass in the right frontal lobe with surrounding edema. Subsequent MRI showed multiple supratentorial and infratentorial enhancing lesions, which were initially presumed to be intracranial metastases. CT of the chest, abdomen, and pelvis was unremarkable. Lumbar puncture showed no evidence of malignancy or infectious etiology.

The patient underwent stereotactic biopsy of the dominant right frontal lobe lesion, which demonstrated reactive white matter with areas of vacuolization and foci of florid macrophage infiltrate, highlighted by CD163 (block A1 only) and CD68 immunohistochemical stains. CD1a was negative. These results were ultimately considered nonspecific.

Approximately 3 months after initial presentation, the patient was readmitted to the neurology service due to worsening functional status and progressive neurological deficits. Repeat MRI of the head showed several new lesions in the right frontal lobe and along the left interhemispheric falx. MRI of the entire spine showed scattered enhancing lesions throughout the cervical and thoracic cord. Whole-body PET was unremarkable. An additional extensive infectious and inflammatory workup was unrevealing.

Targeted next-generation sequencing was then performed on the specimen from the right frontal lobe biopsy, which demonstrated a BRAF p.V600E mutation. A combination of clinical, radiologic, and pathologic findings, therefore, led to a presumptive diagnosis of Erdheim-Chester disease (ECD).

Imaging Findings

CT of the head demonstrated a hyperdense mass in the right frontal lobe with mild surrounding vasogenic edema (Figure 1). Subsequent MRI of the head showed numerous enhancing foci throughout the cerebral and cerebellar hemispheres and the brainstem (Figure 1).

Follow-up MRI of the head approximately 3 months after initial presentation showed increasingly conspicuous punctate enhancing lesions in the posterior right frontal lobe with a new small dural-based lesion along the left interhemispheric falx (Figure 2). MRI of the spine showed multiple small and ill-defined T2 hyperintense enhancing intramedullary lesions within the cervical and thoracic cord (Figure 3).

Diagnosis

Erdheim-Chester disease.

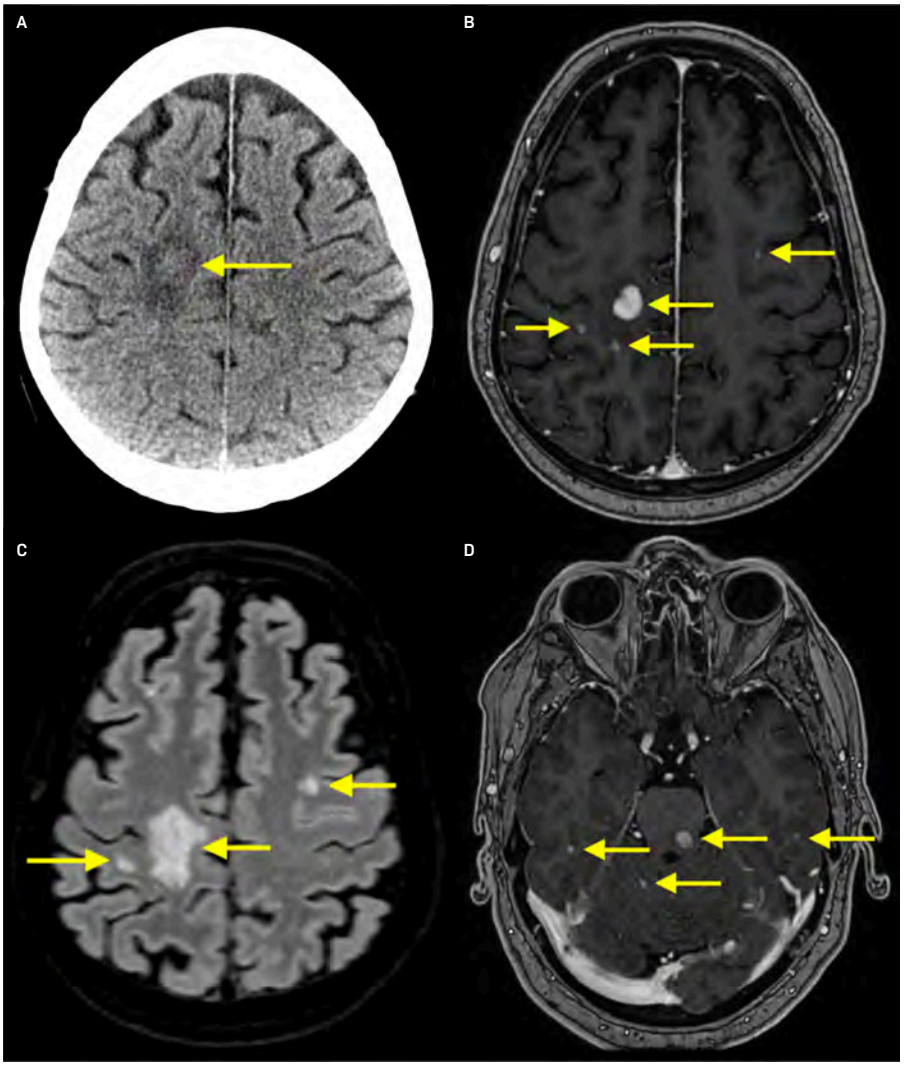
Differential considerations would include intracranial metastases, central nervous system (CNS) lymphoma, or possibly neurosarcoidosis. Alternative BRAF p.V600E mutant histiocytic neoplasms would include Rosai-Dorfman disease and Langerhans cell histiocytosis (LCH).

Affiliations: Department of Radiology, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin (Pierson, Willbrand, Yu); Medical Scientist Training Program, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin (Willbrand, Yu); Neuroscience Training Program, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin (Willbrand, Yu); Department of Psychiatry, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin (Yu); Department of Biomedical Engineering, College of Engineering, University of Wisconsin–Madison, Madison, Wisconsin (Yu); Department of Biostatistics and Medical Informatics, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin (Yu).

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Figure 1. (A) Axial noncontrast CT of the head showing a rounded hyperdense mass in the posterior aspect of the right superior frontal gyrus with surrounding vasogenic edema (yellow arrow). (B) Axial T1-weighted postcontrast and (C) axial FLAIR MRI images showing multiple enhancing and FLAIR hyperintense lesions in the right greater than left frontal lobes (yellow arrows), the largest of which corresponds to the hyperdense mass noted on noncontrast CT of the head. (D) Axial T1-weighted postcontrast images showing multiple additional enhancing foci in the left pons, bilateral temporal lobes, and right cerebellar hemisphere (yellow arrows).



Discussion

ECD is a rare and potentially fatal multiorgan hematopoietic histiocytic neoplasm occurring primarily in middle-aged adults.[1] Tumors are characterized by the accumulation of foamy macrophages that are CD68$^+$, CD163$^+$, and CD1a$^-$. S100 is typically negative or only weakly positive, which, when taken in conjunction with the negative CD1a, can help to distinguish it from LCH.[2] BRAF V600E point mutation is present in approximately 50% of cases. BRAF V600-mutant ECD can be treated with BRAF inhibitors such as vemurafenib, while BRAF wild-type ECD may be treated with mitogen-activated extracellular signal-regulated kinase pathway inhibitors.[3]

Clinical manifestations and disease progression are varied and highly dependent on the specific systems involved. While skeletal manifestations are most common (noted in up to 90% of reported cases), ECD can also manifest with retroperitoneal fibrosis, renal failure, diabetes insipidus (DI), and cardiac disease.[2] CNS involvement is far less common, with only an estimated 15-25% of cases demonstrating disease within the neuraxis.[4] Cerebellar and pyramidal syndromes are the most frequent neurologic manifestations, in addition to cognitive difficulties, neuropsychiatric disturbances, and cranial nerve palsies.[4] CNS involvement has also been shown to carry a worse prognosis with higher mortality. Notably, isolated CNS disease without involvement of other organ systems, such as in this case, is exceedingly rare.

Neuroradiologic manifestations of ECD are varied and can include dural-based masses, supratentorial and infratentorial enhancing foci, orbital lesions, invasion of the hypothalamic pituitary axis (HPA), and spinal cord involvement.[5] While both meningiomas and ECD-related dural-based masses will show homogeneous enhancement, the lesions associated with ECD will more often demonstrate T2 hypointensity.[6] Obstructive hydrocephalus may also develop due to dural involvement.

Parenchymal lesions typically demonstrate T2/FLAIR hyperintensity with relatively homogeneous enhancement. These lesions are often found in the brainstem and cerebellum, followed by the frontal and parietal lobes.[7] The pons is the most common site of disease in the brainstem.

Disease involving the HPA typically manifests with loss of the posterior pituitary bright spot and thickening of the infundibulum.[7] DI is a common association with ECD, although the diagnosis of DI often precedes the confirmation of ECD by several years.

Despite being started on vemurafenib and repeat courses of steroids, the patient's functional status continued to decline

Figure 2. (A) Axial postcontrast MRI image showing slightly enlarged enhancing lesions in the posterior right frontal lobe (yellow arrow). (B) Coronal T1-weighted postcontrast MRI demonstrating a new small dural-based lesion along the left interhemispheric falx (yellow arrow).

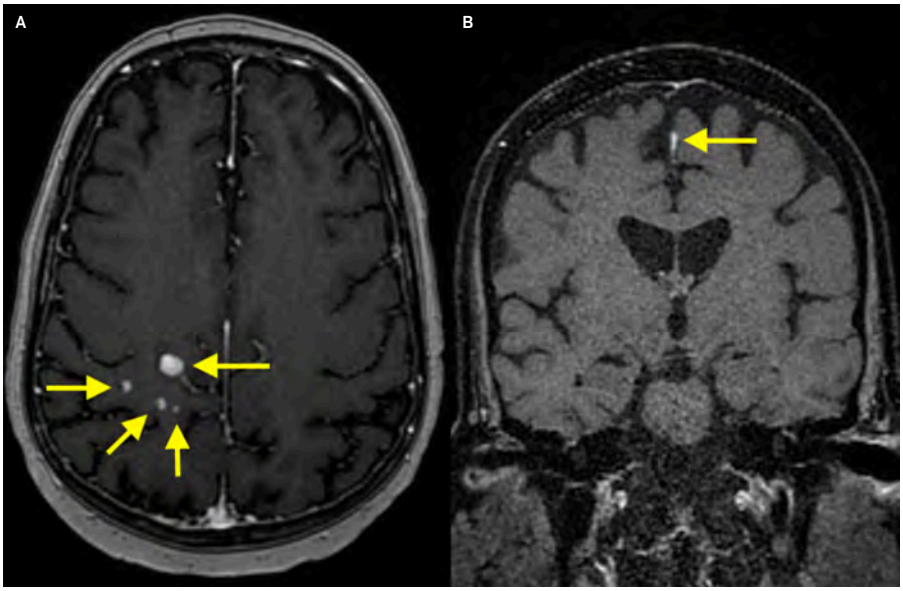
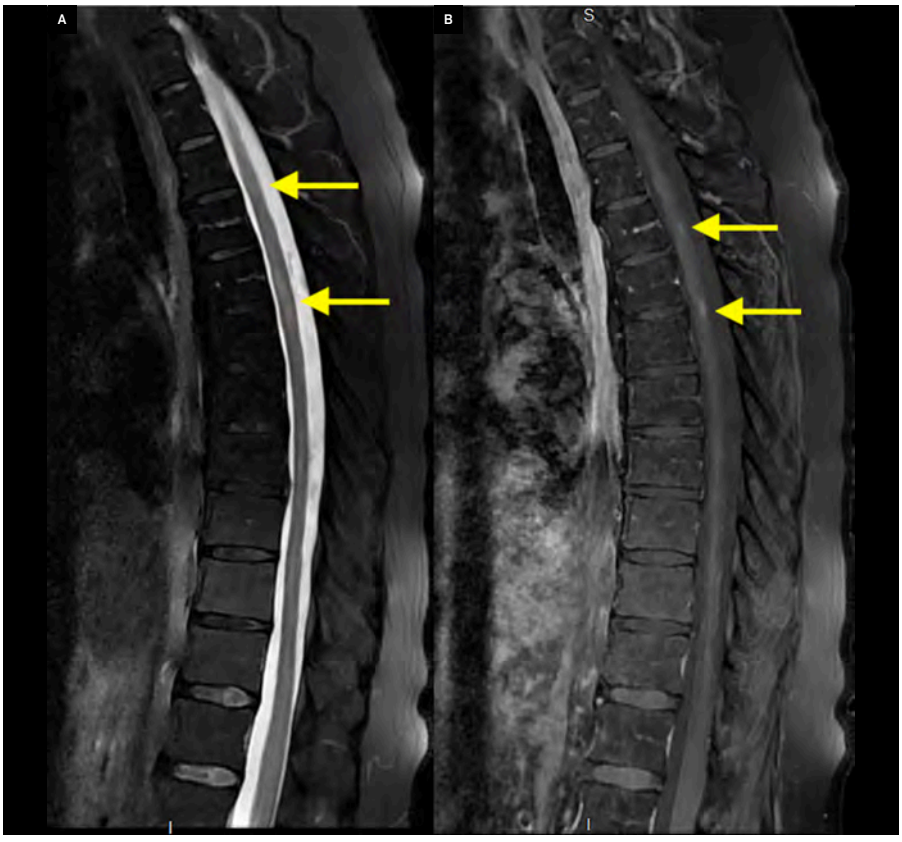


Figure 3. (A) Sagittal T2-weighted and (B) T1-weighted postcontrast MRI images showing subtle T2 hyperintense and enhancing intramedullary lesions within the thoracic cord (yellow arrows).



with worsened global weakness, decreased verbal output, and failure to thrive. Due to the patient's poor prognosis and global decline, the patient was discharged to a hospice facility.

Conclusion

ECD is an uncommon but increasingly recognized multiorgan histiocytic neoplasm with an estimated 1500 reported cases in the literature. Isolated involvement of the CNS without disease in other organ systems is exceedingly rare. Timely diagnosis of ECD can be challenging, especially given the rarity of the disease and the highly variable clinical presentation. This case highlights the value of utilizing all available clinical, radiologic, and histologic data to improve diagnostic accuracy and facilitate optimal patient outcomes.

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Beyond the AI Upgrade: Extending MRI Performance Across the Imaging Fleet

Joseph Jalkiewicz



This platform has allowed us to take an existing, well-run system and improve it far beyond the cost of the product.

Robert P. Jones, MD
Jackson Hole Medical Imaging and St. John's Health

Today's radiology departments face a dual balancing act. The first is to meet exponential growth in demand for magnetic resonance imaging (MRI) exams while allocating fixed operational resources. The second is to optimize department throughput when clinical protocols must constantly be adjusted to balance acquisition speed against image quality, diagnostic resolution, and radiologist confidence.

This is no small challenge for many health care enterprises that operate a widely disparate fleet of scanners. Managing equipment across different ages, field strengths, and original equipment manufacturers (OEMs) creates systemic variations in software capabilities, hardware metrics, and imaging consistency. As a result, many institutions are engaged in a continual search for tools that optimize existing assets without forcing them to rely on costly hardware upgrades.

Bringing Contemporary AI to Existing MRI Systems

To this end, imaging centers are increasingly turning to scanner-neutral AI post-processing software. Advanced deep-learning applications, such as SubtleHD™(MR) (Subtle Medical), function independently of specific hardware providers, offering a scalable method to modernize legacy scanners.

By applying deep-learning denoising and sharpening to reconstructed images from accelerated scans, SubtleHD(MR) mitigates the classic trade-off between scan time and image quality. Older hardware systems that cannot natively support modern, vendor-proprietary software upgrades can still achieve significant enhancements in signal-to-noise ratio and image sharpness. As a result, these technologies can extend the clinical and financial lifecycle of MRI scanners, unlocking high-field capabilities on standard legacy configurations.

"This has been somewhat of a sea change for us at our small institution," says Robert P. Jones, MD, a board-certified radiologist specializing in diagnostic and pediatric radiology at Jackson Hole Medical Imaging and St. John's Health. "We have a single MR scanner, and it's at least 12 to 15 years old, so it is not a young scanner."

Jones explains that for independent or tight-budget facilities such as St. John's, a rural community hospital, the software delivers significant clinical benefit with a financial footprint far smaller than that associated with frequent upgrades.

The Evolution of OEM AI Reconstruction

Medical imaging has witnessed a major evolution in scanner-specific hardware capabilities. Large manufacturers are building proprietary, deep-learning reconstruction models directly into their newest scanners. Key technologies driving this shift include Deep Resolve (Siemens Healthineers), AIR Recon DL (GE HealthCare), SmartSpeed (Philips), and Advanced Intelligent Clear-IQ Engine (AiCE; Canon Medical Systems).

These tools have elevated baseline clinical expectations for MRI acquisition speed and efficiency, as well as for automated spatial resolution. Their usefulness, however, is limited by the inherent capabilities of the hardware. Consequently, they can

Joseph Jalkiewicz is a medical writer for *Applied Radiology.*

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widen the performance gap between a medical facility's premium systems and its legacy fleet.

From Alternative to Complement: The "Layered AI" Approach

While early deployment strategies framed scanner-neutral applications strictly as alternatives for scanners lacking built-in AI, emerging protocols are leading to a new paradigm, one centered on a complementary, layered framework. Rather than replacing scanner-specific technology, scanner-neutral software can be applied in addition to OEM deep-learning reconstructions, effectively creating an "Layered AI" pipeline.

Jones says St. John's Health serves as an ideal use case for this approach, layering SubtleHD(MR) on top of Siemens Deep Resolve. Rather than forcing administrators and clinicians to choose between proprietary and independent systems, they function synergistically. The OEM scanner optimizes initial data acquisition and k-space reconstruction, while SubtleHD(MR) applies secondary, highly specialized noise-reduction and increased sharpness for an increase in image speed and diagnostic quality, he notes.

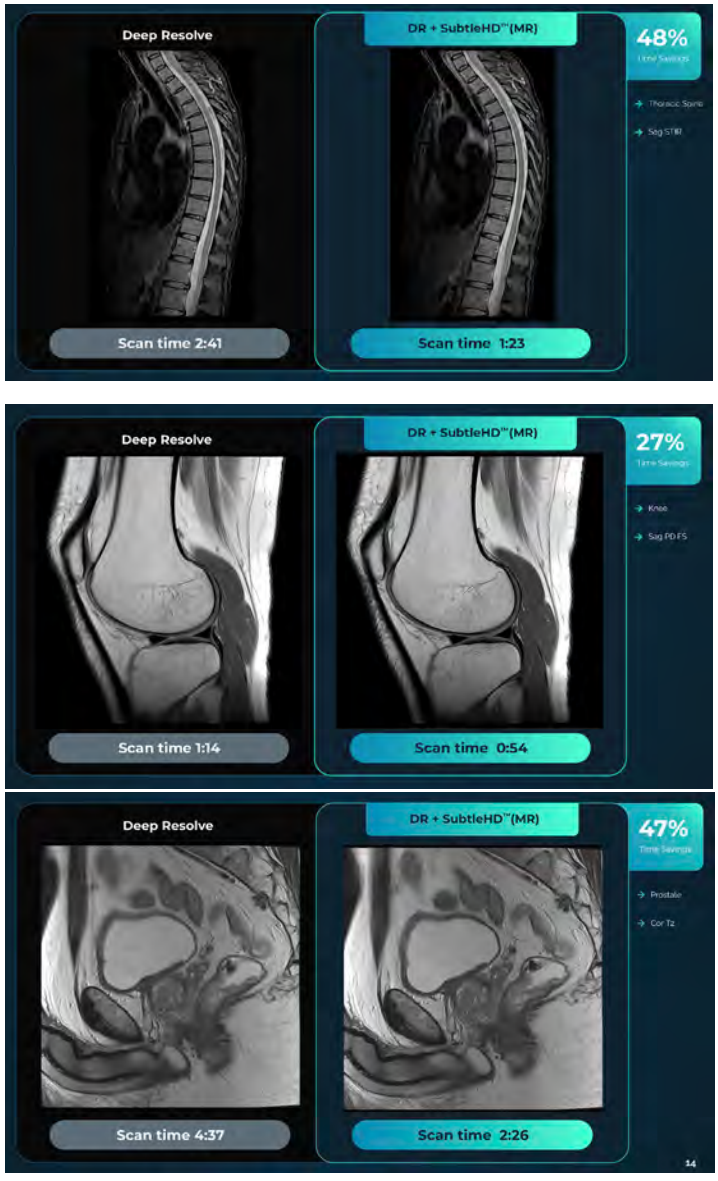
In 2022, the hardware and software of the department's original Siemens Aera 1.5 T MRI system were upgraded to the Siemens Magnetom Sola Fit, while the magnet itself, which dated to 2012, was kept in place, Jones says. The MRI currently operates on Siemens' syngo MR XB10, which is the upgraded software component.

"If Deep Resolve gives you a 20 percent time savings and then you add SubtleHD(MR) on top of that, you're getting images that are less noisy," Jones says. "I particularly find that the postcontrast images are clear in a way that they weren't to the same degree before."

He draws an analogy to dental hygiene: "The OEM software is sort of like the regular toothbrush, whereas Subtle is the electric toothbrush," he says. "You have your teeth, but having an electric toothbrush really adds a lot."

Extending AI Across the MRI Fleet

The usefulness of open-architecture AI applications like SubtleHD(MR) is especially apparent when the goal is to standardize a diverse, multi-vendor fleet. Many imaging networks wrestle with variance; a scan sequence performed on a newly installed system may look vastly



different from the same sequence executed on an older system across town.

By leveraging an external, hardware-agnostic AI layer, Jones says, imaging networks can establish uniform image quality across all their locations. For example, the technology can bring the diagnostic output of older 1.5-T systems closer to the baseline of modern 3T systems, as well as harmonize images produced by different vendor platforms. Jones calls this capability a vital tool for reducing daily friction.

"We read for several remote sites that don't have SubtleHD(MR), so I always have to do a mental reset with each MR machine that I'm reading from," he says. "Having homogeneity is really nice because it can remove a

lot of the head-scratching: Is this artifact? Is this just the machine? Or is this real?"

In addition, he says, the vendor-neutral framework bypasses complex cross-vendor IT bottlenecks, creating a seamless overlay that works natively across mixed environments.

Measuring the Impact

Ultimately, the value of a comprehensive AI strategy must be measured in terms of clinical impact and the financial bottom line. According to Jones, his department experienced a rapid transformation in five areas after integrating SubtleHD(MR):

- **Acquisition Efficiency.** Adding SubtleHD(MR) on top of Deep Resolve yielded an average reduction in scan time of approximately 15% per patient, translating to a savings of 1-8 minutes per exam.
- **Targeted Workflow Acceleration.** High-volume examinations, such as stroke brain protocols, knee studies without contrast, and hip studies without contrast, saw total scan times cut by nearly 50%.
- **Scheduling Capacity.** Overcoming scheduling bottlenecks allowed the center to seamlessly add 1-2 extra patient slots per day to the active MRI register.
- **Financial Performance.** With an institution baseline of $815 in average net revenue per MRI study, the added throughput created an immediate, tangible financial benefit to total net revenue.
- **Patient Experience.** Faster sequences mitigated patient movement, reducing motion artifacts and preserving overall diagnostic confidence.

"SubtleHD(MR) is helpful for patients. It's helpful for technologists. It's helpful for radiologists. It's helpful for the CEO of the hospital," Jones says. "The image-quality improvement may be an option for some people, but the time savings and the money savings are real, tangible metrics that are hard to ignore."

Looking Ahead

As medical imaging continues its digital transformation, enterprise AI is transitioning from a localized, temporary hardware patch to a foundational, long-term fleet management strategy. The successful implementation of a multi-tiered, "Layered AI" workflow demonstrates that software solutions can continuously optimize clinical throughput without compounding hardware expenses.

Jones believes health care networks that adopt a unified, vendor-neutral layer on top of their current scanner's capabilities will be positioned to maximize scanner utilization, maintain cross-facility consistency, and deliver superior patient care well into the future.

"This platform has allowed us to take an existing, well-run system and improve it far beyond the cost of the product," Jones concludes. "We've been really happy with it. It has truly delivered on what was promised."

Acute Exertional Compartment Syndrome of the Medial Foot

Andre Liu, MD; Pamela Walsh, MD

Abstract

Acute compartment syndrome is a surgical emergency where increased pressure within a myofascial compartment restricts blood flow, potentially leading to muscle necrosis. While acute compartment syndrome is well-described in the setting of trauma, instances of atraumatic acute exertional compartment syndrome are rare. We describe a case of acute compartment syndrome of the medial foot in an adult patient in the setting of physical exertion.

Keywords: compartment syndrome, foot, musculoskeletal

Case Summary

An adult patient with no significant medical history presented to the emergency department with right medial foot pain and swelling. These symptoms began the previous evening after the patient played soccer for 2 hours. The patient also complained of left foot pain and swelling, which was described as less severe. Vital signs were within normal limits. Physical examination was significant for erythema and swelling at the medial arch of the right foot. Pedal pulses were palpable. Laboratory values were significant for serum creatine kinase level of 7404 and aspartate aminotransferase level of 98. Radiographs of the right foot were performed, followed by CT of the right lower extremity and MRI of the right foot.

Imaging Findings

Radiographs of the right foot demonstrated no abnormality (Figure 1). Subsequent CT of the right lower extremity demonstrated mild soft tissue inflammatory changes of the medial and posterior foot, with subtle low density in the abductor hallucis muscle (Figure 2). Subsequent MRI of the right foot demonstrated an enlarged, edematous abductor hallucis muscle (Figure 3). The musculotendinous portions of the adjacent quadratus plantae and flexor digitorum brevis were also edematous without muscle enlargement (Figure 3). Post-contrast images demonstrated heterogeneous enhancement of the abductor hallucis, with foci of nonenhancement representing areas of ischemic/nonviable muscle (Figure 3).

Diagnosis

Acute exertional compartment syndrome of the medial foot

Discussion

Acute compartment syndrome is a condition characterized by an increase in intracompartment pressure, with a resultant decrease in tissue perfusion. This decrease in muscle oxygenation can result in muscle tissue ischemia and irreversible muscle damage, including necrosis.[1] Acute compartment syndrome occurs most commonly in the lower leg and can also be seen in the hand, foot, forearm, and proximal limbs. Acute compartment syndrome is more commonly seen in the setting of trauma to the foot, particularly a crush injury.[2] Few cases have been published regarding acute medial compartment syndrome of the foot in the setting of physical activity without distinct trauma.

Compartment syndrome is typically a clinical diagnosis which is suggested by the constellation of signs and symptoms often

Affiliation: Department of Radiology, Lenox Hill Hospital, New York, New York
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Figure 1. Anteroposterior radiograph of the right foot showing no abnormality.



Figure 2. Axial CT through the right foot showing localized subcutaneous fat stranding along the medial and posterior foot (arrow). There is subtle hypodensity of the abductor hallucis muscle (arrowhead).

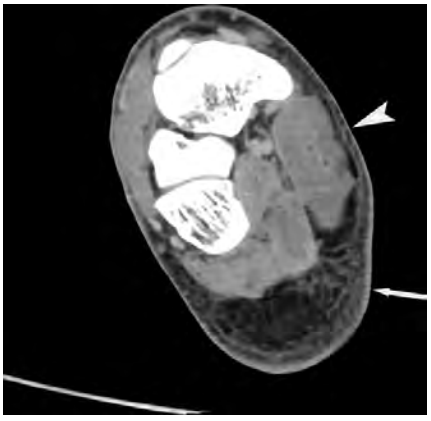
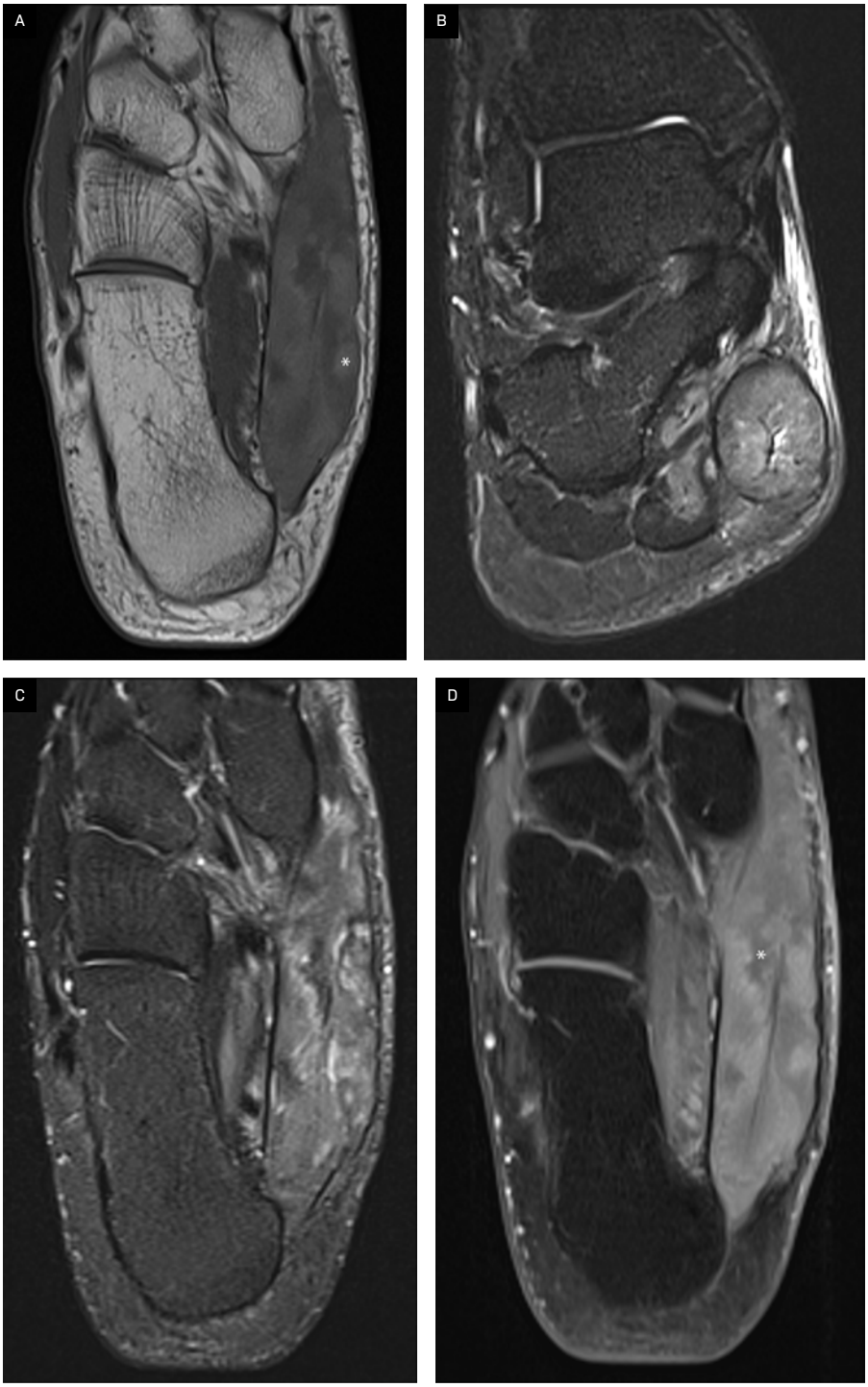


Figure 3. Axial T1-weighted MR image through the right foot (A) showing an enlarged abductor hallucis muscle with multifocal areas of increased T1 signal intensity, which may represent hemorrhage (asterisk). Coronal (B) and axial (C) short tau inversion recovery MR images showing diffuse patchy fluid-intensity signal within the abductor hallucis. The myotendinous portions of the quadratus plantae and flexor digitorum brevis also demonstrate high-intensity signal without muscle enlargement. Axial T1-weighted fat-suppressed post-contrast MR image (D) showing heterogeneous enhancement of the abductor hallucis with foci of nonenhancement within the muscle (asterisk).



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referred to as the "6 Ps": pain, pallor, pulselessness, paresthesia, paralysis, and poikothermia. The diagnosis can be confirmed with measurement of compartment pressures. A normal resting compartment pressure measures less than 10 mm Hg.[3] A compartment pressure of greater than 30 mm Hg traditionally indicates a patient for a fasciotomy. If untreated, compartment syndrome may lead to muscle fibrosis, loss of function, and contracture.[3,4]

There are 9 compartments of the foot described anatomically, and the compartments are categorized into 4 main groups: (1) the medial compartment containing the abductor hallucis and variably the flexor hallucis brevis; (2) the central compartment containing the flexor digitorum brevis, quadratus plantae, and adductor hallucis; (3) the lateral compartment containing the flexor digiti minimi brevis and abductor digiti minimi; and (4) the intrinsic compartment containing 4 interossei muscles between the 1st and 5th metatarsals. The medial and lateral compartments do not communicate with the other compartments.[5]

MRI features that can be seen in acute compartment syndrome include infiltrative or feather-like pattern of fluid signal of the muscle within a compartment, increased muscle volume, bulging of the fascia, and increased signal intensity on T1-weighted imaging indicating foci of hemorrhage and/or muscle herniation or fascia tear.[6-9] If muscle necrosis has occurred, there may be decreased or absent muscle enhancement on post-contrast sequences. Myositis may have a similar imaging appearance and may even result in compartment syndrome; therefore, it is important to have knowledge of the clinical scenario.

In this case, a diagnosis of rhabdomyolysis was made, with elevated serum creatine kinase level of 7404. MRI was performed due to worsening pain despite pain medication and hydration. Though MRI is not necessarily required for the diagnosis of compartment syndrome, awareness of where compartment syndrome can occur in less frequent locations is important and should be reported for possible intervention. MRI can help determine where to perform compartment measurements and assess for a potential underlying mass lesion or hematoma. In this case, after the MRI was performed and interpreted, the patient's right medial foot compartment pressures were measured to be 70-90 mm Hg. The patient subsequently underwent a fasciotomy, which revealed an enlarged, heterogeneous abductor hallucis. The patient returned to the operating room 2 days later for debridement of the necrotic muscle, resulting in 40% loss of the muscle.

Conclusion

While acute compartment syndrome is typically associated with trauma, this case shows a rare example of atraumatic acute compartment syndrome of the foot in the setting of physical exertion. MRI of acute compartment syndrome characteristically shows enlarged, edematous muscles within a fascial compartment. Familiarity with the imaging characteristics of this condition is important for facilitating prompt diagnosis and guiding management of this less common entity. Timely surgical intervention can prevent irreversible loss of muscle function.

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I refuse to join any club that would have me as a member.
—Groucho Marx



Dr Phillips is a Professor of Radiology, Director of Head and Neck Imaging, at Weill Cornell Medical College, NewYork-Presbyterian Hospital, New York, New York. He is a member of the *Applied Radiology* Editorial Advisory Board.

Societies

C. Douglas Phillips, MD, FACR

As is more than often correct with comedians, Groucho was not wrong about too many things.

Societies. Yep, we've got them. Hundreds of them. Thousands, maybe? We like to be members of groups and often find some clarity in our categorization of ourselves and our roles by the groups we are members of. Human race? Yep, I identify with that group. American? Yes, I was born and continue to remain within the confines of that portion of the Earth.

Straightforward, easy to understand.

Professional societies are additional and finely honed (in some instances) continuations of this. Here's the problem: the granularity or diffuse nature of these societies is daunting. I think I could potentially belong to about a thousand professional organizations right now and make a reasonable case that each was correctly chosen and right for me.

Holy &$?!!! What do you do? What are reasonable choices?

I refuse to name any names in this screed. I belong to a few. How were they chosen? Why have I persisted with them? What's in it for me?

As a physician in a generic sense, you might choose to belong to any of hundreds of organizations of MDs, and again, you would be right. You are an MD. However, more than a few of us radiologist types don't always feel like those organizations are doing much for radiology, and as a dispassionate observer, I would note that I agree with that opinion.

Okay, you're a radiologist. We've certainly got organizations that are for radiologists. Plenty. So, which one do you choose? And, likely you have some subspecialization. Are there organizations for your subspecialty? Absolutely. Again, likely several. Which of those? What if you practice several subspecialty areas? Whoa back, now this is spiraling out of control.

Here is my opinion. I initially wanted to be a member of everything I could get at. My first chair thought it was important for us all to join the societies. And, as a resident, the cost is negligible, or maybe even zero. Easy call. However, once you're making some money, THEY WANT SOME OF IT. Dues. Covers your subscription to the magazine. Lower cost to go to the meeting. But it is cash out of hand. We all must balance our inner need to belong with the cost of being in the group. I have sought value, returns on my investment, and the friends/colleagues/members of the organizations who I also value being with. I am now at the stage of my career where I am paring societies away. I find I don't miss too many of them, although from their letters asking me to please come back (*WE MISS YOU! SEND MONEY!*), they at least profess to miss me.

Let me know what you think. And keep doing that good work. Mahalo.

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